Electromagnetic & Light Scattering XIV

17-21 June 2013 – Lille, France

Abstracts

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Electromagnetic & Light Scattering XIV 2013

ELS XIV Program

Invited Lecture -> 20 mn (17 mn for presentation / 3 mn for questions)
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* Maximum size of the poster is 96cm x 118cm

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B1
Light scattering

(June 17th, 9:00 AM)

Benchmark calculations with the discrete dipole approximation and the T-matrix method for cubes

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Keywords: discrete dipole approximation, T-matrix, cube, benchmark results

Light scattering by a cube is relevant for many practical applications, including powdered crystal samples, ice crystals in atmosphere, and metallic nanoparticles. But even more often cubes are used in benchmark studies of light-scattering codes to contrast with spheres and spheroids. Although a cube is a geometrically simple object, it is unexpectedly complicated in terms of light-scattering simulation. The Mie theory was proposed more than a century ago, and currently optical properties of spheres can be evaluated with machine precision. By contrast, methods to rigorously evaluate light-scattering by cubes appeared only during the last two decades, and their accuracy is rarely discussed.

In this talk we will present the simulation results of light-scattering by cubes with sizes $kD = 0.1$ and 8 (where k is free-space wavenumber and D is the side length of the cube) and with three values of the refractive index (1.6 + 0.01i, 0.1 + i, and 10 + 10i) using the discrete dipole approximation (DDA) and the T-matrix method. Our main goal was to push the accuracy of both methods to the limit. For the DDA we used an earlier developed extrapolation technique based on simulation results for different levels of discretization. It allowed us to present unprecedentedly accurate benchmark results with estimated relative uncertainty from 10^{-7} to 10^{-3} depending on cube size and refractive index, as well as on the particular scattering quantity of interest.

For the T-matrix method we analyzed convergence curves (versus the number of multipoles n_{cut}) and showed that some cases feature almost monotonous convergence. Based on this we proposed a simple procedure to fit this curve by a power function, which allowed us to compress the whole convergence curve into a confidence range (i.e. a certain value and its uncertainty estimate). Comparison of the DDA and T-matrix results showed that the obtained estimate is, overall, reliable, although an underestimation of the real error up to a factor of four was obtained in rare cases.

Both the proposed error estimate of the T-matrix method and its difference against the DDA results showed relative errors from 10^{-4} to 0.2. Moreover, T-matrix error estimate was always from 100 to 10^4 times larger than the DDA error estimate. Although we could not directly verify the accuracy claimed by the DDA, even the less remarkable agreement between the two methods is unprecedently good in some cases. Thus we believe that the presented benchmark results would be useful for developers of light scattering codes, as well as for those who apply these codes to cubes in practical applications. A detailed account of these results can be found in the paper [1].

[1] Yurkin MA, Kahnert M. Light scattering by a cube: Accuracy limits of the discrete dipole approximation and the T-matrix method. *J. Quant. Spectrosc. Radiat. Transfer* (2012), doi: 10.1016/j.jqsrt.2012.10.001

Electromagnetic scattering by magnetodielectric small spheres

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Keywords: Electromagnetic scattering, Nanophotonics, Mie theory.

During the last two decades there has been an explosion of research around the world of nanoscience and nanotechnology. The need for device miniaturization when working with light has launched new research and technological challenges. In particular, light scattering by metallic nanoparticles has been the focus of attention, especially when incident radiation excites plasmonic resonances. In their applications in the visible range (biomedicine, optical communications, metamaterials building blocks, etc.), metals produce strong losses. This has stimulated a new race for finding materials which could overcome that difficulty. In very recent works[1,2], attention has been turned to high-permittivity low-loss subwavelength sized particles with non-overlapping magnetic or electric dipolar resonances (like Si and Ge in the VIS-NIR regions). Here we present a detailed numerical and experimental study (in the GHz range) of the electromagnetic scattering behavior of small magnetodielectric spheres of moderately high refractive index ($n \approx 4$) in both far- and near-field configurations. A study of the scattering directionality (either absence of backscattering or almost suppression of forward scattering), as a consequence of the coherence effects between the dipolar electric and magnetic contributions, will be shown. Other coherent phenomena, like possible Fano-like effects will be discussed both theoretically and experimentally. Since these scattering properties are fully scalable, i.e. they only depend on the ratio *(particle size)/(wavelength)*, our results open new technological challenges from nano- and micro-photonics to science and engineering of antennas, metamaterials and electromagnetic devices.

1. García-Etxarri, A. et al. Strong magnetic response of submicron silicon particles in the infrared. *Opt. Express* **19**, 4815–4820 (2011).
2. Geffrin, J.M. et al. Magnetic and electric coherence in forward- and back-scattered electromagnetic waves by a single dielectric subwavelength sphere. *Nat. Commun.* **3**:1171 doi: 10.1038/ncomms2167 (2012).

Note: the name of the person who will make the actual presentation is underlined.

Effect of particle nonsphericity on the behavior of Lorenz–Mie resonances in radiative characteristics of liquid-cloud particles

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Keywords: electromagnetic scattering, optical resonance, *T*-matrix method

Cloud particles always exist in the atmosphere as polydisperse mixtures. Therefore, the numerical modeling of their scattering and absorption properties (such as the optical cross sections, single scattering albedo, and scattering matrix elements) must include averaging over a size distribution by using a quadrature integration formula. For a given type of quadrature formula, the total number of quadrature division points and the integration range determine the respective size-parameter resolution Δx ($x = 2\pi r / \lambda$, where r is the sphere radius and λ is the wavelength in the surrounding medium). From the Lorenz–Mie theory, it is known that electromagnetic scattering by a perfect dielectric sphere results in interference structure and optical resonances in a form of high-frequency ripples and supernarrow spikelike features in the plots of various scattering characteristics versus size parameter x. The existence of numerous morphology-dependent resonances requires an extremely small value of Δx in polydisperse Lorenz–Mie computations for example in the case of liquid water clouds. But it has been shown (Mishchenko, Lacis 2003) that for spheroids and Chebyshev particles with the refractive index $m = 1.4$ the deformation of a sphere by as little as one hundredth of a wavelength can essentially suppress super-narrow optical resonances. This factor may be very helpful in adopting a value of Δx when performing polydisperse computations for cloud particles.

Given the great practical importance of the problem of potential effects of size-parameter resolution on the outcome of polydisperse computations of optical characteristics for liquid water particles, firstly we analyze the influence of a deviation of particle shape from perfect sphericity on the behavior of optical resonances. This analysis is based on the results of computations performed for nearly spherical oblate and prolate spheroids and high-order Chebyshev particles with the refractive index $m = 1.31$ in the range of size parameters affected by some Lorenz–Mie resonances. In our computations, we use the extended-precision version of the *T*-matrix method (Mishchenko et al., 2002), and the relative accuracy is set to be better than 10^{-9}. The results of our computations do demonstrate that: i) super-narrow optical resonances can be significantly suppressed upon extremely small shape deformations from a perfect sphere; ii) the positions and profiles of resonances change with increasing asphericity; iii) larger deviations from a perfect sphere are required to suppress broader resonances.

Note: oral presentation.

Computation of Radiation Pressure Force on Arbitrary Shaped Homogenous Particles by the Multilevel Fast Multipole Algorithm

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Keywords: radiation pressure, arbitrary shaped particle, surface integral equation method, multilevel fast multipole algorithm

When a particle is illuminated by a beam of light, it experiences the radiation pressure force (RPF). Theories on RPF computations for homogeneous spherical and spheroidal particles have been developed in framework of rigorous solutions of Maxwell. But this method cannot be applied to an irregular shaped particle. Some researchers used the discrete dipole approximation (DDA) or T matrix theory to calculate the RPF on non-spherical particles.

Compared to the theoretical efforts in the calculation of RPF on spherical particles, much less work on the RPF prediction for irregular particles has been reported. This is because, in one hand, the rigorous solutions of Maxwell equations exist only for the particles whose shape corresponds to a type of coordinates system and, on the other hand, even for the regular shaped particle as spheroid or ellipsoid, the numerical evaluation of the special function is still another obstacle. The numerical techniques, such as the MoM, FEM and FDTD, are possible ways to overcome these limitations. In this communication, we will present our approach for the computation of the RPF exerted on an arbitrary homogenous particles illuminated by an arbitrary shaped beam. This approach is based on the multilevel fast multipole algorithm (MLFMA) enhanced surface integral equation (SIE) method. This approach has the following advantages. First, SIE with triangles patches is used, which limits the discretization of the unknowns to the surface of the particle. Compared with the volume discrete methods, it is more flexible and efficient. Furthermore, it is easier to generate meshes for modeling the irregular shape particle. Second, the MLFMA is used to enhance the SIE. The MLFMA can reduce the computational complexity of $O(N^2 \sim N^3)$ and storage complexity of $O(N^2)$ for SIE to $O(NlogN)$. Hence it can greatly improve the capability of the SIE method. Third, the RPF is computed by integrating the dot product of the outwardly directed normal unit vector and the Maxwell's stress tensor over a spherical surface tightly enclosed the particle in this work. On the other hand, we use the accurately computed near region electromagnetic fields instead of the far-field approximation, which is often used in such kind of calculation. As known to all, for arbitrary shaped beams, it is hard or even impossible to get the detailed mathematical description of the electromagnetic field components, which accurately satisfies Maxwell's equations in far-field region. Since only those near fields are needed, the calculation of far field components of the incident beams is avoided. It's convenient to use the same detailed mathematical description of the incident beam which accurately satisfies Maxwell's equations both for computing equivalent sources in SIE and the Maxwell stress tensor, as the surface can be chosen tightly from the particle surface. As an example, we will present the RPF exerted on a spheroid by a Gaussian beam. However, by following similar treatment, readers can easily use such method to deal with other types of beams on an arbitrary particle, as long as the electromagnetic field components of the incident beam is known at any spherical surface tightly enclosing the whole outer surface of the particle.

Experimental scattering matrices of desert dust samples

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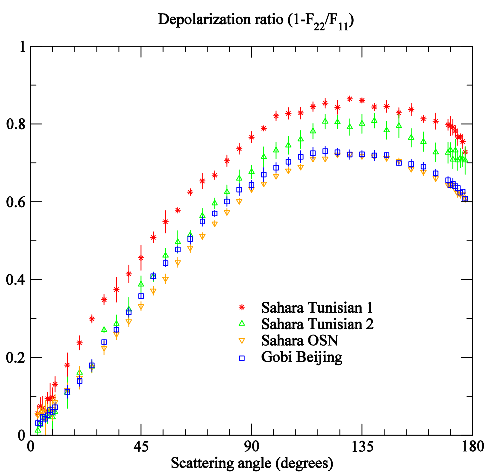
Keywords: polarization, scattering matrix, desert dust, experiments

Desert dust aerosols play an important role in the Earth's radiative balance. Computational characterization of small desert dust particles from the observed scattered light remains a difficult task due to their complicated morphology. Therefore, laboratory measurements are valuable references. In this work we experimentally study the complete scattering matrices as functions of the scattering angle of four desert dust samples. The measurements are performed at the IAA Cosmic Dust laboratory (*Muñoz et al. JQSRT, 11(1), 2010*) at a wavelength of 647 nm in the scattering angle range from 3 to 177 degrees. Two of the samples, *Sahara Tunisia1* and *Sahara Tunisia2*, were collected from the ground in two locations in south Tunisia. The samples were collected in recesses that are able to trap airborne fine clay-fraction particles (*Nousiainen et al. JGR, 114, D7, 2009*). The third sample, *Sahara OSN*, was collected during a Sahara sand event at the Observatory of Sierra Nevada (OSN) in Granada, Spain. The OSN is located at 2896 m above sea level in Sierra Nevada Mountains at a distance of more than 1500 km from the source. The fourth sample, *Gobi Beijing*, was collected in Beijing during a desert dust storm. The color of the samples ranges from whitish for the *Sahara Tunisian1* to dark brown for the *Gobi Beijing* sample including reddish and light brown for the *Sahara Tunisian2* and *Sahara OSN* samples, respectively. The volume distribution of the four desert dust samples is measured with a Mastersizer 2000 from Malvern instruments. The Mastersizer uses either Mie theory or Fraunhofer theory for spheres to retrieve the volume distribution of the sample under study. In the table we present the corresponding effective radii and effective variances obtained from the measured size distributions based on both the Mie and Fraunhofer theories.

Sample	Sahara Tunisian1	Sahara Tunisian2	Sahara OSN	Gobi Beijing
r_{eff}; v_{eff} Fraunhofer	4.6 µm; 4.1	6.4 µm; 5.4	2.5 µm; 2.3	4.6 µm; 2.9
r_{eff}; v_{eff} Mie	9.8 µm; 1.6	12.4 µm; 2.5	4.0 µm;1.8	7.6 µm; 1.6



As an example in the figure we present the measured depolarization ratio ($1-F_{22}/F_{11}$) as a function of the scattering angle for the four desert dust samples. The measurements seem to indicate that the value of the depolarization ratio as function of the scattering angle is not only dependent on the size of the particles but also on other properties such as their shape and refractive index. A detailed characterization of the samples will be presented at the conference together with the measured scattering matrices.

The physical-optics approximation and its application to light backscattering by hexagonal ice crystals

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Keywords: electromagnetic scattering, physical optics, ice crystals

Since typical sizes of ice crystals constituting cirrus clouds are much larger than incident wavelength, the problem of light scattering by such particles, at present, is not solvable with the common methods based on the Maxwell equations. In this case, the geometric-optics and physical-optics approximations are the natural ways to solve such problems. However, while geometric optics is a well-defined field of physics, physical optics has not been commonly defined. In literature, there are a lot of terminologies and method names corresponding to physical optics. In this talk, the terminologies and methods are systemized and a simple definition of the physical optics approximation is proposed. Such an approximation is the direct extension of the classical Kirchhoff approximation from a large aperture to any large 3D scatterers.

In lidar investigations of cirrus clouds, the backscattering Mueller matrix is the basic quantity that completely determines the lidar signals within the single-scattering approximation. Nevertheless, this quantity has not been calculated by anyone yet because of the singularity inherent to the backward scattering direction. In this talk we are filling this gap. The backscattering Mueller matrix has been calculated in the physical-optics approximation for both randomly and preferably oriented hexagonal ice crystals. Some applications of the results are also discussed.

G1
Remote sensing

(June 17th, 11:00 AM)

Remote sensing of aerosols and clouds by using polarized, directional and spectral measurements within the A-Train: the PARASOL mission

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PARASOL is the second in the Myriade line of microsatellites developed by CNES, the French Space Agency. The platform was launched in December 2004 in order to be part of the A-Train and has a sunsynchronous orbit with 1:30 pm ascending node at an altitude of 705 km. The mission takes advantage of the other instruments in the constellation, which for our objectives mainly include MODIS on the AQUA satellite and CALIOP on CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation).

The PARASOL payload consists of a digital camera with a 274x242-pixel CCD detector array, wide-field telecentric optics and a rotating filter wheel enabling measurements in 9 spectral channels from blue through to near-infrared (443, 490, 565, 670, 763, 765, 865, 910 and 1020 nm). Polarization measurements are performed at 0.490µm, 0.670µm and 0.865µm. The pixel size is 5.3km x 6.2km at nadir. Because it acquires a sequence of images every 20 seconds, the instrument can observe ground targets from different view directions, +/- 51° along track and +/– 43° across track. This measurement strategy provides unique information on aerosols and clouds.

The aerosol parameters that are usually accessible from remote sensing are the aerosol optical depth (AOD) and the Ångström Exponent that gives an indication of the column integrated aerosol size distribution. With the polarized and directional signatures, POLDER data are better suited to select the aerosol model in the inversion algorithm and to determine the size and shape of particles. Over land for highly reflective surfaces, only polarization data are presently used in the operational data processing. Since polarization is mainly controlled by small particles, only the small (or accumulation) mode can be retrieved. This existing limitation will be overcome with the more sophisticated inversion scheme under development. Polarization observations at 0.865µm are used to distinguish cloud droplets and cloud ice crystals. The cloud level pressure is derived using polarization at wavelength 0.490µm and by measuring oxygen at 0.763µm. Differences between the Rayleigh and the oxygen pressures provide information on the cloud structure.

Combination of different approaches helps to discriminate ambiguous cases. Combination of different data helps to retrieve new parameters; for instance, the detection of aerosols in cloudy scenes constitutes a new field of research in remote sensing.

Retrieval of aerosol microphysical and optical properties above liquid clouds from POLDER/PARASOL polarization measurements.

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Most of the current aerosol retrievals from passive sensors are restricted to cloud-free scenes, which strongly reduce our ability to monitor the aerosol properties at a global scale. When a high loading of strong absorbing aerosols is present above clouds, a rather strong positive radiative forcing is expected (warming) as well as significant biases on the retrieved cloud properties. The presence of aerosol layers above liquid clouds may also affect the dynamical evolution of clouds. The monitoring of multi-layer scenes at global scale is therefore of importance for climate study. The presence of Aerosols Above Clouds (AAC) affects the polarized light reflected by the cloud layer, as shown by the spaceborne measurements provided by the POlarization and Directionality of Earth Reflectances (POLDER) instrument. A First retrieval method was developed for AAC scenes and evaluated for biomass burning aerosols transported over stratocumulus clouds (Waquet et al., 2009). The method was restricted to the use of observations acquired at forward scattering angles where polarized measurements are highly sensitive to fine mode particles scattering. Coarse mode non-spherical particles, such as mineral dust particles, do not much polarize light and cannot be handled with this method. We present new developments that allow retrieving the properties of natural coarse non-spherical particles present above clouds using measurements acquired in the polarized cloud bow. The polarized cloud bow is a feature of liquid water cloud that corresponds to an intense and highly directional peak. When an aerosol layer is transported above a liquid cloud, the cloud bow is attenuated and this attenuation is directly related to the optical thickness of the lofted layer. We present a sensitivity study analysis that evaluates the contribution of the POLDER polarized radiance measurements for the simultaneous retrieval of the aerosol and clouds properties. The use of spheroid models is evaluated for the modeling of the polarized data acquired for mineral dust and volcanic dust observed above clouds. The potential impact of three-dimensional radiative transfer effects on the retrievals will also be discussed. The seasonal and spatial variability of the AAC properties retrieved for one year of data will also be presented.

An algorithm to estimate optical properties of carbonaceous aerosols based on combined use of polarization and reflectance measurements

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Keywords: biomass burning aerosols, POLDER, CAI, GOSAT

Carbonaceous aerosols play an important role in the Earth's radiation budget. The AERONET sun/sky radiometer network shows the detail information of biomass burning aerosols. However, distribution of their properties is limited with AERONET sites. This work intends to develop an algorithm for estimating optical properties of carbonaceous aerosols from satellite dataset. The Polarization and Directionality of the Earth's Reflectances (POLDER) gives us with directional polarization information (I, Q, and U) at several wavelengths. Such spectral polarization information is useful to estimate the aerosol optical thickness (AOT) and its spectral tendency from visible to near infrared wavelength. The carbonaceous aerosols absorb the incident light in the ultra violet wavelength. This feature is available to distinguish the absorbing and non absorbing aerosols and also to estimate the single scattering albedo (SSA). Therefore, our targets of aerosol properties are spectral AOTs as well as SSA information, and/or complex refractive index at a specific wavelength.

The predefined aerosol model is a key of retrieving these parameters, therefore we carefully compile the AERONET inversion results which give us the appropriate variation of biomass burning aerosols with wavelength tendency. Finally, such an internal mixture model as Maxwell-Garnett theory is adopted to express the biomass burning aerosols as mixing of black and organic carbons.

Our algorithm is applied to several biomass burning event scenes which are simultaneously observed by POLDER and CAI (cloud aerosol imager) on GOSAT data set. Since the CAI / GOSAT provides the reflectance at 0.38 μm, our method shows good performance to estimate the optical properties of carbonaceous aerosols.

Polarization of the Earth reflectance. Lessons learnt from Parasol observations

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Keywords: scattering, polarization, PARASOL, reflectance

The POLDER instrument was flown for relatively short periods onboard the ADEOS-I and II platforms, while a third version has been onboard the PARASOL microsatellite for more than 5 years. POLDER remains the only spaceborne instrument to provide full quantitative information about the linear polarization state of the spectral reflectances. Polarization has been used to monitor aerosol over land surfaces, to identify the nature of the aerosols over the oceans, to distinguish liquid and ice phase clouds, to estimate the droplet radius of liquid phase clouds. However, the knowledge of typical polarization is also necessary for the design of future instruments whose calibration is sensitive to the polarization state of the measured radiance. Typical polarization from land surfaces is needed to remove their contributions when retrieving aerosol load from the measured radiances.

This talk is intended to summarize the findings about Earth polarization derived from POLDER measurements. We will discuss the typical values of polarized reflectance, degree of polarization and polarization angle observed over various surfaces. We will then present a few examples of application of remote sensing using the polarization information. The talk will finish with recommendations on the way to present and process polarization information.

iSPEX: Measure polarized light scattering with your smartphone!

H. Volten[a] representing the iSPEX team[a,b,c,d,e,f]

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Keywords: polarization, aerosol characterization, aerosol instrumentation, air quality network

An increasing number of people carry a smartphone with internet connection, a camera and considerable computing power in their pocket. iSPEX, a spectropolarimetric add-on with complementary App makes use of this opportunity, and instantly turns a smartphone into a scientific instrument to measure dust and other aerosols in our atmosphere. A measurement involves scanning the blue sky, which yields the angular behavior of the degree of linear polarization as a function of wavelength, which may be interpreted in terms of size, shape and chemical composition of the aerosols in the sky. The measurements are automatically tagged with location and pointing information, and submitted to a central database where they will be interpreted. Together with observations from other users at random locations, the data are compiled into a map. Through crowd sourcing, the general public will thus be able to contribute to a better assessment of the presence of different types of aerosols in the atmosphere.

iSPEX is based on SPEX technology. SPEX (Spectropolarimeter for Planetary Exploration) provides multi-angle, multi-wavelength measurements of the intensity and polarization of sunlight scattered by aerosols in planetary atmospheres. A ground-based SPEX-like instrument was recently deployed at CESAR, the Cabauw Experimental Site for Atmospheric Research, which also hosts a comprehensive suite of aerosol measurement equipment. A single smartphone iSPEX spectropolarimeter is less accurate than its SPEX counterpart at a meteorological site, but we expect that an ensemble of simultaneous measurements suppresses errors through averaging. Therefore, we will distribute 10,000 iSPEX units throughout the Netherlands and we are organizing a national iSPEX measurement day in the spring or summer of 2013. By analyzing not only the measured results, but -just as importantly- the motivation of the general public to participate, we learn about the possibilities to create a totally new kind of air quality measurement network. Such a network of smartphone users has the potential both for global coverage and for detecting localized effects.

We will give a live demonstration of the iSPEX add-on and App. We hope to convince you that iSPEX is not only a great outreach tool to engage the public in issues pertaining to atmospheric aerosols, but that it may also contribute to the solution of several urgent social and scientific problems.

Note: The iSPEX team consists of the following people: UL: Frans Snik, Christoph Keller, Ritse Heinsbroek, Felix Bettonvil, Gerard van Harten, Stephanie Heikamp, Jos de Boer, Esben Zeegers, Lars Einarsen, SRON: Jeroen Rietjens, Otto Hasekamp, Martijn Smit, Antonio di Noia, KNMI: Arnoud Apituley, Bas Mijling, Elise Hendriks, Piet Stammes, RIVM: Hester Volten, Jan Vonk, Stijn Berkhout, Marty Haaima, René van der Hoff, TUD: Daphne Stam, NOVA: Ramon Navarro

Polarimetric Remote Sensing of Atmospheric Aerosols

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Keywords: Polarization, Aerosols, Inverse Methods, Remote Sensing

To reduce the large uncertainty on the aerosol effects on cloud formation and climate, accurate satellite measurements of aerosol optical properties (optical thickness, single scattering albedo, phase function) and microphysical properties (size distribution, refractive index, shape) are essential. Satellite instruments that perform multi-angle photopolarimetric measurements have the capability to provide these aerosol properties with sufficient accuracy. The only satellite instrument currently in space that performs multi-angle photopolarimetric measurements is the POLDER-3 instrument onboard the PARASOL microsatellite. PARASOL provides measurements of a ground scene under (up to) 16 viewing geometries in 9 spectral bands (3 for polarization). In order to make full use of the capability of PARASOL measurements of intensity and polarization properties of reflected light at multiple viewing angles and multiple wavelengths, we developed a retrieval algorithm that considers a continuous parameter space for aerosol microphysical properties (size distribution and refractive index) and properly accounts for land or ocean reflection by retrieving land and ocean parameters simultaneously with aerosol properties. Here, we present the key aspects of our PARASOL retrievals (inverse method, forward model, information content, cloud screening, computational aspects) as well as a validation of retrieved aerosol properties with ground-based measurements of the AERONET network. Also, we discuss required improvements for the next generation of polarimetric instruments dedicated to aerosol remote sensing.

D1
Radiative transfer

(June 17th, 2:00 PM)

Modeling of OCT imaging in scattering media using analytical and numerical solutions of Maxwell's equations

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Keywords: electromagnetic scattering, OCT, FDTD, Mie theory, cylinder theory

Optical coherence tomography (OCT) is a non-invasive optical technique for the three-dimensional imaging of biological tissue. Whereas the technical enhancement of OCT devices has been enormous in the recent years allowing faster imaging and higher resolution, only little work has been reported examining the OCT method theoretically. However, a thorough theoretical investigation would allow a closer insight in the origin of the OCT image formation which could help to improve OCT measurement systems. Since the OCT method strongly depends on the coherency of light, intensity-based solutions to calculate the light propagation in biological tissue like the radiative transfer theory can only provide limited insight. For a full understanding, wave solutions based on Maxwell's equations regarding interference effects have to be utilized.

In this contribution some means to simulate OCT measurement setups on the basis of Maxwell's equations will be presented. These simulations take into account the illumination source, the detection setup as well as the interaction of the incoming light with the scattering sample. For the solution of Maxwell's equations different methods have been used. Beside analytical methods based on extensions of Mie or cylinder theory, numerical methods like the finite-difference time-domain (FDTD) method have been used. Some fundamental results will be presented and some interesting phenomena will be shown.

Single particle, angle and wavelength resolved polarized elastic scatter measurement

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Keywords: aerosol, particle, electromagnetic scattering, polarized scattering, Mueller matrix elements

We report our work to investigate the scattering profiles of individual aerosol particles as a function of scattering angle and wavelength-dependent polarization state, with the goal of correlating these signature patterns with the structure and composition of different particle types. If successful, this method of aerosol particle characterization could provide a basis for discrimination between various particle classes such as generated aerosols versus naturally occurring, ambient aerosols. In order to implement this characterization, we have developed an experimental approach to measure scattered light at multiple angles, and multiple polarization states simultaneously from single aerosol particles. This novel technique is a significant departure from traditional polarization scattering studies that typically use a single wavelength source with polarization modulated in time, to interrogate a population of aerosol particles. A key element of our technique is to utilize a super-continuum light source that provides a broad spectrum of wavelengths at relatively high intensities. This illumination source is passed through a multiple-order retarder that creates different light source polarization states as a function of wavelength. Scattered light is collected at discrete angles by an array of optical fibers coupled to an imaging spectrometer and EMCCD camera. By this means, it is possible to simultaneously acquire a two-dimensional image of scattered light data in which the spatial coordinate can be designated to a particular scattering angle, while the wavelength coordinate can be calibrated to the input light polarization state.

Initially, we used an optical trap (at 405 nm) to hold droplet particles stably at a point for long periods (minutes to hours) for investigation. Under these conditions, we acquired scattered intensity data as a function of both wavelength and scattering angle. By comparing these measurements with computational model results, both droplet size and refractive index could be recovered with a precision on the order of 1%. We have acquired different Muller matrix elements from slowly drifting micron-sized individual particles. Our current objective is to improve our experimental parameters that will allow us to make such measurements on slowly flowing particles. We will present the details of our experimental arrangement, and our latest particle scattering results.

Coherent backscattering by discrete random media composed of clusters

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Keywords: electromagnetic scattering, particulate media, opposition effects, weak localization

Many objects of natural and artificial origin demonstrate the well-known opposition features in the brightness and polarization. In many cases, they are mostly caused by the coherent backscattering (weak localization) phenomenon. Due to its interference nature, the manifestation of the opposition effects strongly depends on the sizes, refractive index, shape, and packing density of the particles composing a scattering medium. This makes the opposition effects to be important for interpretation of the remote sensing data. The weak-localization theory rigorously describes the effects for sparse media. However, in the real particulate surfaces, the scatterers are in the near-field zones of each other, which makes the multiple scattering theory of such a medium to be extremely complicated. The approximate method recently developed by Tishkovets and Mishchenko (2009) allows the coherent backscattering characteristics to be found for a semi-infinite sparse medium composed of arbitrary particles. We report the results of calculations of the intensity and polarization of light reflected by a discrete random semi-infinite medium composed of chaotically oriented clusters of spherical particles with specified packing density. We used clusters as the scatterers in order to make the model more adequate to a real medium, e.g., planetary regolith. The volume concentration of clusters in the layer was assumed as 7% (corresponding to fluffy surfaces), while the packing density of the constituents (with size parameters x_1=0.5 or 1.0) in clusters was varied from 4 to 30%. Three types of the clusters containing from 1 to 600 non-absorbing monomers were considered. Most of the analyzed individual clusters do not demonstrate the substantial enhancement in brightness and the negative branch of polarization near opposition unless they are closely packed and contain hundreds of monomers. The classical radiative transfer procedure applied to a semi-infinite layer of such clusters produces no opposition effects, while the accounting for the coherent component yields the sharp peak of intensity centered at zero phase and the asymmetric negative polarization branch with a minimum moved to opposition, which clearly reproduces the opposition features observed in bright particulate surfaces.

The specific appearance of the opposition features produced in the coherent backscattering simulations depends on sizes of the constituents in clusters, their number, and the packing density. The smaller the monomers, the sharper the features. If the number of monomers N in the densely packed random clusters or fractal-like clusters increases, the negative branch becomes shallower (from P_{min}≈-3.5 to ≈-1%), though, if N exceeds some value depending on x_1, the opposition features stop to change. The features are sharpest for the layers composed of individual particles (N =1), and the angular position of P_{min} moves from opposition to α_{min}≈1.2-2.0°, if N grows to 100-200. The further increasing of N leaves P_{min} almost stable for the layers of the clusters that do not produce the negative branch in the single scattering, while for the latter P_{min} weakly moves to opposition. It is interesting that the medium composed of the clusters generated by random filling of a spherical volume with specified packing density of monomers (10%) demonstrates practically no evolution in the opposition features with increasing N, which is explained by a negligible influence of the interaction in the near field in such ensembles.

Transmittance and scattering of polymer-dispersed liquid crystal films, containing droplets with modified boundary conditions

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Keywords— electromagnetic scattering, liquid crystals, particulate media, soft matter

Polymer-dispersed liquid crystal (PDLC) films are materials consisting of liquid-crystal droplets dispersed in a polymer matrix. They are used as light modulators for photonics and optoelectronics applications. Controlled light scattering from liquid crystal (LC) materials is achieved by using electrically, magnetically, or thermally induced change in director orientation and molecular configuration to manipulate their optical properties.

Multi-functional devices with controllable parameters on the basis of these films are created. Among them are intensity and phase modulators of light radiation, polarizers and polarization converters of light, lenses, filters, reflectors, flexible displays, etc.

Recently it was proposed and implemented a new method for controlling the structure of liquid crystal droplets in the polymer matrix by an electric field. It is based on a modification of the boundary conditions by the ionic surfactants. It creates heterogeneity of the boundary conditions and reduces value of the electric field intensity in comparison with the ordinary PDLC films.

Since liquid crystals are optically anisotropic materials, scattering problems are more difficult to solve for single LC droplet and droplets ensembles as compared to optically isotropic particles. Typically the single-scattering approximation is used. The major results are obtained under the Rayleigh-Gans approximation and the anomalous diffraction approximation.

In this talk a method of light propagation via a monolayer of liquid-crystal droplets dispersed in polymer matrix for modeling and computing is considered. It allows one to investigate light scattering by films containing droplets with homogeneous and inhomogeneous adhesion of liquid crystal molecules at the interface polymer-liquid crystal.

The effect of asymmetry in polar scattering angle for the light scattered in forward hemisphere for polymer films containing droplets with inhomogeneous boundary conditions has been revealed.

The described results are used to analyze transmittance, angular structure, and polarization characteristics of light scattered by a monolayer of liquid crystal droplets with homogeneous and inhomogeneous boundary conditions. The method can be used to study field- and temperature-induced phase transitions in LC droplets with cylindrical symmetry (bipolar, axial, etc.) by analyzing the transmittance, polarization, and angular distribution of forward-scattered light.

Scattering by multiple metallic cylinders buried in a lossy half space

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Keywords: Electromagnetic scattering, metallic cylinders, absorbing medium

Remote sensing of cylindrical objects buried in a semi-infinite medium has many applications, such as detection of tunnels or cables and non-destructive diagnostics of composite materials. The problem of scattering by obstacles buried in a half space is considerably more complicated than that for an infinite medium due to the presence of a discontinuous interface. Discontinuity of electro-optical properties across the interface gives rise to Fresnel effects that govern the transmission and reflection of radiation. When the half space is lossy, the scattering problem is further complicated by the complex propagation constant that results in the attenuation of EM waves traversing the medium. The scattering solution for obstacles buried in a lossy half space requires rigorous treatment of the interface Fresnel effect and absorption by the medium.

This paper treats the problem of scattering by multiple parallel infinite metallic cylinders buried in a lossy half space. The source radiation is an arbitrarily polarized plane wave propagating at an inclined angle in the plane normal to the axes of the cylinders. The spacing between cylinders is comparable to the diameter of the cylinders and wavelength of the source radiation, so that near field multiple scattering is dominant. The angular distributions of the scattered waves from the cylinders and scattered waves reflected from the half space interface are formulated by utilizing a uniformly convergent Fourier directional distribution for a lossy medium. Closed form expressions are derived for the electric and magnetic fields and Poynting vector of the scattered radiation emerging from the half space. Numerical results are shown to illustrate scattering from an assembly of metallic cylinders buried in a lossy half space.

G2
Remote sensing

(June 17th, 4:00 PM)

The Multi-Viewing Multi-Channel Multi-Polarisation Imaging (3MI) Mission of the EUMETSAT Polar System - Second Generation (EPS-SG) dedicated to aerosol characterisation

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Keywords: satellite remote sensing, VNIR, SWIR, polarisation, multi-viewing, aerosol, cloud, climate monitoring, NWP, nowcasting, air quality

The EUMETSAT Polar System (EPS) will be followed by a second generation system, EPS-SG, in the 2020 timeframe and contribute to the Joint Polar System being jointly set up with NOAA. The satellites will fly, like Metop, in a sun synchronous, low earth orbit at 820 km altitude and 09:30 local time of the descending node, providing observations over the full globe with revisit times of 12 to 24 hours, depending on instrument.

The EPS-SG Multi-Viewing Multi-Channel Multi-Polarisation Imaging mission (3MI) is a push-broom radiometer dedicated to aerosol characterisation for climate monitoring, atmospheric composition, and more specifically air quality and numerical weather prediction. The purpose of the 3MI is to provide multi-spectral (from 410 to 2130 nm), multi-polarisation (-60°, 0°, and +60°), and multi-angular (10 to 14 views) images of the Earth top of atmosphere (TOA) outgoing radiance to accurately measure the aerosol load and thereby resolve the directional anisotropy and to characterise the microphysical properties. Although the 3MI heritage comes from the POLDER and PARASOL missions (3 instruments flown since 1996), the new instrument will provide substantial innovations by measuring over an extended spectral range and with higher spatial resolution.

Although aerosol characterisation is the primary application, 3MI will further support observation of cloud microphysical properties, water vapour load, Earth radiation budget, and land-surface characteristics all of which will benefit from the enhanced directional and polarisation measurements. The 3MI also contributes to artefact correction of other EPS-SG sensors METimage, Sentinel-5, and IASI-NG by providing anisotropy and polarisation information on scattered radiation from aerosols and cirrus clouds. Likewise, the synergy with these instruments will support 3MI with beneficial cross-calibration.

Retrievals of aerosol parameters from ground-based spectro-polarimetric measurements with SPEX

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SPEX, the Spectropolarimeter for Planetary EXploration, is a compact, robust and low-mass multi-viewing angle spectropolarimeter designed to operate from an orbiting satellite platform. Its purpose is to simultaneously measure, with high accuracy, the radiance and the state (degree and angle) of linear polarization at optical wavelengths of sunlight scattered in a planetary atmosphere and/or reflected by a planetary surface. In particular the degree of linear polarization is extremely sensitive to the microphysical properties of atmospheric or surface particles. Spectro-polarimetric measurements as performed by SPEX are therefore crucial for disentangling the many parameters that describe planetary atmospheres and surfaces.

SPEX uses a novel technique for its radiance and polarization measurements: through a series of carefully selected birefringent crystals, the radiance of scattered sunlight is spectrally modulated. The amplitude and phase of the modulation are proportional to the degree and angle of linear polarization respectively. The technique is entirely passive, i.e. there are no moving parts or active components employed to establish the polarization modulation.

We will address in detail SPEX' novel spectral modulation technique and discuss its advantages in comparison with more traditional polarimetric techniques. We will present our prototype instrument, with emphasis on the performance critical elements, and show test results that demonstrate excellent performance and overall behavior. In particular, we find that the prototype instrument has a degree of linear polarization sensitivity of about 0.0002, which is better than the design target.

We will present results of ground-based measurement with the SPEX prototype near the Cabauw Experimental Site for Atmospheric Research (CESAR) during the PEGASOS campaign in May 2012. Retrievals of aerosol parameters have been performed using only polarimetric data as well as both polararimetric and spectral flux data of the SPEX prototype. We will discuss the instrument calibration with respect to polarization and spectral flux and compare the retrieval results. In general, these results compare well with AERONET AOT retrievals and indicate that SPEX has the potential to deliver high quality aerosol parameters.

Surface and atmospheric observations with the Ground-based and Airborne Multiangle SpectroPolarimetric Imagers

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Keywords: remote sensing, multiangle, polarization, imaging, aerosols, clouds

The Ground-based and Airborne Multiangle SpectroPolarimetric Imagers (GroundMSPI, AirMSPI) are 8-band (355, 380, 445, 470, 555, 660, 865, 935 nm) pushbroom cameras, measuring polarization in the 470, 660, and 865 nm bands. These cameras make use of a dual photoelastic modulator (PEM)-based polarimetric imaging technique to simultaneously acquire measurements of intensity (*I*) and the linear polarization Stokes parameters *Q* and *U*. The instrument design determines *Q/I* and *U/I* as relative measurements, enabling accurate imagery of the degree and angle of linear polarization (DOLP, AOLP).

Since characterization of surface reflection is essential for retrieval of aerosols using downward-looking remote sensors, GroundMSPI observations have been used to evaluate a model for the surface polarized bidirectional reflectance distribution function (PBRDF). This model is comprised of a modified Rahman-Pinty-Verstraete term plus a specular reflection term generated by a randomly oriented array of microfacets. We find that, at the high spatial resolution of the GroundMSPI data (3 cm at a target distance of 100 m), the conventional assumption of a single Fresnel reflection from the microfacet array does not always hold, but can be dealt with using empirical adjustments to the model. The data have also been used to examine the assumption of spectral invariance in the angular shape of the unpolarized and polarized surface reflection. Where applicable, such invariance is important because it provides significant constraints on the behavior of the underlying surface in the aerosol retrieval problem.

AirMSPI has been collecting data from NASA's ER-2 high-altitude aircraft since 2010 and has successfully completed a number of flights over various land and ocean targets. The instrument is mounted on a gimbal to acquire multiangular observations over a ±67° along-track range with 10-m spatial resolution across an 11-km wide swath. Example images of clear, hazy, and cloudy scenes over the Pacific ocean and California land targets will be shown, and quantitative interpretations of the data using Markov Chain and Successive Orders of Scattering vector radiative transfer codes and scene models will be provided to highlight the instrument's capabilities for determining aerosol and cloud microphysical properties and cloud 3-D spatial distributions. Sensitivity to parameters such as aerosol particle size distribution, ocean surface wind speed and direction, cloud-top and cloud-base height, and cloud droplet size will also be discussed.

Measurements of Polarized Light Scattering by Atmospheric Particles with the Passive Aerosol and Cloud Suite (PACS)

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The UMBC/NASA GSFC Passive Aerosol and Cloud Suite consists in a combination of in situ and remote sensing instruments designed for the measurement of particle's scattering properties including hyperangular and multi-spectral measurements of polarized radiances. The PACS polarimeter is a hyperangular polarimetric imager designed for the remote sensing of aerosol and clouds in wavelengths ranging from the Ultra-Violet (UV) to Short Wave Infrared (SWIR) bands. The current PACS VNIR (Visible/Near Infrared) prototype has flown on board the NASA ER-2 aircraft collecting data from water and ice clouds, and aerosol particles over a variety of surfaces. The PACS angular resolution varies from 60 to 130 angles depending on the wavelength, with a cross track and along track swaths of +/-55degs. Calibration strategies and field results from the PACS polarimeter instruments will be presented and discussed.
The PACS suite also contains an in situ/laboratory component that is designed to help the development of optical models for aerosol and cloud particles as well as to validate the PACS remote sensing measurements. This component is composed primarily by the Polarized Imaging Nephelometer (PI-Neph) Systems developed at the UMBC-LACO laboratories. The LACO PI-Neph instruments measure the P11 and P12 components of the scattering phase matrices of aerosol and cloud particles from about 2 to 178 degrees of scattering angle with angular resolutions on the order of a fraction of a degree. The first PI-Neph instrument has flown in 3 NASA aircrafts collecting data for different aerosol types and has been used for several laboratory experiments. This first system consists of a closed box that measures aerosol particles drawn from an external inlet system and is limited to measure particles that can make through the instrument inlet. A second open air system is currently under constructions and will allow for the measurement of undisturbed aerosols and cloud particles in suspension in the atmosphere. Preliminary data and inversion results from both instruments will be presented and discussed in detail. The open-I-Neph system is currently being designed to fly in the NASA P3 aircraft but it is also conceived with a modular design that will allow relatively easy integration to multiple platforms. This system is particularly useful for the measurement of large aerosols and/or cirrus particles that have problems making through the inlet of the enclosed PI-Neph instrument.

Keywords: Aerosol, Clouds, Polarized Phase Function, Polarized Remote Sensing, Scattering Matrix

Retrievals of cloud microphysical properties from the Research Scanning Polarimeter measurements made during AITT field campaign in the Azores

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Keywords: electromagnetic scattering, polarimetery, remote sensing, cloud droplet size distribution

We present the retrievals of cloud droplet size distribution parameters (effective radius and variance) from the Research Scanning Polarimeter (RSP) measurements made during NASA Airborne Instrument Technology Transition (AITT) program's field campaign, which was based on the Terceira island of Azores archipelago in October 2012. The RSP is an airborne prototype for the Aerosol Polarimetery Sensor (APS), which was built for the NASA Glory Mission project. This instrument measures both polarized and total reflectances in 9 spectral channels with wavelengths ranging from 410 to 2250 nm.

In the case of water clouds the rainbow, observed in the polarized reflectances in the scattering range between 135° and 170°, provides a unique signature that is being used to accurately determine the droplet size and is not affected by cloud morphology. The droplet size retrieval algorithm in this case is very simple, fast and robust. In addition it is possible to apply a non-parametric method, Rainbow Fourier Transform (RFT), to the analysis of polarized observations of the rainbow that allows the droplet size distribution to be retrieved without a parametric model. Of particular interest is the information contained in droplet size distribution width, which is indicative of cloud life cycle. The absorbing band method is also applied to RSP total reflectance observations. The difference in the retrieved droplet size between polarized and absorbing band techniques is expected to reflect the strength of the vertical gradient in liquid water content.

During the AITT campaign the RSP was onboard the NASA's P-3B aircraft together with the High Spectral Resolution Lidar (HSRL). This campaign's data set provides an opportunity to study how well the droplet number concentration and the physical thickness of a cloud can be retrieved using both lidar and polarimeter data, and to compare that with retrievals that use the polarimeter data alone.

Polarized Imaging Nephelometer for Field and Aircraft Measurements of Aerosol Phase Matrix Elements

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Keywords: light scattering, particulate media, in situ measurements, phase function, degree of linear polarization

Aerosols have a significant impact on the radiative balance and water cycle of our planet through influencing atmospheric radiation. Remote sensing of aerosols relies on scattering phase matrix information to retrieve aerosol properties with frequent global coverage. At the Laboratory for Aerosols, Clouds and Optics (LACO) at the University of Maryland, Baltimore County we developed a new technique to directly measure the aerosol phase function (P11) and the degree of linear polarization of the scattered light (P12). We designed and built a portable instrument called the Polarized Imaging Nephelometer (PI-Neph). The PI-Neph successfully participated in dozens of flights of the NASA Development and Evaluation of satellite ValidatiOn Tools by Experimenters (DEVOTE) project and the Deep Convective Clouds and Chemistry (DC3) project.

The ambient aerosol enters the PI-Neph through an inlet and the sample is illuminated by laser light (wavelength of 532 nm); the scattered light is imaged by a stationary wide field of view camera in the scattering angle range of 2° to 178°. (In some cases stray light limited the scattering angle range to 3° to 176°). Data for P11, P12 and volume scattering coefficient is taken every 12…15 seconds.

We have produced volume scattering coefficient time series in flight that had good correlation with the measurement of a parallel TSI integrating nephelometer. We have measured the P11 and P12 of polystyrene latex spheres in flight and on the ground and found good agreement with Mie theory. We have inverted the measurement data in some instances with an AERONET type algorithm to produce size distributions, refractive index, and single scattering albedo. We have flown spirals over AERONET sites in DEVOTE and we have analyzed a few cases and found good agreement between the PI-Neph column average weighted by the linear scattering coefficient and the AERONET retrieval of the ambient phase function.

Our goals are to finalize the analysis of the DEVOTE and DC3 data and provide a number of comparisons to both the onboard particle sizers and applicable remote sensing retrievals. We are also preparing an online accessible database of PI-Neph data (P11, P12 and volume scattering, and derived parameters such as asymmetry factor and LIDAR ratio) versus relative humidity, and aircraft location.

E1
Astrophysical applications

(June 18th, 8:30 AM)

Polarimetry of solar system bodies

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Keywords: linear polarization, solar system, regolith, planets, moons, asteroids, comets, comae, trans-Neptunian objects, interplanetary dust cloud, laboratory simulations, numerical simulations.

Solar light scattered on surfaces or within clouds of solar system bodies is partially linearly polarized, as already emphasized in the 1970s by the interpretation of the observed polarization of Venus through the presence of sulfuric acid droplets within its clouds. This talk is actually intended to summarize our present understanding of the polarization induced by solar light scattering on *irregular dust particles.* Such particles are found on regolitic surfaces formed by impacts over billion of years on some solar system bodies (planets, moons, asteroids, cometary nuclei, trans-Neptunian objects) or within clouds (atmospheric dust clouds, cometary comae and tails, interplanetary dust cloud).

Polarimetric observations of dust in the solar system may be technically challenging, with some signals needing to be isolated from any contaminating source on the line-of-sight, or being limited to small phase angles, or corresponding to different phase angles along the line-of-sight. They are nevertheless of major interest, since they enable comparisons between different regions of a given object (e.g., lunar or Martian surface, cometary coma) and between different classes of objects of a given category (e.g. asteroids, comets, trans-Neptunian objects). Numerous remote Earth-based observations, as well as a few *in situ* observations, lead to typical polarimetric phase curves with a shallow negative branch in the backscattering region (with possibly an opposition effect) and a wide positive branch with a maximum in the 80°-110° region. The variation of the polarization with the wavelength, for a fixed phase angle, may also be monitored for some categories of objects.

Recent results will be summarized, with emphasis on polarimetry of small solar system bodies (comets, asteroids, interplanetary dust cloud), and specifically on changes likely to be triggered by the gradual evolution of dust particles. Interpretation of the data provides information on the geometric albedo, as well as on some physical properties of the scattering medium (i.e., size distribution, morphology and porosity, complex refractive indices). It mostly stems from elaborate light-scattering numerical and experimental simulations, and of comparisons between their results. Recent progresses related to such approaches will tentatively be presented. Finally, promising future observations and simulations will be mentioned.

Polarimetry of transneptunian objects modeled with RT-CB and DDA

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Keywords: electromagnetic scattering, particulate media, coherent backscattering, radiative transfer

Polarimetric observations of transneptunian objects (TNOs) are interpreted using a radiative-transfer coherent-backscattering model (RT-CB) that makes use of a so-called phenomenological fundamental single scatterer (Muinonen & Videen, JQSRT 113, 2385, 2012). Extensive computations with the discrete-dipole approximation (DDA) are then utilized to extract, from the phenomenological single-scattering solutions, physical solutions in terms of the size, shape, and complex refractive index of the scatterers (Zubko, Light Scattering Rev. 6, 39, 2012). For the validity of RT-CB, see Muinonen et al. (Astrophys. J. 760, 118, 2012) and Penttilä et al. (present meeting).

The new RT-CB-DDA modeling allows us to constrain the single-scattering albedo, phase function, and polarization characteristics as well as the mean free path length between successive scatterings. It further allows us to put constraints on the size, shape, and refractive index of the fundamental scatterers. We concentrate on the explanation of the two main types of polarimetric behaviors observed for TNOs, that is, the shallow polarization signatures observed for large TNOs and the pronounced signatures observed for small TNOs (Bagnulo et al., Astron. Astrophys. 491, L33, 2008). The new modeling allows for a systematic analysis of polarimetric observations of atmosphereless Solar System objects.

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One more evidence of left-handed circular polarization in comets: Comet C/2009 P1 (Garradd)

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Keywords: comets, comet C/2009 P1 (Garradd), linear and circular polarization, spectropolarimetry

Comets consist of primordial icy materials and refractory dust grains. A wide variety of organic compounds have been detected in comets and carbonaceous chondrites, and their relevance to the emergence of terrestrial life is widely discussed. A number of amino acids were detected in water extract of carbonaceous chondrites. Presence of bioorganics as precursors of amino acids in comets is expected, but it is difficult to detect it. One of potential evidences of the presence of prebiological organics characterized by homochirality (dominance of molecules of specific handiness) may be the detection of left-handed (negative) circular polarization. Up to now, the left-handed circular polarization has been measured in seven comets: 1P/Halley, C/1995 O1 (Hale–Bopp), C/1999 S4 (LINEAR), C/2001 Q4 (NEAT), 73P/Schwassmann–Wachmann 3, 8P/Tuttle, and 9P/Tempel 1. Measurements of predominantly left-handed circular polarization in all observed comets may be signature of organic grains and testify in favor of excess in cometary organics.

We present the results of spectropolarimetric measurements of linear polarization in the range 3500–9000 Å and imaging circular polarimetry in the narrow-band cometary continuum filter RC (λ = 6480/90 Å) of comet Garradd. These observations were carried out with the focal reducer SCORPIO at the 6-m telescope BTA of the Special Astrophysical Observatory (Caucasus, Russia) on February 14 and April 21, 2012. The comet was observed at phase angles 14º and 35º, helio- and geocentric distances changed within the ranges of 1.708 – 2.492 AU and 1.387 – 1.924 AU respectively.

The maps of intensity and circular polarization (P_c) over the coma and variations of the degree of circular polarization with the distance from the nucleus of comet Garradd are obtained. In both dates, the left-handed circular polarization is detected throughout the coma and its value is as typically measured for other comets. The observed values of P_c are within the range from approximately –0.02% (near nucleus) up to –0.3% at the distance from the nucleus about 50000 km. An accuracy of measurements varies depending on the distance from the comet nucleus: from 0.01% to 0.08%. These results are in a good agreement with those for other comets in which the circular polarization was measured. Detection of left-handed circular polarization in comet Garradd has confirmed our previous conclusion that the observed circular polarization of comets is predominantly left-handed (Rosenbush et al., 2007, 2008).

We will present additional results from our continuing analysis of linear and circular polarization of comet C/2009 P1 (Garradd) and discuss the possible mechanisms of circular polarization origin in this comet.

Scattering of Palagonite (Mars analog dust) Modeled with Ellipsoids

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Keywords: electromagnetic single scattering, ellipsoid, palagonite, Mars analog, comparison with measurements

We study how well measured single-scattering of palagonite mineral dust can be modeled using ellipsoidal model particles (from the database of [1]) and whether best-fit ellipsoidal shape distribution would allow us to suggest a shape distribution parametrization to be used in retrievals from remote sensing measurements of Mars. Dust is very abundant in the martian atmosphere. Due to future Mars lander missions, namely MetNet [2], with suitable optical instruments on-board, we are interested in using ellipsoids in radiative transfer modeling to reach higher information content and better accuracy on retrievals. Direct shape information is not available; thus finding a flexible shape distribution model would be desirable. Unlike in our previous study [3], we now only have laboratory measurements for one sample at one wavelength (632.8 nm) [4]. The refractive index (m) of the sample is not known accurately so, for simulations, we tried several different refractive indices out of which the best fitting results were achieved with Re(m) = 1.6 and Im(m) = 0.0005. These values were thus used throughout the rest of this study.

As expected, ellipsoids are found to fit the measurements significantly better than Mie spheres and somewhat better than spheroids. However, it seems that best-fit shape distributions vary considerably between different matrix elements, making suggestions for a first-guess shape distribution difficult. Also, fitting each matrix element separately results in almost perfect fits, but when fitting the whole scattering matrix simultaneously some matrix elements show considerable deviations from the measurements. It seems that even a simple equiprobable distribution produces good fits.

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The properties of particles in the upper cloud layer of Venus from the observations of glory by the *Venus Express* mission

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Keywords: Venus, atmosphere, clouds, glory, UV-absorption

The images of a full glory on the upper cloud layer of Venus were acquired for the first time with the Venus Monitoring Camera on the *Venus Express* orbiter. The observations were made in three wavelengths (0.365, 0.513, and 0.965 µm). The fact of the observed glory itself suggests that the scattering medium at a level where the radiance comes from is rather homogeneous, and its particles are spherical and their size distribution is narrow. Glory is an optical phenomenon that poses stringent constraints on the properties of scattering particles, which allowed the effective radius of particles in different cloud regions to be estimated from 1.0 to 1.4 µm. This corresponds to the so-called 1-µm mode of the cloud particles of Venus, which, as is known from the previous studies, are believed to be droplets of concentrated sulfuric acid. However, in some cases, the details of the glory feature cannot be explained by scattering by purely sulfuric acid droplets and require the presence of an additional component with a higher value of the real part of the refractive index. We suppose that this material can be ferric chloride or sulfur; both are also candidates for the so-called unknown ultraviolet absorber in the upper cloud layer of Venus. We suggest that the carrier of this component are submicron particles that can participate in the condensation of sulfuric acid droplets in the clouds and form the complex UV-absorbing particles with an increased, as compared to sulfuric acid, real refractive index. For a number of UV-dark and -bright regions observed at small phase angles, it was shown that the considered UV contrasts are caused by variations in the portion of absorbing particles of the submicron mode in the clouds. From changing of the angular position of the glory maximum in the UV phase profiles observed before the local noon, the decrease of the sizes of sulfuric acid droplets (R_{eff} changes from 1.05 to 0.8-0.9 µm) in the upper cloud layer with increasing latitude (from 40°S to 60°S) was revealed. The increase in the amount of 0.9-µm particles may also cause the UV-bright features often observed at about 50°S.

Lunar mare photometry with SMART-1/AMIE

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Keywords: photometry, particulate media, Moon

The SMART-1 spacecraft was the first European lunar orbiter mission, orbiting the Moon in 2004-2006. Its optical/near-infrared camera AMIE mapped the lunar surface with a resolution of some tens to a few hundred metres per pixel. We have taken a sample of over eight hundred AMIE frames, representing most of the mare regions of the near side. We extracted multi-angular photometry from the images by sampling the brightness of the surface and estimating the local observational geometry. This gave us a data set of some 16000 photometry samples in various observational geometries. Due to a relative sparsity of data for any one mare region, we assume that the photometric properties of mare surfaces are similar in all the regions studied and consider the entire data set as representing "average" mare properties. Mare surfaces were chosen because they are smooth, making the estimation of the observational geometry simpler, and also because they are dark, justifying the use of the Lommel-Seeliger scattering law.

We have applied a semi-analytical scattering law, which takes into account mutual shadowing effects between regolith particles. The shadowing contribution is computed from a ray-tracing simulation for a medium of packed spheres, using a range of different porosities and statistical surface roughness parameters. The shadowing is a function of the full observational geometry, including azimuthal shadowing effects. The shape of the shadowing function is determined by the surface porosity and roughness statistics.

We used different statistical methods to estimate parameters of this scattering law from the SMART-1 data, as well as simulated data sets for comparison. Applying the approach to laboratory measurements is also planned. The set of observational geometries in the data set has a strong influence on the conclusions that can be drawn from the data. In every case, however, the observations show an opposition effect which cannot be explained by the shadowing alone. Our proposed explanation for this is the Coherent Backscatter Effect.

DDA modelling of polarimetric observations of Comet C/1996 B2 (Hyakutake)

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Keywords: electromagnetic scattering, cometary dust, discrete dipole approximation

During the apparition of Comet C/1996 B2 (Hyakutake), independent groups of observers carried out polarimetric measurements of its coma spanning a wide range of phase angles α = 36 – 111°. A compilation of these observations in red light at the wavelength of λ = 0.684 μm is presented in Fig. 1 (right) [1–3]. Using the discrete-dipole approximation (DDA) and agglomerated debris particles (Fig. 1, left; for more details, see, e.g., [4]), we model these measurements. We take into account the size polydispersity of the agglomerated debris particles, mimicking what was measured *in situ* for comets.

We have investigated a wide range of refractive indices *m* and found that the agglomerated debris particles with a single value of *m* cannot reproduce the polarimetric response in Comet C/1996 B2 (Hyakutake). However, a mixture of a few homogeneous agglomerated debris particles can quite satisfactorily fit the observations. For instance, Figure 1 shows the response (solid line) for a mixture of three materials: 11% of $m = 1.5 + 0i$, 55% of $m = 1.7 + 0.1i$, and 34% of $m = 2.43 + 0.59i$. These refractive indices are consistent with Mg-rich silicates, organic material, and amorphous carbon, respectively. We stress that, despite the small abundance of material with $m = 1.5 + 0i$, its contribution to light scattering is extremely significant due to the high reflectivity of non-absorbing materials [4]. It is important to stress that our simulation also predicts the negative polarization branch at small α in Comet C/1996 B2 (Hyakutake); whereas, this comet was not observed at such angles. Note that the predicted negative polarization branch is consistent with what was found for other comets.

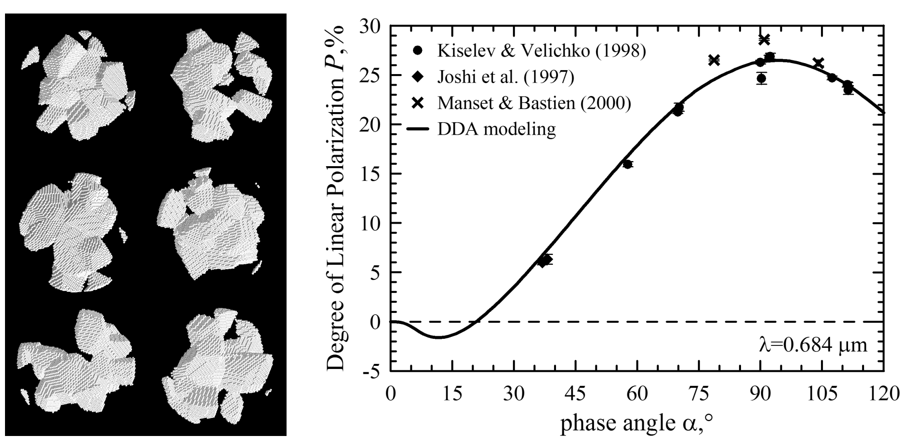

Figure 1 : Agglomerated debris particles (left) and modeling for Comet C/1996 B2 (right).

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Evanescent wave scattering by particles on a surface: Comparison between the discrete dipole approximation with surface interaction and the finite element method

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Keywords: particles on a surface, evanescent wave scattering, DDA-SI, FEM

The need for a real-time, non-obtrusive, nanoparticle characterization system continues to rise. Current methods provide excellent visual imaging of nanoscale materials, yet are unable to provide characteristics such as size, arrangement and composition in real-time without having some effect on the sample. One promising characterization system currently being researched which will provide such characteristics, and in real-time, is the Polarized-Surface-Wave-Scattering System (PSWSS) [1]. This framework functions in a non-invasive manner through measuring the far-field scattering profile of particles on a surface illuminated by evanescent waves generated by total internal reflection of a laser beam. Through inversion techniques, particles characteristics such as the size, shape, arrangement, and composition can be retrieved. A strong theoretical model must first be present in order for this system to provide accurate characterization results.

The discrete-dipole approximation (DDA) is a widely accepted method of solving light scattering by particles from direct illumination. The most well-known application is by Draine and Flatau [2] in the open-source Fortran code DDSCAT. Similarly, ADDA is an open-source C software package developed by Yurkin and Hoekstra [3]. One of the more recent methods developed is the discrete-dipole approximation with surface interaction (DDA-SI) by Loke et al. [4] which was created as an open-source MATLAB computational toolbox based on the work of Schmehl [5]. Being based on discretizing the geometry into dipoles, DDA-SI can accommodate complex-shape scatterers. This can vary from simple geometries such as cylinders, cubes, and spheres, to more complex agglomerates or arrays of particles.

This talk will show how the DDA-SI program package has been verified and validated by comparison against finite element method (FEM) calculations and experimental results. Comparisons are made for the far-field scattering patterns (field and phase) of a sphere placed on a surface and illuminated by an evanescent wave. Results show a good agreement between DDA-SI, FEM and experimental results.

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H1
Waterman session

(June 18th, 11:00 AM)

EM scattering by a bounded obstacle in a parallel plate waveguide

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Keywords: electromagnetic scattering, parallel plate waveguide, T-matrix method

This paper addresses the problem of electromagnetic scattering by a bounded object located inside a parallel plate waveguide. The exciting field in the waveguide is either an arbitrary source located at a finite distance from the obstacle or a plane wave generated far from the obstacle. In the latter case, the generating field corresponds to the lowest propagating mode (TEM) in the waveguide.

A strong motivation behind this paper is that the parallel plate waveguide shows a more controlled environment for scattering measurements than free space. Initial investigations show that measurements utilizing this geometry are accessible [1].

The analytic treatment of the problem relies on an extension of the null field approach, or T-matrix method, originally developed by Peter Waterman, and later generalized to deal with object close to an interface. The entire solution employs the integral representation of the solution. This integral representation approach to solve scattering problems has proven to be a very powerful and useful technique to solve a large variety of scattering problems, not only electromagnetic, but also acoustic and elastodynamic problems. The present paper generalizes this approach further to deal with obstacles inside a parallel waveguide. This problem shows features that reflect both the two-dimensional geometry, as well as the three-dimensional scattering characteristics.

The present scattering problem is to some extent equivalent to a scattering problem with infinite number of images of the scatterer distributed periodically in space. The image approach is usually solved by the introduction of an appropriate Green's dyadic. The bookkeeping problems associated with such an approach are, however, an inconceivable task, and the solution of the problem asks for a more systematic approach.

The results presented in this paper are inclined towards microwave applications. There are, however, no such limitations in the results. The technique applies equally well to applications at higher frequencies, e.g. THz and IR, such as the computation of the scattering effects of impurities in thin films etc.

A series of numerical simulation illustrates the results of the paper.

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Radiative transfer with coherent backscattering compared to exact scattering methods

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Keywords: radiative transfer, coherent backscattering, particulate media, superposition *T*-matrix method

Coherent backscattering (CB) has been recently quantitatively verified as an essential addition to the radiative transfer (RT) approach for correct backscattering enhancement [1]. We continue to develop the RT-CB code by comparing the results against exact simulations using MSTM [2]. We increase the number of constituents in the simulations to 2000 and consider the effect of increasing packing density (*pD*) of the material from 5% up to 30%. The results show good agreement with small *pD*'s (see Fig. 1) and slowly decreasing agreement with larger *pD*'s.

It is known that the RT approach is not valid for large *pD*'s. In Monte Carlo RT the direction of ray after scattering is computed for an independent scatterer. With high *pD* the particles will be in the near-fields of each other which will violate the assumption. The distance between consequent scattering events uses the concept of mean-free-path length but this assumes independent extinction efficiency and Poisson distributed locations. With comparisons against MSTM, we might be able to correct the RT-CB to better adapt to higher *pD*'s. Furthermore, non-spherical scatterers can be tested using, e.g., the discrete-dipole approximation to compute the scattering matrices.

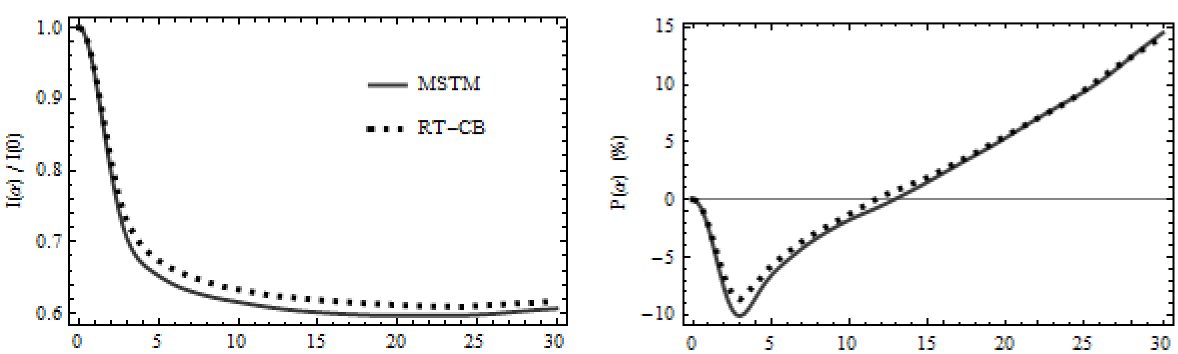

Figure 1. Normalized intensity and degree of linear polarization for phase angle range 0–30° using the MSTM (solid line) and RT-CB codes (dotted line). Computations are for spherical media with kR=68.4 where 2000 spheres with kr=2 and m=1.31+i0 are randomly placed inside with the resulting *pD* of 5%.

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Linearized Mie and T-matrix Scattering: Applications in Aerosol Retrievals and Sensitivity Studies

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Keywords: Linearized Mie/T-matrix scattering, radiative transfer, aerosol microphysics sensitivities

It is important to obtain accurate quantitative information on aerosol optical properties on a global scale. Although retrievals of aerosol optical thickness are common, it is hard to obtain additional aerosol information without polarimetric sensors such as the Research Scanning Polarimeter (RSP). In recent years, the potential for retrieving microphysical aerosol parameters (refractive index, size distribution parameters) has been demonstrated. For example, most of the full-physics X-CO_2 retrieval algorithms for OCO-2 now use microphysical parameterization of ancillary aerosols. These studies use linearized Mie scattering code in combination with linearized vector radiative transfer in order to make accurate forward-model simulations of radiation fields and associated Jacobians with respect to these aerosol parameters.

We extend these methods by means of a linearization of the T-matrix electromagnetic formalism for non-spherical particles. Our starting point is the popular and widely used T-matrix algorithm from NASA-GISS [Mishchenko et al., 1996]. We show that the T-matrix theory for individual particles is analytically differentiable with respect to the three microphysical variables—the real and imaginary parts m_r and m_i of the particle refractive index, and the particle deformation characteristic or shape parameter (for spheroids, this is the ratio of the semi-axes; for cylinders, the diameter/height ratio; for Chebyshev particles, the deformation parameter). The theory for poly-disperse aggregates is also differentiable with respect to particle size distribution parameters, and includes a bimodal-aerosol option. Linearized Mie and T-matrix packages in Fortran 90 are publicly available from the authors [Spurr et al., 2012].

We have combined the linearized Mie/T-matrix codes with the linearized vector radiative transfer model VLIDORT as part of a comprehensive tool for aerosol sensitivity studies and retrievals. The tool also contains a line-by-line absorption cross-section facility, and is able to generate a wide range of Jacobians for spherical and non-spherical aerosol microphysical parameters. The tool can be deployed for ground-based aerosols (e.g. AERONET) as well as sensors such as RSP on aircraft. We have used the tool to investigate sensitivity for non-spherical dust particles. We find that polarization measurements from multiple angles and wavelengths provide a rich source of information on aerosol particle size and refractive index, and we demonstrate that retrieval sensitivities and uncertainties from polarization measurements also show strong dependence on sun-satellite-Earth geometrical configurations.

Note: the name of the person who will make the actual presentation is underlined.

Determining the extinction coefficient of powders by using a comparison between Mie-theory and *T*-Matrix

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Keywords: electromagnetic scattering, particulate media, *T*-matrix method, extinction coefficient

In 1908 Gustav Mie published "*Beiträge zur Optik trüber Medien*" where he showed a complete analytical solution to the Maxwell equations concerning the scattering problem of a sphere. To describe non-spherical particles, Peter Waterman developed the *T*-matrix method which made it possible to numerically solve the scattering of radiation at such particles. But the question arises in which limit it is feasible to use the analytical solution of Mie scattering to predict the radiative transfer in materials like powders and to calculate its extinction coefficient which is an important parameter to characterize the radiative thermal conductivity [1].

The aim of this talk is to describe the influence of the shape of absorbing and scattering particles on the radiation transfer. Therefore the *T*-matrix method based on the null-field theory as suggested by Doicu was used. First it has been shown that the analytical solutions of Mie scattering and the used *T*-matrix code are identical for spheres. Afterwards the T-matrix model was extended in order to describe the scattering at ellipsoids and the influence on radiation transfer for spherical particles with a different shape was studied in order to find a more ideal shape for the particles to raise its extinction coefficient. Additionally the limiting case of a round sphere Mie approximation for real powders was examined.

Another important point was the examination of a two particle system. Therefore it was analyzed how different parameters e.g. the distance between the particles have influence on radiation scattering. All these models were confirmed with IR optical measurements on two material systems (highly absorbing and highly scattering TiO powder and Al powder). As a result the experimental data could be predicted with Mie theory using a bimodal particle size distribution.

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Near-field and far-field optical behaviour of gold nanostructures in the T-matrix approach

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Keywords: plasmon resonance, electromagnetic scattering, optical properties, nanoparticles, *T*-matrix method, SERS

Metal nanoparticles (MNPs) have been intensively studied within the past decade due to their unique properties which find applications in a broad range of different fields, ranging from chemistry to physics, from biology to materials science and medicine. The optical behaviour of MNPs is mainly due to the fact that they support localized surface plasmon resonances (LSPRs), which are excited when an incident electromagnetic radiation creates collective coherent oscillations of the particle free electrons. Such plasmon excitations result in a large enhancement of the electromagnetic field around the nanoparticle, yielding both a strong absorption and scattering of light by the nanoparticle at the plasmon resonance.

We investigate the near-field and far-field optical behaviour of gold nanoparticles through a computational approach based on the multipole expansion of the electromagnetic field and the Transition matrix method. We model the nanoparticles as isolated spheres or dimers, considering both the case of homogeneous composition and the case of nano-shell structures. Upon optical excitation, the maximum near-field enhancements in metal nanoparticles occur at lower energies than the maximum of the corresponding far-field quantities. This effect has been much debated in the literature, but the physical explanation of this apparently universal behaviour of metal particles is still controversial. The understanding of the red shift effect appears particularly important for the optimization of surface enhanced spectroscopies.

In this presentation we will investigate the dependence of the red shift effect on the nanoparticle size and shape, starting our investigation with a homogeneous gold nanosphere and successively extending the description to the case of nanoshell particles and dimers. We will also discuss the physical origin of this effect in terms of the radial field components, following the inspiring work by Messinger et al (1981). Finally we will attempt to draw a comparison with data obtained from Surface Enhanced Raman Scattering (SERS) experiments on gold nanoparticle samples deposited on a substrate.

F1
Micro and nano-optics, biomedical applications

(June 18th, 2:00 PM)

Biomedical applications of gold nanoparticles and multifunctional nanocomposites

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Keywords: Gold nanoparticles, multifunctional nanocomposites, immunoassay, SERS, DNA detection, cell bioimaging, photodynamic and photothermal therapy, materno-embryonic transfer of gold nanoparticles

In the past decade, gold nanoparticles (GNPs) have been widely used in various biomedical applications, including analytical chemical and biological sensing; genomics and immunoassays; optical bioimaging and monitoring of cells and tissues; detection and photodynamic therapy of pathogenic microorganisms; detection and photothermolysis of cancer cells and tumors; wound repair; and targeted delivery of drugs, peptides, DNA, and antigens [1]. The unique optical properties of GNPs are related to localized plasmonic excitations in metal nanostructures interacting with light. These excitations result in resonance-enhanced local fields and, accordingly, in enhanced optical phenomena such as absorption, Mie scattering, Raman scattering, and various nonlinear effects.

Multifunctional nanocomposites that combine therapeutic, diagnostic, and sensing modalities in a single nanostructure are widely used in a new field of nanobiotechnology called theranostics. Although the term "theranostics" has been employed for the first time quite recently [2, 3], it is now rapidly growing and promising field at the crossroads of plasmonics and nanomedicine.

This talk is intended to summarize our recent efforts [4] in analytical and theranostic applications of engineered GNPs and nanocomposites by using plasmonic properties of GNPs and various optical techniques. Specifically, we provide examples SERS platforms for analytical biosensing; visualization and bioimaging of bacterial, mammalian, and plant cells; photodynamic treatment of pathogenic bacteria; and photothermal therapy of xenografted tumors. In addition to recently published reports, we discuss new data on dot immunoassay diagnostics of mycobacteria, multiplexed immunoelectron microscopy analysis of *Azospirillum brasilense*, materno-embryonic transfer of GNPs in pregnant rats, and combined photodynamic and photothermal treatment of rat xenografted tumors with gold nanorods covered by a mesoporous silica shell doped with hematoporphyrin.

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Low loss Electron Energy Loss Spectroscopy: Simulation based on the Generalized Multipole Technique

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Keywords: electromagnetic modelling, electron energy loss spectroscopy, generalized multipole technique

Low-loss Electron Energy Loss Spectroscopy (EELS) has become a powerful tool for characterization of micro- and nanostructures. Here, fast electrons with kinetic energy ranging from 50 keV to 300 keV (approximately 40% to 80% of the vacuum speed of light, considering relativistic effects) are focused on a specimen. In the configurations considered here, the electrons do not hit the specimen, but pass close to its surface. The resulting electron energy loss (EEL) spectrum shows distinct peaks at energy losses of a few electron volts. As the position and shape of the peaks depend on the geometry and the material of the specimen under investigation, the information contained in the EEL spectrum can be used to characterize nanoparticles with respect to their size, shape, and dielectric properties.

To numerically simulate low-loss Electron Energy Loss Spectroscopy (EELS) of isolated spheroidal nanoparticles we developed an electromagnetic model based on the Generalized Multipole Technique (GMT). The GMT is fast and accurate, and flexible regarding nanoparticle shape and the incident electron beam. In GMT the total interior and scattered exterior electromagnetic fields are modeled by several multipoles distributed along the axis of rotational symmetry of the spheroidal scatterer. The unknown expansion coefficients are determined using a Generalized Point Matching (GPM) method. Knowing the expansion coefficients the scattered field can be computed in the nearfield. The incident electron is modeled by the electromagnetic field caused by a point charge in uniform straight motion. Filially for EELS simulations, the scattered exterior electric field intensity is integrated along the path of the electron to compute the energy loss probability.

The implemented method is validated against reference analytical and numerical methods for plane-wave scattering by spherical and spheroidal nanoparticles. Also, simulated electron energy loss (EEL) spectra of spherical and spheroidal nanoparticles are compared to available analytical and numerical solutions. An EEL spectrum is predicted numerically for a prolate spheroidal aluminum nanoparticle. The presented method is a powerful tool for the computation, analysis and interpretation of EEL spectra of general geometric configurations.

Light scattering by a system of nanoparticles upon a thin gold film based on the Discrete Sources Method.

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Keywords: extreme scattering effect, optical antenna, discrete sources method

Light scattering by system of nanoparticles has become a subject of great interest due to a vast field of their potential applications. In particular considerable attention has been paid to the analysis of light scattering properties of optical antennas, which are usually systems of noble metal nanoparticles deposited at an interface. Due to the unique properties of noble metal nanostructures at optical frequencies optical antennas allow to enhance the interaction between light and matter and provide a desired directivity of the radiation.

The extreme scattering effect (ESE) that has been reported recently [1] appears in the evanescent wave region and consists in a sharp increase of the energy transmitted through thin noble metal film with an irregularity inside or near the film. It has been demonstrated that ESE doesn't depend on the thickness of the film, as well as on the shape and material of the irregularity, but is strongly affected by the film's material.

The discrete sources method (DSM) is known to be one the most flexible and inexpensive techniques for solving boundary value problems for Maxwell equations [2]. The DSM is a semi-analytical surface based meshless method and doesn't require any integration procedure over the scatterer surface. In the frame of the DSM the approximate solution for scattered field everywhere outside a local obstacle is constructed as a finite linear combination of the fields of discrete sources (DS) distributed inside the scatterer. If the sources incorporate the Green Tensor of the layered structure the solution satisfies Maxwell's equations, the required conditions at infinity and transmission conditions enforced at the layered interface. Advantages of the DSM can be attributed to the flexibility of the choice of the DS system as well as to the possibility to control the actual convergence of the approximate solution to the exact one by posterior evaluation of the obstacle surface residual in the least square norm.

Inspired by the optical antennas research and the extreme scattering effect we would like to present a research devoted to the analysis of light scattering by a system of gold nanoparticles upon a thin gold film in the presence of ESE. Differential scattering cross-sections in the far field are going to be presented during the conference for different configurations of gold nanoparticles.

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Scattering of surface plasmon-polaritons and evanescent waves by shallow diffraction grating

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Keywords: scattering of surface waves, diffraction grating, enhancement, focusing

Experimental measurements of diffraction intensity under conditions when polarization of incident beam is changed from S (TE) to P (TM) give possibility to clearly show the effect of surface plasmon-polaritons (SPPs) excitation and their participation in scattering and diffraction, contrary to the case when they are not excited. The diffraction of S-polarized light characterizes scattering conditions when SPPs are absent, while for P-polarization they are excited and significantly increase the scattered intensity.

The sample under investigation was a gold film (of optimal thickness for SPPs excitation) on a glass (BK-7) substrate. A 20 nm transparent dielectric polymethylmethacrylate (PMMA) film was evaporated onto the gold film. Using electron beam lithography, a diffraction grating (DG) was made in it, with rectangular holes of 1.25 μm width and period of 2.5 μm. SPPs were excited by a semiconductor laser (λ = 650 nm). Polarization of the incident laser light can be set to be S or P. The angles of incidence (γ) and scattering (θ) can be varied. The DG surface can be observed with an optical microscope, showing local distribution of scattered light along the surface of DG grooves.

The experimental measurements showed that, despite the theoretical predictions, cross polarized components of rather significant intensity were present in scattered light. An analyzer in front of the photoreceiver was used to decrease their influence. For this reason all the measured intensities are marked by two indices indicating orientation of the polarizer and analyzer.

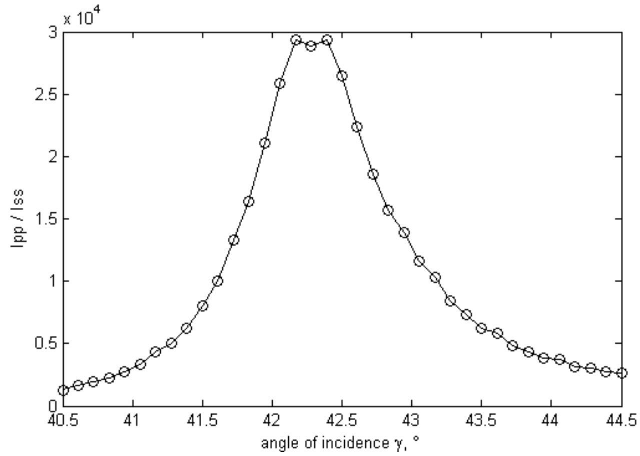

Fig. 1. Angular dependence of enhancement factor Ipp/Iss of DG with 2.5 μm period.

Angular dependence of scattered intensity was measured for each γ value, and its peak intensity was related to this γ value. In such a way the Ipp(γ) and Iss(γ) dependencies were measured and their ratio was calculated and plotted in Fig. 1. From these data it follows that the enhancement factor under optimal conditions can be as high as 30000. This means that SPPs excitation enhances diffraction so significantly as compared to the case of evanescent wave diffraction by the same DG.

The microscopic image of DG surface shows focalization of scattered light into very narrow (about 0.2 μm) sub-wavelength strips.

The described properties of SPPs scattering seem to be promising for elaboration of optical biosensors and actuators that allow optical catching of particles from gas or liquid media.

Possibilities of functionalized probes in optical near-field microscopy

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Keywords: near-field microscopy, tip-enhanced Raman scattering, functionalized probe

Functionalized probes found wide application in Atomic Force Microscopy for the specific recognition of single molecules and in force spectroscopy. At the same time it found only minor application in Near-Field Optical Microscopy in spite of the possibility to separate specific interactions cannot be excessive in any investigations.

Main obstacle in this way may be the consideration of fluorescence as the only way to receive optical signal from the system of interest. However fluorescence presumes resonant excitation what in the case of strong local fields in near-field optics results in fast bleaching and photodegradation of probes based on fluorescence. Only few examples of the use of rare earth ions or nitride-vacancy luminescent centers in diamond exist at the moment as the use of Forster energy transfer from the tip-donor to the acceptors in the system of interest didn't find wide application.

At the same time the use of Raman scattering doesn't demand resonance excitation and opens the way for the production stable probes providing optical signal of Raman scattering from molecules functionalizing tips. Tip-enhanced Raman scattering (TERS) from molecules functionalizing tips provides optical signal sensitive to the local environment of the probe during the scan in different branches of scanning probe microscopy. Basing on such approach we propose optical Raman probes sensitive for different specific interactions for near-field microscopy itself or acting as the supplement for the existed methods of atomic force microscopy.

From the other side such probes should help to resolve the problem of the normalization in TERS itself. The map of the TERS signal obtained at scanning cannot be considered as the distribution of the material of interest because the registered intensity depends on the unknown distribution of the local enhancement factor. The addition of a reference material to the investigated system cannot be considered as appropriate as that material would contaminate the system and in no way can provide the uniform distribution of that material on the atomic scale. At the same time the idea of currying of the constant amount of a reference material on the tip to any measurement points to register additional reference signal proportional in such a way only to the local enhancement gives elegance solution of this problem. Examples of the proposed applications are presented.

Theory of light absorption in nanoscale dielectric conical particles

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Keywords: electromagnetic absorption, conical particle, silicon

Due to their combined light guiding and focusing capabilities, conical particles have always been at the forefront of many technological advances. They have recently gained further attention in the field of metrology and, more particularly, in the context of the Laser-assisted Atom Probe Tomography technique where the question of their peculiar light absorption properties has been raised. Conical silicon tips irradiated with high-fluence (~100 mJ/cm^2) laser pulses have indeed shown sharp holes, indicative of strongly localized optical absorption (Fig 1). Furthermore, according to the cone angle α, the holes distribute in two distinct ways. While particles with a large cone angle (α ~ 10° or more) are characterized by thick single holes in each resonant cross-section [Fig. 1(a)], particles with smaller cone angles (α ~ 5°) present multiple sharper holes [Fig. 1(b)].

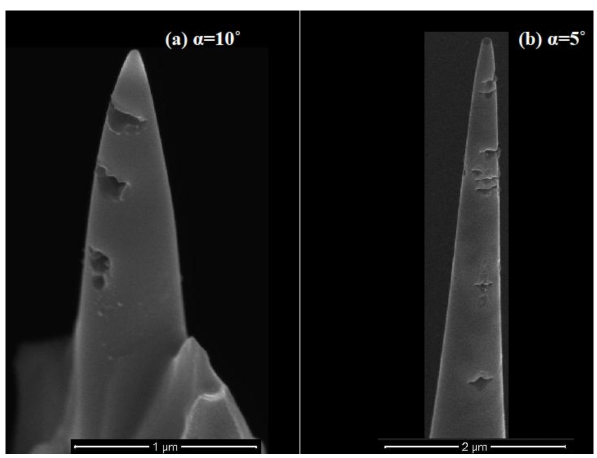

Figure 1. Scanning Electron Micrographs of conical Si tips with (a) 10° and (b) 5° cone angles after high-fluence infrared irradiation (~100 mJ/cm^2)

In this talk, we develop a theory of absorption in conical particles. First, we show that the analytical Mie theory of absorption by infinite cylinders can be generalized to conical particles by assimilating a cone to a stack of cylinders with varying radius. The location of the holes indeed proves to precisely correspond to the radii of resonant absorption in infinite cylinders. Next we show that, in addition to the Mie field, a perturbation wave is generated at each resonant cross-section and guided into the cone. The interference between these guided waves and the Mie field explains the shape of the holes and the presence of multiple holes.

G3
Remote sensing

(June 18th, 4:00 PM)

On the sensitivity of space-born photometry and polarimetry in the UV to natural variations in radiance emerging from open oceans

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Keywords: remote sensing, UV, photometry, polarimetry, ocean color, CDOM, electromagnetic scattering,

Future ocean-color observing missions such the NASA/Pre-ACE (Aerosols-Clouds-Ecosystem) mission will include observations in the ultraviolet (UV) part of the spectrum to *(i)* better constrain the amount and variation of colored dissolved organic matter (CDOM) in the ocean, and *(ii)* detect and possibly correct for the presence of absorbing aerosols. In addition, they are considering the benefits of obtaining space-borne polarimetric data to support these two objectives. In this talk, we focus on the sensitivity of total and polarized reflectance observed in the UV at the top of the atmosphere (TOA) to variations in ocean color caused by changes in CDOM. Not only does CDOM absorption strongly affect the underwater light in the UV, it is also highly variable both spatially and temporally. We discuss quantifying the variability of CDOM UV absorption for open oceans, apply the results to radiative transfer studies of total and polarized water-leaving radiance, and assess the corresponding impact on TOA observations. We also analyze the corresponding impact on TOA observations of the *un*-polarized radiance, which is obtained by subtracting the polarized TOA radiance from the total TOA radiance. This radiance is more sensitive to changes in oceanic scattering properties than the total radiance; thus, properties of the *un*-polarized TOA radiance may form the basis for a novel approach to remote sensing of atmosphere-ocean systems.

Note: the name of the person who will make the actual presentation is underlined.

Abstract, XIV Conference on Electromagnetic & Light Scattering
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Aerosol Classification Using Multiparameter Retrievals from Remote Measurements Made on Space and Other Platforms

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Keywords: aerosol, classification, remote sensing, AERONET, PARASOL, POLDER, polarimeter

Over the past several decades, since the development of global aerosol measurements by satellites and AERONET, it has proven useful to classify observed aerosols into several major types (e.g., urban-industrial, biomass burning, mineral dust, maritime, and various subtypes or mixtures of these). Such classification can help in understanding aerosol sources, effects, and feedback mechanisms, in improving accuracy of satellite retrievals and in quantifying assessments of aerosol radiative impacts on climate. With ongoing improvements in measurement capability, the number of aerosol parameters retrieved from spaceborne and suborbital remote sensors has been growing, from the initial aerosol optical depth at one or a few wavelengths to an extensive list. These parameters are obtained from a variety of sensors such as the AERONET surface-based sun-sky photometers, the POLDER spaceborne polarimeters, the RSP airborne polarimeter, the new 4STAR airborne sun-sky spectrometer, and combinations of data from these sensors with data from the OMI spaceborne spectrograph, or vertically resolved data from the CALIOP spaceborne lidar and the HSRL airborne lidar. Examples of aerosol intensive parameters available from these sensors include complex refractive index, single scattering albedo (SSA), and depolarization of backscatter, each at several wavelengths; wavelength dependences of extinction, scattering, absorption, SSA, and backscatter; and several particle size and shape parameters.

Making optimal use of these varied data products requires objective, multi-dimensional analysis methods. Our methods, analogous to those used with HSRL data, use Mahalanobis distance to assign any given multidimensional (i.e., multiparameter) observation to the pre-specified cluster (aerosol type) to which it is most similar. The pre-specified clusters are defined using AERONET-retrieved parameters for sites and months where a specific type of aerosol is known to dominate. These aerosol types include urban industrial (for both developed and developing economies), biomass burning (for both Amazonian and African Savanna smoke), mineral dust, and marine. Dimensions we currently use include extinction angstrom exponent, absorption angstrom exponent, single scattering albedo and its wavelength dependence, real and imaginary refractive index, and indicators of particle size and sphericity. We show example results including identification of aerosol type using aerosol parameters retrieved from the POLDER-3 polarimeter on the PARASOL microsatellite.

Preferred mode of presentation: Oral.

Development of an AERONET Aerosol Climatology Using Cluster Analysis

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Keywords: Aerosol Climatology, AERONET, Mahalanobis distance, Cluster Analysis

The Mahalanobis distance is a statistical tool that can be used to determine if a particular data point belongs to a specific cluster as well as to determine whether two clusters of data points are similar or different. We apply this concept to the AERONET Level 2 data set. Using Mahalanobis distances we are able to distinguish six aerosol types which can be classified as (1) Urban Industrial (U.S. and European cities), (2) Developing Urban (primarily Asian cities), (3) Smoldering biomass (mainly South America), (4) Flaming biomass (mainly Africa), (5) Dust (Saudi Arabia, Cape Verde, etc.) and (6) Maritime (Hawaii, Midway Island, etc.). To define the Maritime cluster we use the approach of Sayer *et al.* (JGR 117, 2012), *i.e.,* filter AERONET data at island sites using criteria on optical depth and extinction Angstrom exponent ($\tau_{500} \leq 0.2$, $0.1 \leq \alpha_{ext} \leq 1.0$) and calculate other optical properties using AERONET-retrieved volume size distributions and model refractive indices. Of the many AERONET parameters available for the analysis we have chosen the following basic set: Extinction and Absorption Angstrom Exponents (870nm/440nm), Single Scattering Albedo, and Real and Imaginary Index of Refraction (at 440 nm). In some of our studies we have used parameters at different wavelengths and have included other parameters such as the sphericity of the particles and the wavelength dependence of single scattering albedo. We describe the effect of including more or different parameters in our analysis. Using cluster-to-cluster five-dimensional Mahalanobis distances for a variety of sites at different seasons, we are able to generate well defined reference clusters for the various aerosol types. After defining the basic clusters for each aerosol type we analyzed nearly all of the AERONET data sites and determined the Mahalanobis distance from each point to the six reference clusters and thus determined the frequency of aerosol type for each site. For each site we generated pie charts showing the fraction of aerosol measurements for each aerosol classification. We have also generated month-by-month histograms of the aerosol type at each site. Using these results we are able to produce a map showing the dominant aerosol type in various regions of the world. This work is a first step towards developing a global aerosol climatology. We compare our results with previous AERONET climatologies (Dubovik *et al*. J. Atmos. Sci., 59, 590 2002; Cattrall *et al.* JGR, 110, 2005) as well as with results generated by MODIS, OMI and CALIPSO.

(Oral presentation preferred)

GRASP Algorithm: Rationale, Structure, Applications, Performance

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Keywords: remote sensing, atmospheric aerosol, high performance computing

We present unified GRASP (Generalized Retrieval of Aerosol and Surface Properties) algorithm developed for aerosol properties from diverse remote sensing observations including observations by radiometers and lidars from space and ground. GRASP is designed for retrieval of the properties of both aerosol- and land-surface-reflectance from remote sensing observations in cloud-free conditions. The idea of a single unified algorithm occurred during efforts on developing and improving the AERONET inversion algorithm for ground-based radiometers, the PARASOL imager algorithm that derives both aerosol and surface properties, and the LiRIC and GARRLiC algorithms for inverting a combination of measurements by lidar and radiometer. The developments of retrieval algorithms for ground-based and satellite observations are commonly considered as completely independent and different efforts. At the same time, there are fundamental similarities in content and structure of many aerosol retrieval algorithms. For example, accurate modeling of solar radiances observed from both ground and space requires similar calculations of gaseous absorption, light scattering by aerosol and cloud particles, surface reflection, and full transfer of radiation in the atmosphere. In addition, the principles used for optimizing the performance of numerical inversion are very similar, and even identical in most of our inversion algorithms. During our efforts to develop the AERONET, PARASOL, LiRIC and GARRLiC retrievals, the clear benefits of emphasizing the similarities in the different retrievals became evident. First, using the same blocks of programs for forward modeling and inversion assures consistency of the different algorithms and the resulting aerosol products. Second, any improvement achieved for one application can be easily transferred and implemented for another related application. The third and probably most promising aspect is the possibility of a relatively straightforward adaptation of the developed code/algorithm to a multi-instrument inversion. For example, the latest version of the PARASOL algorithm (a prototype of GRASP) can be applied to either PARASOL or AERONET, or their combination; with minor modifications it can include lidar data (when available). Moreover, the algorithm can use the *new multi-pixel concept* - a simultaneous fitting of a large group of pixels with additional constraints limiting the time variability of surface properties and spatial variability of aerosol properties. This principle provides a possibility to benefit from multi-instrument inversion even if the observations by different instruments are not exactly co-incident or co-located. Such synergetic multi-instrument retrievals are expected to result in higher consistency and accuracy than typical aerosol products.

We discuss the algorithm structure and illustrate its application to a variety of remote sensing applications. Additionally, we present the implementation of GRASP as highly parallelized routine ported to GPGPU accelerator. This approach was developed to achieve sufficient speed of calculations for applying such complex algorithm as GRASP for processing large volumes of satellite data.

Speeding Up Radiative Transfer Calculations and Complex Satellite Retrievals with GPGPU Computing

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Keywords: radiative transfer, multiple scattering, remote sensing, high performance computing, GPGPU, algorithm evolution

We discuss the possibility to accelerate the latest generation retrieval algorithm developed by Dubovik et al. (2011) for deriving enhanced aerosol properties from satellite observations. This algorithm has been recently named GRASP (Generalized Retrieval of Aerosol Surface Properties). GRASP retrieves properties of both aerosol- and land-surface-reflectance in cloud-free environments. The algorithm is based on highly advanced statistically optimized fitting and deduces nearly 50 unknowns for each observed site. The algorithm derives a similar set of aerosol parameters as AERONET including detailed particle size, the spectral dependence on the complex index of refraction and the fraction of non-spherical particles. The algorithm uses detailed aerosol and surface models and fully accounts for all multiple interactions of scattered solar light with aerosol, gases and the underlying surface. All calculations are done on-line without using traditional look-up tables. As a result, GRASP retrievals take much longer than a look-up table based algorithm. Initially, it took ~10 sec. for inverting data over one pixel. With this calculation speed it would be difficult to apply GRASP to satellites data processing, which has to handle millions of pixels per day. The bulk of computing time is spent for radiative transfer calculations.

Accelerators like GPGPUs – General Purpose Graphic Processing Units – have a highly parallel design, which suites perfectly for many scientific calculations. CPU based systems show a performance increase of about 100 fold within one decade, yet hybrid CPU - Accelerator based systems can give a performance increase of about 1000 fold within one decade due to energy- and cost-efficient scalability. 10 TFlop/s of performance and more are readily available even for smaller sized companies and organizations.

We achieved a remarkable performance increase of the GRASP algorithm by porting it to a GPGPU accelerator. We will demonstrate the speedup and the process how to achieve this speedup on the example of the radiative transfer calculations of the GRASP algorithm. Additionally, we show how scientists and software engineers need to cooperate to evolve the algorithm to production capabilities.

References:

Dubovik, O., M. Herman, A. Holdak, T. Lapyonok, D. Tanré, J. L. Deuzé, F. Ducos, A. Sinyuk, and A. Lopatin, “Statistically optimized inversion algorithm for enhanced retrieval of aerosol properties from spectral multi-angle polarimetric satellite observations”, Atmos. Meas. Tech., 4, 975-1018, 2011.

B2
Light scattering

(June 19th, 8:30 AM)

The optical properties of ice crystals: the solutions based on the invariant imbedding method

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Keywords: electromagnetic scattering, invariant imbedding method, hexagonal ice crystal

The invariant imbedding method (IIM) pioneered by Johnson (1988) offers an approach different from the extended boundary condition method (Waterman, 1971) to compute the T-matrix of a dielectric particle. In the IIM, an arbitrarily shaped particle is treated as an inhomogeneous sphere that is then divided into a number of layers. A recursive formula based on an integral volume equation is used to compute the T-matrix of the layered sphere. Recently, we applied the IIM method to compute the optical properties of spheroids and circular cylinders with size parameters up to 300 (Bi et al. in press). The IIM was also applied to simulate the optical properties of various inhomogeneous particles.

In this talk, we will present some new advances in applying the IIM to the simulation of the optical properties of ice crystals that do not have rotational symmetry. Because IIM offers a rigorous way to account for the random orientations of the scattering particles, the IIM solutions offer a benchmark reference for the validation of some numerical approaches such as the finite difference time domain (FDTD) technique, the discrete dipole approach (DDA), and the pseudo spectral time domain (PSTD) method that require repeated computations for different orientations in order to average the optical properties of randomly oriented particles.

Note: the name of the person who will make the actual presentation is underlined.

The slope of the scattering function for strict forward and backward scattering

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Keywords: electromagnetic scattering, scattering function, forward and backward scattering

We consider single light scattering by a collection of particles. An important role is played by the scattering function. This determines the intensity of the light scattered in a certain direction when polarization is ignored. Many computed and measured scattering functions can be found in the literature for a great variety of particles. The scattering function depends, in general, on a polar angle, θ, in the closed range $[0,\pi]$ and an azimuthal angle, φ, in the closed range $[0,2\pi]$. However, we only consider collections of randomly oriented particles in which each particle has a plane of symmetry or, otherwise, the mirror particle of each particle is also present in the collection. In this case there is no dependence on azimuth and the scattering function can be written as $F(\theta)$.

To study the behavior of $F(\theta)$ near strict forward scattering ($\theta=0$) and strict backward scattering ($\theta=\pi$) we can extend the range of θ to the range $[-\pi,\pi]$, in such a way, that if θ lies in the range $[0,\pi]$ for an arbitrary value of φ, it lies in the range $[-\pi,0]$ for $\varphi+\pi$. Thus, two half planes are combined into one complete plane of scattering. This enables us to introduce an extended scattering function $G(\theta)$ with θ in the range $[-\pi,\pi]$, which equals $F(\theta)$ for θ in the range $[0,\pi]$, while the relation $G(-\theta)=G(\theta)$ can be used to obtain $G(\theta)$ in the range $[-\pi,0]$ from $F(\theta)$. Thus, $G(\theta)$ is an even function of θ and has the well-known property that its derivative with respect to θ is the odd function $G'(\theta)=-G'(-\theta)$. By letting θ tend to zero in this equation we find $G'(0)=0$. So the slope of $G(\theta)$ is zero in the case of exact forward scattering or, in other words, the tangent is horizontal at $\theta=0$. This means that the right-hand derivative of $F(\theta)$ is zero when θ is zero or, equivalently, that the tangent of $F(\theta)$ tends to become horizontal when θ approaches zero. In a similar way we can show that the left-hand derivative of $F(\theta)$ is zero when $\theta=\pi$ or, equivalently, that the tangent of $F(\theta)$ tends to become horizontal when θ approaches π.

Summarizing, by using the properties of the extended scattering function we have revealed the behavior of the tangent of $F(\theta)$ near the strict forward and backward scattering directions. This is not only interesting in itself, but also has several applications, like devising approximate scattering functions, checking numerical calculations and serving as a constraint for the extrapolation of experimental data to $\theta=0$ and $\theta=\pi$.

Multipole light scattering by arbitrary shaped nanoparticles

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Keywords: light scattering, multipoles, extinction, scattering cross sections, discrete dipole approximation, Si nanoparticles

Experimental and theoretical investigations of multipole light scattering by nanoparticles located in homogeneous or non-homogeneous environments are performed. The discrete dipole approximation is used. In general, only total extinction, absorption, and scattering cross sections are calculated within this approach, without obtaining explicit information about separate contributions of different multipole moments. For spherical nanoparticles in homogeneous environment, contributions of multipole moments can be obtained with the help of Mie theory. In our work, a novel theoretical approach allowing the multipole decomposition of extinction and scattering spectra by arbitrary shaped nanoparticles located in homogeneous environment or near a plane surface is developed. Using this approach it is possible to get information about the role of different multipole moments in the resonant light scattering. Special attention is given to the first multipoles up to magnetic quadrupole and electric octupole moments. Angular distributions of light radiated by these multipoles located close to a dielectric or metal plane surface can be obtained by this method. Multipole scattering of surface plasmon polaritons by nanoparticles located on a metal surface is also discussed.

The developed approach is applied for analysis of experimental scattering spectra by spherical Si nanoparticles located on dielectric substrates. Si nanoparticles were fabricated by laser ablation of bulk and thin film substrates. The scattering properties of Si nanoparticles were measured by single particle spectroscopy. It is demonstrated that spherical Si particles with radii between 50-100 nm have strong resonant magnetic dipole and electric dipole responses in the visible spectral range. Si nanoparticles resonantly interact with both electric and magnetic light fields. Comparison of theoretical results with experimental data shows good agreement with respect to spectral positions of the multipole resonances and their relative strengths. Multipole optical responses of Si nanoparticles with cylindrical, conical, and cubic shapes are also calculated and discussed. In particular, it is showed that it is possible to design Si nanoparticles having the electric dipole and magnetic dipole resonances at the same wavelength. Generalization of the developed approach to complex nanoparticle systems is discussed as well.

Parallel scattering-order formulation for the discrete dipole approximation method

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Keywords: Discrete dipole approximation, parallel processing, scattering-order formulation

The discrete dipole approximation (DDA) is a widely-used method in modelling light interaction with arbitrarily-shaped scatterers. It is common knowledge that the limitations of this method lie in the size of the target object, exacerbated by high refractive indices; the amount of available RAM and computational time becomes a bottleneck. To overcome this, schemes that distribute the memory and processing have utilized.

We implement a scheme to parallelize the system of linear equations DDA based on the scattering-order formulation. In this approach, only a small fraction of the total RAM required for the interaction matrix is used at any one time. Moreover, the iterative calculation can be performed in parallel as operations on chunks of the linear system are distributed over multiple processors. The availability multiple and multi-core CPUs as well as GPUs have made parallel processing feasible on personal computers and portable devices.

The conditions under which this method attains convergence (or otherwise) is investigated. With regard to the scatterer, its refractive index, size, shape and how the matter is distributed will affect how quickly convergence is attained, if at all. We apply this method to model large optically-driven micro rotors with complex geometry. We also compare the convergence against our implementation of the Gauss-Seidel method.

Calibration of optical traps with nonspherical particles using pseudopotentials

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Keywords: optical tweezers, optical torque, *T*-matrix method

Optical tweezers can be used to measure forces on the order of piconewtons, as well as to use such forces to trap and move microscopic particles. This has enabled optical tweezers to become a valuable quantitative tool in biophysics, cell biology, and other fields. However, it is first necessary to calibrate the optical tweezers system. The most common approach is to assume that the trap can be represented by a linear spring or, equivalently, by a quadratic potential. This reduces the calibration task to determining the spring constant. The most common methods involve displacing the particle by viscous drag due to a known flow speed by moving the microscope slide or the trapping beam, or by measuring the power spectrum of thermal motion within the trap. The power spectrum is Lorentzian, with a corner frequency where the effect of the trap and free diffusion are equal. Since the diffusion coefficient depends on the viscous drag, both of these methods depend on the size and shape of the particle, and the viscosity of the surrounding fluid being known. This restricts the applicability of these methods. An alternative approach is the determine the potential from the statistics of thermal motion in the trap using the Boltzmann distribution, often called the “equipartition method”. It is usual to assume that the potential is quadratic, and to fit measured position occupation data to a Gaussian in order to obtain a smooth potential.

It has been suggested that for some measurement tasks, such as atomic force microscopy using an optical trapped probe, non-spherical particles are desired. Since the force on a non-spherical particle in an optical trap depends on its orientation as well as its position, the force can no longer be described by a potential (in 3D space). Such non-spherical particles typically have a preferred orientation within the trap, and will occupy a range of orientations about this equilibrium orientation due to rotational Brownian motion. Therefore, while the force will vary over time, we can determine a time-averaged force that will be a function of position. This suggests that the position occupation probability of the particle can used to find a “pseudopotential” from which the time-averaged force can be found.

Here, we aims to see if the pseudopotential potential can accurately give the time-averaged forces on a nonspherical particle in our trap. We consider the case of a cylinder trapped by either one or two traps, through calculation of the optical forces and torques using the *T*-matrix method. We find that, for small displacements, the time-averaged force is linear with displacement, and accurately given by the pseudopotential. For larger displacements, we see that the gradient of the pseudopotential deviates significantly from the time-averaged force, and that the pseudopotential is non-quadratic. The method has promise as a calibration technique, but it is important to determine the range of displacements over which results will be accurate.

Work done on particles in optical tweezers and frequency shifts

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Keywords: optical tweezers, optical force, optical torque, rotational frequency shift

While optical tweezers, where a tightly focused laser beam is used to trap a dielectric particle, is usually described in terms of elastic light scattering, it, strictly speaking, involves inelastic scattering. When the trapped particle moves or rotates, as it will due to Brownian motion even after it has been trapped, work will be done by the optical force and torque. This energy is lost from the trapping beam, and results in a frequency shift of the beam. The relationship between work done by radiation pressure and Doppler shifts has been known for a long time, having been used by Bartoli in 1876 to obtain a quantitative prediction of radiation pressure, and Zander in 1924 to model solar sails. The rotational equivalent, rotational frequency shift, was noted by Righi in 1884, and linked to angular momentum by Atkinson in 1935 (motivated by Beth's work on optical torque). These serve to explain the work done by radiation pressure, which is responsible for the "scattering force" in optical tweezers, and optical torques.

However, frequency shifts must also occur when work is done by the gradient force, which acts to move dielectric particles towards the focus. This is unlike the Doppler shift which gives the work done by radiation pressure. With the Doppler shift, as the particle moves in the direction of propagation, the light is red-shifted in the rest frame of the particle, resulting in the same frequency shift for side-scattered light, and double that for back-scattered light, as viewed in the original reference frame. Thus, positive work is done when the particle moves in the direction of propagation, and the beam loses energy. Similarly, negative work is done when the particle moves against the direction of propagation, and the beam gains energy. The frequency shift due to the gradient force, on the other hand, must be a red-shift when the particle moves towards the focus, whether it does so with or against the direction of propagation, or from the side.

Therefore, the frequency shifts that accompany work done by the gradient force arise from a physically distinct origin compared to the conventional Doppler effect accompanying work done by radiation pressure. A key feature is that a focused beam is required for the gradient force frequency shift. We discuss the role of the Gouy phase shift in the gradient force frequency shift, and discuss how frequency shifts highlight features of optical tweezers, such as the balance between scattering and gradient forces, the conservative nature of the gradient force and the non-conservative nature of the scattering force, and the roles of spin and orbital angular momentum.

On linear operators constituting Green's function for polarized radiative transfer equation

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Keywords: radiative transfer, Green's function, linear operators, eigenfunctions

Clear expressions for polarized radiative transfer equation in different curvilinear coordinate systems were obtained recently, but the solution of these equations is still a problem. Green's functions for plane-parallel, spherical and cylindrical symmetry of radiation field in homogeneous isotropic infinite medium are known, but only in plane-parallel case this is a classical expansion in eigenfunctions and adjoint functions of homogeneous polarized radiative transfer equation (PRTE).

This talk is a discussion of possibilities to proceed further. Eigenfunctions of homogeneous PRTE are considered as linear operators in some Banach spaces, and their properties are reviewed. The construction of eigenfunctions in curvilinear coordinate systems other than spherical and cylindrical is discussed.

Radar Circular-Polarization Ratios from DDA Computations for Realistic Inhomogeneous Media

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Keywords: electromagnetic scattering, circular-polarization ratio, inhomogeneous media, DDA, radar

A basic strategy for observing a small Solar System object using radar is to measure the distribution of echo power in time delay and Doppler frequency for a circularly polarized transmitted wave, in the same and opposite senses of circular polarization. The circular-polarization ratio (μ) is the ratio of the echo power in the same circular-polarization state to that in the opposite circular-polarization state relative to the transmitted signal. Earlier, we have shown that μ is a function of the refractive index and size parameter of the material using the superposition *T*-matrix method for aggregates of spheres (Virkki et al., JQSRT, in press). For more realistic material in terms of composition, we intend to compute electromagnetic scattering using the discrete dipole approximation (DDA) for an inhomogeneous sphere. For a homogeneous sphere, μ is zero at backscattering direction, implying that the spherically symmetric shape does not affect μ increasingly but all contribution to μ is due to the composition. The method is to divide a sphere into N domains by selecting N random seed positions with different refractive indices (n_i), and then setting for each dipole the refractive index of the seed closest to the dipole. For an example result, we use size parameter $x = 5$ for the sphere, orientation-averaged computations, $N = 4$, and mean refractive index 1.50 (no absorption) for two different standard deviations of n (σ_n). Thus, we get $\mu = 0.08$ and $\mu = 0.31$ (at backscattering direction), using $\sigma_n = 0.13$ and $\sigma_n = 0.25$, respectively. This shows that the increase in standard deviation of the refractive indices increases μ. Later on, values measured for materials observed in atmosphereless Solar System bodies at radar wavelengths will be chosen for the refractive indices (e.g., 2.6 + 0.002i for anorthosite). The number of different refractive indices can be increased up to 255 in the ADDA software that we are using for the DDA computations (Yurkin and Hoekstra, JQSRT 112, 2011).

A0
Aerosols / LIDAR / Clouds

(June 19th, 11:00 AM)

Virtual generation of realistic soot particles: Impact to their optical properties.

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Keywords: Nanoparticles aggregates, numerical simulation, light scattering, cirrus clouds, DDSCAT method

Since the emergence of the fractal concept (Jullien and Botet, 1987), the taking into account of soot particles non sphericity gave rise to multiple studies. The experimental interpretation of light scattering by fractal aggregates by Static Light Scattering (SLS) or light extinction implied the development of adapted theory for light-particle interaction (Dobbins and Megaridis, 1991). These studies enabled theoretical calculations of angular scattering cross sections related to the particle fractal dimension d_f, amount of absorbed light and albedo. Up to now, all the studies meaning with aggregate particles usually employ these results.

For these studies, virtual aggregates are usually generated by using DLCA (Diffusion Limited Cluster Aggregation)(Meakin, 1999). The resulting aggregates are most of the time made of primary spheres monodisperse in size and characterized by one point contact between two spheres. Most of the time, TEM pictures present aggregates with primary spheres in overlapping and a coating that may increase the surface of contact between two spheres. The impact of spheres overlapping on fractal prefactor has been evaluated by Brasil, et al., (2001) who introduced the overlapping parameter $\boldsymbol{Cov}$**.** Eggersdorfer, et al., 2011 simulated the thermal sintering effect which creates aggregates with softened outlines but they did not evaluated the impact of this smoothed shape on interpretation of SLS on extinction or albedo.

The aim of this work is firstly to present a method for generating more realistic aggregates by using a 3D level set function. Additionally to the overlapping coefficient $\boldsymbol{Cov}$, we introduced a coating parameter $\boldsymbol{\alpha}$. The second objective of the present work is to evaluate the impact of this realistic morphology on the optical properties of soot aggregates. Furthermore, the evaluation of angular or total light scattering and extinction cross sections for realistic aggregates is based on the Discrete Dipole Approximation Code DDSCAT7.1 (Draine and Flatau, 2010). For the optical calculations, uniform optical index have been considered. It will be seen that fractal dimension measurement by SLS is affected by $\boldsymbol{Cov}$ and $\boldsymbol{\alpha}$ parameters. Additionally, the impact on light scattered depolarization and albedo will be also presented.

Moreover, one of the advantages of the level set method for generating realistic aggregates resides in its ability to control a space dependent optical property. Indeed, we will evaluate the albedo of soot aggregates covered by a thin layer of ice (Hong, et al., 2008) for the practical study of aeronautics emissions.

Finally, this numerical investigation will be compared to experimental SLS measurements for soot particles generated by MiniCAST 5201C©. For each selected operating conditions of this soot generator, a TEM analysis will be performed in order to determine the corresponding overlapping and coating parameters.

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Effect of surface reflection models uncertainties on aerosol retrieval over land: consideration using PARASOL measurements

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Keywords: remote sensing, surface reflectance, bidirectional reflectance distribution Function.

Different models for surface reflection (different BRDF and BPDF) have been used in the new LOA PARASOL algorithm (GRASP, Generalized Retrieval of Aerosol and Surface Properties) of aerosol retrieval over land. We perform simultaneous retrieval of aerosol and surface properties over different AERONET station, which differ their aerosol and surface properties. The results of the retrievals are compared with AERONET measurements and retrieval. The effect of BRDF and BPDF model uncertainties on aerosol retrieval over land is investigated.

Surface reflectance derivation for the Sentinel-4 atmospheric mission with the GRASP algorithm

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Keywords: Sentinel-4, GMES, Surface reflectance, aerosol properties

Sentinel-4 is an operational mission aiming at continuous monitoring of atmospheric composition over Europe with a short revisit time of one hour. This mission is part of European initiative Global Monitoring for Environment and Security (GMES), which includes the implementation of a sustained operational capacity for Earth observation. The Sentinel-4/UVN instrument is a high-resolution spectrometer covering the ultraviolet (305-400 nm), visible (400-500 nm) and near-infrared (750-775 nm) bands with a respective spectral resolution of 0.5 nm in the ultraviolet and visible bands and 0.12 nm in the near-infrared. The geographical coverage comprises Europe and part of Northern Africa, while the spatial sampling distance is 8 km at 45°N. The Sentinel-4/UVN spectrometer will be embarked on the EUMETSAT MTG-S platforms in a geostationary orbit. The short revisit time should allow the monitoring of the daily cycle of O_3, SO_2, HCHO, and NO_2 concentrations. Requirements have been established by the users' community for the retrieval of these trace gas concentrations, both in terms of total tropospheric column and surface amount. Some of these trace gases such as NO_2 are located in a thin layer close to the surface so that their retrieval requires a very accurate knowledge of the underlying surface reflectance. A specific study, the SURMACED one supported by ESA, has addressed the accuracy with which surface reflectance needs to be determined in order to allow the retrieval of these gas species concentration according to the required accuracy. The study concluded that in order to meet tropospheric NO_2 retrieval requirements, the surface reflectance needs to be known with an accuracy of about 0.005 in the 450nm spectral band, which is much higher than the accuracy currently delivered from space observations (0.1 – 0.03). This objective is particularly challenging due to the radiative processes taking place in this spectral region that are dominated by Rayleigh and aerosol scattering and the generally very low magnitude of surface reflectance. The GRASP[1] (Generalized Retrieval of Aerosol and Surface) method developed at LOA has been selected to meet these requirements. This method simultaneously retrieves the surface reflectance and aerosol properties, these two quantities being tightly radiatively coupled. The GRASP algorithm presents decisive advantages as it is based on highly advanced statistically optimized fitting which deduces nearly 50 state parameters for each observation including detailed particle size distribution, the spectral dependence of complex index of refraction and fraction of non-spherical particles in addition to surface reflectance. The algorithm uses complex aerosol and surface models and fully accounts for all multiple interactions of scattered solar light with aerosol, gas and underlying surface. All calculations are done on-line without look-up tables allowing a continuous variation of the state variables in the solution space. The possibility to meet the surface reflectance requirements from this algorithm applied on Sentinel-4 observations are presented and discussed.

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A Markov chain method for polarized radiative transfer: Forward modeling, and retrievals of aerosol and surface properties

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Keywords: Radiative Transfer, Plane-parallel atmosphere, Spherical atmosphere, Aerosol/surface Retrieval

The Markov chain method (MarCh) is developed for efficient modeling of polarized radiative transfer (RT) in planetary atmosphere / surface systems.

With the plane-parallel atmosphere assumption, MarCh is numerically validated through ongoing benchmarking studies assuming different atmosphere / surface systems and other vector radiative transfer codes. Aiming for aerosol and surface retrieval as well as information content analysis, the calculations are linearized with respect to the surface reflection and to the aerosol properties including refractive index, size distribution, and number density. The surface reflection is composed of a depolarizing term parameterized by the modified Rahman-Pinty-Verstraete (mRPV) model and a polarizing term parameterized by the microfacet model. On such a basis, surface retrieval was tested using Airborne Multiangle SpectroPolarimeric Imager (AirMSPI) measurements of radiance and polarization over targets in California.

With further development of MarCh for pseudo-spherical atmosphere, and using this model as an initial guess, convergent solutions to Titan's full spherical-shell atmosphere are obtained via a combination of Picard iteration and the short characteristic method. Numerical verification is performed against the Monte Carlo method. Using this MarCh methodology, Titan's intensity and Q Stokes component images returned from the Imaging Science Subsystem (ISS) camera on board the Cassini spacecraft are modeled with *a priori* knowledge of aerosol and surface properties measured by the Descent Imager / Spectral Radiometer along the landing trajectory of Cassini-Huygens probe in 2005. Basic agreement is obtained. Current work aims at extending these results to interpreting the photometric properties of Titan's aerosol and surface over the whole planet in various spectral channels.

E2 + I Astrophysical applications + 20 years of "PROGRA2"

(June 20th, 8:30 AM)

20 years of light scattering measurements by the PROGRA2 program Instrumental concept and new developments

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Keywords: polarization, instruments PROGRA2, microgravity, solid particles

The analysis of light scattered by dust in planetary and cometary atmospheres, by interplanetary dust and by regolith on small body surfaces, can provide some information on the physical properties of the grains, mainly their nature, size and porosity. Many remote sensing observations of these bodies have been conducted from telescopes on the ground and from space. A laboratory data base is needed to interpret such measurements, for various kinds of irregularly shaped dust grains. This is the aim of the PROGRA2 project, for deposited and free-floating particles.

The PROGRA2 concept encompasses a suite of five instruments carrying out measurements at different wavelengths between 540 and 1500 nm: PROGRA2-VIS (visible domain), PROGRA2-IR (near infra red domain), PROGRA2-SURF (laboratory deposited grains, in the visible domain), PROGRA2-REGOLITH (deposited particles during reduced gravity, preliminary studies), and PROGRA2-AERO (measurements on liquid aerosols, under development). This instrumental suite enables documenting optical properties (polarization, brightness) of particles in various configurations, ranging from large several hundreds of micrometers free-floating grains to micron-sized grains, and for deposited particles. In particular the instrument allows the measurement of these parameters on very absorbing particles (carbonaceous compounds).

For free-floating particles typically larger than 10 micrometers, the project operates during parabolic flight campaigns on board the European Airbus 300 "Zero-G", and will have logged 45 campaigns at the end of 2012. CNES and ESA have been sponsoring this project and associated campaigns since 1993. For the smaller free-floating particles, the measurements are conducted on the ground using an air draught technique. PROGRA2-VIS, -IR, and –SURFACE use cameras as detectors to distinguish between isolated grains, aggregates, and to reject images with multiple scattering.

We will present the instrumental technique of measurement, and the new results obtained with PROGRA2-IR.

The database of measurements done with PROGRA2-VIS and –SURF is available at the PROGRA2 website: http://www.icare.univ-lille1.fr/progra2/indexeng.html

Experimental simulations of optically thin clouds of dust by imaging polarimetry: application to comets and interplanetary dust.

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Keywords: experiment, linear polarization, comet, interplanetary dust

We use remote light scattering observations to tentatively infer the physical properties of the particles in cometary and interplanetary dust clouds. To interpret the results, numerical and experimental models are necessary. Laboratory scattering measurements on levitating particles with the PROGRA^2 experiment -in dedicated microgravity flights or on ground for low-density particles- offer an alternative to simulate the scattering properties of real particles, which can present large size distributions and a large variety of structures and materials. Previous systematic experiments, numerical models and laboratory analysis of cosmic particles (e.g. Stardust samples) are used to optimize samples' properties -such as particles structures, sizes, and silicate to organics ratios-.

We present cometary observations showing the evolution of the structures and of the polarization in the internal regions of the coma, linked to the evolution of particles properties. Associated experimental simulations help us to interpret how particles evolve within different coma regions and at different solar distances.

Observations of the light scattered by the interplanetary dust cloud (IDC) particles have shown polarisation changes with the solar distance. Such changes are interpreted using numerical models to be related to variations in the composition and physical properties of the particles through various processes including thermal degradation. This interpretation is now validated on real mixtures of particles corresponding to the composition of the IDC at different solar distances.

We acknowledge CNES and ESA support for the microgravity flights and experimental work

Scattering properties of sands: influence of the conditions of measurements and main results (PROGRA2 experiment)

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Keywords: polarization, sands, PROGRA2

When dealing with non-spherical particles with complex shapes, there is no calculation method of diffusion available. Some measurements however allow to describe the diffusion of particles easily whatever their sizes. The protocol used to scatter irregularly-shaped particles can influence their orientation during the diffusion measurement process and therefore modify the polarimetric properties that can be observed. Because of the velocity gradient, some grains can be oriented directly outside the scatterer, even in a turbulent jet *(N, Rajaratnam, 1976; P. A. Baron et al, 2001)*.

Diffusion measurements have been compared on three types of sand, using two sand grain selection techniques *(Daugeron et al, 2006).* The first one consisted to use the RGB 1000 scatterer (Pallas) and measure the polarimetric state of diffusion along two polarizing directions, one perpendicular to the other, considering the different sand grain flow rates right out of the scatterer. The other technique consisted to carry out the sand grain diffusion measurements with the PROGRA² device *(Renard et al, 2002)* in a laboratory, under microgravity, by injecting air into the area containing the samples to be analyzed.

The sands used were collected on the ground in various deserts: *(Alfaro, 2004),* China (Gobi desert), Niger (Niamey), and Tunisia (Tataouine). Under an electronic microscope, the samples show round-edged grains, a part of them are elongated or "potato-shaped". The sand grains from China are smaller than the others, their distribution is centered around 100 µm, the distribution of the Tunisian sand grains is around 150 µm whereas the distribution of the grains from Niger is flat up to several hundreds of µm in size.

The measurements obtained with the PROGRA² device under microgravity can be compared with the measurements of a nephelometer although different wavelengths were applied. The polarization measurements obtained by nephelometry are highly dependent on the rate of the sand grain flow. One can notice the nephelometer data obtained at a 2m/s rate are close to those of the PROGRA² device under microgravity. Conversely the polarization values differ with a high speed particulate flow. Strong negative values, which will remain constant at a speed exceeding 10m/s, will be reached. We will then conclude that the effect identified here for solid and irregularly-shaped particles is quite significant. For the three samples the nephelometer shows the air flow rate conveying the particles influences the orientation of some of them and as a consequence the polarimetric signature observed.

The measurements carried out on different types of sands have allowed to underline the influence the experimental protocol can have on diffusion measurement for non-spherical large size particles. The advantage of measurements under microgravity on board the A300 zero G aircraft is that one can postulate that all the grains are indiscriminately suspended in the air since they are no longer submitted to gravity. It will not be the case on the ground where smaller and/or less dense grains will be privileged.

Similar type studies will have to be made for non-spherical small size particles, much closer to atmospheric particle sizes.

PROGRA2: Numerical simulations and experiments

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Keywords: light scattering, non-spherical particles, measurements, Monte Carlo ray-tracing code

PROGRA2 database comprises of great number of intensity and polarization measurements that gives researchers an opportunity to study wide range of aspects concerning light scattering by particulate matter. The experiments provided in microgravity are especially valuable for study of optical properties of large non-spherical particles and agglomerates at random orientation. This kind of experiments on free-floating large particles ensure an unique possibility for validation of the theoretical and computational models of single and multiple light scattering by non-spherical particles. That is why some progress in development and implementation of the numerical techniques for simulation of light scattering by large sizes particles has been done as a part of PROGRA2 project.

This talk has two main aims. The first is to summarize the results of the numerical and experimental study of single and multiple light scattering by large non-spherical particles performed within the framework of PROGRA2 project. The second is to present the recent development of Monte Carlo ray tracing code for large sized particles with surface roughness and comparisons of the computational results with new measurements. We demonstrate the flexibility of the solver to simulate light scattering by particles in various configurations. The comparisons between experimental and numerical results for cubes, cubes with rounded edges (crystals of NaCl and KBr), and hexagonal prisms (crystals of Na_2SO_3) with perfect or rough surfaces are shown. In particular the effect of surface roughness is discussed.

On the polarization opposition effect for various high-albedo Solar System bodies

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Keywords: planetary satellites, asteroids, polarization opposition effect

We present the results of new near-oppositions polarimetric observations of high-albedo Solar System bodies obtained in 2010–2012. In addition to the program of study of polarization opposition effect (POE) for the E-type asteroids, the Galilean satellites of Jupiter (Io, Europa, Ganymede, Callisto), and satellite of Saturn Iapetus, the Saturn's high-albedo satellites Enceladus and Rhea were included.

The measurements of linear polarization for Iapetus, Enceladus, Rhea, and the Galilean satellites of Jupiter were carried out at the 2.6-m telescope of the Crimean Astrophysical Observatory (Nauchnyj) in the R and RW filter (550–750 nm). The Galilean satellites were observed with the photoelectric polarimeter at the 0.7-m telescope of the Chuguyev Observation Station (Institute of Astronomy of Kharkiv National University) and at the 1-m RC telescope of the Crimean Astrophysical Observatory (Simeiz) in the V and R filters.

Comparison of new and available observations allows us to make the following conclusions:

- New observations fully confirm the presence of the POE for satellites Io (the geometric albedo is p_v=0.62), Europa (p_v=0.68), Ganymede (p_v=0.44), bright trailing hemisphere of Iapetus (p_v=0.6), and asteroid 64 Angelina (p_v=0.48). The POE for the Galilean satellites of Jupiter and asteroid Angelina are manifested in the form of secondary minima of polarization which distinctly separated from the minima of negative polarization branch (NPB).
- The POE for the bright side of Iapetus has sharply asymmetric minimum with a value about −0.7% at phase angle $\alpha \approx 1^{o}$. In the range of phase angles 1−6°, the degree of polarization increases linearly up to about −0.3%. Nothing can be said about the behavior of polarization for Iapetus at largest phase angles because they are not reached for ground-based observations.
- The POE was revealed for satellites Enceladus (p_v=1.04) and Rhea (p_v=0.70). The degree of polarization for Enceladus and Rhea coincides very well with that for Iapetus in the range of phase angles ~2–6°. It is possible that the minimum value of the POE for Rhea is ~–0.6% at phase angle less than 2°.
- The parameters of the NPB and POE for the investigated objects are significantly different. The most symmetrical POE for the object with a minimum value of albedo (Angelina) is in region 0–3°, with the minimum polarization $P_{\min,POE} \approx -0.3\%$ at $\alpha \approx 1.5^{o}$. Minimum of slightly asymmetrical NPB is $P_{\min,NPB} \approx -0.2\%$ at $\alpha \approx 7^{o}$. The POE for objects with higher albedo (the Galilean satellites) is more asymmetrical with $P_{\min,POE} \approx -0.3\%$ at $\alpha \approx 0.5^{o}$. Minimum of asymmetrical NPB is $P_{\min,NPB} \approx -0.2\%$ at $\alpha \approx 4^{o}$. The highest amplitude of the POE is about –0.7% for satellite Iapetus. Thus, the differences are not directly related to albedo of these

bodies.

D2
Radiative transfer

(June 20th, 11:00 AM)

Modelling light scattering by rough particles and particulate layers using RTDF

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Keywords: light scattering, rough particle, particulate layer, RTDF

Computations of light-scattering properties for non-axisymmetric particles based on exact methods like the T-matrix [1] and discrete dipole approximation (DDA) [2] have upper size parameter limits of applicability, depending on particle shape and complex refractive index. For moderate values of the sizeparameter $2\pi a/\lambda$, where a is a characteristic length of the particle and λ the wavelength, the finite difference time domain (FDTD) method can be used [3], but it places too severe demands on computational resources. Thus, despite its limitations, geometric optics and/or physical optics [4] are still the most widely used models for moderate to large size parameters. Improved methods to combine ray-tracing and diffraction have been presented [5-7].

RTDF [7] combines ray-tracing with diffraction by individual facets. It can be applied to arbitrary shapes, as long as they are approximated by planar facets. Implementation of a bounding box method [8] reduces the computational cost. This makes the method suitable for modelling light scattering by rough particles of intermediate size such as ice crystals and dust grains. Recently, it has been found that ice crystal roughness affects important scattering parameters like the asymmetry parameter [9]. In this contribution, RTDF results for rough hexagonal ice crystals [10] will be presented. Furthermore, RTDF has been applied to model ice crystal layers in order to study backcattering. Since, unlike in radiative transfer, the amplitudes of the reflected as well as the refracted ray are traced for each ray-surface interaction, and diffraction of light leaving the layer is taken account of, it should be possible to model coherent backscattering.

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Numerical simulation of near-field thermal radiation using the Thermal Discrete Dipole Approximation (T-DDA)

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Keywords: Near-field thermal radiation, thermal discrete dipole approximation, complex geometries

Radiative heat transfer between bodies separated by sub-wavelength distances exceeds the blackbody predictions due to tunneling of evanescent modes in the near-field. Therefore, the classical theory of thermal radiation cannot be applied to the near field-regime. Instead, Maxwell's equations combined with fluctuational electrodynamics (stochastic Maxwell's equations) [1] are used to describe thermal radiation [2,3]. In fluctuational electrodynamics, the source of thermal emission is modeled as zero-mean stochastic current. The second moment (twice the variance) of the current is given by fluctuation-dissipation theorem (FDT). The FDT bridge the chaotic motion of charges, through a macroscopic stochastic current, to the local temperature of the medium.

Traditionally, the stochastic Maxwell equations have been solved by deriving analytical expressions for the dyadic Green's functions, thus limiting the prediction of near-field thermal radiation problems to relatively simple geometries such as one-dimensional layered medium [4], two large spheres [5] as well as a sphere and a surface [6] to name only a few. There is a growing interest in numerical solution of near-field thermal radiation problems in arbitrary geometries due to numerous potential applications in imaging, power generation and thermal management. Finite-difference time-domain and finite-difference frequency-domain approaches have been used for numerical simulation of near-field heat transfer [7,8]. However, these methods were only applied to one-dimensional systems due to prohibitive calculation time. Very recently, a boundary element method was proposed for near-field thermal radiation calculations [9].

In this work, we describe a new method called the Thermal Discrete Dipole Approximation (T-DDA) for solving the stochastic Maxwell's equations. The T-DDA essentially follows the same procedure as the standard DDA. The incident field, however, is specified by the FDT and is thus related to the local temperature of the bodies. Additionally, the discretization of the bodies into point dipoles results in a stochastic system of equations, which is used to calculate the correlation matrix of the unknown dipole moment vector. The heat absorbed by each object can then be computed using the dipole moment correlation matrix. The T-DDA procedure is verified against thermal conductance results obtained between two micron-size silica spheres separated by a nano-size vacuum gap [5].

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Puzzling polarisation signatures from particulate media

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We report measured polarised reflectances from number of particulate samples, such as snow, gravel, and soil, as a function of direction and wavelength. The measurements are performed using the portable FIGIFIGO instrument consisting of an ASD field spec PRO FR spectrometer, rotating calcite wedge polariser, and a moving arm. Typically, the polarisation is positive in the forward directions, and negative near backward angles. But the degree of polarisation, location of maximum, and the spectral features vary, depending on the sample properties. Also, polarisation properties vary in the large range, and thus are very sensitive to the measurement conditions. In particular, phenomenon of *blue color of the negative polarisation* measured in single-scattering cometary dust particles (Zubko et al., JQSRT 2011, 112, 1848–1863) also appears in the powder.

Linearized Principal Component Analysis as a Tool to Speed up Remote Sensing Retrievals

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Keywords: principal component analysis, linearization, radiative transfer, retrievals

Radiative transfer (RT) computations are an essential component of many remote sensing retrieval problems. In particular, RT models are required for the generation of simulated radiances from satellite, ground-based and other platforms. In many inverse-modeling applications, RT models are also needed to calculate Jacobians (partial derivatives of radiances with respect to atmospheric, surface or other parameters). However, full treatment of RT processes is computationally expensive. This is particularly true for Observation System Simulation Experiments (OSSEs); these experiments are often designed to investigate possible strategies for instrument synergy, and they invariably require massive RT forward modeling over wide spectral ranges. Furthermore, new-generation low-orbit and geostationary satellite instruments coming up for launch in the next decade will be generating data at rates that current computing power is unlikely to match. For these and other reasons, there is a pressing need for RT performance enhancement for a wide range of applications.

Over the years, several techniques have been proposed to enhance the speed of RT modeling; these include correlated-k methods [Lacis and Oinas, 1991], spectral binning [Crisp, 1997]; optimal spectral sampling [Moncet et al., 2008], asymptotic methods for semi-transparent media (see [Nauss and Kokhanovsky, 2011] for a review), low-stream interpolation methods [Duan et al, 2005; O'Dell et al., 2010], and low-orders of scattering approximations [Natraj and Spurr, 2007]. A comprehensive review of RT performance enhancement methods has appeared in a recent paper [Natraj, 2013].

Natraj et al. [2005] demonstrated the ability of a technique using principal component analysis (PCA) to speed up scalar RT simulations (no polarization) at high resolution in and around the O2 A band; this technique was later expanded to RT modeling with polarization for the O2 A band and the weak and strong CO2 absorptions bands (1.61 µm, 2.03 µm) [Natraj et al., 2010]. In the PCA method for RT performance enhancement, empirical orthogonal functions (EOFs) are developed for binned sets of inherent optical properties that possess some redundancy; costly multiple-scattering RT calculations are only done for those (few) optical states corresponding to the most important principal components, and correction factors are applied to approximate radiation fields.

Here, we extend the PCA method to a much wider set of applications in remote sensing and OSSEs. This work has a number of new theoretical developments, mainly concerning the analytic linearization of the PCA itself, and the subsequent development of analytic Jacobians for the PCA-based radiation fields. We will present results for applications involving extended backscatter simulations over the UV and visible ranges, and over spectral ranges requiring treatment of thermal emission (alone) and coupled scattering/emission. We also show that the PCA method may be employed to speed up total ozone retrievals using spectral fitting.

Note: Vijay Natraj and Robert Spurr will share the presentation.

Broadband Photon Time of Flight Spectroscopy for characterisation of highly scattering media

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Keywords: Diffuse optical spectroscopy, Absorption and scattering measurements, Photon time of flight

Diffuse optical spectroscopy (DOS) is an indispensible component in the modern photonics sensor toolbox. Diverse DOS applications range from biomedical diagnostics and medical treatment monitoring to the quality control and analysis in food, pharmaceutical, wood and other industries. In the field of biomedicine DOS offers minimally or non-invasive and correspondingly pain-free means for evaluation of key physiological parameters of living tissue. This is increasingly used for diagnostics and protective treatment of numerous severe diseases such as e.g. cancer. Of particular interest for the diverse industrial VIS/NIR DOS applications its comparably low price and ability to assess both chemical and physical properties of very diverse samples without the need for special sample preparation. DOS spectroscopy offers advantages of being fast and easy to implement and can be set up for remote operation. These advantages are of vital importance in the manufacturing industry and therefore VIS/NIR DOS spectroscopy plays an increasingly important role for process monitoring and quality control in industry.
In this contribution we give an account for performance characteristics and state of the art for the novel broadband absorption/scattering the spectrometer for analysis of turbid media. The instrument is based on photon time of flight technique and utilizes short (~30ps) optical pulses to probe absorption and scattering in a tested sample. By monitoring the shape of the probe pulse and analyzing it with appropriate mode of turbid light propagation we are able to precisely determine absorption and reduced scattering coefficients of the sample. Continuous tuning the wavelength of the probe pulses enables to evaluate continuous absorption and scattering spectra of the tested media in the ultra broad range from ca. 400nm up to 1400nm.
In order to further improve measurement performance in our instrument we implemented an advanced stabilization scheme that enables reducing temporal drifts and ultimately allows us to attain superior precision of 0.5%. in determination of absorption and scattering.
We illustrate outstanding performance of our instrument by presenting our new results on highly accurate quantitative analysis of pharmaceutical tablets as well as on process control in dairy industry. Moreover we also report on application of the spectrometer to monitoring of cardio-vascular activity in human patients.

Monte-Carlo simulation of light transport through thin slabs of highly concentrated scattering media

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Keywords: multiple light scattering, Monte-Carlo simulation, dependent light scattering, Percus Yevick model, Yukawa model, Photon Density Wave spectroscopy

The control of light transmission through thin slabs of scattering and absorbing media is an interesting and important topic as it has wide applications in daily life, e.g. for cosmetics, paints or solar cells. A deep understanding of the light transport in these layers and a quantification of the transmitted or reflected light is therefore of utmost importance for the design of the above mentioned materials.

For small volume fractions ϕ of scattering particles, where only single light scattering occurs, the extinction E of light is proportional to the scattering coefficient μ_s and to ϕ. However, at higher ϕ multiple light scattering arises causing a negative deviation from this linearity. Additionally, in case of the presence of an absorber (expressed by the absorption coefficient μ_a), scattering events influence absorption and vice versa. For even higher volume fractions of scatterers ($\phi > 5\%$) or for small scattering particles compared to the wavelength of light, so-called dependent scattering arises due to interaction and hence spatial ordering between the particles. This causes interference of scattered light from different particles leading to a decrease of μ_s and hence a decrease of E resulting in an inverse cost-benefit relation in cases when a maximum of opacity is desirable (e.g. for sun-oil or paints).

As a simple linear approach to calculate E from absorber and scatterer concentration analog to the well-known Beer-Lambert law is not possible for such systems, Monte-Carlo simulations provide an excellent alternative to model the light transport in these layers. In Monte-Carlo method light transport is treated as consecutive scattering and absorption events of photons launched into the material. The probability for scattering and absorption is calculated from their mean free paths (μ_s^{-1} and μ_a^{-1}, respectively).

In this study the transmission of monodisperse highly concentrated ($\phi > 30\%$) polymer/water dispersions is measured. Monte-Carlo simulations are performed and compared to the experimental results. Dependent scattering is considered applying the well-known hard sphere model in the Percus-Yevick approximation (HSPYA) and the Yukawa model in the Mean Spherical Approximation (YMSA). Both models assume either only hard sphere interaction (HSPYA) or an additional electrostatic interaction between the scattering particles (YMSA). Reflection of light at surface boundaries is calculated using Fresnel equations. μ_a and μ_s of the studied materials are calculated from known concentrations, particle sizes and complex refractive indices using Mie theory and determined additionally by Photon Density Wave (PDW) spectroscopy [1,2]. PDW spectroscopy is also applied to verify the parameters for dependent light scattering used during Monte-Carlo modeling.

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A1
Aerosols / LIDAR / Clouds

(June 20th, 2:00 PM)

Potential and limitations of non-spherical particle scattering models in lidar applications

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Keywords: remote sensing, non-spherical particles, polarization lidar

Polarization lidar is a powerful tool in atmospheric remote sensing of aerosols, in particular when used in combination with the multi-wavelength Raman lidar technique. Large mineral particles of non-spherical shape originating from deserts, soil erosion, or volcanic eruptions cause a strong depolarization of linearly polarized laser light that is scattered under 180°. By measuring the linear particle depolarization ratio with lidar, non-spherical particles can be distinguished from other atmospheric aerosols such as anthropogenic pollution or biomass-burning smoke. Combining spectral and polarization information allows us to determine vertical concentration profiles of the different aerosol components. A number of retrieval schemes have been developed in recent years which either make use of lidar-only measurements of spectral extinction, backscatter and depolarization data or combine spectral and polarization information from vertically resolved lidar and columnar radiometer (sunphotometer) observations.

In order to describe the signature of scattering from non-spherical particles in the retrieval schemes, spheroid models are typically applied. Such models consider shape mixtures of randomly oriented spheroids with prescribed size and axis-ratio distributions. The models have proven to provide a good approximation for many atmospheric applications. They are regularly used for the inversion of sunphotometer data, and they are applied in combined lidar/sunphotometer algorithms. However, lidar measurements also revealed discrepancies between modeled and observed parameters, in particular for large, irregularly shaped particles with sharp edges as they occur close to the deserts or in fresh volcanic ash. Such discrepancies might be attributed to the specific lidar detection geometry that requires a very accurate description of 180° light scattering.

We will present an overview on state-of-the-art lidar and combined lidar/sunphotometer detection and inversion schemes. Measurement examples, including observations of Saharan dust and of the Eyjafjallajökull and Grimsvötn ash plumes, will be shown. Requirements for the modeling of 180° scattering properties of large, irregularly shaped particles to be used in microphysical retrieval algorithms will be discussed.

Regularized inversion algorisms and software for lidar data processing

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Keywords: lidar, aerosol, inverse problem

Nowadays lidars are among the base equipment in complex systems aimed at atmospheric aerosol monitoring. The amount of data produced by lidars constantly increases as these systems pass into regime of regular measurements. Developing of algorithms and software for automatic data processing of simple single-wavelength lidar sounding, as well as combined measurements of lidar, radiometer and other systems is very urgent.
Retrieving aerosol parameters through lidar data processing acquires properties of ill-posed inverse problems, as soon as we turn from single-wavelength solutions of the lidar equation to inversion of Raman sounding data and, especially, to processing data of complex measurements. Regularized inversion algorithm and program package LIRIC (Lidar and Radiometer Inversion Code) has been developed to retrieve aerosol microphysical parameters from combined lidar and radiometer measurements. Later, processing of Raman measurements was incorporated into LIRIC.
The recent talk aims at characterization of regularized inversion algorithm as a perspective approach for creation of multifunctional code for automatic data processing of lidar measurements in lidar networks.

Oral

Characterization of aerosol physical parameters with multi-wavelength lidar. Can we trust it?

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Keywords: multiwavelength lidar, aerosol, microphysical parameters, inversion algorithm

Multiwavelength Raman and HSRL aerosol lidars are recognized as powerful tools for aerosol characterization. The height resolved spectra of particle backscattering, extinction and depolarization provided by such lidars are important for Earth radiation budget studies and can also be used for aerosol classification. But even more attractive is the possibility of inverting lidar measurements to height profiles of particle physical properties, such as size, concentration and complex refractive index. During the last decade numerous theoretical and experimental studies have been performed attempting to realize such inversions and the results obtained look rather promising. However, before applying multiwavelength technology to regular aerosol observations, numerous issues should be resolved. First of all, the number of lidar measurements is very limited, typically only three backscattering and two extinction measurements are available. Thus the inverse problem is underdetermined and the family of solutions obtained using different initial guesses about particle complex refractive index and inversion interval should be considered. Second, the particles may be of irregular shape, the complex refractive index may be spectrally dependent and the aerosols may be represented by external or internal mixtures. And finally, the retrieval algorithm should be fast to manage large volumes of data. This talk is intended to analyze the uncertainties arising from the factors mentioned above, to present different approaches for inversion of lidar measurements and to apply these algorithms to long-term lidar observations. Retrieved time series of particle physical parameters are compared with column integrated values provided by AERONET. The results of the application of an algorithm based on a model of randomly oriented spheroids to the inversion of multi-wavelength lidar dust measurements will be also discussed.

Why the 46° halo is seen far less often than the 22° halo?

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Keywords: light scattering, surface roughness, ice clouds, Monte Carlo ray tracing

The goal of this study is to explore some effects of surface roughness on phase functions of hexagonal ice crystals. The simulations were performed using a Monte-Carlo ray-tracing method. The peculiarity of our statistical model of surface roughness is the following: (a) the surface roughness of the prismatic facets can be anisotropic, and (b) the roughness degree of basal and prismatic facets can be different. The main result is the existence of a sufficiently large range of the roughness parameters when a phase function of hexagonal ice crystals has a pronounced 22° halo whereas the 46° halo is totally smoothed. It is speculated that the anisotropic roughness is the unique model that is able to explain the only-22°-halo feature of phase functions of thin plates. It is also proposed to use the model of rough basal-facets as a proxy for ensembles of hollow-ended columns and/or bullets.

A database of polarized light scattering properties of ice crystals

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Keywords: optical properties, ice crystals, Research Scanning Polarimeter

We present a database of polarized light scattering properties of ice crystals to support the analysis and interpretation of measurements of the airborne Research Scanning Polarimeter obtained during multiple field campaigns. The instrument has nine spectral channels ranging from the visible (410 nm) to the near infrared (2250 nm) and continuously scans in the plane of the aircraft velocity and nadir vectors to obtain high precision polarimetric measurements of each field of view over more than 150 viewing angles. To interpret the RSP data over ice clouds, two ice crystal habits are used in the database: simple hexagonal plates and columns and more complex bullet-rosettes. Ice crystal optical properties are calculated using the Geometrics Optics (GO) code developed by Macke et al. (1996) that includes an efficient treatment of microscale surface roughness. The aspect ratio of columns is varied between 1 and 50 with 26 geometrically increasing steps. The aspect ratios of plates are the inverse of those for columns, for a total of 51 aspect ratios. The roughness parameter is varied between 0 and 0.7 in steps of 0.05. The optical properties can be interpolated yielding optical properties for a continuous set of aspect ratios and roughness parameters. Sizes are varied so that the projected areas of the particles, assuming random orientation, correspond to the projected areas of spheres with radii from 5 to 320 μm in geometrically increasing steps. This allows integration over various size distributions. The database could be easily expanded with, e.g., more extreme aspect ratios, greater roughness parameters and other instruments' channels in the future. We analyze the dependence of the ice phase matrix on the input parameters of the database. We also discuss the phase matrix accuracy requirements for inverting RSP measurements.

C1
Laboratory and field experiments

(June 20th, 4:00 PM)

A new concept for single-particle material characterization

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Keywords: electromagnetic scattering, particulate media, optical absorption, holography, interferometry

This work will present the development of a new photothermal technique to gather information related to a particle's composition simultaneously with an image of it. Here, particles flowing in a sample stream are illuminated by a pulsed ultraviolet (UV) laser. This light combines across a detector with the light forward scattered by the particle. The resulting interference pattern constitutes a digital hologram, from which an image of the particle is reconstructed computationally. To obtain composition information, the particle is illuminated by the UV light twice in rapid succession while also being exposed to light from a pulsed infrared (IR) laser. Two holograms are thus formed on the detector. Performing the computational reconstruction on this double-exposed hologram yields an image of the particle superimposed with interference fringes. The fringes originate from any change in the particle's physical state that occurs between the two UV pulses. Absorption of the IR light by the particle may cause photothermal expansion, and thus register as fringes in the reconstructed image. Since the degree of expansion depends on the light absorbed, the fringes indirectly convey information related to the particle material.

Inverse Light Scattering with Holography and the Discrete Dipole Approximation

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Keywords: holography, discrete dipole approximation, inverse problems, electromagnetic scattering

The pattern of light scattered by an object contains information about the three-dimensional distribution of matter comprising the scatterer. The inverse problem of determining this three-dimensional structure from the scattering pattern can be made tractable in certain cases, for example holography. An in-line hologram – the pattern arising from interference between light scattered by an object and transmitted light – contains a term that is linear in the (usually inaccessible) scattered electric field. The traditional inversion technique for holograms, numerical reconstruction, neglects nonlinear terms and the presence of the scatterer itself, unacceptably degrading reconstructed results. However, because the linear term dominates a hologram, the position and size of collections of micrometer-sized spheres can be determined precisely through iterative inversion methods. The aim now is to use this technique to image complex soft matter and biological systems that lack simplifying symmetries.

This talk will cover our recent developments on inverse light scattering for non-symmetric objects. We use two iterative refinement procedures to solve for refractive index distributions of scatterers. In the first, we parameterize an object and use a nonlinear fitting algorithm to match computed holograms to our recorded hologram. We compute these holograms using the discrete dipole approximation (DDA), in the form of the ADDA scattering code, which represents scatterers by discretization and makes no default assumption of symmetry. This fitting is applicable for samples such as Janus spheres or normal modes of a fluctuating membrane, samples which have straightforward parameterizations. The second, more powerful, technique is based on iterative evaluation of a topological derivative to directly solve for the shape of an arbitrary object. This derivative directly evaluates which regions of space are most likely to contain matter given a field equation, a boundary condition from a measured hologram, and a matter distribution from the previous iteration. Taking such a derivative requires a modified DDA calculation to evaluate forward and adjoint fields throughout the region containing a scatterer. This method requires no *a priori* information about shape, making it especially promising for biological samples which defy simple parameterization.

Spectralon as a Surface Polarimetry Standard

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Keywords: electromagnetic scattering, surface scattering, polarimetry, polatrimetry standard.

Since Spectralon was made up and commercialized by Labsphere, inc. in 1986, it has been used in reflectometry calibration purposes as the closest commercial material to a perfect Lambertian surface. Spectralon is composed of polytetrafluoroethylene (PTFE) powder compressed by a special process with heat and pressure. It has very high diffuse reflectance, generally more than 99%, over the UV-VIS-NIR region of the spectrum, and its surface and subsurface, structured as a porous network of thermoplastic, exhibits its characteristic reflectance behavior.

In the last years, several studies of Spectralon's Bidirectional Reflectance Function have been carried out on from a spectro-polarimetric point of view (some of them reporting the inherent speckle effects associated to their laser measurements). More recently some researchers have made an effort pursuing a polarimetric description of the Spectralon by giving priority to some polarization parameters, scattering angles, wavelengths or, in many cases, by driving the attention to common reflectometry applications [1]. Areas in which surface polarimetric analysis has been introduced include tissue exploration and oral disease diagnosis in medicine, imaging polarimetry, or equipment testing. For all these working fields, mastering the full polarimetric response of surface reflectance standards is an important objective.

The Mueller matrix is a complete polarimetric description of a scattering system illuminated by a given incident wavelength, in the sense that it contains all information about the scattered light in some given experimental conditions. Handling the polarization states and the MM algebraic properties [2], a complete polarimetric description of the Spectralon reflectance standard in a wide visible range can be made, in spite of its highly depolarizing activity.

The aim of this research is to make a full polarimetric analysis of the scattering behavior of Spectralon within the visible spectrum and in a broad range of scattering geometries. This procedure will give us new guidelines for a right use of Spectralon not only to reflectance standard but also to polarimetry standard. In this sense, further results comparing this standard with other rough surfaces (such as Sahara sand surfaces) will be presented.

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Note: the name of the person who will make the actual presentation is underlined.

Optical super-resolution for characterization of individual non-spherical particles from polarized light-scattering profiles

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Keywords: light scattering, inverse light-scattering problem, *T*-matrix simulation, polarization

Polarization measurements have been widely used for analysis of particles. Usually only the intensity of light scattered by a particle or an ensemble of particles is detected. An analysis of individual microscopic particles assumes a solution of identification and characterization problems. These problems can be solved from measurement of light-scattering intensity just for particles described by a simple optical model. To solve identification and especially characterization problems for particles described by a complex optical model it is necessary to measure additional information. The polarizing measurement of scattering supports the solution with extra independent information required. In particular polarization of scattered light is sensitive to deviations of a particle shape from spherical symmetry.

A scanning flow cytometer was improved to provide large amount of data necessary for solution of such characterization problems. The current device measures angle-resolved intensity of light scattered by individual particles (light-scattering profiles, LSPs) in regular and polarized states. It was fabricated by CytoNova Ltd., Novosibirsk, Russian Federation. (http://cyto.kinetics.nsc.ru).

First, we measured regular LSPs of individual spherical beads to verify proper alignment of the laser beam and the flow. The solution of the inverse light-scattering problem was applied for these LSPs to retrieve bead sizes and refractive indices. The bead sizes were determined with uncertainty of about 10 nm - an exeptionally high precision for optical methods. Second, we developed a method to characterize polymer bead dimers, as an example of non-spherical particles, based on regular and polarized LSPs. Characteristics of a dimer, such as sizes and refractive indices of constituent monomers, were successfully retrieved from the solution of the inverse light-scattering problem. Orientation of each dimer in a flow relatively to the direction of the incident laser beam were also determined. Both ordinary and polarized measured LSPs are in good agreement with T-matrix simulations, which leads to average uncertaintly of 50 nm for determined bead sizes in a dimer.

Measurement of the polarized LSP opens the way for optical characterization of particles with complex shape and internal structure. For example, this approach looks promising for detailed characterization of red blood cells (RBCs). Implementation of this approach into a hematological analyzer should lead to substantial decrease of systematic errors in RBC indices. The polarized LSP can also be used for assessing the homogeneity of cell nucleus and for analysis of blood platelets microaggregates.

Infrared Elastic Scattering Spectroscopy of Individual Aerosol Particles

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Keywords: electromagnetic scattering, infrared, aerosol, optical absorption, vibrational spectroscopy

We have performed chemical composition classification of individual micron-sized aerosol particles using infrared elastic scattering spectroscopy. We describe electromagnetic scattering calculations and experiments that demonstrate that the absorption features of single aerosol particles may be inferred from the particle's spectrum of elastically scattered infrared light.

An experimental setup was constructed to collect infrared elastic scattering spectra from individual aerosol particles. A Wavelength Beam Combined-Quantum Cascade Laser (WBC-QCL) array was used as the multi-wavelength, long-wave infrared (LWIR) source to illuminate individual aerosol particles entrained in an airflow. Elastically scattered light from each individual aerosol particle was collected onto a single-element HgCdTe detector. The laser elements of the WBC-QCL array were time-multiplexed in order to generate a spectrum. A variety of materials, including laboratory particle standards such as polystyrene latex spheres and poly-methyl methacrylate spheres were measured. In addition, outdoor aerosols were sampled by the apparatus and the elastic scattering spectra for a few hundred thousand individual particles were collected.

For a few of the materials, the complex index of refraction versus wavelength was available for use in computational scattering modeling. Mie scattering calculations were performed that show good agreement with experimental results. In addition, T-matrix scattering calculations were made for oblate and prolate spheroids, which suggest that the infrared elastic scattering spectra should be robust to changes in particle shape for particles having a diameter of 1 – 10 microns. This work demonstrates that single-aerosol particle infrared elastic scattering spectroscopy can be used as a fingerprint of the vibrational modes of aerosol materials to allow differentiation of aerosol species based upon their chemical structure in real time on a particle-by-particle basis.

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Comparison between PROGRA^2 polarization measurements and numerical simulations

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Keywords: numerical simulations, laboratory simulations, linear polarization, micro-gravity

The PROGRA^2 experiment is a laboratory light scattering facility providing measurements on levitating particles (either during microgravity flights or on the ground with air-draught for low-density particles) [1]. This enables the realistic simulation of clouds of particles with large sizes and complex structures. Experimental samples can present a variety of size distributions (nm to hundreds of microns), different particles' shapes and structures (e.g. spheres, aggregates, plates, etc.) and mixtures of particles with different compositions can also be studied.
To validate the experimental system and its results, systematic comparisons with numerical simulations of light scattering by dust particles have been performed. This presentation reports on the results obtained so far for compact particles and small aggregates and presents tentative interpretations of the results measured and calculated for aggregates of dust particles.
Initial validations and results used spherical particles with different absorption properties, including homogeneous particles and particles covered with different materials. Numerical simulation results compare very well with the measured signals and properties such as optical indices, or layers' thicknesses can be determined [2].
During levitation small grains tend to form aggregates. The measured polarimetric properties vary strongly with the properties of the constituent particles as well as the structure and size of the aggregate. Numerical simulations of such systems are challenging, but provide insights into the light scattering properties of small aggregates and the influence of the different parameters [3, 4]. PROGRA^2 measurements and related simulations are presented to further interpret the transition from single grain polarization phase curves to larger aggregates scattering properties that is relevant to interpret cometary dust light scattering observations [*e.g.* 5].

CNES and ESA support for the microgravity flights and experimental work is acknowledged

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B3
Light scattering

(June 21th, 8:30 AM)

Light scattering from feldspar particles: comparison with agglomerated debris particles

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Keywords: light scattering, feldspar, agglomerated debris particles, DDA, experimental results

We present comparisons of the non-zero light-scattering Mueller-matrix elements of agglomerated debris particles with those of well-characterized experimentally measured feldspar samples at blue and red wavelengths. The only completely free parameter in our comparisons is the small-size cut-off of the sample, which was not known. The significance is that both the light scattering and the measured properties of model and real particles agree very well. While some tweaking of the particle parameters could achieve some improvement, the fits are remarkably good, with significant deviations (~5%) occurring in portions of the polarization elements, e.g. S_{34}. We suggest that the reason for the good fits is not that the model particles exactly represent those of the sample particles, but rather that both sets of particles belong to a class of highly irregular particles, whose high degree of irregularity dominates the resulting scattering behavior, suppressing the effect of any characteristic morphological features.

The advantages of analysing the scattering of light in terms of angular momentum and helicity

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Keywords: helicity, duality, angular momentum, multipolar, resonance, WGM

The field of the angular momentum (AM) of light has been quickly expanding since the seminal contribution of Allen and co-workers in 1992 [1]. It is used in optical tweezers to rotate particles and drive micro-rotors [2], in quantum communication to create multidimensional entangled states [3] and in astrophysics to detect exotic cosmic objects [4]. In contrast, the helicity of light has been overlooked and often confused with the spin of light [5]. However, recently Fernandez-Corbaton *et al*. have revealed its importance in the light-matter interactions and its connection to Maxwell's generalized duality symmetry [5,6]. This new finding has come along with a growing interest in the field of optical active metamaterials, and it is starting to be used in this field, among others [7].

In this talk, I will analyze the scattering of light from spheres from the point of view of symmetries, conserved quantities and within the Generalized Lorenz-Mie Theory framework. We will see that we can simplify and extract more information from the scattering problem if we probe our system with light beams which have well-defined properties such as the helicity and the angular momentum. In addition, we will see that this combined framework enables us to control the resonant modes of the sphere, as well as the scattered field with much more precision [8]. Finally, I will present our latest experimental results using the helicity of light and the angular momentum to control multipolar resonances and excite whispering gallery modes (WGM) for micrometric particles. I will also show how we can restore the duality symmetry of Maxwell Equations in material media, as well as other applications of this framework in nanopositioning and sensing.

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Spectral and angular light-scattering from silica fractal aggregates in absorbing media

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Keywords: hyperspectral, spectral, light-scattering, silica, fractal, aggregates, discrete-dipole approximation, q-space analysis.

Silica ultrafine particles are found as aerosols or as colloidal suspensions and tend to form fractal-like aggregates. This work reports a spectral and angular light-scattering study of silica fractal aggregates in absorbing media. A spectral model based on the discrete-dipole approximation is used to simulate the scattering of coherent broadband light from fixed and randomly oriented aggregates. Our method computes accurately the full spectral and angular light-scattering signature of silica fractal aggregates generated from a Diffusion-Limited Cluster-Aggregation model. Simulations are done for aggregates with spectrally dependent refractive index in absorbing media over the short wave infrared to ultraviolet spectral range. The influence of the host media is discussed.

A fast and non-contact method using a supercontinuum-based instrument was developed at Onera. We measure the spectral and angular light-scattering from dense media. Hyperspectral and angular light-scattering measurements are carried out to probe optical properties of silica fractal-like aggregates in absorbing media. A comparison between numerical results and measurements is presented. The important role played by the wavelength in the angular scattered-intensities is first reported. Then, a spectral q-space analysis is undertaken to retrieve fundamental microphysical parameters of silica aggregates: fractal dimensions, gyration radius and monomer size of aggregates.

Oral presentation is preferred.

Two models for studying the single particle scattering properties of rough particles over a wide size-parameter range

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Keywords: electromagnetic scattering, surface roughness, pseudo-spectral time-domain method, improved geometric optics method

The importance of electromagnetic scattering by atmospheric aerosols is well known in fields ranging from astrophysics to terrestrial climate dynamics. In fact, uncertainty concerning even the *sign* of the net "direct" effect of aerosols in the atmospheric radiation budget is one of the more troubling aspects of climate simulations. Also well known are the computational challenges in representing scattering in the so-called resonance regime intermediate between the small size-parameter (Rayleigh) and the large size parameter (geometric optics) regimes. The difficulties are particularly acute for the study of particles in the resonance regime that are rough and hence lack convenient symmetries. Yet recent studies have indicated that effects of surface roughness first become noticeable as this resonance regime is entered, and grow increasingly important as size increases. Thus it is desirable to develop models of rough particles and computational strategies that make investigation of irregular surface roughness effects computationally feasible in the range of intermediate to large size parameters.

In this talk we present results on optical scattering properties that have been obtained using two particle models having different kinds of highly irregular surface roughness. Our computational strategy combines a powerful pseudo-spectral time domain (PSTD) method and an improved geometric optics method (IGOM). The first particle model is constructed to qualitatively reproduce scattering properties of mineral aerosols having fractal-like structure. The construction proceeds through successive refinements on progressively smaller scales using stochastically perturbed self-similar tetrahedra. The approach gives a hierarchy of generations of fractal particles, with increasing generation number reflecting increased degrees of surface complexity and concavity. The second model is based on a milder form of roughness whose representation uses ideas that have proven useful in scattering studies of random sea-surface wave fields. Although our model is perfectly general in conception, we only discuss its application to the case of roughened hexagonal column ice crystals.

We show the effects of certain measures of surface irregularity on the particle extinction efficiency, asymmetry factor, and phase matrix over a range of size parameters extending from the Rayleigh regime to the geometric optics regime. For each model, to cover the size range we use the PSTD for small-to-medium sized particles and the IGOM for moderate-to-large particles, and we demonstrate the agreement of results in an overlap size range. Unlike previous studies that have relied on a parameterized mixture of sizes and shapes of particles to reproduce observations of mineral aerosols, we are able to get agreement using a single fractal particle model. A particularly surprising result is the success of the IGOM, as validated by the PSTD, in the intermediate size parameter regime where the smallness of individual facet sizes would suggest the IGOM to be inappropriate.

Note: the name of the person who will make the actual presentation is underlined.

Computational Design of Non-Spherical Super-Scattering Particles at Visible Wavelengths

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Keywords: electromagnetic scattering, photonic design, extinction

When studying scattering problems that arise in nature, researchers often consider a limited set of geometries (e.g. spheres) with interesting but difficult constraints (e.g. multi-particle interactions). But as nano-fabrication techniques improve, *design* problems become relevant, as artificial scatterers with intricate shapes can be manufactured. For such problems the constraints are self-imposed and can be simplified, while the space of allowable structures increases greatly. At optical frequencies, with the combination of wavelength-scale structures and greater material choice emerges new potential scattering phenomena, if the computational burden of solving Maxwell's Equations many times can be alleviated.

We employ a variety of techniques to optimize single-particle extinction per unit volume over a broad bandwidth and all incidence angles. To quickly solve Maxwell's Equations, we combine the efficient boundary element representations with a contour-integration technique that replaces broad frequency averaging with a single, complex-frequency calculation. A global optimization of ellipsoid parameters reveals that optimal, uncoated ellipsoids can perform more than six times better than optimal core-shell spheres in the [600,800]nm wavelength range, due to the nature of their plasmonic modes. Surprisingly, oblate (disk-like) spheroids were optimal and better than prolate (needle-like) spheroids, in contrast with the conventional wisdom that prevails in the infrared. This occurs because of the very different dielectric functions for metals in the visible as opposed to the infrared, demonstrating the new possibilities that arise.

We also discuss more general structures that enable even better performance. Treating the single particle as a generic structure composed of many spherical harmonic basis functions, we explore a much larger design space through adjoint-based shape derivatives. With only a little additional effort for each simulation, the derivatives with respect to every parameter can be calculated. Large parameter spaces can be quickly explored, and new designs arise that greatly outperform the highly symmetric structures previously studied.

Plasmon resonance on a single metallic particle: general properties and accurate near-field extraction

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Keywords: metal nanoparticles, localized plasmon resonance, null-field method, pole searching algorithm

Metal nanoparticles exhibit localized surface plasmon resonances (LSPRs) in the visible spectrum in the case of noble metals such as silver or gold [1]. These resonances are due to the electromagnetic excitation of conduction electrons of the metal, and strongly depend on the particle shape, size and also on the surrounding medium refractive index. This specific ability is widely used in chemical and biological sensing, biomedicine, nano-photonics and for surface enhanced Raman spectroscopy (SERS). Modeling the nanoparticle optical properties is of great interest to theoretically understand LSPRs mechanisms and to predict their spectral positions, which then can help to design experimental specific applications.

We implement the Null-Field Method [2] (NFM), also known as the Extended Boundary Condition Method (EBCM), which is an elegant semi-analytical method based on Maxwell's equation and on spherical harmonics, and consists to express the scattering problem in a matrix form. This method, particularly well-suited for single axis-symmetric particles, permits to compute various scattering parameters such as optical cross-sections and near-fields. We propose a fast and original numerical method, based on a previous study [3], to extract accurately the LSPRs characteristics in terms of spectral position, bandwidth and near-field, directly from few scattering parameter computations. This method is first applied to silver nano-spheres, for which the different resonance properties are studied depending on the particle size. The plasmon field is extracted, showing a specific mode spatial distribution. We then study in a similar manner the degenerated dipole modes in the case of small spheroids. We discuss through this method a theoretical approach to plasmon resonance phenomena.

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Simulation of light scattering by particles much larger than the wavelength with Discontinuous Galerkin Time Domain method

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Keywords: electromagnetic scattering, irregular particles, scattering matrix

A Discontinuous Galerkin Time Domain (DGTD) method is applied for calculation of scattering matrices of transparent random irregular particles with dimensions much larger than the wavelength of the incident light. The applicability of the method for such a problem is verified and the results are compared with those derived from simple geometrical optics (GO) model.

The solution of Maxwell equations in DGTD is realized in the unstructured tetrahedral grid. The electric and magnetic fields are expanded locally in the nodal points of every single cell in terms of interpolating polynomials. Time integration of the differential equations introduced in the DG scheme is done via Runge-Kutta time stepping. Unstructured meshing allows optimal and flexible discretization of complex shapes whereas with polynomial representation comparatively coarse meshes can be used.

In the test computations, DGTD method demonstrated excellent scalability and applicability to large problems. In this work samples of irregular grain-like particles generated by means of Gaussian random field are considered. The real part of the refractive index taken is n=1.313. Particle length is taken to define the size parameter $X=2\pi r/\lambda$. Tests showed that light scattering simulations for single orientations of particles with X up to 100 can be realized in reasonable time on a middle-sized HPC cluster. At smaller size parameters ($X<60$) averaging over samples and orientations is possible. Acceptable agreement with GO for phase functions is observed already at X=50 for an ensemble of arbitrarily oriented particles as well as their single orientations. The result converges as the size parameters increases. At the same time linear polarization and other elements of the scattering matrix appear to be more sensitive to the wave effects and require size parameters $X > 100$ for accurate GO calculations.

Fast modeling of electromagnetic scattering in 3D Fourier space

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Keywords: electromagnetic scattering, Fourier space, generalized source method

Modal *T*-matrix method perfectly describes many-body electromagnetic scattering. It calculates the light scattering at best for spherical particles, but for arbitrary shaped scatterers it requires an additional effort for numerical evaluation of individual particles *T*-matrix components. When the latter problem is too complex, alternative methods like finite-difference, finite element, or volume integral equation (VIE) method can be applied. However, they possess too high numerical complexity to describe as large ensembles of wavelength-scale particle as the T-matrix method does with limited computational resources. With a view of solution of the last issue we continued our development of Fourier-space based methods and in this work present a method of the electromagnetic many-body scattering calculation that operates in the 3D Fourier space.

Representation of the Maxwell's equations in the 3D Fourier space is commonly used in analysis of photonic crystal bands which includes the solution of eigenvalue problem. Instead we use the generalized source method [1] to separate the scattering problem into a basis medium part and a scattering medium part (which is treated as a source), which yields a self-consistent linear equation system. The procedure is analogous to the VIE method operating in the coordinate space [2], and allows using the same fast numerical algorithm comprising the fast Fourier transform and a Krylov subspace iteration method. The possibility of outperforming the VIE comes from the observation made on the basis of our previous work [3] that the required number of Fourier space points is often less than the corresponding coordinate space point number providing the same calculation accuracy is required.

Note: the name of the person who will make the actual presentation is underlined.

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F2
Micro and nano-optics, biomedical applications

(June 21th, 11:00 AM)

Optical Scattering From Coalescing Micro-droplets And The Measurement Of Ultra-high Viscosities

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Keywords: electromagnetic scattering, aerosol droplets, *T*-matrix method, holographic optical tweezers, optical frequency combs

The apparent simplicity of a liquid aerosol droplet belies the richness of the optical effects that they can sustain. In this contribution, we will be primarily concerned with optical scattering from deformed liquid droplets. However, a brief description, and tentative analysis of some recently observed nonlinear effects in optically trapped droplets will also be presented.

Small amplitude shape oscillations of a liquid droplet can be decomposed into a spectrum of normal modes. The frequencies and decay constants of these modes carry information about the physical properties of the liquid. As has recently been shown [2] a powerful new form of viscometry can be realized by optically measuring this motion. In this approach, holographic optical traps are used to induce coalescence between pairs of droplets and the relaxation into a single, spherical particle is monitored through the back scattered intensity of the trapping laser.

First, we present experimental results showing how this technique can be used to measure viscosities over a range spanning twelve orders of magnitude, from the dilute solution limit to viscosities approaching the glass transition. The timescale for the relaxation in shape is estimated from measurements of the elastic light scattering, brightfield imaging and Raman spectroscopy.

Next, we undertake a closer examination of this experimental technique. The generalized point matching method is used to compute T-matrices for deformed liquid droplets, and thereby their optical scattering properties. Initially, each mode of the mechanical oscillation is considered independently. Cross-sections and back scatter are shown to vary with the amplitude of the distortion in characteristic ways. Morphology dependent resonances are observed, even for quite severely deformed droplets. We go onto describe scattering from droplets whose shape is determined by mixtures of modes. Finally, simulations of the time evolution of the optical properties of typical droplets, suffering damped oscillations of multiple mechanical modes, are presented. The extent to which these mechanical modes can be optically distinguished is discussed. For sufficiently large droplets, it is noted that the back scattered signal is determined principally by the optical height of the droplet in the direction of the trapping beam axis, providing an effective way to monitor its trajectory in time.

Finally, we describe some recent observations of nonlinear optical effects in optically trapped saline droplets. Under certain conditions, stimulation of the whispering gallery modes falling under the Raman band is seen to lead to frequency comb generation. Representative experimental data are presented, and a tentative description of the underlying physical mechanism is provided.

Electromagnetic Multiple Scattering by Periodic Assemblies of Gyrotropic Spheres

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Keywords: electromagnetic scattering, gyrotropic sphere, layer-multiple-scattering method

Electromagnetic scattering by gyrotropic particles, e.g., spheres consisting of a magnetic or non-magnetic (metallic or dielectric) material in a static magnetic field, attracts growing interest over the last decades from both physics and engineering communities, and various computational methods have been developed for a rigorous numerical solution of this problem. Among them, the Mie approach, which is based on a full multipole expansion of the wave field in the scatterer and host media and proper matching at the surface of the sphere, appears particularly attractive since it provides in an efficient and straightforward manner the scattering T matrix. The only complication is that, at a given frequency, the multipole expansion inside the sphere involves vector spherical waves of different wave numbers, which are obtained from an eigensystem determined by the appropriate gyrotropic tensor.

In the present communication, we report on the implementation of this T-matrix algorithm into our full electrodynamic layer-multiple-scattering method, which calculates the complex photonic band structure of an infinite periodic array of non-overlapping scatterers in a homogeneous host medium as well as the reflectance and transmittance of a finite slab of such a crystal. In the spirit of the multiple-scattering approach, the scattering properties of the entire composite structure are obtained from those of its individual building units through the corresponding T matrix. The main idea of the layer-multiple-scattering method relies on the combined optimal use of two distinct basis sets: A spherical-wave basis for the description of in-plane multiple scattering; and a plane-wave basis for the description of interlayer multiple scattering. The applicability of the method is demonstrated on specific examples of periodic assemblies of gyrotropic spheres and some intriguing phenomena, such as enhanced Faraday effect, giant optical magnetoresistance, and spectral non-reciprocity are discussed.

Pre-cancer diagnostic from hyperspectral polarimetric and angular light-scattering

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Keywords: hyperspectral, polarimetric, angular, light scattering, supercontinuum laser, tumor, in-vitro, MCTS, optical signature

Onera developed a fast, in-line and comprehensive optical characterization method based on hyperspectral, polarimetric and angular light measurements. Supercontinuum laser sources provide a very useful tool to characterize materials and scattering media such as nanomaterials in suspensions, aerosols or paint coatings. Our instrument (Melopee Lab) is also dedicated to study the unique signature of the light scattered by tumor cells. In this talk, we propose an original way to probe tumor cells in in-vitro samples. Experimental results will be presented with potential applications. This is the first time in our knowledge that hyperspectral, polarimetric and angular signature of Multi Cellular Tumor Spheroid (MCTS) is reported.

The 3D culture of MCTS offers a level of complexity that recapitulates the 3D organization of a tumor and integrates the notion of tumor microenvironment. The MCTS model is largely used to study cancer biology and to evaluate the response to anticancer drugs. These features make of the MCTS a model of choice to study the optical properties of cancer tissues. Melopee Lab investigates angular and spectral domains. It is fully dedicated to characterizing materials and studying their optical properties. This original, fast, in-line, non-contact, and highly resolved instrument provides specific angular, polarized (unpolarized or linearly polarized), and hyperspectral BRDFs (bidirectional reflectance distribution function). These functions can be used to retrieve optical properties of tumor cells in in-vitro samples. First experiments were done. The tumor cells used are Human colon cancer cell line HCT116. The spheroid formation was preceded by the ITAV Laboratory. Onera tested different samples with different spheroid sizes (from 200µm to 1mm) and concentrations in a flow cell. Optical signatures (BRDFs and DOLP) depend on the scatter's properties (size, geometrical aspect and 3D arrangement, refractive index, aggregated particles…). Hyperspectral polarimetric BRDF provides a comprehensive tool for non-destructive investigations in medical domains. First measurements have been carried out in suspensions on tumor cells: we will illustrate our talk with typical signatures obtained on this kind of samples. Distinguishing healthy and cancer cells from their optical signature would be the goal of this study.

Oral presentation is preferred

Realistic analytic cell modelling

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Keywords: cell morphology, light scattering, diffraction imaging

Light scattering pattern formed through the interferences of the scattering waves from various components in the cell is rather complicated due to the complexity of the internal structure of the cell. In order to establish relation between specific characteristics in the scattering pattern and particular components of the cell, it is necessary to be able to alter the structure of a cell model analytically. To this end, we have developed a procedure to model realistic cell analytically. The analytic cell model consists of three parts: the main cell structure, which consists of the nucleus and cell membrane shapes, the mitochondria, and the structure within nucleus.

The shapes of reallistic biological cells and their nuclei are nonspherical in general with various degrees of surface fluctuations. In this study, we have modeled the shapes of the cell and nucleus membranes as deformed ellipsoids. The parameters of the base ellipsoid shapes are obtained by fitting the sample points of the z-stacks of confocal microscopic images of cells to ellipsoids. The deformation is described by a random process that is implemented though a Gaussian Random Sphere (G-sphere) method. We extract the parameters of the G-sphere by fitting the covariance of the sample points of the z-stacks of confocal microscopic images to that of a G-sphere. The parameters extraction procedure has been validated by recovering the parameters of analytically created ellipsoids with G-sphere types of deformation. Validation has been carried out for various set of parameters, and the recovered parameters are within 10% accuracy for a pool of 50 samples for each case.

We modeled the inhomogeneity in the nucleus as variations in index of refraction. Based on the characterization the confocal images from Jurkat and Ramos cells, a random walk method is used to create the index fluctuation within the nucleus. Here small ellipsoids of various shape and size of different index of refraction are placed inside the nucleus in a random walk fashion, a window average is used in the last step to smooth out the edges. The mitochondria can added to the cytoplasm with different density, size, shape, or spatial distribution in this analytic model.

Light scattering patterns from these analytic cell models are calculated using the Discrete Dipole Approximation (DDA) method, and they are compared with the experimental results with different polarization setting.

Analysis of Extreme Energy Transformation in the Evanescent Wave Area via the Discrete Sources Method.

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Keywords: extreme energy transformation, evanescent wave, light scattering, Discrete Sources Method

The extreme scattering effect has been recently reported [1]. It consists in a sharp increase of the scattered intensity transmitted through a thin noble metal film deposited upon a glass prism with an irregularity located inside or near the film. This plasmonic effect has some specific features distinguishing it from the conventional plasmon resonance, which occurs in frequency domain:

- It appears in the evanescent wave area when the incident angle exceeds the total internal reflection angle;
- It consists in a sharp increase (several orders of magnitude) of the scattered intensity both transmitted through the film and reflected to the glass prism;
- It is stable with respect to variation of the film thickness, irregularity material, its dimension and shape.

The Discrete Sources Method (DSM) is known to be one the most flexible and inexpensive techniques for solving boundary value scattering problems for Maxwell equations [2]. The DSM is a semi-analytical surface based meshless method and doesn't require any integration procedure over the obstacle surface. In the frame of the DSM the approximate solution for scattered field everywhere outside a local obstacle is constructed as a finite linear combination of the fields of discrete sources (DS) distributed inside the scatterer. The DS fields incorporate the Green Tensor of the layered structure. So, the solution satisfies Maxwell's equations, the infinity conditions and transmission conditions enforced at the layered interface. The DS amplitudes are to be determined from the transmission conditions imposed at the surface of the local obstacle. The advantages of the DSM can be attributed to the possibility to control the actual convergence of the approximate solution by posterior evaluation of the fields residual at the obstacle surface in the least square norm.

In the presentation we will show that the scattered intensity can be essentially enhanced by adding a thin transparent spacer layer between the obstacle and film. Influence of the film thickness, irregularity shape and material will be demonstrated as well.

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Comparison of Au and Ag Nanoshells' Metal-Enhanced Fluorescence

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Keywords: nanoshell, metal-enhanced fluorescence, average enhancement factor, Mie theory, dyadic Green's functions, excitation rate, radiative power, nonradiative power, apparent quantum yield

The average enhancement factors (AEF) of Au and Ag nanoshells (NSs) for metal-enhanced fluorescence (MEF) are analyzed theoretically to compare their overall performances on the photoluminescence of a nearby molecule. The NS structure is consisted of a silica bead coated by a layer of metal shell. To analyze the MEF of NS, the process of molecular fluorescence is simply divided into two stages: the excitation and the emission stages. In the excitation stage, the enhanced electric field around NS provides a strong excitation rate for a nearby molecule. Once the molecule is excited, it starts to emit the fluorescence under the influence of the nearby NS at the emission stage. At this stage, the molecule can be modeled as an electric dipole. The roles played by NS at each stage are discussed individually, and then the overall enhancement factor (EF) for the whole process is studied.

We use the Mie theory to calculate the electromagnetic fields around NS illuminated by a plane wave; the excitation rate of NS for the molecule at the excitation stage is obtained. At the emission stage, the excited molecule is modeled as an electric dipole. We use the dyadic Green's functions to analyze the radiative and nonradiative powers of the dipole under the influence of NS, and then to obtain the apparent quantum yield of the emission of an excited molecule affected by the NS. Combining these two factors, excitation rate and apparent quantum yield, we can obtain the EF of NS for a molecule with a specific orientation at a specific location. Moreover, the effective enhancement factor (EEF) of NS for a nearby molecule at a specific position with an arbitrarily oriented dipole moment is calculated. Furthermore, the AEF of NS for the fluorescence of a nearby molecule is obtained by averaging all possible locations of the molecule with a constant distance from NS. Our results show that the maximum AEF of Au NS is at the wavelength of the dipole mode of NS, which is broadband. In contrast, the maximum AEF of Ag NS is at the quadrupole mode, which is narrowband. In fact, Ag NS is a dual-band enhancer at the dipole and quadrupole modes. In addition, there is an optimal distance to obtain the maximum AEF for each mode. Our analysis shows that AEF of NS is useful to estimate the performance of a large number of NSs on MEF, which is usually overestimated by only considering the maximum EF.

C2
Laboratory and field experiments

(June 21th, 2:00 PM)

Microwave analog experiments of surface wave scattering

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Keywords: scaled analog measurements, evanescent waves, amplitude, phase.

The characterization of nanostructured materials and surfaces is crucial for a large number of manufacturing processes. Some existing methods provide an excellent way of imaging nano-objects deposited on a surface, but are unable to provide quantitative information on the size, arrangement and composition. With far-field electromagnetic evanescent wave scattering data and through inversion techniques, these characteristics are likely to be retrieved[1-3]. Although the proof of concept has been provided theoretically, the experimental implementation with optical waves for characterization of nanoparticles on a surface remains a tremendous challenge. In particular, the full control of both the nanostructured samples and the components of the setup can hardly be achieved. Finally, because of the previous reasons, assessing via experiments the numerical tools which simulate surface wave scattering by any type of target is a critical issue.

To overcome these difficulties, one can think about having recourse to scaled objects and scaled frequencies to perform analog to light scattering experiments[4,5]. This talk will present a new device which, in the microwave range of the electromagnetic spectrum, measures the amplitude and the phase of the electric and magnetic fields scattered by different targets submerged in electromagnetic evanescent waves.

The methods to take on the aforementioned challenges will be described in details. A series of original experimental results will be presented. Whenever possible, a combined analysis of these data and simulations will be proposed. This new measurement device is likely to help solving a series of issues that could not be tackled yet.

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Note: the name of the person who will make the actual presentation is underlined.

Backscattering of externally-mixed nonspherical particles: partitioning using UV-VIS polarimetric field experiments and T-matrix simulations

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Keywords: remote sensing, polarization, *T*-matrix method, nonspherical particles, dust, sea-salt.

As shown by electron microscope images, atmospheric particles, such as desert dust or sea-salt particles, exhibit a nonspherical shape (T. Nousiainen, 2009), which must be precisely addressed from both a fundamental (light scattering theory M.I. Mishchenko et al., 2002) and a practical (climate forcing assessment) point of view. Following the discussions held in Taormina at the ELSXIII Conference, we further developed our UV-polarization backscattering field experiment (G. David et al., 2012a) to partition three-component external mixtures of atmospheric particles (G. David et al., 2012b). We hence developed a new methodology to specifically address the backscattering properties of dust, sea-salt and water-soluble particles in a three-component particles external mixture, as observed at Lyon (France) during Saharan dust outbreaks. This new methodology relies on the combined use of a sensitive and accurate UV-VIS Lidar remote sensing field experiment and accurate T-matrix numerical simulations (M.I. Mishchenko et al., 2002), used to specifically address dust and sea-salt particles backscattering in the three-component external mixture. The dust particles scattering matrix elements were computed by assuming a shape distribution of spheroids, used as a proxy to represent atmospheric dust particles. For sea-salt particles, an extension of the T-matrix code, developed by M. Kahnert, was used to account for the cubic shape exhibited by sea-salt particles below their deliquescence point. In addition, we extended our UV-remote sensing field experiment to UV-VIS polarization particles backscattering (G. David et al., 2012a), leading to a sensitive and accurate evaluation of particles backscattering in the Lyon troposphere.

This talk is intended to summarize these new recent developments. In particular, we will detail the new methodology to retrieve separate vertical profiles of atmospheric dust, sea-salt and water-soluble particles, by combining 2λ-polarization field experiments with T-matrix numerical simulations (G. David et al., 2012b). Moreover, new findings on the detection of extremely complex particles formation events in the atmosphere will be presented (Y. Dupart et al., 2012), as a result of our increased sensitivity to particles backscattering. In complement to this approach, particles UV-backscattering laboratory experiments will also be presented.

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A polarization-resolved diffraction imaging flow cytometry method to detect subtle morphological differences in lymphocyte cell lines

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Keywords: polarization, light scattering, diffraction imaging, white blood cells

Single cells can be rapidly measured by flow cytometry (FC). Existing FC methods, however, rely on a few signals of fluorescence and scatter to analyze and classify cells with very limited morphology information extracted. We have developed a new FC method for rapid acquisition of high-contrast diffraction images. Analysis of diffraction images acquired from cells and microspheres demonstrated clearly that these images, unlike the non-coherent ones, require no segmentation and their features such as textures or spatially varying oscillation frequencies can be extracted rapidly with existing algorithms. With these feature parameters the diffraction image data serve as the "fingerprints" encoded by the 3D morphological traits for characterization of an imaged particle. The approach of diffraction image acquisition and automated analysis thus forms a new method of diffraction imaging flow cytometry (DIFC) that allows rapid and label-free assay and classification of single cells

We will present in this talk our recent results on improving the DIFC method with two cameras to acquire cross-polarized images. The utilization of polarization imaging for cell assay was motivated by the well-known fact that both intensity and polarization of the coherently scattered light relate to the volumetric distribution of refractive index within a cell. By controlling the polarization directions in both incident beam and scattered light, the improved DIFC system allows the latent difference of intracellular refractive index to be efficiently exploited for cell characterization and classification. We chose two cell lines of Jurkat lymphoblastoid T cells and Burkitt's lymphoma Ramos B cells to test if the polarization DIFC method can distinguish them without fluorescent labels. For quantitative analysis we have developed an image processing software to extract 17 texture parameters from each normalized image of I_8 using the GLCM algorithm. The parameters were investigated individually for their potential usage as the components of a feature vector or quantitative "fingerprint" for characterization of the imaged cells with a supervised machine learning algorithm of support vector machine (SVM). A classification accuracy of 98.8% was obtained with the polarization resolved DIFC method in distinguishing the Jurkat and Ramos cells.

Note: the name of the person who will make the actual presentation is underlined.

Laboratory Measurements of the Scattering Properties of Ice Crystals

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Keywords: Cirrus, climate change, geometric optics, remote sensing

The recent 2007 report of the International Panel on Climate Change (IPCC) concluded that understanding the role of clouds in the Earth-Atmosphere radiation balance is currently one of the largest uncertainties in predicting climate change. Cirrus clouds pose an interesting problem due to their large natural variability in composition and size distribution. In most current light scattering models, ice crystals are represented by simplified geometric shapes, leading to errors in predicted phase function, asymmetry parameter and planetary albedo. Many studies have highlighted the sensitivity of scattering behavior on crystal habit, and thus more accurate representations are sought. Further to this, surface roughness and internal structure are gaining recognition as important contributors to the scattering properties of cirrus. Some models have begun to take these properties into account, although further laboratory studies are crucial in order to parameterize these correctly, and to test light scattering models.

In this talk, we discuss ongoing work in the Manchester Ice Cloud Chamber (MICC). The cloud chamber comprises a 10 meter fall tube and can produce a variety of size ranges and habits known to cirrus. A rotating diode array spectrometer is used to measure the intensity of radiation scattered by the cloud falling through the chamber. The cloud composition is monitored simultaneously by the use of a Cloud Particle Imager (CPI). Further to this, formvar replicas are taken alongside CPI data in order to gather more in depth data of the crystal habit including the internal structure, and surface roughness. These replicas are used to make more complex geometric models. The ray tracing results of these are compared with measured scattering data.

Static and dynamic light scattering from granular media

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Keywords: static light scattering, diffusing wave spectroscopy, particle characterization, terahertz radiation

While it is established to measure quantities like size, shape, distribution, mobility or spatial arrangement of particles in sub-micron colloids conveniently with visible light scattering, such techniques are restricted for larger densely packed sub-millimeter granular particles. We apply Terahertz radiation to regain the limiting case of Rayleigh-Debye scattering for such particles. An experimental setup using a quantum cascade laser as monochromatic light source is realized. A convenient optical bench setup is obtained by adapting the wavelength to a transmission band of air at 3.6 THz. The thermal background is suppressed by lock-in amplification. Here we demonstrate the possibility to use static Terahertz radiation scattering to determine particle size and arrangement in polystyrene particle powders from angular-resolved intensity measurements.

The obvious white appearance of many powders suggests applicability of interferometric techniques like diffusing wave spectroscopy to measure motion in fluidized powder particles. The autocorrelation of the intensity fluctuation is used to probe motion on length scales much smaller than the particle size. Owing to the granular nature of the powders the obtained decays in autocorrelation characterize the response of the particles to the driving mechanism, which can in turn be used to characterize the particles and the state of fluidization. Additionally, the much smaller number of probed powder particles as compared to colloidal particles makes the dynamic light scattering much more sensitive to particle number fluctuations. We show that the non-gaussian intensity fluctuations from number fluctuations can be used to extract additional information on the flowing powder.

Note: the name of the person who will make the actual presentation is underlined, oral presentation is preferred.

Application of the scanning flow cytometry for characterization of blood platelets

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Keywords: scanning flow cytometry, discrete dipole approximation, particle characterization, global optimization

Scanning flow cytometer (SFC) is capable of measuring angle-resolved light-scattering pattern (LSP) of individual particles in flow. Specifically, the LSP is an intensity of scattered light integrated over the azimuthal scattering angle as a function of the polar scattering angle. An analysis of the LSP potentially allows one to determine morphological characteristics of biological particles. However, such characterization constitutes the inverse light-scattering problem. This work is dedicated to characterization of blood platelets from LSPs measured with the SFC.

Blood platelets are small disc-shaped cells without nuclei. Their main function is the formation of hemostatic plugs after vessel wall injury. This is achieved by platelet activation in response to the injury, followed by platelet aggregation and adhesion to the damaged area. Activated platelet rapidly changes its shape from discoid to more spherical with numerous pseudopodia. The study of platelets morphology, activation and aggregation are of clinical importance.

We use an oblate spheroid as an optical model of a blood platelet. Since pseudopodia were shown to slightly affect the LSP, activated platelets were also modeled as oblate spheroids. This model has four parameters which are to be obtained by solving the inverse light scattering problem: refractive index, two dimensions and one orientation angle. Theoretical LSPs for oblate spheroids were calculated using the discrete dipole approximation (DDA). In particular, we used open-source code ADDA v.1.0. Calculation of one LSP took approximately 1 min on a single core. The computations were verified by comparison with other light-scattering codes. We also performed simulations for dimers of platelets to effectively separate them from single cells based on LSPs.

Given the optical model, the inverse light scattering problem is transformed to global optimization, minimizing the discrepancy between experimental and theoretical LSPs. Direct fitting is unfeasible due to large computational time, therefore a pre-calculated set of LSPs is used to perform global optimization by nearest-neighbor interpolation. The best estimate of parameters, mathematical expectations and covariance matrix are determined for each experimental LSP. This general approach is applicable not only for blood platelets but also for any particles with optical model described by a few parameters.

The approach was applied to characterize blood platelets from healthy donors. LSPs of resting platelets and ones stimulated by several agonists were measured with the SFC. The activation state of platelets additionally monitored using activation-dependent fluorescent label showed a correlation with platelets shape obtained with our approach. The results of global optimization are also in good agreement with microscopic measurements and resistive-particle counting. A detailed account of some of these results can be found in the paper [1].

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A2
Aerosols and clouds

(June 21th, 4:00 PM)

Light absorbing carbon mixed with soluble compounds: modelling the impact of aerosol morphology on climate forcing and remote sensing observations

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Keywords: electromagnetic scattering, light absorbing carbon, climate impact, remote sensing

Light absorbing carbon (LAC) aerosols originating from fossil fuel combustion and biomass burning play an important role as a short-lived climate forcing agent. LAC is emitted as fractal aggregates consisting of some tens to hundreds of carbonaceous monomers with monomer radii in the range of 10-25 nm. Following emission, the initially lacy aggregates quickly collapse to form more compact aggregates. In the ambient atmosphere, the mostly hydrophobic LAC particles undergo oxidation and become more hydrophilic. Condensation of soluble compounds, such as sulphate and organic matter, produces complex morphologies of LAC aggregates encapsulated in a shell of weakly absorbing material.

We employ data from recent field observations to build morphologically realistic model particles of such encapsulated aggregates that cover the size range from Aitken to accumulation mode aerosols. Detailed reference computations with the discrete dipole approximation (DDA) are performed, where we used 14 wavelength bands from the UV-C to the mid-IR. The reference computations are compared to corresponding results obtained with commonly employed simplified model geometries, such as external mixtures of homogeneous spheres, internal homogeneous mixtures in conjunction with effective medium theory, and core-shell particles with an LAC core and a concentric coating of soluble material. In contradiction to commonly made assumptions, we find that the core-shell model does not provide a good representation of the optical cross sections and the single scattering albedo (SSA). Most notably, this model significantly underestimates the absorption cross section C_{abs}. The homogeneous internal mixture model overestimates C_{abs}, but the error tends to be less than that for the core-shell model. The origin of the problem is associated with the distribution of the carbon mass in these simplified models. We discuss two different models that provide a better representation of the optical properties of encapsulated LAC aggregates, namely, a core-shell-shell model, and a core-grey shell model. While both of these models yield significant improvements in C_{abs}, SSA, and in the asymmetry parameter, g, over the commonly used models, only the core-grey shell model is likely to be sufficiently fast for broadband computations as required for climate modelling.

The phase function and the other elements of the Mueller matrix tend to be mostly dominated by the spherical shell of weakly absorbing material. They are, therefore, reasonably well reproduced by most models. However, the total scattering cross section is highly sensitive to particle morphology. So, quantities such as the backscattering coefficient differ significantly among different particle models. We find that the core-grey shell model reproduces the backscattering cross section of the encapsulated aggregates most accurately.

A self-consistent scattering model for cirrus and its relationship to the atmospheric state

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Keywords: Humidity, ice crystals, light scattering, phase functions, randomization, remote sensing

Predicting the scattering properties of cirrus is generally problematic, due to these clouds consisting of highly irregular and large, as well as small, ice crystals. However, more recently there have been proposed, a number of idealized ice crystal models that attempt to take account of the observed variability in ice crystal size, irregularity and scattering properties.

One such proposed habit mixture model is called the "ensemble" model of ice crystals. This model consists of six elements, the first of which is assumed to be a hexagonal ice column of aspect ratio unity, then six-branched bullet rosette. Thereafter, hexagonal ice monomers are arbitrarily attached to form chains of hexagonal ice aggregates, until the sixth element consists of a spatial chain of ten hexagonal monomers. The hexagonal ice aggregates are spatial so as to minimise multiple reflections between individual monomers, in this way, the mass of hexagonal ice aggregates follows generally observed approximate power laws, which relate the mass to the maximum dimension of the ice crystal. A number of papers have demonstrated that the ensemble model conserves mass and predicts the experimentally determined volume extinction coefficient to within current observational uncertainties.

In this talk, the scattering phase functions predicted by the ensemble model, under a number of assumed randomizations, are compared against PARASOL pixel-by-pixel multi-directional angular observations, between the scattering angles of about 80° and 130°, to estimate the most likely ice crystal randomization that best describes the measurements. The ensemble model randomizations are tested using a semi-transparent cirrus case that occurred over the UK during the winter of 2010.

Moreover, for this same case the Met Office high-resolution Numerical Weather Prediction (MONWP) model is run at a horizontal resolution of 1 km to obtain predicted relative humidity with respect to ice fields (RH_i). The MONWP RH_i 1 km fields are averaged to the PARASOL pixel resolution of 6 km × 6km to explore the relationship between the ensemble model randomized phase function and RH_i. To validate the MONWP RH_i fields, independent retrievals of RH_i are compared against the model fields. The independent retrievals are based on airborne data from high-resolution infrared measurements between about 3000 cm^{-1} and 507 cm^{-1}, at a resolution of 1 cm^{-1}, and space-based microwave data. If such a relationship is found to exist, between the scattering phase function (hence also the asymmetry parameter) and RH_i, the implications of this for climate models will be discussed in the talk.

Towards global constraints on ice cloud asymmetry parameters

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Keywords: ice clouds, remote sensing, asymmetry parameter, polarization

The asymmetry parameter of the scattering phase function is a fundamental microphysical parameter that determines the radiative properties of ice clouds. However, our current knowledge about the asymmetry parameter of natural ice clouds and its variation is very poor. Global assessments of the asymmetry parameter are crucial to providing better constraints on the optical properties used in climate models and to improving retrievals of the other fundamental properties of ice clouds, such as optical thickness and effective radius. Here, we present the first results of a newly developed technique to remotely sense the asymmetry parameter of ice clouds from satellite measurements. While ice crystal habits are highly variable, it has been shown that the optical properties of complex crystals strongly resemble those of their components and that observed variations in the asymmetry parameter of ice clouds can be represented in terms of the aspect ratio and surface roughness of simple hexagonal ice crystal components. We show that multidirectional polarization measurements, such as those made with the POLDER instruments, provide sufficient constraints on aspect ratio and surface roughness to allow for an accurate, precise, and robust retrieval of the asymmetry parameter. We will briefly outline the technique and its evaluation using a range of simulated conditions and applications to the airborne Research Scanning Polarimeter (RSP). Then we will present the first application of this technique to combined observations from the MODIS and POLDER instruments in the NASA A-train.

Preferred presentation mode: Oral

Analysis of assumptions and uncertainties in direct aerosol radiative forcing calculation based on AERONET retrievals

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Keywords: radiative forcing, aerosol non-sphericity, aerosol mixtures

Evaluation of direct radiative forcing often relies on assumptions about aerosol shape, external aerosol mixture and lambertian surface albedo. In this work we examine uncertainties in radiative forcing calculations that can be introduced by neglecting aerosol non-sphericity, internal mixture of aerosols and directional hemispherical reflectance. The broadband solar fluxes in our study are simulated using an extract from the AERONET operational code that implements spectral integration of radiances calculated in range from 0.2 to 4.0 µm. These calculations were adopted for modeling various scenarios assuming spherical or spheroid aerosol particles, external or internal (the core-shell structure) aerosol mixture, and lambertian or directional hemispherical reflectance (BRDF based surface albedo). The computations employed for evaluation of aerosol non-sphericity account for the details of the aerosol phase function and not limited to usage of simplifications relying on the asymmetry parameter only. The spectral variations of the phase function and all other parameters are accurately taken into account by recalculating them for about two hundred subintervals over the whole spectral range. The radiative effect of internal and external aerosol mixture is calculated using consistent aerosol volume concentrations in order to test effect of the aerosol morphology.

Our results show that neglecting non-sphericity of aerosol particle shape for dust results in a pronounced bias of the daily averaged aerosol forcing. The simulations that rely on AERONET retrieved dust and biomass burning aerosol models show that the core-shell mixture of mineral dust with carbonaceous material enhances the aerosol radiative forcing efficiency. These simulations may explain strong absorption observed in the Sahel region during the season when biomass burning can be mixed with mineral dust. Possible uncertainties in diurnal radiative forcing due to lambertian surface assumption are evaluated and illustrated in some examples. The importance of the non-sphericity and mixing state effects are also analyzed for varying surface reflectance and effect of the BRDF.

Note: the name of the person who will make the actual presentation is underlined.

SENSITIVITY STUDY OF POLARIZATION MEASUREMENTS OVER SNOW SURFACES

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Keywords: electromagnetic scattering, particulate media, superposition *T*-matrix method

The brightness of snow landscapes bewilders passive remote sensing instruments especially regarding the retrieval the properties of atmospheric particulates. Following recent progress on the collection of high-accuracy polarimetric measurements, we present an investigation on the potential value of multi-wavelength, multi-directional polarimetry in detecting relevant parameters of aerosols suspended or deposited over snow surfaces.

To model the snowpack, we exploit a newly assembled database of optical properties of hexagonal ice crystals, with a virtually continuous selection of aspect ratios and microscale roughness parameters.

These theoretical calculations demonstrate promising sensitivity to grain shape and aerosol vertical distribution, exploitable by Earth-orbiting remote sensors with polarization capabilities, such as POLDER, to provide fundamental data for climate-related studies in the polar regions.

P1
Poster Session

(June 17th, 5:35 PM)

Experimental analysis of interstellar graphite dust analogue by forward scattering behavior of monochromatic light.

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Keywords: Light scattering experiment, interstellar dust, Mie theory

Observations and simulations of the absorption and scattering properties of interstellar dust gives information of the physical properties of their constituent particles. Such particles are present everywhere in the solar system, cometary comae and tail, interstellar dust clouds, circum-planetary dust rings, asteroidal atmospheres and aerosols of other planetary atmospheres. *In-situ* investigation on the composition of the cometary dust particles, conducted by CIDA (Cometary and Interstellar Dust Analyzer) onboard the NASA spacecraft STARDUST, provided evidence that the interstellar dust is a mixture of irregularly shaped silicate and carbonaceous materials that are also highly porous in nature (fluffy). These particles act as the heterogeneous media to scatter solar or steller light which is unpolarized in nature. Measurement of the volume scattering function and degree of linear polarization can be used to estimate parameters like size, porosity and roughness of the dust particles.

The analysis of optical scattering properties of carbonaceous graphite dust particle analogue at 543.5 nm, 594.5 nm and 632.8 nm laser wavelengths by using an original laboratory light scattering setup are presented in this contribution. The setup consisted of laser sources, optical units, aerosol sprayer, data acquisition system and associated instrumentation. The instrument measured scattered light signals from 10° to 170° in steps of 1°. The accuracy and the reliability of the setup were verified by conducting light scattering measurements on spherical water droplets and comparing the results with theoretical Mie calculations. The results of the measurements of the volume scattering function and degree of linear polarization of the carbonaceous graphite dust particles that were suspended in front of the laser beam by using an aerosol sprayer are presented. The experimental results were subsequently compared with theoretically generated Mie plots with estimated parameters to draw conclusions. It was found that at 632.8 nm laser wavelength, highest positive polarization of 0.54 (equivalent percent of polarization ~54%) was observed. The measured lowest negative polarization was 0.16 (equivalent percent of polarization ~16%) and it was obtained at 543.5 nm incident wavelength.

Improved technique for retrieving the aerosol optical and microphysical properties using sun and sky radiance measurements

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Keywords: aerosol, solar radiation, inverse problem of aerosol light scattering

An algorithm, close in idea to approach of T. Nakajima (1996), was developed earlier by authors to solve the inverse problem of aerosol light scattering using the data of measurements of the spectral atmospheric extinction and sky radiance in the solar almucantar in the visible and near-IR spectral ranges. In an initial version, the algorithm ensured retrieval of such aerosol parameters as single scattering albedo, scattering phase function, particle size distribution, and complex refractive index under the assumption that its real and imaginary parts are constant within the spectral interval considered. The inverse problem was solved for homogeneous spherical particles. The method was based on the iterative procedure of retrieving the aerosol optical characteristics directly from measured sky radiance and subsequent solution of the linear inverse problem for recovered spectral volume scattering phase functions and measured spectral aerosol optical depth.

In this paper, we present the algorithm modified to take into account (1) the spectral variability of refractive index of aerosol substance and (2) the nonsphericity of aerosol particles through their approximation by randomly oriented spheroids. On the basis of numerical experiments, accuracy estimates for the retrieved aerosol characteristics are obtained with and without accounting for the measurement errors.

A consequence of accounting for previously mentioned factors had been a high computational complexity of the algorithm. The inefficiency of the algorithm was reduced through optimization of the set of procedures (calculating the kernel of Fredholm integral equation on the set of variables, etc.) with the help of parallel programming for multi-core processors.

This work was supported in part by RFBR (Projects Nos. 12-05-31007 and 13-05-00806).

Depolarization of the light reflected by a layer of nanoparticles at the frequency of localized surface plasmon resonance.

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Keywords: electromagnetic scattering, depolarization, nanoparticle, energy transfer, localized plasmon

Mutual interactions in a system of metallic nanoparticles result in the creation of common plasmonic modes of the system from the localized surface plasmons of separated particles due to interparticle electromagnetic interactions. As the consequence the properties of scattered light in far-field zone is defined by those interactions in the near-field zone. More over, if the direct investigation of the near-field distribution by SNOM is possible for ordered systems, it has much less sense for a disordered one because of big variations of the local configuration. At the same time macroscopic averaging methods, especially investigation of the polarization state of light by ellipsometry can also shine light on such near-field interactions.

Ellipsometry of disordered layers of gold nanoparticles on silicon prepared by thermal flash-annealing of thin sputtered gold films at different temperature demonstrates remarkable depolarization of reflected light at the frequency of the excitation of the plasmon in this system. The depolarization is stronger for the case of lower temperature of the annealing when constituting particles have wider spreading of the size and shape. It can be explained by strong interparticle interaction and the energy transfer between constituting particles just in the case of the resonance excitation, when the intensity of the field and interparticle coupling is enhanced. In such a case spreading of size and shape of interacting particles should result in wider spreading of the dephasing time as well as the direction of oscillations of plasmons of the same energy localized on individual constituting particles. The former effect can give the depolarization of the scattered light but the later one does the polarized scattered light with the spreading of the polarization direction. In the case of the loose of the coherence it will be registered as the enhanced depolarization of the reflected light.

Noticed and recorded effect of the light depolarization clearly demonstrates the possibility to monitor the near-field interactions in nanoparticle systems by macroscopic method of ellipsometry.

Particles characteristic over Hampton, USA using ground based and space borne lidar and sunphotometer

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Keywords: backscatter, aerosols, Lidar

The optical properties of atmospheric aerosol particles were analyzed using a Raman Lidar operating at 3 wavelengths 1064, 532 and 355nm over Hampton University (37.02°N, 76.33°W) and a close by sunphotometer at Nasalangly and Calipso data during 2011 and 2012. Unique features of the observations with multiple wavelengths ground based lidar and Spaceborne Calipso lidar enabled precise determinations of particle characteristics, layers of aerosol, and vertical structure.
The combination of (a) an sun photometer , which measured a complete set of aerosol optical properties, such as extinction, scattering, and absorption coefficients, single scattering albedo, apparent complex refractive index, asymmetry parameter of the phase function of scattering, ..., (b) a multiple wavelength lidar which is retrieved the particle back scatter coefficient, extinction coefficient and Lidar ratio and (c) closest over pass of Calipso measurement have been used to compare the optical properties of the observed particle,to calibrate ground based lidar products and to understand the impact of long range transport of aerosol on local aerosol load including some particular event of smoke and dustalofts or high pollution events in the east coast of United states.
This paper presents a closure study of the different measurement methods. Several wildfire,smoke and dust events have been revealed by Hampton University Lidar observations (Hampton, Virginia, United State). The smoke fire produced by western US wildfires or close by in the Virginia sate. Several dust aloft in the lower altitude of the troposphere have been observed and the optical properties of particles have been analyzed.

Imaging Polarimetry of Comets 78P/Gehrels, 22P/Kopff and asteroid 5 Astraea

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Keywords: Comets 78P/Gehrels, 22P/Kopff and asteroid 5 Astraea – Light scattering – Polarization – Intensity enhancement techniques – Features of cometary coma

The Jupiter family comets 78P/Gehrels, 22P/Kopff and the large S-type main-belt asteroid 5 Astraea were observed in different observing runs during 2009 to 2012 by Indian and French astronomers in joint campaigns. The observations were taken from the 2m IUCAA Girawali Observatory (India) and from the 0.80 m OHP telescope in France. They were mostly made in polarimetric mode with a CCD as image detector. During the observations the phase angle of 78P/Gehrels lied between 14°-15° at IGO and 28° at OHP, and that of 22P/Kopff lied between 38°-39° at IGO. Phase angle of 5 Astraea decreased from 12° to 11° at IGO. In case of comets, a broadband red filter (*R*, λ=630 nm, $\Delta\lambda$=120 nm at IGO; and λ=670 nm, $\Delta\lambda$=90 nm at OHP) along with a narrowband Comet-Red (CR, λ=684 nm, $\Delta\lambda$=9 nm at IGO) filter to avoid gaseous contaminations were used during the observations. At IGO, the asteroid 5 Astraea was observed through the following different filters: B=420 nm, $\Delta\lambda$B=100; V=520 nm, $\Delta\lambda$V=90; R=630 nm, $\Delta\lambda$R=120 nm; I=850 nm, $\Delta\lambda$I=300 nm. The linear polarization computation from the light scattered by the dust particles allowed us to suggest some physical properties for the cometary and asteroidal particles. The observed polarizations of both comets and asteroid are compared to the respective classical polarimetric phase curves at the phase angles and wavelength of the observations and that of comet 22P/Kopff to its previous observations. The polarization values of comets are also compared to those obtained previously for other Jupiter Family comets. Along with the polarization measurements of different regions of cometary coma, different enhancement techniques have been used to emphasize different dust regions in the cometary coma.

The properties of urban aerosols: Moscow-Zvenigorod long-term aerosol experiment

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Keywords: urban aerosol, radiative aerosol properties, spherical and non-spherical particle approaches, remote sensing, validation

The properties of urban aerosols according to long-term simultaneous measurements by the collocated AERONET CIMEL sun/sky photometers in Moscow (large megacity) and at Zvenigorod (nearby clean area) were studied in various atmospheric conditions in 2006-2012. Additional measurements of PM10 and PM2.5, as well as soot content observations were used for evaluating the effects of local urban sources and their influence on columnar aerosol properties (single scattering albedo, aerosol optical thickness, etc.). For the conditions, when the spherical particle approach did not work properly in the inversion algorithm, the supporting data and backward trajectory analysis have been applied to reveal if these cases are affected by urban pollution or by other reasons. The comparisons of simulated radiative fluxes were made against the high quality ground-based radiative measurements at the Meteorological Observatory of Moscow State University for the validation of the obtained urban radiative effects in clear-sky conditions with different aerosol types. In addition, we also tested the retrievals of several aerosol parameters (AOT, single scattering albedo, Angstrom exponent, etc.) by different satellite instruments (MISR, MODIS, SEAWIFS, OMI) against the data of collocated AERONET CIMEL sun/sky photometers in different atmospheric situations over snow and snow-free surfaces for their ability to detect the urban aerosol pollution.

Type of presentation: oral

ARTDECO an Atmospheric Radiative Transfer Database for Earth and Climate Observation

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ARTDECO ('Atmospheric Radiative Transfer Database for Earth and Climate Observation') is a numerical tool that gathers models and data for the 1D simulation of Earth atmosphere radiances (total and polarized) and fluxes as observed with passive sensors (hyperspectral excluded) in the UV to thermal IR range. It is developed and maintained at the Laboratoire d'Optique Atmosphérique and is funded by the TOSCA program of the French space agency (CNES). In ARTDECO, users can either access a library for the scene definition (atmosphere profile, k-distribution coefficients for gas absorption, surface, aerosol and cloud description, filter transmission, etc) or use their own description through ASCII input files. New optical properties for aerosols and clouds can be computed. Then, the user can choose among available models (several methods for the truncation of the phase matrix, several RTE solver) to compute radiative quantities corresponding to the scene. Technical parameters for these models are also accessible through ASCII files. ARTDECO is thus a flexible tool that is especially powerful to study and optimize performances of different methodologies to model radiances for a given scene. Trough the poster, we will present ARTDECO. We will also show, as an example use, the results of a study on the error induced on polarized radiances after phase matrix truncation.

Irreducible 3D radiative transfer effects in multi-angle/multi-spectral radiometric and polarimetric signals (not noise!) from a single large-footprint pixel with a mixture of clouds and aerosols

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Keywords: 3D vector radiative transfer, aerosol remote sensing, cloud adjacency effects, Glory, APS, POLDER

Although the Glory satellite mission failed at launch, the atmospheric observation strategy implemented in its Aerosol Polarization Sensor (APS) is alive and well. This strategy is based on APS's along-track scanning spectro-polarimetric measurement system that captures the three main Stokes vector elements (I_λ,Q_λ,U_λ) at a large number (>200) viewing directions (θ_v) for 9 wavelengths λ emanating from a single pixel that is >6 km in diameter at nadir ($\theta_v = 0^o$) and stretches into a 6^+ x ~20 km^2 ellipse at the most oblique views to be considered ($\theta_v \approx 70^o$). Two cloud cameras (CCs) are also onboard and provide spatial context. If the relatively large APS footprint is cloud-free or fully-cloudy, then a 1D vector radiative transfer (RT) model is adequate for predicting the APS signals and, upon iteration over its input parameters, aerosol and cloud property retrievals are expected to be of high quality. And this level of accuracy is indeed required to make a real breakthrough in climate modeling where the radiative properties of aerosols and clouds remain one of the main sources of uncertainty.

However, the CCs will often show that the APS field-of-view is a spatially complex cloud scene to be dealt with, but where we are mostly interested in the ambient aerosols. And, moreover, it is precisely these aerosols in contact with clouds that will influence their microphysical and optical properties, leading to the manifold indirect aerosol effects on the climate system that need to be far better understood in order to incorporate them into climate models. Therefore, the research presented here addresses the challenge of characterizing simultaneously aerosols and clouds in a single APS observation. Access to polarization can, in principal, be used to separate clouds and aerosols using the cloud-bow directions that will often be sampled by APS, assuming another one is launched and joins the A-train orbit. In practice, however, we need to assess the extent of 3D polarized RT that is unfolding inside the APS pixel and that can *not* be estimated using a linear mixture of 1D vector RT (vRT) computations assuming either aerosol or cloud is present. Differences between the 1D vRT-based prediction and simulated APS data derived from a high-fidelity 3D vRT model is what we call "irreducible" 3D RT effects. To this end, we have used the Monte Carlo 3D vRT model (vMYSTIC).

Based on computations for a typical scene with a 3D cumulus cloud field embedded in a horizontally uniform aerosol we find that the irreducible 3D vRT effects are in the APS's signal—not its noise level—especially if the aerosol burden is significant. The cloud-bow region, which is key to any practical cloud-aerosol unmixing algorithm, is particularly vulnerable. Moreover, the adopted 1D vRT-based forward model is assumed to be very well informed about the actual aerosol/cloud properties, meaning that the predicted irreducible 3D vRT effects a best-case scenario. In reality, the problem will be far more severe. We nonetheless propose a promising path toward a mitigation scheme.

Utilization of AERONET polarimetric measurements for improving retrieval of aerosol microphysics: GSFC and Beijing data analysis.

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Keywords: aerosol remote sensing, sun-photometer, polarimetry, data inversion

The use of additional information about polarization of light scattered in the atmosphere can improve aerosol retrieval. This new tendency is widely applied already for satellite observations. A new sun-photometer CIMEL CE318-DP enabling multi-wavelength polarization characteristics of the downward field radiation has been developed to improve quality and accuracy of ground-based observations. In order to process the data from this instrument the data preparation tool for the retrieval was developed for semi-operational processing of the data using AERONET inversion code adapted for inversion of both intensity and polarization measurements (Dubovik et al. 2006). The data processing program includes calibration of the raw measurements, calculation of aerosol (AOD), gas and molecular optical depths, degree of linear polarization (DOLP) and other characteristics. It also obtains parameters of surface reflectance from satellite climatology (BRDF parameters), applies "clouds screening" function to remove unrealistic measurements etc.

In order to estimate a contribution of polarized measurements to inversion results the data for two different regions have been chosen: GSFC, USA, (clean urban aerosol dominated by fine mode particles) and Beijing, China, (polluted industrial aerosol characterized by the pronounced mixture of both fine and coarse mode). The inversion results show that polarization does not bring significant improvements for the case of clean urban aerosols dominated by small particles like in GSFC case (see climatology by Dubovik et al. 2002). At the same time, in several cases use of polarization resulting in notable change: decrease of the fine mode of particles and increase of the real part of the refractive index. In the case of Beijing industrial dust the use of polarimetric measurements brings considerable advantages that are fully consistent with the conclusions of study by Li et al. (2009). Specifically, use of polarization corrects particles size distribution by decreasing seemingly overestimated fine mode and increasing coarse mode. Furthermore, it increases likely underestimated real part of refractive index and the spherical particles fraction retrieved due to high sensitivity of polarization to particles shape.

Thus, the study clarifies the possibility of improving ground-based retrieval of aerosol by using the polarization measurements and suggests a significant value in polarimetric data especially beneficial for improving characterization of complex aerosol mixed fine and coarse mode aerosols, such as observed over Beijing and likely other regions with the presence of heavy pollution.

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Development of a web application for the analysis of electromagnetic scattering from small particles

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Keywords: Web application, electromagnetic scattering, Mie theory, *T*-matrix method

Light scattering behavior of spherical or nonspherical particles, whose size ranges from micrometer to nanometer, and its computation has become a subject of intensive research in the fields of atmospheric radiation, remote sensing, climatology, astrophysics, biophysics and so on and forth. A number of efficient theoretical approaches such as Mie theory, T-matrix method, discrete dipole approximation (DDA), *etc.* have been developed to explain experimentally observed light scattering patterns due to particulate matter. The recent growth in high performance computing systems, helped in developing fast, accurate and reliable computer programmes or software based on these theories to simulate light scattering problems; quite a few of which are also integrated with Graphical User Interfaces (GUIs) to make the interaction between a user and the software easier. However, adequate knowledge of the respective programming language or local installation is necessary to run such softwares which sometimes represent major difficulties like platform dependency, availability of suitable compiler [1]. In this context, there is a growing need for user friendly web based interfaces to enable the researchers to run light scattering simulations online.

In this contribution, we intend to demonstrate the extended version of TUSCAT (**T**ezpur **U**niversity **SCAT**tering Software) [2] in the form of a web application to simulate and display plane wave scattering from small particles. The package uses and involves Java Server Faces (JSF) coupled with Primefaces [3] component suite, which features more than 90 Ajax powered rich set of JSF components, in order to develop a user friendly web based user interface to enable the researchers to enter the required input parameters for light scattering calculations and observe the results more intuitively. The numerical results of the scattering matrix elements and the efficiencies can be saved in a user defined data file. This preliminary version of the application is capable of simulating light scattering properties of spherical (both bare and coated), cylindrical and spheroidal particles having gamma, normal, log-normal and power law size distribution. The computational programs behind the web application are based on Mie theory for spherical particles and T-matrix theory for nonspherical particles (cylindrical and spheroids). Moreover in order to provide an analytical tool for light scattering experiments from monodisperse and polydisperse particles, a facility for comparing experimental results from some unknown particle with computed data was also incorporated in the web application.

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FIGIFIGO: An Advanced Portable System for Spectropolarimetry

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Keywords: FIGIFIGO, goniospectrometer, light scattering experiments, polarization

We provide an overview of Finnish Geodetic Institute Field Goniospectrometer FIGIFIGO, a portable automated system developed over past decade in FGI for polarized multiangular reflectance measurements. FIGIFIGO can be operated both, in field under sunlight conditions (hemispherical directional reflectance factor, HDRF), and in laboratory using artificial illumination (bidirectional reflectance factor, BRF). The instrument design is primarily for field operation, as the total weight of the system has been kept as low as possible, at around 40 kg, and all critical components are designed to withstand field conditions. The instrument is highly automated and can be operated by two persons. Instrument setup is fast and only takes about 10 minutes. A typical measurement of full hemisphere (200-400 spectra) takes about 15 minutes after setup.

The primary instrument of FIGIFIGO is an ASD FieldSpec Pro FR optical fiber spectroradiometer (350-2500 nm), which is housed inside a rugged casing along with lead acid batteries, electronics and an electric motor. The motor is used to drive a telescopic measurement arm (1.55-2.65 m) from vertical to ±90° for the zenith angle adjustment. The azimuth angle is adjusted by turning the whole device around the sample. The sample is viewed by downward looking optics mounted to the top of the measurement arm and the optics are connected to the spectroradiometer by a 3 meter optical fiber. In addition to regular optics, a set of polarizing optics have been constructed using a Glan-Thompson polarizer inside a rotator. The polarizing optics can be used to measure the sample with two or more polarization directions. The whole system is controlled by LabVIEW control software running in a rugged laptop.

During measurements FIGIFIGO is positioned next to the sample and calibrated for current illumination conditions using a Labsphere Spectralon reference panel. The system measures the current GPS position and time, and calculates the Sun zenith and azimuth angles. A hemispherical (fish eye) camera is used to measure the direction of the measurement plane relative to the Sun direction (sensor azimuth direction). An inclinometer is used to measure the zenith angle of the measurement arm (sensor zenith direction). The sample surface is measured from several azimuth directions by moving FIGIFIGO around the sample, and simultaneously a silicon pyranometer is used to record the illumination conditions, clouds, haze, and other atmospheric disturbances.

After the measurements the data are processed using FGI Reflectance toolbox for Matlab that takes in all the sensor data, does interpolations to match the spectra and the direction data, calculates BRF from the measured HDRF data using the diffuse measurements, corrects the spectra with the pyranometer data, and then outputs the data to a library format for easy processing. All library files are stored in the FGI Reflectance Library.

Retrieval of Non-spherical Dust Aerosol over the Source Region

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Keywords: aerosol retrieval, polarimetry, non-sphericity, inverse problem, land surface

The dust aerosol may influence the global climate and radiation budget through its long range transportation in the atmosphere. However, the retrieval of dust aerosol in the source region from satellite is still challenging due to the comparatively large aerosol optical thickness, the significant land surface signal and the considerable non-spherical effect. In this work, an efficient forward model based on adding-doubling technique is developed to take into account the bright land surface contribution and multiple scattering effects. In order to correctly retrieve the non-spherical dust aerosol optical properties, a tri-axial ellipsoid dust aerosol database is imbedded in the forward model. Due to the high sensitivity of multi-angle polarimetric measurements of PARASOL to the microphysical properties of dust aerosols, the three components I, Q, U of the Stokes vector in up to 16 directions for each pixel are used in the retrieval process. The inverse problem is solved iteratively by using the Levenberg-Marquardt method, where the aerosol aspect ratio, the particle size distribution, the optical depth and the land surface properties are simultaneously retrieved. To fully make use of the multi-spectral measurements, the spectral independent variables retrieved by the 670P channel are compared with the 490P results. Moreover, comparisons with MODIS deep blue aerosol product have also been made.

Note: the name of the person who will make the actual presentation is underlined.

Vectorial Complex Ray Model for Light Scattering of Gaussian beam by an elliptical cylinder

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Keywords: light scattering, elliptical cylinder, vectorial ray, geometrical optics

Among numerous theories and models in light scattering, the geometrical optics (GO) is the most flexible and can be applied to the particles of complex shape. But its precision is often limited because the interference or wave property is usually not taken into account. To overcome this flaw, Ren et al have developed Vectorial Complex Ray Model (VCRM) [1] for the scattering of large arbitrary shaped particles of smooth surface by introducing the wave front curvatures in the ray model, such that the divergence /convergence and the phase shift due to the focal line of the wave are correctly taken into account. In this model, all the waves are described as a bundle of vectorial complex rays. Each time a ray encounters the particle surface, the directions of the reflected and refracted rays are calculated by vectorial Snell law and the wave front curvatures of reflected and refracted waves are deduced from the wave front equation. The total scattering wave is just the summation of all the rays arrived at the same direction.

This model has been applied to the scattering of a plane wave by an ellipsoidal particle [1, 2] and an infinite elliptical cylinder [3]. In this communication, we will present how to deal with the scattering of a shaped beam in VCRM. The scattering of a Gaussian beam by an infinite elliptical cylinder will be taken as an example. To validate our code, the results have been compared with the diagrams calculated by the rigorous Generalized Lorenz-Mie Theory for a circular cylinder illuminated by Gaussian beam. Then some special properties of Gaussian beam scattering by elliptical cylinder with different incident angles are analyzed, such as the scattered intensity magnitudes with different observed distance and the rainbow phenomenon for different position of incident Gaussian beam.

The scattering of an infinite elliptical cylinder by diagonal illumination Gaussian beam is under study.

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Using polarimetry to improve cloud remote sensing from radiometers

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Keywords: remote sensing, cloud, vector radiative transfer, polarimeter design

Clouds play a fundamental role in the radiative balance of the Earth, and measurement of their optical properties is essential for climate change and earth system research. A fundamental parameter is the cloud optical depth (COD), which describes the total atmospheric column extinction of direct-beam light due to a cloud. COD is retrieved from satellite measurements, but with limited spatial resolution and temporal coverage. Therefore, ground and aircraft observations are essential to further improve and validate climate model predictions.

The AERosol Robotic NETwork (AERONET) is globally distributed, ground-based network of more than 450 multi-channel sun and sky-scanning spectral radiometers, intended to monitor aerosol optical depth and microphysical and radiative properties useful for research and satellite validation. A cloud mode remote sensing capability has been added to the AERONET measurement suite, but so far has been limited to selected sites for research and evaluation. The unique temporal and spatial COD measurements from the cloud mode may help to understand the role of clouds in climate, but have limited accuracy without prior knowledge of cloud thermodynamic phase. For example, recent cloud observations during the DRAGON (Distributed Regional Aerosol Gridded Observation Networks) field campaign were consistent with a COD of 18 for an ice phase cloud, but 30 for a water phase cloud. Since this uncertainty significantly impacts our ability to improve climate models, we have searched for methods to determine cloud thermodynamic phase from radiometers.

Our preliminary tests indicate that the direction of linearly polarized light by clouds contains information about thermodynamic phase. This property could dramatically improve our understanding of clouds in climate, but has yet to be exploited by ground and aircraft based instruments. We will discuss efforts to use vector radiative transfer simulations to understand the capabilities of this method. We will also describe investigations with the recently added polarization capability of some Cimel radiometers, and the potential for adding polarimetric capability to the airborne Spectrometer for Sky-Scanning Sun-Tracking Atmospheric Research (4STAR) instrument, which is based at the NASA Ames Research Center.

Characterization of E. coli morphology by scanning flow cytometry

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Keywords: E. coli, light scattering, inverse light-scattering problem, scanning flow cytometry, discrete dipole approximation.

Light scattering is a powerful physical method for identification and characterization of bacteria. Light scattering by a particle is determined by its overall morphology, including shape and internal distribution of the refractive index. Therefore, angle-resolved light scattering contains valuable information on morphological properties of the particle. In addition to identifying or distinguishing microorganisms by its morphology, light-scattering can also potentially provide real-time monitoring of bacterial growth in order to study cell cycle kinetics or analyze growth rate for antibiotic sensitivity testing. Scanning Flow Cytometer (SFC) is a technique capable of measuring angle-resolved intensity light scattering patterns (LSPs) of individual particles in flow. Characterization of particles morphology from measured LSP requires the solution of the inverse light-scattering (ILS) problem. This abstract describes a method for characterization of individual *E. coli* cells using SFC.

E. coli cell was modeled as a cylinder capped with hemispheres of the same radius. This model is described by three morphological parameters (length, diameter, and refractive index) and an auxiliary parameter (orientation angle of cell in the flow of the SFC). The light scattering by a single *E. coli* cell was simulated by the discrete dipole approximation (DDA). In particular, open-source code ADDA v.1.0 was used. Thus the solution of ILS problem is reduced to a fit of an experimental LSP by theoretical ones. To accelerate the fit we used a precalculated database of 80 000 LSPs in a wide range of model parameters and performed the nearest-neighbor interpolation on it. This allowed us to determine length and diameter of individual bacterium including errors of these estimates.

This method allows characterization of population of any rod-shaped bacteria cells by their length and diameter distributions. The only additional effort may be needed for extension of the database to larger or smaller bacteria sizes.

The developed method was tested by two strains of *E. coli,* showing 135 and 15 nm median precision in determination of length and diameter of single cells, respectively, which is very good for optical methods. Obtained length and diameter distributions showed a good agreement with microscopic measurements of the same samples. A detailed account of these results can be found in the paper [1].

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Advanced light scattering methods for studying supramolecular inhomogeneities in H-bonded liquids

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Keywords: Raman light scattering, intensity fluctuations, H-bonded liquids, supramolecular structure

H-bonded liquids can be considered as mediums that have supramolecular heterogeneities, the existence of which is proved by static and dynamic laser scattering (M.Sedlak, 2006). Percolation model and concept of supramolecular inhomogeneities were successfully applied to describe inelastic light scattering spectra of amorphous media (S.Alexander, 1989). In the percolation model bonds are placed randomly on a regular or random lattice. The structure of H-bonded liquids can be presented as an infinite cluster, whose cavities contain clusters of lower dimensions, small groups of bond molecules and separate molecules. Distribution of cavity size depends on temperature and impurities. The average sizes of inhomogeneities are determined by the length correlation. The mass of the infinite cluster for regions larger than correlation length scales in accordance with power law which exponent represents Euclidian space dimensionality. However for smaller regions the exponent is less than Euclidian and could be fractional, which is characteristic of fractal objects. The low-frequency region of inelastic light scattering spectrum is shown to reflect fractal features of structure in H-bonded liquids. Low-frequency inelastic scattering in liquids occurs on thermal vibrational excitations. Owing to thermal disorder the vibrational excitations are damped and behave mostly similar to those in amorphous media. Vibrational excitations which have wave length larger than the correlation length do not feel fractality of the medium and therefore their dispersion remains linear. This transition wave length corresponds to the crossover frequency. Vibrational excitations with lower frequencies are damped acoustic phonons and with higher – fractons.

The effective vibrational state density of some H-bonded liquids was measured by the Raman scattering technique. The existence of the liner region in low-frequency spectral range for reduced intensity in log-log scale proves the fractal percolation clusters model to be valid in case of such medium. The concentration dependences of the linear region's slope for different solutions are in good agreement with the behavior of other physicochemical parameters that depend on the H-bond network structure.

T.Musha and G.Borbely (1990, 1992) showed that the light scattering by acoustic phonons is accompanied by 1/f fluctuations of intensity and the law $S(f)\sim 1/f^{\alpha}$ reflects the phonon energy fluctuations. Light scattering in the liquid systems occurs on phonons localized at inhomogeneities (clusters). Thus, intensity fluctuations might reflect fluctuations of the cross section scattering centers and/or fluctuations in the number of such centers in the volume of scattering.

In this work fluctuations of light scattering in H-bonded liquids (distilled water and water-glycerol solutions) have been investigated. The calculation of the power spectrum corresponds to time series in the range on 0.1 – 50 Hz for the expression $S(f)\sim 1/f^{\alpha}$, where the value α µ [1.1 ÷ 1.3]. We found that the index α depends on the type of liquid and solution concentration.

We consider two mechanisms of $1/f$ - process forming: fluctuations of phonon energy and fluctuations caused by dynamical inhomogeneities, predicted by percolation model. Thus, they represent Brillouin-Mandelstam scattering and Rayleigh one correspondingly. The α variability can be explained by different contributions of the both scattering mechanisms, which form an overall picture of low-frequency fluctuations of scattering light intensity in complex liquids.

Our work provides new experimental evidences for existence of supramolecular inhomogeneities in hydrogen-bonded liquids.

The T-matrix method on the basis of discrete sources

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Keywords: T-matrix method, discrete sources, null field condition

The T-matrix method, proposed by P.C.Waterman [1], belongs to the most actively used methods of solving wave diffraction and scattering problems [2]. It's popularity is caused mainly by simple relation, connecting coefficients of some spherical or cylindrical basis expansion of incident and reflected waves, interacting with the scatterer. However, as it was recently shown in our papers [3, 4], the T-matrix method is valid only for so called rayleigh scatterers, which have all diffracted field analytical continuation beyond area of original definition singularities contained inside of a sphere (circle), entirely inscribed in the scatterer. The class of such geometries is quite limited.

In the present work we propose the approach, in which the null field condition, underlying T-matrix method, is satisfied on some surface (or curve), obtained by analytical deformation of the scatterer boundary, which incorporate all wave field analytical continuation singularities, rather than on a sphere (or a circle in two-dimensional case). As a result, we obtain the T-matrix relation between scattered wave coefficients of spherical (cylindrical) basis expansion and values of incident wave at discrete points of surface (curve). As opposed to traditional T-matrix method, the proposed modification is applicable to solving diffraction problems on scatterers with practically any geometry.

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Calculation of Stokes parameters from CE-318 polarized skylight measurements in solar principle plane

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Keywords: Stokes parameters, CE-318, polarized skylight,principle plane

Polarization effects of light play an important role in atmospheric aerosol optics.They are sensitive to the shape, size, and refractive index of aerosol particles. So measurement and qualitative explanations of polarization of skylight can help to study the properties of atmospheric particles and the climate effects of aerosols in further. The polarized skylight can be described by the Stokes parameters, e.g. the intensity of light I, the linearly polarized radiation Q and U, the circular polarized radiation V, the degree of linear polarization, the polarization angle and the ellipticity angle. Among them, Q, U, and polarization angle depend on the reference plane, those are more complicated to calculate.

Ground-based automatic CIMEL sun-sky radiometers CE-318 have been widely used in the field of remote sensing of atmospheric aerosols. Although they do not provide global coverage, but those continuous, multi-angular, multi-spectral measurements of solar and sky radiation can provide the detailed aerosol optical, microphysical, and chemical components properties in key locations. Some of them are equipped with polarization capability that can provide polarized skylight measurements in solar principle plane. For each wavelength, they use 3 polarizers with 0°,60°, and 120° angles to measure the linearly polarized radiation. It is easy to calculate the intensity I and the degree of linear polarization from CE-318 polarized skylight measurements, but when we calculate Q and U, we have to choose a reference plane. For principle plane polarization (‘PPP’) measurements, we generally choose the solar principle plane as reference plane. However, the 0°polarizer preferred transmittance axis is usually not exact within the principle plane and we don’t know the angle between them due to angular error caused by the installation process of the instrument.

In this talk, we intend to introduce the method to calculate Stokes parameters, particularly Q and U, from the CE-318 polarized skylight measurements in solar principle plane. In this method, we transform the instrumental coordinate system to the observer’s coordinate system. Then we calculate Stokes parameters Q , U , and polarization angle in the observer’s coordinate system those can be compared with the radiative transfer simulated results. The results show that, after transforming, the Stokes parameters Q and U are coincide with the polarization pattern of skylight in nature. Therefore, we can take advantage of the results of Stokes parameters to analyze the influence of difference aerosol properties on the linearly polarized skylight in future.

(The preferred mode of presentation: Oral)

Evaluation of the fraction of poorly deformable erythrocytes in blood samples by means of laser diffractometry

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Keywords: laser diffractometry, ektacytometry, diffraction pattern, isointensity line, small angle scattering, shear flow, erythrocytes, particle deformability distribution

One of the important characteristics of human blood is the fraction of erythrocytes, which by one reason or another have a reduced ability to deform passing through thin capillaries (the fraction of poorly deformable erythrocytes). Laser diffractometry is one of the convenient, fast and relatively simple techniques for measuring the erythrocytes deformability in blood samples. This technique allows for quick evaluation of the mean deformability of the erythrocytes [1].

In this paper, we present a new method of evaluation of the fraction of poorly deformable cells in erythrocyte suspension. It is based on the model, in which the erythrocytes moving in the shear flow within the rheologic gap of the ektacytometer are considered as optically soft transparent elliptical disk [2]. Using this model we analytically calculated the light intensity distribution on the observation screen as well as the shapes of the isointensity lines in the vicinity of the central diffraction maximum of the diffraction pattern. We introduced the definition of isointensity line polar points as an intersection of this line with horizontal and vertical coordinate axes. Furthermore, we introduced the curvature radii of the isointensity line at the polar points. We note that the coordinates of the polar points as well as the curvature radii of the isointensity line at the polar points can be determined from the experimental data obtained with laser diffractometry. As a result, we obtained a set of equations binding together the measured parameters of the diffraction pattern and the statistical characteristics of the erythrocyte suspension under study. Using these equations we developed an algorithm, which allows for evaluating the mean value of the shape parameter (a function of the relative elongation) of shear-elongated erythrocytes, the variance and the coefficient of asymmetry of erythrocyte shape parameter distribution on the basis of the laser ektacytometry data. For example, in the case of a bimodal ensemble, i.e. an ensemble, which contains cells of only two types in terms of their deformability, we can evaluate the fractions of cells of both types as well as the shapes of both components of the ensemble.

Thus, in this work a novel method of evaluation of the fraction of poorly deformable erythrocytes in blood samples is proposed. The method is based on the analysis of the isointensity lines shapes arising at scattering of a laser beam on erythrocyte suspension in the ektacytometer. The algorithm efficiency was experimentally verified with specially prepared blood samples containing different fractions of poorly deformable erythrocytes.

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Layered structure of silicon particles: theoretical study of the solar cells efficiency increasing

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Keywords: single scattering approximation, transfer matrix method, silicon, solar cell, disperse structure

Silicon is one of the most widely used semiconductor materials to create solar cells (SC) due to its relatively low cost, non-toxicity, etc. Since it is the nondirect gap semiconductor, the probability of electron transition from valence to conduction band due to absorption of a photon with energy larger than the band gap is small. To increase the absorption of light by a homogeneous layer of silicon it is necessary to increase its volume. This reduces the efficiency of solar cells produced from silicon. One of the ways of increasing the efficiency of solar cells is reducing the optical loss at the interaction of light with an absorbing semiconductor material. For this purpose different designs that allow decrease reflection of light, as well as increase the path of the radiation in the structure are developed.

In this paper the possibility of increasing the efficiency of radiation absorption in silicon solar cell by creating a dispersed layered structure (multilayer), consisting of monolayers of spherical silicon particles is theoretically investigated. It is shown that in this structure it is possible to reduce the reflection, increase the length of the light path due to the scattering, and, therefore, increase the portion of absorbed radiation as compared to the plane-parallel homogeneous layer of an equivalent amount of the same semiconductor material. The use of silicon particles with sizes of the minority carriers diffusion length order allows more effectively absorb radiation in the structure in terms of photoelectromotive force (photo-emf).

In the single scattering approximation (SSA) the spectra of transmission, reflection, and absorption of individual monolayers of crystalline silicon (c-Si) monodisperse spherical particles are calculated. The absorption of layered system consisting of such monolayers is estimated in the framework of transfer matrix method (TMM). The normal radiation incidence and wavelength range from 0.28 μm to 1.1 μm are considered. It is shown that multilayer system of silicon particles absorbs radiation significantly more than plane-parallel homogeneous silicon plate of the equivalent material volume. In particular, for the solar illumination, the integral absorption of four monolayers of c-Si particles with diameter of 1 μm can be 1.7 times higher than the one of the corresponding homogeneous plane-parallel layer. The absolute value of the integral absorption coefficient of 10 monolayers of silicon particles with a diameter of 200 μm attains 0.88. The obtained results describe the way to increase efficiency of the solar cells by using dispersed structures of the semiconductor.

Variability of aerosol properties, vertical distribution and impact on the radiative forcing over Dakar using sun-photometer/micro-Lidar combination

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Keywords: lidar, sun-photometer, aerosol distribution, radiative forcing

Africa is one of the most important sources of airborne mineral dust and biomass burning aerosol emissions from Sahara and Sahel regions. Therefore, continuous observations in this region are important for better understanding of the aerosol effect on local and global scales as well as for the effect on health of local population. In 2003, Laboratoire d'Optique Atmosphérique (LOA) initiated remote sensing observations in M'Bour (West Senegal) with a CIMEL Sunphotometer integrated into the worldwide AErosol RObotic NETwork (AERONET). This device measures atmospheric transmittance during the daytime at several wavelengths (UV to near IR) and for different scattering angles. The processing of such data provides information on the atmospheric column Aerosol Optical Depth, Angström Exponent, Refractive Index, Size Distribution, etc. In 2006, the LOA reinforced observations through active remote sensing with an elastic micro-pulsed Lidar (CAML) that measures the backscattered signal at 532nm during day and night. The synergy between two instruments provides extinction profiles (km-1), extinction to backscatter ratio, also called Lidar ratio, and permits an assessment of aerosol mass concentration during the daytime and, under some assumptions, during the night time as well. Since 2006, the PM_{10} measurements became also available at the observation site; these observations serve us as a validation point for the lidar retrievals. In order to assess the aerosol direct radiative forcing, the column integrated aerosol characteristics and vertical distributions of AOD have been used to compute the solar fluxes. These efforts lead to an estimation of the direct aerosol radiative forcing in solar spectrum and provide heating rate in the atmospheric layer. We will present analysis of various retrieved parameters for the whole observing period, highlighting seasonal and long-time trends and variability. The first results and comparisons with intensive measurements, which will be conducted by LOA during a field campaign in March 2013, are also expected be presented in the second part of the presentation.

Semi-specular reflection from particulate media

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Keywords: specular reflection, gloss, glint, particulate media

Specular reflection is known to play an important role in many fields of scattering applications, e.g., in remote sensing, computer graphics, optimization of visual appearance of industrial products. Usually it can be assumed that the object has a solid surface and that the properties of the surface will dictate the scattering behavior. The approach that is used for surfaces not ideally flat is that there is a diffuse component and a specular component in the scattered signal. This approximation is based on the microfacet idea where it is assumed that the surface constitutes of small planar facets. The facets are thought to be small, but still significantly larger than the wavelength so that their scattering can be modeled by specular reflection to the direction that is governed by the local normal vector of the facet. The more rough the surface is, the more the local normals are deviated from the average normal, and the more the specular signal is decreased and spread around the average specular direction.

Industrial materials where specularity is needed use pigments for surface finish. Pigments are quite small, often mineral particles. The sizes can vary, but for example with high-gloss paper products the coating pigments are typically in the size range of 1–10 μm. With this small particles it is quite difficult to claim that parts of the particle's surface can act as a microfacet, since these parts can easily be smaller than the wavelength. It seems that the microfacet approach is not reasonable in cases where we clearly have an interface constituting of wavelength-scale particles. However, very glossy papers, for example, can be produced using particulate media with high reflectance in the specular direction. To distinct this 'glint' or 'gloss' or 'specular-type peak' from the traditional specular reflectance from flat solid surface I will call this effect as semi-specular reflection.

In this talk I will show, using exact light scattering simulations, that semi-specular effects can be seen from particulate media. Furthermore, I will demonstrate that the required planar structure in the media needs not to be on the very top of the slab but can be obscured by non-ordered layer and still give raise to semi-specular scattering (see Fig. 1). I will study the required level of order in the structure that is needed for detectable semi-specular reflection.

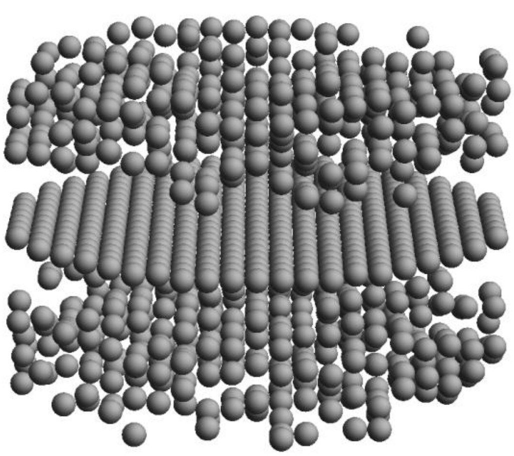

Figure 1. Example of slab consisting of three layers of particles. The middle layer has ordered structure and will give raise to semi-specular reflection from the slab.

Kinetic measurements of morphological changes in human lymphocytes during early stages of apoptosis

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Keywords: apoptosis, scanning flow cytometry, human lymphocytes, cell morphology kinetics during apoptosis

Apoptosis is the process of programmed cell death that is morphologically characterized by a decrease in the cell size, chromatin condensation and chromosomal DNA fragmentation. At the end of this process the cell is fragmented into separate apoptotic bodies that are phagocytized by macrophages. Apoptosis in the human body is involved in inherited and acquired humoral and cellular immune system response. Researches of this process open new perspectives in the cell biology and immunology. Studies of dysfunction of many genes that regulate apoptosis provide an opportunity to develop a new direction in the treatment of these diseases. The development of drugs that can regulate apoptosis gives new possibilities in the treatment of cancers, viral infections, certain diseases of the nervous system, immune deficiencies and autoimmune diseases. Therefore the purpose of this research is to study the kinetics of morphological changes in human lymphocytes during early stages of apoptosis.

Usually the early stages of apoptosis are indentified by biochemical or immunological methods. However, such methods may have an undesirable effect on the object studied. On the other hand, apoptosis is accompanied by significant morphological changes of cellular nucleus which can be measured with non-invasive optical methods. Therefore this work is devoted to development of a new fluorescence-free technique for the kinetic study of the early stages of apoptosis by means of measuring morphological changes of mononuclear cells population with a scanning flow cytometer.

Experimental basis of this work is scanning flow cytometry technique that allows one to study the light scattering of individual cells. Solving the inverse light scattering problem one can obtain some characteristics of cell. In our work in flow cytometric study we used lymphocyte samples obtained with a density-gradient separation procedure from the whole human blood. We applied a bilayer sphere as an optical model of a lymphocyte. This model has four parameters: cell diameter, ratio between nucleus and cell diameter, the refractive indices of the nucleus and the cytoplasm. We measured the distribution of lymphocytes in these parameters from light scattering profiles of the cells. Lymphocytes were analyzed before induction of apoptosis and during 3 hours after induction.

The flow cytometric experimental data demonstrated the s-shaped dependence of the nuclear cells volume on time. Applying the function proposed by us for the processing of the experimental kinetic data we calculated such parameters of apoptosis as the characteristic time of the apoptosis lag phase, the fraction of apoptotic cells and the nucleus size.

Thus this new fluorescence-free method allows one to determine such lymphocytes characteristics as the size of cells and cell nuclei before and after the initiation of apoptosis, the refractive index of the cytoplasm, the refractive index of the nucleus, the characteristic time of the apoptosis lag phase and the fraction of apoptotic cells, that are important for medical diagnostics. Also, this information may be useful in the assessment of individual sensitivity of tumors to chemotherapy drugs. The advantage of this fluorescence-free technique is a high speed of cell analysis which provides high statistical accuracy.

Photometric and polarimetric study of Bok globules

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Keywords: star-forming clouds, polarization, extinction

The small interstellar molecular clouds called Bok globules are known to be the sites of low-mass star formation. Our understanding of this important process and the nature of the globules still has several gaps. As dust is tightly related to other components of these objects, its study can provide useful information. The most reliable way to diagnose some properties of dust grains looks to be analysis of the wavelength dependences of extinction and polarization produced by dust particles located in the line of sight, even keeping in mind the limitations of this approach.

We present results of multicolor photometric and polarimetric (and some spectral) observations of dozens of stars in the vicinity of several Bok globules including both the distant ones like CB54 and the close ones like B5. The observations were mainly made with the 2-m telescope at the Giravali observatory of IUCAA (Pune, India) during the last 2 years. The data obtained showed the direction of the magnetic fields near the globules and in their external layers, which further extended the results of Sen et al. (2010, A&A, 522, A45). We found that the typical E(B-V) values in vicinities of CB54 were about 0.2-0.3 mag with the polarization being of about 1 %. For some stars, the spectral classification was made and the interstellar extinction and polarization curves were obtained. The observational data derived were supplemented with the data available in the literature and interpreted using the cosmic dust model of Das et al. (2010, MNRAS, 404, 265).

Note: the name of the person who will make the actual presentation is underlined.

Remote Sensing of Droplet Number Concentration: A Comparison of Different Approaches

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Keywords: remote sensing, indirect effects, polarimetry, lidar, electromagnetic scattering,

One of the most interesting cloud properties that can be obtained from remote sensing for the evaluation of the effects of aerosols on clouds is the droplet number concentration. Methods have been developed that, by making certain assumptions about the profile of liquid water concentration in a cloud, map the usual retrieval of optical depth and droplet effective radius into a retrieval of droplet number concentration and cloud physical thickness. Lidar depolarization measurements in conjunction with droplet size retrievals have also been used to estimate droplet number concentration. In this paper we make use of a unique high vertical resolution lidar capability that has been implemented in the NASA Langley Research Center High Spectral Resolution Lidar to directly measure the extinction coefficient of clouds. These measurements are used in conjunction with the extremely accurate size distribution retrievals that can be obtained from polarized observations of the cloud bow, made by the Research Scanning Polarimeter, to make retrievals of droplet number concentration that do not require any assumptions about the properties of the cloud. These retrievals are compared against the previously published methods and also a new approach using only passive measurements that estimates cloud physical thickness and droplet number concentration without any assumption about the behavior of the profile of liquid water within the cloud.

Note: the name of the person who will make the actual presentation is underlined.

A Variational Approach for the Retrievals of Ice and Liquid Water Cloud Properties from Passive Measurements

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It is nowadays well recognized that the study of clouds is of prime importance for a better understanding of the Earth-atmosphere radiative balance. More particularly, the study of ice cloud appears to be challenging due to the large variability of their optical, radiative and microphysical properties. Precise retrievals of ice and liquid cloud properties from remote sensing observations therefore appear as a necessity for an optimal calibration of climate model parameterizations.

In this prospect, numerous algorithms have been developed during the last decades for the retrieval of cloud properties from satellite measurements. More recently, variational methods have become commonplace due to their high efficiency to treat different kind of measurements, to retrieve a large number of parameters. Additionally, these methods posses the strong advantage to allow a thorough calculation of uncertainties attached to the parameters to be retrieved, and to be perfectly compatible with the Shannon information theory. Most of the current algorithms however aim to retrieve the properties of ice or liquid cloud properties separately. It has nevertheless been shown that possibilities of overlapping between these two cloud types are non-negligible, and that such cases can, if not properly taken into account, strongly impact the retrievals of the properties of each cloud layer.

The present study introduces an algorithm dedicated to perform simultaneous retrievals of ice and liquid water clouds. This algorithm uses a variational method based on a Bayesian approach of inverse problems. The state vector is composed of the ice water path of one ice cloud layer, and of the optical thickness and droplet effective radius of two possible liquid cloud layers. The ice cloud microphysics is given by a parameterization developed by A. J. Baran, which describes their optical properties as function of the ice water content and in-cloud temperature. In order to retrieve the state vector, the information is brought by space-borne radiometric measurements from five channels situated in the visible, near-infrared, and thermal-infrared spectral ranges.

The first part of this study presents a thorough analysis of the information content attached to the state and measurement vectors in different atmospheric configurations (single, double, or triple layer). We here seek to understand, *a priori*, how much information should be expected on each parameter to be retrieved, and what combination of channels provides this information. Such a study appears to be extremely helpful for a better understanding of the capacities and limitations of the algorithm. We for instance show that our set of measurements should allow a precise retrieval of each parameter to be retrieved in case of double layer (ice and liquid) if the ice water path is not too high (lesser than 130 $g.m^{-2}$). In triple layer configuration, the full retrieval of the full state vector should however not be successful, as some information appears to be missing on the effective radius of the lowest liquid cloud layer. Further comparisons of these theoretical results with retrievals obtained alone a short case study are presented in the second part of this study, and show strong coherence. This case study proves that the ice water path, and the liquid cloud optical thickness and droplet effective radius can each be simultaneously retrieved with reasonable accuracy (lesser than 10%).

Aerosol study in background conditions and during forest fires by means of aureole nephelometer

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Keywords: aerosol, aureole scattering, inverse problem

Measurements of near-forward scattering provide the information about coarse fraction of atmospheric aerosol. Almucantar radiance measurements, including aureole region, are widely used for the aerosol monitoring in the atmospheric column. On the contrary, ground based aureole measurements in a local scattering volume with an artificial light source are rarely reported. One of the reasons is that open air photometers can operate only in night time. Round-the-clock aureole nephelometer with a closed scattering volume was developed in V.E. Zuev Institute of Atmospheric Optics. It is capable to measure aerosol phase functions at the range of scattering angles from 1.2° to 20°. The light source is diode laser KLM-650-40 operating at wavelength of 650 nm with power of 40 mW. Scattered light is detected by matrix digital video camera SDU285. The duration of one measurement is 1 - 5 minutes (with averaging over 100 images). The chamber of the nephelometer is supplied with sensors of temperature and humidity, placed near the inlet and outlet of the air flow. The instrument is calibrated in absolute ($km^{-1}sr^{-1}$) units with the help of ethalon scatter with known optical properties.

In the present paper, the results of measurements in Tomsk (West Siberia) in July, 2012 at background and smoke conditions are analyzed. It was found that both at background conditions and in smoke episodes aureole phase functions in general follow van de Hulst parameterization $D(\varphi) \sim \varphi^{-q}$ with q in smokes less than at background conditions. Phase functions measured were inverted to the particle size distributions using the iterative algorithm. Since the greatest scattering angle (20°) is out of the aureole region, the fine aerosol fraction was also involved into inversion. The aerosol volume size spectra retrieved was found to be bimodal with distinct fine and coarse fractions. Their volume concentrations are comparable in background conditions, but in smoke situations the fine mode prevails. Volume size distributions are qualitatively similar to those in the atmospheric column obtained from the data of the nearest AERONET site. In all situations volume concentration of the coarse fraction is well correlated with the angular scattering coefficient at 1.5°.

The retrieved size distributions were compared with results of the parallel measurements by means of the photoelectric particle counters. The reasons of some discrepancies are discussed. In parallel with aureole observations, spectral extinction in visible and IR spectral range was also measured at horizontal path. The results of these measurements were also compared with simulated from retrieved size distribution spectral extinction.

Particle sizing by laser diffractometry of polydisperse suspensions: uniqueness of the inverse problem solution

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Keywords: laser diffractometry, ektacytometry, diffraction pattern, particle sizing, small angle scattering, erythrocytes, inverse problem

Ektacytometry is a fast diagnostic technique, which is based on the illumination of a dilute suspension of erythrocytes moving in the shear flow within the thin gap of a rotational couvette with a laser beam. Small angle light scattering results in a diffraction pattern (DP) containing valuable clinical information about the microrheologic properties of the cells. A number of DP-processing techniques were proposed for obtaining the sizes and shapes of the particles [1]. Almost all of them rely on the assumption that a random mixture of two different sets of particles cannot generate the same DP. However, in practice it could happen that the same DPs correspond to two different ensembles of the particles (for instance, because of the orientation of the particles, etc.). In such a case the particle size distribution cannot be reconstructed basing on data obtained from the measured DP. The aim of this work is to examine the situations when the particle ensemble is unique for a given DP. This is the so-called uniqueness problem.

We assume the erythrocytes to be optically soft particles, which sizes are an order of magnitude higher than the laser wavelength that equals, e.g., to 633 nm. During the experiment the particles are oriented along the direction perpendicular to the direction of the incident laser beam. Thus we consider the small angle light scattering. We have calculated a lot of DPs corresponding to different ensembles of particles, namely sets of spheres, ellipsoids and erythrocyte-like shapes. To calculate the scattering of light we have used the Anomalous Diffraction Approximation (for spheres), the T-matrix method (for ellipsoids) and the Discrete Dipole Approximation (for particles with more complex shapes). From the obtained results we have assessed the exact ranges of particle sizes, for which the uniqueness is not broken. Different problem statements were considered and thus different size ranges were obtained.

In the second part of the work, we have assessed the spread of the particle sizes in ektacytometer. We have estimated the diffraction pattern visibility in the region of the first diffraction minimum and the first diffraction maximum as a function of particle size variation. We have obtained the dependency between the visibility of the DP and the spread of the particle sizes. In comparison with our earlier results [2], this dependency is confirmed by using more adequate shapes of the particles mimicking the shear-deformed erythrocytes, in particular, ellipsoids.

This work was partially supported by RFBR grants № 12-02-01329 and № 12-02-92008-NSC.

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New analytical long-wavelength approximation for non-spherical particles of different shapes

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Keywords: electromagnetic scattering, Rayleigh approximation

The well-known Rayleigh approximation provides analytical expressions for the optical properties of ellipsoids small in comparison with the wavelength of incident radiation. The field inside such ellipsoids is known to be uniform.

In this paper we suggest a new long-wavelength approximation based on the replacement of the field inside a small non-spherical particle with an uniform one. This allows us to get simple analytical expressions for polarizability and hence the optical properties of a large number of non-spherical particles having simple shapes: finite length cylinders, cylindrical capsules, merging spheres, circular cones, touching cones, drops, spherical segments, Chebyshev particles with $n = 1$ and 2, cubes, parallelepipeds, etc. For example, for a cylinder of the length L and the diameter D, we get the polarizability along the direction perpendicular to the particle symmetry axis as simple as $\alpha_x = \cos\theta / 2$, where $\theta = \arctan D/L$.

We compare the results derived by using our approximations and numerical simulations of light scattering and find that the applicability ranges (in terms of the size parameter $x_v = 2\pi r_v/\lambda$, where r_v is the radius of a sphere having the same volume as the nonspherical particle and λ is the wavelength) of our approximation applied to the particles mentioned and that of the Rayleigh approximation applied to ellipsoids are very close. Obviously, for ellipsoids, our approximation coincides with the Rayleigh one.

We also consider the accuracy of our approximation in the whole range of the parameter values: for the relative dielectric permittivity $\varepsilon = \varepsilon_2 / \varepsilon_1$, where ε_2 and ε_1 are the permittivity inside and outside the particle, respectively, from 0 to ∞ and for the shape parameter being the ratio of the maximum to minimum dimension of the particle x_{max}/x_{min}, from 1 to ∞, and confine the region where the accuracy is of a few percent.

Our approximation of uniform internal field is unexpectedly nearly equally accurate for the particles with edges and sharp peaks like finite cylinders, cones, etc. and for the particles with the smooth surface like Chebyshev ones. On the other hand, the approximation is again surprisingly not quite good for intermediate and large values of the shape parameter x_{max}/x_{min}.

Note: the name of the person who will make the actual presentation is underlined.

Aerosol optical characteristics over Western Siberia retrieved according to data of ground-based and aircraft measurements during winter season

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Keywords: aerosol, sun photometry data, inverse problem, aircraft sensing

The aerosol optical characteristics on the territory of Western Siberia are retrieved using two approaches.

The first approach for retrieving the *columnar* aerosol characteristics is based on data of Sun/Sky measurements: spectral aerosol optical depth (AOD) and radiance phase function $D(\theta)$ measured in the solar almucantar, θ is the scattering angle. The task of retrieving the microphysical and optical parameters is solved in two stages. At the first stage, we iteratively retrieve aerosol angular scattering coefficients and single scattering albedo from the measured $D(\theta)$ using a solution of the radiative transfer equation. The second stage involves solution of the linear inverse problem of aerosol light scattering using the iterative algorithm which is similar to (Twitty, 1975). The aerosol optical characteristics are calculated in the framework of the Mie theory on the basis of the retrieved particle size distribution function and the complex refractive index.

In implementation of the first approach, data of photometric measurements at Tomsk AERONET station (56.5°N, 85.1°E) for 70 atmospheric situations in Decembers-Februaries of 2003-2010 were used as input information. We present examples of retrieving the aerosol optical and microphysical characteristics under different conditions of aerosol turbidity of the atmosphere and compare them with results, obtained on the basis of the algorithm (Dubovik and King, 2000). We note that low AOD values (the mean AOD value for the considered situations at λ=440 nm is 0.19) and anisotropy of the snow cover are among the factors that determine the retrieval quality of aerosol characteristics under winter conditions of Siberia.

The second approach involves the use of empirical model of the *vertical profiles* of aerosol optical characteristics. This model was developed based on data acquired from multiyear (1997-2009) airborne sensing of optical and microphysical characteristics of the tropospheric aerosol over Western Siberia. The main initial characteristics for the creation of the model were measurement data on the vertical profiles of the aerosol angular scattering coefficients in the visible wavelength range, particle size distribution functions, and mass concentrations of black carbon.

It is shown that, in the interval 440-870 nm, the winter-season-*averaged* columnar values of aerosol single scattering albedo, retrieved on the basis of these approaches, are in satisfactory agreement. At the same time, the asymmetry factor of the scattering phase function, obtained according to results of aircraft measurements, is underestimated relative to photometric data.

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P2
Poster Session

(June 18th, 5:35 PM)

Metallic nanoparticles sizing in both the VIS and UV ranges by means of spectroscopic and polarimetric methods

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Keywords: Plasmonics, Nanoparticles sizing

Metallic nanoparticles are widely used as a tool in nanophotonics due to their applications in different fields, such as biology, medicine, solar cells, etc. [1]. One of the main properties of these particles is that, when irradiated with the right frequency, they are able to produce localized plasmonic resonances. This means that very strong fields can be generated around the nanoparticle, in a region very close to the nanoparticle surface. The position and shape of the peaks found in the spectral curves help to describe such resonant behavior, and show that it depends both on the geometry (size and shape) and on the optical properties of the nanoparticles, as well as on the surrounding medium.

Many works have shown that, when the size of nanoparticles illuminated with a fixed wavelength is increased, the position of the plasmonic resonances shift to longer wavelengths (redshift) [2]. Recently, it has been shown also that the linear polarization degree, P_L, of the light scattered at right angle by nanoparticles, shows an angular minimum due to the shape of the far-field light scattering depending on the polarization [3]. The deviation from the dipolar regime as the size increases produces a fast variation of the parameter P_L.

Taking advantage of these two properties, the objective of this study is to compare both methods in the characterization of metallic spherical nanoparticles with radii between 15 and 100nm. First, we will try to establish a relation between the plasmonic spectrum shift and the particle size, and secondly, we will look for a dependence between the P_L minimum and the particle size. Finally, both methods are compared for the case of nanoparticles with plasmonic resonances in the visible range (a spherical particle of Silver with radius R=40nm presents a dipolar resonance at $\lambda \approx 377$ nm) and in the ultraviolet range (a spherical particle of Magnesium with radius R=40nm presents a dipolar resonance at $\lambda \approx 223$ nm). The results show the precision and validity range of both methods.

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The optical properties of absorbing aerosols model with fractal soot aggregates

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Keywords: absorbing aerosol model, fractal soot aggregates, superposition *T*-matrix method

The fine-sized dominated aerosol models with fractal soot aggregates are mainly of anthropogenic origin, which are the dominant light absorbing component of atmospheric aerosols, playing an important role in the climate model and environment pollution. we model the optical properties of absorbing fine-sized dominated aerosol models which are taking into account the fresh emitted soot particles (externally mixed agglomerates of primary spherules), aged soot particles (internally mixed with other weakly absorbing aerosols), and coarse aerosol particles (dust particles), with the corresponding optical properties of sphere absorbing aerosol models using Lorenz-Mie solutions presented for comparison.

The single scattering properties of the randomly oriented fractal soot aggregates and soot-containing mixtures are computed using the superposition T-matrix method. The ensemble averaged scattering matrices and single scattering albedos are integrated and compared by different soot aggregates with different morphological and chemical parameters. The fresh and aged soot particles are studied for different volumes of soot-sulfate mixtures.

The difference between the optical properties of absorbing fine-sized dominated aerosol models with fractal soot aggregates and the sphere absorbing aerosol models demonstrate that the sphere absorbing aerosol models underestimate the absorption ability of the fine-sized dominated aerosol particles. Our study also demonstrates that the fine-sized dominated aerosol models with fractal soot aggregates can cause large errors in the retrieved aerosol properties if satellite reflectance measurements are analyzed using conventional Mie theory for spherical particles.

Light scattering by Gaussian rough ice crystals: experimental and modelling results

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Keywords: rough ice crystals, cirrus, RTDF, ADDA, ice analogues

It is qualitatively well understood that ice and mixed-phase clouds have an important role in the radiation balance and climate of the Earth [1,2]. However, quantitative understanding of these clouds is poor, and is one of the biggest uncertainties within climate models [3]. Efforts to solve this problem are particularly focusing on light scattering by ice crystals within these clouds [1], especially on why the haloes that should be a regular occurrence with crystals that are hexagonal prisms are so rare. One of the primary candidates to explain the lack of haloes is ice crystal roughness, but the structure of ice crystals in clouds cannot be directly determined and so indirect methods have to be used.

This presentation will describe the generation of crystal geometry from a Gaussian rough surface [4] and cover the applications of these roughened crystals, as well as results obtained through their use. Previous results show that ice crystals found in cirrus have similar surface roughness to mineral dust grains [5,6]; atomic force microscope scans of these grains are used to derive roughness parameters that can be utilised to generate realistic crystal geometries. Light scattering simulations are then performed using the RTDF [7] and discrete dipole approximation [8] scattering methods with these realistic geometries. The phase function, degree of linear polarisation and asymmetry parameter can be compared between results from simulations using smooth or moderately rough geometries. The Gaussian roughness used in light scattering simulations can also be created on ice analogue crystals [9] using a microfabrication technique relying on focused ion beam milling [5,10]. This enables laboratory light scattering measurements of these rough geometries to be obtained, and these can be compared to the simulation results.

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CLOUD HETEROGENEITIES EFFECTS ON ANGULAR POLARIZED VISIBLE REFLECTANCES AS MEASURED BY POLDER/PARASOL

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Clouds play a crucial role in the climate system and several sensors are thus dedicated to their observations. Among them, POLDER/PARASOL measures total and polarized visible radiances up to 16 directions. Its multi-angular polarized reflectances are used to retrieve cloud microphysical information such as effective radius and effective variance and also aerosol properties above a cloud layer. However, principally for computational reasons, POLDER as others sensor retrieval algorithm assumes that clouds are plan-parallel, homogeneous and infinite which is not the case in reality. Clouds have complex structures and present macro and microphysical variabilities. Several studies on total reflectances and retrieved optical thickness have showed that the effects of cloud heterogeneities can be important and should not be negligible. Are polarized reflectances also sensitive to cloud heterogeneities effects ?
In this work, we study the impacts of cloud heterogeneities on angular POLDER polarized reflectances. We will present results concerning (i) the impacts of optical thickness variabilities obtained from a model called 3Dcloud, which is based on a simplified dynamic/thermodynamic scheme and (ii) the impacts of microphysical variabilities using output of a cloud-resolving model.

Poster

Inferences about pressures and vertical extent of monolayer clouds from POLDER3/PARASOL measurements in the oxygen A band

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Abstract :

Clouds are a key component of the climate system. Their radiative effects are particularly important : clouds impact the Earth's energy budget, and their structures affect the vertical distribution of radiative heating in the atmosphere. Consequently, there is a growing interest in an enhanced description and modelling of cloud properties.

Nowadays satellite instruments allow the monitoring of the cloudiness and its evolution at a global scale. Among them, active instruments have the inherent ability to provide informations on the vertical profile of cloud covers with a limited spatial coverage, while passive sensors provide vertically integrated quantities with a large spatial coverage. The radiometer POLDER3 on PARASOL platform performs multi-angular measurements in the oxygen A band. Oxygen is well-mixed in the atmosphere and as a consequence, the depth of oxygen absorption between the cloud and the spaceborne sensor is related to the cloud vertical location. A cloud oxygen pressure PO_2 can thus be deduced. As the penetration of photons within the cloud layer is neglected in the POLDER algorithm, PO_2 corresponds to a level of pressure inside the cloud.

In this study, we infer new cloud parameters from POLDER A band measurements by understanding the complex sensitivity of these measurements to the scene's geometry, cloud optical thickness and cloud geometrical thickness. The latter is accounted for through its correlation with the angular standard deviation of POLDER oxygen pressure. In the case of monolayer clouds, we correct PO_2 to make it close to the cloud top and middle pressures and hence obtain two new cloud oxygen pressures. Our developments lead also to an estimate of the cloud geometrical thickness. These retrievals are calibrated and validated through an intercomparison with data from the two active sensors of the A-train, a satellite constellation dedicated to the study of the atmosphere and its components.

FINITE DIFFERENCE TIME DOMAIN METHOD FOR ANALYSIS OF NEAR FIELD-EMISSION WITHIN NANO-GAPS USING

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Keywords: Near-field thermal radiation, Local density of electromagnetic states, finite difference time domain method, thermophotovoltaic systems

Polariton-enhanced near field thermal radiation with its possible applications in variety of fields such as smart solar power generations has become a promising field in recent years. Modelling structures whose sizes are smaller than the dominant wavelength of radiation requires a good knowledge of quantum mechanics and special treatment of stability criteria when it comes to using computational electromagnetic techniques such as Finite Difference Time Domain Method (FDTD). The foundation of the required approach is electromagnetic wave propagation and absorption, based on the Maxwell equations for electromagnetic waves.

In this work, we investigate the possibility of modelling thermophotovoltaics through FDTD method. TPV power generation has significant potential for applications in industrial energy conversion technologies and in principle similar to solar photovoltaic energy conversion.
We aim to present that FDTD is capable of taking in to consideration all the near-field thermal radiation non-equilibrium effects when dealing with such geometries regardless of the shape or size of the geometry. The model considered here is consisted of two thin homogenous, isotropic and non-magnetic Silicon Carbide (SIC) films supporting surface phonon polaritons (SphP) and separated by a vacuum gap. The films are assumed to have temperature difference, where one has T>0 K (emitting layer) and the other one is kept at T=0 K (non-emitting layer). The near-filed thermal radiation emission is calculated through calculation of TM evanescent component of local density of electromagnetic states (LDOS) within the vacuum nano-gap separating the films.

Optical properties of Silicon Carbide at near infrared frequencies (NIR) require modelling of frequency dependent relative permittivity for which, Drude-lorentz permittivity model which also accounts for the effect of valance electrons, has been used in this work.

We herein discuss the challenges we faced with during the course of this research and possible solutions to overcome these difficulties and present that our computational method of choice confirms the analytical solutions for the problem of choice.

FDTD simulation of a reversed dipole using a combination of phase conjugation and angular spectrum method to achive focusing enhancement in scattering media

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Keywords: phase conjugation, angular spectrum method, FDTD, focusing enhancement, electromagnetic scattering

Many systems for three-dimensional imaging of biological tissue like confocal microscopy or optical coherence tomography (OCT) use focused light sources for the gathering of image data. The problem is that the deeper the wave propagates in the sample, the more the focus is distorted due to the scattering in the turbid media. This leads to resolution loss and image degradation at larger depths. One way to decrease the distortion in the focus is to use wave front shaping. In this method the phase of the illumination light is spatially modulated to compensate for the scattering effects by using spatial light modulators (SLM). An optimization process can be performed by iteratively altering the phases of the incoming waves until an optimal focusing is achieved. However, this optimization process is time consuming and the optimal solution might not be reached. To overcome the disadvantage of this optimization process, a reference source can be used in the medium. By detecting the waves going out of the scattering media, the phase shifts of the phase waves introduced by the SLM can be estimated beforehand. An example of such a reference source, is a dipole. There were several investigations done in this field, however most of these works were experimental. A theoretical study of these methods is necessary in order to advance the understanding of the underlying processes which could help in increasing the performance of the focusing enhancement.

In this work a dipole source is simulated in the position where the focus is required inside the scattering media. The simulated far field results of this dipole source are phase conjugated and decomposed into plane waves. Using the angular spectrum method, the phase conjugated solution is then reinjected into the simulation grid. This process allows the waves to propagate through the turbid media and to form the focus in the required position. Several numerical anomalies were detected which will be explained and the means to get rid of them will be highlighted.

Cirrus Clouds Heterogeneities Impacts on the Brightness Temperature in the Thermal Infrared.

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Keywords: 3D Radiative transfer, Cirrus, IIR/CALIPSO, thermal infrared

The constellation A-train, which is operational since 2006 combines advantages of passive instruments (MODIS/AQUA, IIR/CALIPSO, POLDER/PARASOL) and active sensors (CALIOP/CALIPSO, CPR/CLOUDSAT). Currently, operational constraints (CPU time, 3D atmosphere definition) impose the use of a simplified cloud model in the retrieved algorithms of cloud parameters. Indeed, at the observation pixel scale, clouds are assumed homogeneous and spatially infinite between two planes and no interaction between cloudy columns is taken into account. Studies undertaken in the visible showed that this assumption so-called the Independent Pixel Approximation (IPA) may lead to errors in the interpretation of the measured radiative quantity and consequently on the retrieved cloud parameters (particles size, optical thickness, emissivity, etc) from satellite data.

This study aims to quantify the effects of cirrus heterogeneities on the brightness temperatures simulated in the thermal infrared. The simulations were done for typical channels used in the thermal infrared (8.65 µm, 10.60 µm, 12.05 µm) in particular with MODIS and IIR. Two different three-dimensional cirrus clouds were built with the stochastic cloud model 3DCLOUD in respect to realistic atmospheric conditions. One was modeled from *in situ* cirrus measurements observed the 25 may 2007 during the CIRCLE II campaign. The 3DMCPOL radiative transfer code was next used to simulate IIR infrared radiometer measurements. For each cirrus, simulations are done i) under the IPA (1D radiative transfer) at the spatial resolution of the IIR (1km x 1km) and ii) with a high spatial resolution (100m x 100m) next averaged to 1km x 1km (3D radiative transfer). The simulations were done for different cloud parameters (mean optical thickness, heterogeneity parameter, effective diameter) in order to characterize their influence on the differences between the two simulations. The results show that for thick cirrus clouds, brightness temperatures differences between 1D radiative transfer at 1km x 1km and 3D radiative transfer at 100m x 100m next averaged to 1km x 1km can reach more than 10 K in the nadir direction and increases with the view zenith angle. This lead consequently to non-negligible errors on the retrieved parameters (up to 25% for the optical thickness and up to 60% for the effective diameter). The differences are explained principally by the average of the cloud properties from high spatial resolution (100m x 100m) to lower spatial resolution (1km x 1km).

Talk presentation.

Investigation of absorption and scattering properties of potato tuber tissues

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Keywords: Reduced scattering coefficient, diffuse reflectance, oblique incidence reflectometry, food quality monitoring.

Research on the absorption and scattering properties of biological tissues is a subject of considerable interest at the present time because of its applicability in the crucial areas of tissue diagnosis and biomedical imaging. Tissues are formed by the aggregation of cells and consequently the light propagation in tissues (averaged scattering properties) depends on the individual scattering from the constituent cellular and sub-cellular structures and their relative concentrations. When light travels through a biological tissue, in addition to absorption, it gets scattered by the constituent structures due to the refractive index mismatch between them. Eventually the original beam of light broadens, looses directionality and become diffuse. Under these circumstances the tissue optical properties can be quantitatively described by absorption coefficient, μ_a and reduced (or transport) scattering coefficient, $\mu_s' = \mu_s(1-g)$ where μ_s is the scattering coefficient and g is the scattering anisotropy (expectation value for the cosine of the scattering angle, $g = <\cos\theta>$). Proper interpretation of these quantities can help in discriminating between cells or tissue structures when their composition (structural and biochemical) and concentration gets altered due to degradation or rotting.

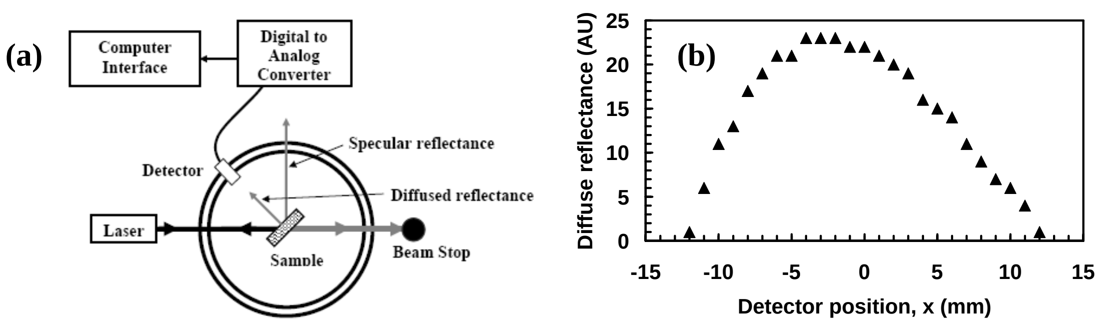

Fig. 1(a) Schematic design of the diffuse reflectometer, (b) reflectance profile of potato tissues.

In this work, the technique of oblique incidence diffuse reflectometry was used to measure the optical properties (μ_a and μ_s') of healthy potato tuber tissues. Potato is one of the major global food products and the study of the scattering properties of potato tissues can provide useful information to completely characterize their biophysical and morphological properties so that the changes in ultrastructures of the tissues due to different pathologies can be monitored. Fig.1(a) and fig. 1(b) show the schematic diagram of the indigenously designed reflectometer that can be used for both oblique and normal incidence reflectometry and the reflectance profile of the potato tuber tissue at 543.5 nm laser wavelength respectively. Form the preliminary measurements μ_a and μ_s' of potato tuber tissues were found to be 0.11 cm^{-1} and 2.8 cm^{-1} respectively. The results presented in this study can be used for developing appropriate optical sensing approaches to monitor the quality of fruits and vegetables.

Light scattering by surfaces: Monte Carlo calculations compared to measurements

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Keywords: scattering matrix, surface scattering, surface polarimetry, surface measurements , Monte Carlo modeling.

A Monte Carlo model that simulates multiple scattering in a dense medium was developed in order to simulate light scattering of polarized light by a surface [1]. Such model calculates all of the four Stokes parameters of light scattered in all directions by a surface made of any material. Although multiple scattering is allowed, a limitation exists in the packing density of the medium, as independent scattering is assumed.

In this work we compare Monte Carlo calculations to the experimental 4x4 scattering matrix as a function of the phase angle of a Sahara sand surface. The experimental scattering matrix is measured at the new experimental apparatus developed at the University of Cantabria (Spain) [2]. Sample surfaces are prepared by putting together dust grains with a water-diluted glue coating. Surface's top layer was made with pure sand, to preserve air-sand refractive index ratio. Calibration measurements have been already carried out successfully (see Sanz et al. this conference) by using Spectralon as a Lambertian surface. After calibration, measurements of a surface made of Sahara sand were performed. In such measurements, deviations from Lambertian behaviour were found, as well as a very prominent forward peak in the 11-element of the matrix for grazing illumination.

This work has a triple goal: i) the validation of the Monte Carlo model, ii) the validation of the experimental results and iii) the explanation of the deviations from Lambertian behavior and the forward-peak feature observed in the Sahara sand measurements. The values of I and -Q/I calculated by the model for the vertical scattering plane and non-polarized incident light were compared to the measured F_{11} and $-F_{21}/F_{11}$ elements for several incident directions. A good agreement between measurements and calculations was achieved, better than that obtained when considering Lambertian reflection. On the other hand, the forward-peak of the 11-element was interpreted as a consequence of single scattering of horizontally incident light by the small features of the non-flat surface. In this case, light does not penetrate the material. Fitting this peak by considering the refractive index of the sample and spherical grains gives us an approximate assessment on the typical size of the external features of the surface, which is extra information, as it does not have to coincide with the size distribution of the dust sample forming the block.

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Coupling of the microphysical and optical properties of Arctic mixed phase clouds during ASTAR experiments: Implications for light scattering modelling

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Keywords: in situ optical measurements of mixed phase clouds, ice crystal light scattering modelling

Airborne measurements in an Arctic mixed-phase nimbostratus cloud were conducted in Spitsbergen on 21 May 2004 during the international Arctic Study of Tropospheric Aerosol, Clouds and Radiation (ASTAR) campaign. The *in situ* instrument suite aboard the AWI (Alfred Wegener Institute) Polar 2 aircraft included a Polar Nephelometer (PN), a Cloud Particle Imager (CPI), a Nevzorov probe and a standard PMS 2DC probe to measure the cloud particle single scattering properties (at a wavelength of 0.8µm), the particle morphology and size, as well as the in-cloud partioning of ice/water content. The main objective of this work is to present a technique based on principal component analysis and light scattering modelling to link the microphysical properties of cloud particles to their optical characteristics. The technique is applied to the data collected during the 21 May case study where a wide variety of ice crystal shapes and liquid water fractions were observed at temperatures ranging from -1°C to -12°C. CPI measurements highlight the presence of large supercooled water droplets with diameters close to 500 µm. Although the majority of ice particles were found to have irregular shapes, columns and needles were the prevailing regular habits between -3°C and -6°C while stellars and plates were observed at temperatures below -8°C. The implementation of the principal component analysis of the PN scattering phase function measurements revealed representative optical patterns that were consistent with the particle habit classification derived from the CPI. This indicates that the synergy between the CPI and the PN can be exploited to link the microphysical and shape properties of cloud particles to their single scattering characteristics. Using light scattering modelling, we have established equivalent microphysical models based on a limited set of free parameters (roughness, mixture of idealized particle habits and aspect ratio of ice crystals) that reproduce the main optical features assessed for cloud regions with different particle geometries and liquid water fractions. However, the retrieved bulk microphysical parameters can substantially differ from the measurements (by several times for the effective size and up to three orders of magnitude for the number concentration). Several possible explanations for these discrepancies are discussed. The retrievals show that the optical contribution of small particles with sizes lower than 50µm (droplets and ice crystals) is significant, always exceeding 50% of the total scattering signal and thus needs to be more accurately quantified. The shattering of large ice crystals on the shrouded inlet of the PN could also strongly affect the retrieved microphysical parameters.

POSTER

Light Scattering studies of various fractal geometries in domain morphologies.

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Keywords: electromagnetic scattering, structure factor,fractals

We introduce a method based on static light scattering by fractal aggregates to extract their structural information. In this study, we determine the scattered intensity of fractal aggregates of different morphologies by calculating the structure factor S(q) in *q*-space (reciprocal space with units of inverse length) giving the description of the structure. The fractal aggregates are generated by a sequential algorithm that satisfies the scaling law of fractals $N=k\,(R/a)^{Df}$ at each step. Since the process of aggregation is integral to how the system evolves, we aim to understand the properties of the resulting clusters. The presence of various fractal morphologies is characterized by power laws in the structure factor. The structure factor S(q) vs *q* curves show various regimes of *q* at which the scattering occurs and varies. The structure factor falls off as a power law characteristic of fractal morphologies. We see a cross- over from the fractal regime at intermediate *q* values to Porod's regime at high *q* values. These are a consequence of distinct fractal organization in the bulk of the clusters. Structure factor is directly proportional to the intensity of scattered light. Hence, the results that we obtain are important in the context of light scattering by dust particles (*application in Astrophysics*) that are known to have complex geometries. Our results can be directly compared with the intensities obtained from other light scattering theories such as Discrete Dipole Approximation (DDA). The method introduced by us is much faster than DDA.

We also present the results for the two point density correlations function in fractal geometries which are calculated by taking the inverse Fourier transformation of the structure factor.

Application of modified method of discrete sources for solving a problem of wave diffraction on a multilayered body of revolution

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Keywords: electromagnetic scattering, scattering problems, discrete sources, orthogonal coordinates, analytical continuation of scattered field

The paper considers the vector problem of diffraction of a plane wave on a multilayered dielectric body of revolution. To solve the problem we use a modified method of discrete sources (MMDS) which has previously been successfully applied to the solution of a wide class of problems, in particular to diffraction on an impedance single body [1], on a group of coaxial bodies of revolution [2,3], on a body of revolution with chiral covering [4] etc. There are two ideas distinguishing MMDS from other versions of the method of discrete sources. First the support of discrete sources should cover all the singularities of continuation of scattered wave field inside the domain of the scatterer. This requirement provides the correctness of numerical algorithm. Secondly one should construct the support of discrete sources by the analytical deformation of the initial surface of the body. This technique permits to calculate both near and far field with high accuracy.

In the paper [5] the problem of wave diffraction on strongly elongated or strongly flattened bodies as well as toroidal bodies of revolution has been considered. To solve the problem we use the elongated or flattened spheroidal or toroidal coordinates. In the listed systems of coordinates the suitable complex coordinate is introduced that permits to apply analytical deformation of the contour of axial cross-section of the scatterer. With such approach, first, it is possible to get high accuracy of calculations for diffraction on strongly elongated or flattened bodies and bodies of toroidal shape. Secondly, the class of bodies to which MMDS could be applied is extended, in particular, diffraction on various multi-lobes of revolution (including Chebyshev's particles and deformed toruses) has been considered. In the present work we generalize this technique on the problem of wave diffraction on a multilayered dielectric body of revolution. We analyze diffraction of the plane wave on the multilayered body with absorbed media as well as the body with metamaterial covering. Different geometries of the body are considered in the paper.

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Scattering of axicon-generated Bessel beams by a sphere

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Keywords: scattering, Bessel beam, generalized Lorenz-Mie thoery, Debye series

Bessel beams have attracted wide attention in various fields, including optical trapping and manipulation, optical acceleration, nonlinear optics et al, because of their special characteristics of non-diffraction and self-reconstruction. Ideal Bessel beams are of infinite transverse extent and energy, and can not be generated experimentally. However, pseudo-non-diffracting Bessel beams can be generated experimentally using an annular aperture, hologram, or axicon. Because the deviations of the axicon-generated Bessel beams and the ideal Bessel beams are not significant, axicon-generated Bessel beams are extensively used in many fields, for instance optical trapping, manipulation, guiding and arrangements of micro-objects.

Most applications of Bessel beams involve the scattering of Bessel beams by particles. Several researchers have been devoted to the scattering of a Bessel beam by spheres. All researches are based on the electromagnetic theory, and the incident Bessel beams are expanded using plane-wave decomposition, or partial wave series involving beam-shape coefficients (BSCs). The BSCs can be calculated using the method of integral or Integral Localized Approximation (ILA), which is derived in our previous work.

Whereas in such theories, the incident beam is ideal Bessel beams. On the basis of our previous work, this presentation is devote to the rigorous theory for the scattering of an axicon-generated Bessel beam by a sphere. An analytical expression of BSCs is derived using ILA, and the scattering coefficients are expanded using Debye series. The far-field scattered intensity is calculated, and the effect of the particle parameters and the scattering process on the far-field scatted intensity is discussed.

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Ice crystals in the near-IR: ray optics for inhomogeneous plane waves compared to exact methods

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Keywords: ice crystals, ray optics, inhomogeneous plane waves, absorption

Optical properties of tropospheric ice crystals are necessary in estimations of the radiative properties of cirrus clouds and, for short-wave solar radiation, are mostly computed using ray optics. In traditional ray-optics approximations, absorption by particles much larger than the wavelength is taken into account by an exponential attenuation of intensity inside the particle. However, the reflection and refraction processes are treated with the well-known Snel and Fresnel equations for non-absorbing media. This approximation is naturally valid for ice crystals in the visible spectrum where ice is transparent but, at near-infrared wavelengths, absorption by ice becomes significant (see Fig. 1) while size parameters remain large enough for ray optics. In an absorbing medium, the plane waves propagate as inhomogeneous waves, i.e. the planes of constant phase and amplitude do not generally coincide. Thus, for a more precise treatment of scattering by absorbing ice crystals, the basic equations of traditional geometric optics must be replaced with those derived for inhomogeneous plane waves. This treatment forms the basis for a new implementation of the publicly available ray-optics code Siris.

Results of the new code will be verified by comparing to those of exact methods. As a first step, scattering by a hexagonal particle in fixed orientation is studied against the well-established discrete-dipole approximation over a relevant range of large size parameters. In addition, the overall impact of the less approximate theoretical approach in geometric optics is assessed by comparing the results against the previous Siris code. If the results show significant differences, the complex refractive index values for which the traditional ray optics becomes invalid will be identified. Ultimately, the objective is to publish an updated, publicly available ray-optics code for the light-scattering community.

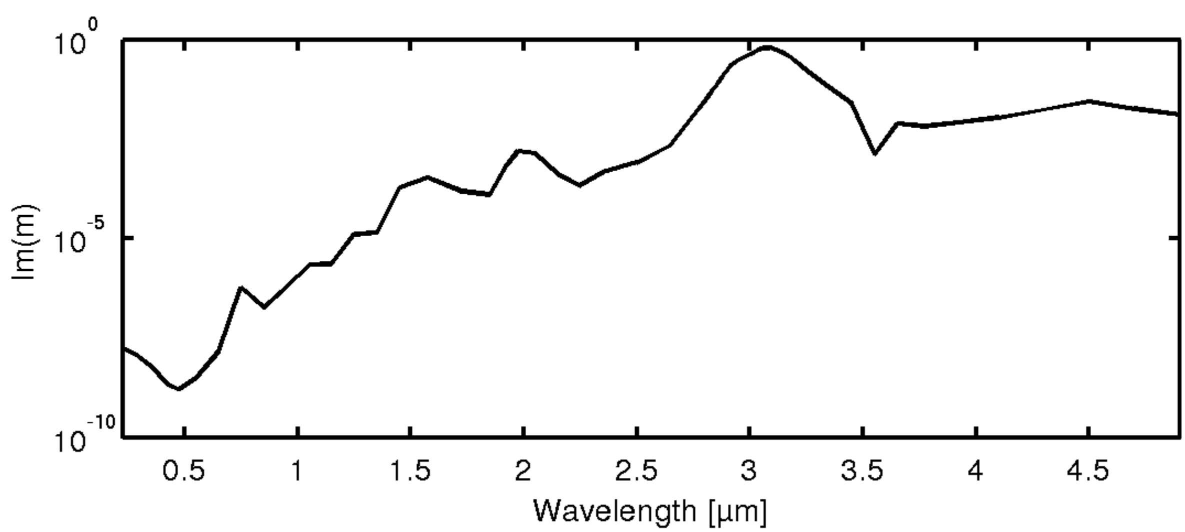

Figure 1. Imaginary part of the refractive index of ice at visible and near-IR wavelengths.

Multi-satellite aerosol observations in the vicinity of clouds

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Keywords: CALIPSO, MODIS and CERES observations, aerosol-cloud radiative interactions, near-cloud aerosol properties

Improved characterization of aerosol properties in the vicinity of clouds is important for better understanding two critical aspects of climate: aerosol-cloud interactions and the direct radiative effect of aerosols. Satellite measurements have provided important insights into aerosol properties near clouds, but also suggested that the observations can be affected by 3D radiative processes and instrument blurring not considered in current data interpretation methods. This presentation will examine systematic changes in particle properties and radiation fields that influence satellite measurements of aerosols in the vicinity of clouds. For this, we will present a statistical analysis of a yearlong global dataset of co-located MODIS and CALIOP observations and theoretical simulations. The results reveal that CALIOP-observed aerosol particle size and optical thickness, and MODIS-observed solar reflectance increase systematically in a wide transition zone around clouds. It is estimated that near-cloud changes in particle populations—including both aerosols and undetected cloud particles—are responsible for roughly two thirds of the observed increase in 0.55 μm MODIS reflectance. The results also indicate that 3D radiative processes significantly contribute to near-cloud reflectance enhancements, while instrument blurring does not.

We will also discuss a simple model to compute clear-sky radiance enhancement due to radiative interaction between boundary layer clouds and the molecular layer above. For the first time, the model has been applied to a full MODIS granule. The process of the correction includes converting CERES broadband flux to visible narrowband flux, computing the clear-sky radiance enhancement, and aerosol retrieval. It was found that correction leads to smaller values in aerosol optical thickness (AOT), the Ångström exponent, and the small mode fraction of AOT. The presentation will discuss the first results of implementation of the correction algorithm to MODIS aerosol retrievals near clouds.

Intracavity optical trapping with feedback-locked diode lasers

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Keywords: optical trapping, feedback-locked diode lasers, *T*-matrix calculations

Optical tweezers (OT) are generally realized by highly focusing a laser beam in order to trap a mesoscopic dielectric particle near the focal spot. The resulting radiation forces are typically distinguished in scattering forces, which are due to the light forward pressure, and gradient forces, generated by the gradient of the light intensity. OT have been extensively applied to cellular and molecular biology, soft matter, nanotechnology and nanoscale thermodynamics. One of the issues in using OT with sensitive samples, e.g., living cells and biomolecules, is the fact that they may induce photodamage when the average radiation intensity exceeds some threshold.

Here, we describe a novel approach to optical trapping based on optical feedback-locking. In this novel configuration, the optical feedback on a diode laser source is controlled by the light scattering from a trapped particle. When no particle is in the trap, the optical feedback from a dielectric mirror posed above the microscope objective will increase the trapping power in the focal spot. Instead, when a particle falls in the trap the optical feedback will be reduced and trap will work at low power preventing damage and relaxing the stringent conditions on high numerical aperture for standard OT. One of the key advantages is that with this approach it is possible to use low numerical aperture lenses (NA= 0.45) and, therefore, large field of view (in excess of 1000μm x 1000μm). Furthermore, this technique enables a reduction of the average light intensity employed for a given trap stiffness minimizing the photodamage at the sample. We obtained stable trapping at power as low as 0.32 mW with an injection current close to the diode laser free-running threshold. This corresponds to an intensity two order of magnitude lower than a standard OT based on a high NA objective lens. Finally we show how T-matrix calculations give account of optical binding between mirror and trapped particle in this novel intracavity configuration.

This open perspectives for novel applications of optical trapping to samples that require lower intensity and increased fields of view. Such applications are particularly interesting for dealing with biological samples that are prone to photodamage.

Optical trapping of linear nanostructures: Brownian dynamics and non-conservative effects

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Keywords: optical trapping, linear nanostructures, *T*-matrix calculations of optical trapping

Optical trapping (OT) of nanostructures has acquired tremendous momentum in the last few years. Manipulating nanoparticles with OT is generally difficult because radiation forces scale approximately with particle volume and thermal fluctuations can easily overwhelm trapping forces at the nanoscale. However carbon nanotubes, graphene, polymer nanofibers, plasmonic nanoparticles, and semiconductor nanowires have now been stably trapped thanks either to their highly anisotropic geometry or to their intrinsic resonant behavior. In particular, the small transverse size of carbon nanotubes and nanowires is the key to achieve nanometric resolution in Photonic Force Microscopy applications, while an axial dimension in the micron range ensures stable trapping and force sensing in the femtonewton regime.

Here we show our results on optical trapping, force sensing and spectroscopy of linear nanostructures (carbon nanotubes and silicon nanowires). We use correlation function analysis to calibrate the tracking signals for optically trapped nanostructures with near-infrared (NIR) light. This yields the Brownian dynamics in the trap and is the starting point for the investigation of non-conservative effects caused by the interplay between the non-spherical shape and the non-conservative scattering force. Furthermore, we discuss the use of laser beams with radial and azimuthal polarization for optical trapping where the reconstruction of the Brownian motion of nanotube bundles in the trap highlights the dramatic change in the optical trapping potential.

Aerosol remote sensing in an atmosphere–reflecting surface system

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Keywords: radiative transfer

This work aims at developing the practical and efficient algorithms for retrieving aerosol characteristics from space. The aerosol properties such as the aerosol optical thickness (AOT), refractive index (m), and angstrom exponential (α) are estimated by comparing satellite measurements with the numerical values of radiation simulations in the Earth - atmosphere - surface model. This process is simply represented in Fig.1.

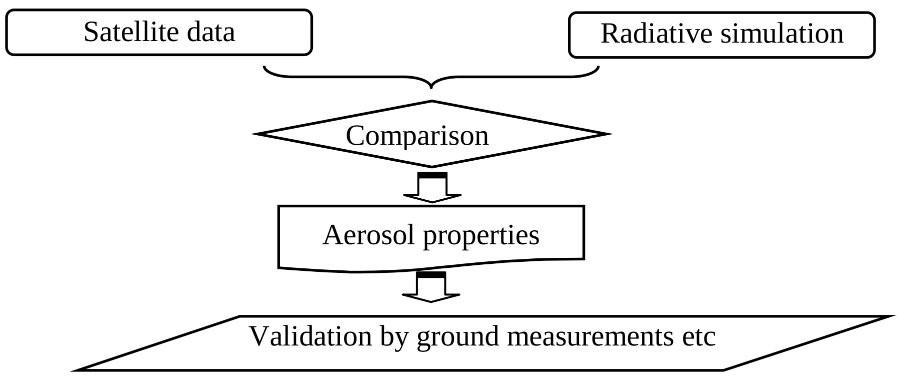

Fig.1 Block flow of aerosol remote sensing.

The radiative transfer problem in a case of finite optical thickness atmosphere bounded by the reflecting bottom surface is considered here. The equation of radiative transfer describes this circumstance as follows:

$$\mu \frac{dI}{d\tau} = I - \frac{\omega}{4\pi} \int P(\Omega, \Omega') I(\tau, \Omega')\, d\Omega', \qquad (1)$$

where τ represents the optical depth of atmosphere, ω is the albedo for single scattering, and $P(\Omega, \Omega')$ represents the phase function for single scattering, where μ is the cosine of the angle between the direction of light and outward normal of the medium. The boundary conditions for this problem are (i) at the top of the medium, $\tau = 0$, there are no radiation falling except in direction $-\mu_0$, and (ii) the bottom of the medium, $\tau = \tau_0$, for the finite medium is represented by Ross-Li BRDF model [1)]. The space-borne sensors measure the upwelling radiance at the top of the atmosphere. Then the superposition method is effective for this case. Our new computation code is validated by Aqua/MODIS sensor and will be available to retrieve aerosol properties to be given by Japanese planned mission GCOM/SGLI.

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On the plasmonic behavior of metallic materials in the UV

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Keywords: UltraViolet Plasmonics, Electromagnetic scattering, Numerical methods

The use of metallic nanoparticles as nanosensors has a great number of applications in plasmonic nanotechnology: biosensors, nanocircuits, spectroscopy, photovoltaic devices, microscopy, etc. When the electronic plasma in a metal is confined in small structures at the nanometric scale, its interaction with electromagnetic radiation in the UV-VIS-NIR frequency range can generate very fast oscillations that, when properly tuned to the frequency of the incident radiation, lead to interesting resonance effects known as Localized Surface Plasmons (LSP's). When this happens, two important physical consequences are obtained: a localization of the incident electromagnetic energy at dimensions much smaller than the incident wavelength, produced by its transformation into electromechanical energy, and secondly, a strong enhancement of the electromagnetic field in the proximity of the nanostructure. In most of the plasmonic applications, gold and silver are commonly used metals. Their plasmonic resonances are located in the VIS-NIR range (1-3eV). So, noble metals constitute the basis of many nano-tools for biosensing applications in this spectral range. Furthermore, they show a good biocompatibility and also, they are easy to functionalize. Given the great impact of such tools for "biosensing", and bearing in mind that many biological molecules absorb in the UV range, the study of LSP's in such spectral domain is an important challenge that may open the door to materials with a new role at higher incident photon energies. Pursuing this objective, the purpose of this research is to make a comparative numerical analysis through the Discrete Dipole Approximation method (DDA), of the plasmonic behaviour of metallic nanoparticles made of different metals like Indium, Rhodium, Ruthenium, Tungsten, Titanium, Chromium, Palladium, Copper, Platinum and Magnesium (in principle, their plasma frequencies are high enough to be UV plasmonic candidates). The scattering system will be constituted by small nanoparticles (<100nm) made of those metals, located on a dielectric substrate (glass, sapphire) and illuminated by a monochromatic linearly polarized plane wave at normal incidence. Near and far-field configurations will be considered for both spherical and hemispherical geometries. In particular, the spectral and geometrical characteristics of hot-spots (near-field) together with more conventional far-field parameters, like the absortion efficiency and the plasmonic performance, will be studied. The general plasmonic behaviour of the considered materials will be compared to others already characterized such as noble metals (Au, Ag) for VIS-NIR as well as Ga and Al for UV. The main conclusions about the suitability of the different materials as a structure with plasmonic activity in the UV will be presented.

Note: the name of the person who will make the actual presentation is underlined.

Aerosols in cloudy scenes: properties and impacts

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The impact of anthropogenic aerosols is believed to be the second most important anthropogenic forcing in climate models. However, the estimation of this radiative forcing is also the most uncertain because of the difficulty to account for the different processes involved in their formation and evolution as well as the variability of their spatial and temporal distribution. This is why large scale observation of aerosols distribution, loading and properties is a task of importance. The use of cloud-screening for most of the current aerosols retrieval schemes prevents from taking account of a large quantities of aerosols that are lifted up above clouds. This limitation to cloud-free scenes may induce important bias in the estimation of the aerosol direct effect (i.e. scattering and absorption) since this radiative forcing depends strongly on the albedo of the underneath surface. In fact, Aerosols Above Cloud (AAC) can reduce the local albedo and thus, they may lead to an important warming (direct effect). Another key point is that cloud properties retrieved by passive sensors measurements (i.e. cloud optical thickness and effective radius) are affected by AAC, which increases the difficulty of evaluating the aerosol indirect effect on cloud.

An operational algorithm which allows to retrieve of the AAC load and properties has been developed at the LOA and has already been applied to one year of data. It uses POLDER's polarized radiance measurements which have shown sensitivity to detect multilayer scenes. Based on these results, we have developed a method to evaluate biases on cloud parameters retrieved in AAC scenes. Finally corrected cloud parameters, aerosols optical thicknesses and microphysical properties are used to compute the radiative forcing induced by AAC with a radiative transfer code. The impact of an error in the aerosol absorption will be shown. In order to reduce the computation time, the possibility of an approximate approach has been explored and comparison with the exact calculation will be presented.

Active imaging systems to see through adverse conditions: light-scattering based models and experimental validation

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Keywords: adverse conditions, bad weather conditions, light scattering, laser imaging, surveillance, defense, security, aeronautics

Weather conditions influence the incidence of aircraft accidents in a number of ways. As an example, one can remember the 11th April 2011 when an A380, taxiing along the runway of JFK Airport in New York, clipped the wing of a smaller CRJ jet, sending it into a spin. There were no reports of injuries but both aircraft have been grounded pending an investigation. This accident is mainly due to bad weather conditions (strong rain) and low visibility (night vision).

Onera identified different sensor technologies in order to detect, to recognize and to localize objects of the scene in all weather conditions (rain, snow, fog, haze, dust wind…) to provide enhanced visions to the crew. One distinguishes two kinds of sensors to fulfill the target: large Field of View (FOV) sensors (passive visible/IR Camera, Radar) and, high spatial resolution - small FOV optical laser sensors prototypes. On the one hand, large FOV sensors technologies are often chosen to offer the best solution to the pilot to maneuver on the taxi way. On the other hand, small FOV sensors are dedicated to recognize and to localize fixed and mobile objects on the taxiway. We plan to improve the obstacle detection, the localization of obstacles previously detected and the recognition of these objects. Bad weather conditions (rain, snow, fog, haze, dust wind…) impact the visibility and also the contrast of the scene.

We develop and model active imaging systems to understand the relevant physical phenomena impacting on their performances. For small FOV applications, we distinguish 2D and 3D active imaging devices as the description of the physical phenomena can be different in these two cases. Efforts have been done both on the propagation of a pulse through the atmosphere (*e.g.* scintillation and turbulence effects) and, on target geometries and their optical properties (*e.g.* radiometric and speckle effects). For aeronautical applications, these imaging systems must operate in all ambient illuminations (day and night vision) and weather conditions in order to perform the strategic surveillance of the environment for various worldwide operations or to perform the enhanced navigation of an aircraft. We have implemented codes for both 2D and 3D laser imaging systems. As we aim to image a scene even in the presence of rain, snow, fog or haze, we introduce such meteorological effects in these numerical models and compare simulated images with measurements provided by commercial imaging systems. As a consequence, we will focus our talk on the description of the scattered light by various meteorological events. Then, we will describe numerical models and compare simulated and experimental results.

Oral presentation is preferred

Light scattering by inhomogeneous elliptical birefringent medium

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Keywords: light scattering, depolarization, Mueller matrix, birefringence.

Mueller matrix polarimetry is a particularly promising approach to the retrieval of the depolarization and anisotropy properties of the medium investigated in a polarized light scattering experiment. The purpose of the paper is to provide rigorous analysis of light scattering by inhomogeneous elliptical birefringent medium in single scattering case. The medium under consideration is an anisotropic crystalline slab with surface inhomogeneity. For analysis we use the Mueller matrix model of such class of media derived in [1].

$$\mathbf{M}=\begin{pmatrix} F_{11}+F_{22} & F_{11}-F_{22} & 0 & 0 \\ F_{11}-F_{22} & F_{11}+F_{22} & 0 & 0 \\ 0 & 0 & F_{12}+F_{21} & -i\left(F_{12}-F_{21}\right) \\ 0 & 0 & i\left(F_{12}-F_{21}\right) & F_{12}+F_{21} \end{pmatrix}, \tag{1}$$

where

$$F_{ij}=F_{ij}^{0}\left(\left(1-\eta_{ij}\right)\exp\left\{-\left(\frac{k\boldsymbol{\rho}w}{2z}\right)^{2}\right\}+\frac{\eta_{ij}}{\tilde{\sigma}_{ij}^{2}w^{2}+1}\exp\left\{-\frac{1}{\tilde{\sigma}_{ij}^{2}w^{2}+1}\left(\frac{k\boldsymbol{\rho}w}{2z}\right)^{2}\right\}\right),$$

$$F_{ij}^{0}=\exp\left(ik\left(n_{i}-n_{j}\right)\bar{h}-k^{2}\sigma_{h}^{2}\left(n_{i}-n_{j}\right)^{2}/2\right),$$

$$\sigma_{ij}^{2}=k^{2}\sigma_{h}^{2}\left(n_{i}-1\right)\left(n_{j}-1\right),$$

$$w=a\left(1+4z^{2}/a^{4}k^{2}\right)^{1/2},$$

$$\tilde{\sigma}_{ij}^{2}=\sigma_{ij}^{2}/\eta_{ij}\rho_{0}^{2} \text{ and } \eta_{ij}=1-\exp\left(-\sigma_{ij}^{2}\right).$$

To describe depolarization, we use several the so-called “single value depolarization metrics” (depolarization index, $Q(\mathbf{M})$-metrics, Cloude and Lorenz entropies) and multiplicative models of depolarization objects with different depolarization matrices [2,3]. These quantities provide insights into the particular depolarization mechanisms of different media. We compare the depolarization information on the inhomogeneous elliptical birefringent medium Eq.(1) that can be obtained by all these approaches.

To characterize the polarizing properties of the matrix model Eq.(1) the dependency of effective dichroism on observation angle was addressed. All results were obtained for three crystals: calcite $CaCO_3$, paratellurite TeO_2 and lithium niobate $LiNbO_3$.

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Comparison of the near field solutions for electromagnetic scattering by infinite and finite cylinders

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Keywords: electromagnetic scattering, FDTD, cylinder theory

In many research areas a knowledge about the light propagation in complex media is of fundamental interest. Beside experimental measurements a theoretical investigation helps to gain deeper insight into the basic mechanism of light propagation in scattering media. For the theoretical treatment simple models can be used as primal approximation of the scattering samples. Many scattering structures, e.g. cells in tissue or aerosols in the atmosphere, contain spherical structures and theoretical solutions based on Mie theory can be utilized. However, often the medium of interest consists of cylindrical structures, e.g. fibrous materials or biological media like skin, muscle or tendon. If the length of a cylindrical structure is large compared to their diameter, these finite structures are often approximated as infinite cylinders in the theoretical treatment. Different analytical solutions for the scattering by infinite cylinders have been developed and can be applied. The validity of this approximation for the far field results has been well examined while the validity in the near field remains unclear.

In this contribution the infinite cylinder approximation is examined in the near field. For the calculation of the near field scattering by one or more infinite cylinders, an analytical near field solution that allows the treatment of perpendicular as well as obliquely incoming light is used. For the near field calculation of the scattering by finite cylinders a three-dimensional FDTD numerical simulation has been utilized. Using these two different approaches the near field solution for the infinite and the finite cylinders has been analyzed at different positions along the cylinder axis. Comparisons between these results are shown for different optical parameters, cylinder diameters and cylinder lengths in order to assess the validity of the infinite cylinder approximation in the near field. Results are shown for single cylinder and multiple cylinder scattering for perpendicular and oblique incidence.

Simultaneous measurement of bubble's size and 3D velocity in a channel using cylindrical interferometric out-of-focus imaging

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Keywords: bubble sizing, interferometric out-of-focus imaging, 3D tracking, generalized Huygens-Fresnel integrals

The characterization of droplets or bubbles in a complete volume of study has important applications in fluid mechanics, energetics, biology. In this domain, interferometric out-of-focus imaging has high potentialities. It is a simple, robust technique, often used when investigating droplets or bubbles illuminated by a planar laser sheet [1,2]. We propose a configuration which allows the simultaneous measurement of bubble's size and 3D velocity using a single CCD sensor located in an out-of-focus plane. Other techniques as digital holography or shadowgraphy have already shown their performance in 3D location. However, holography distinguishes badly dust from transparent bubbles while shadowgraphy requires high magnification for small bubble detection. Interferometric out-of-focus imaging [1] rises up as a size measurement technique for transparent spherical particles, using an out of focus imaging of scattered light.

This work is thus devoted to the development of original interferometric out-of-focus imaging configurations and corresponding simulations based on generalized Huygens-Fresnel integrals. We design a cylindrical imaging set-up to track the 3D location of spherical bubbles. Cylindrical imaging can be performed either using cylindrical lens, or imaging directly bubbles in a cylindrical channel. The design and calibration of the systems are done using generalized Huygens-Fresnel integrals [3]. Experiments are performed in the case of air bubbles in water. The measurement's volume is about $100mm^3$ with the field depth of 10mm. The center of the out of focus bubble image gives the bubble's position in the plane parallel to the captor while the interferometic fringe orientation corresponds to the bubble's axial location. The 3D locations with this technique allow 3D velocity measurements using two successive frame acquisitions. The bubble's size is obtained from the frequency of the interferometic fringe as the normal ILIDS technique does. These results illustrate and substantiate the performance of cylindrical interferometric out-of-focus imaging for simultaneous bubble sizing and 3D location measurement. We will further present the image processing techniques developed to analyse the images rapidly. The developed technique is also suitable for the characterization of droplets in air in the case of ILIDS [4].

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Aerosol retrievals in cloud-contaminated scenes

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Small amounts of cloud-contamination can cause large errors and/or biases in the retrieval of micro-physical and optical aerosol parameters from satellite observations. Therefore, it is common practice to only perform aerosol retrievals for scenes that are strictly screened for clouds. This, unfortunately, removes many near-cloud scenes from data-sets, while exactly those scenes are interesting for analyses of the aerosol cloud interactions. Observations and retrieval methods that can deal with cloud-contamination are required. Instruments that do multi-angle observations of intensity and especially polarization are most capable to separate between aerosols and cloud-contamination, since scattering by cloud droplets produces a distinctive feature in the degree of linear polarization at a scattering angle of about 140 degrees. The only instrument that currently performs those observations is POLDER3 on board the PARASOL satellite. Hasekamp et.al. [J. Geophys. Res., 116, D14204, 2011] have developed an algorithm that makes full use of the information in POLDER3 measurements for clear sky scenes. Our aim is to extend the retrieval scheme to also retrieve aerosol properties in cloud contaminated scenes. As a first step, the effects of residual cloud cover/cloud-contamination on the aerosol retrieval algorithm are analyzed. In order to do so cloud properties obtained from the MODIS Cloud Product have been co-located with the POLDER3 observations and the retrieved micro-physical and optical aerosol parameters are compared with independent ground based measurements from AERONET for different amounts and types of cloud contamination. The validity and limitations of the retrievals in cloud-contaminated scenes are discussed and the latest results of retrievals with an algorithm that simultaneous retrieves the cloud properties are presented.

Optimal dimensions of gold nanoshells for light scattering and absorption based applications

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Keywords: nanoshell, surface plasmon resonance, scattering, absorption, Mie theory

Gold nanoshells, spherical nanoparticles with silica cores and gold shells, are of great interest in optical imaging, based on their light scattering properties, and photothermal therapy, due to light absorption properties, in the near-infrared (NIR) region. Nanoshells illuminated at resonance wavelength are either strong light absorbers or scatterers. A high light scattering is essential for optical imaging applications, while effective photothermal therapy with minimal laser dosage requires a high light absorption.

Silica-gold nanoshells and hollow gold nanoshells, frequently-used nanoparticles in biomedical applications, were designed that possess maximal NIR light scattering or absorption properties by using the Mie theory of coated sphere. From the numerical comparison, the hollow gold nanoshells are seen to offer the little superior near-infrared (NIR) scattering or absorption at smaller particle size. Large sized nanoshells of a high aspect ratio are the efficient contrast for biomedical imaging applications, while smaller nanoshells with high aspect ratio are the ideal photoabsorbing agents for photothermal therapeutic applications. Fitted expressions of optimal dimensions (i.e. core radius and shell thickness) of nanoshells with two different cores (silica and vacuum) were provided, which may be used as design guidelines by experimentalists, in order to optimize the synthesis of gold nanoshells for different applications at their various growth stages.

Theoretical study of the anchoring influence on plasmonic resonance tunability of metallic nano-particles embedded in a liquid crystal cell

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Keywords: Liquid Crystals, FDTD, LSPR, Nanoparticles

Liquid crystals (LCs) are an outstanding material as a surrounding environment for metallic nanoparticles, owing to their anisotropy. Indeed, by applying an external electric field, the environment of the particle can be modified, leading to a LSPR shift. Using LCs in conjunction with gold gratings or nano-particles, for example gold nanorods, gold nanodots and nanodisks, gold dimer, and nanohole arrays have been reported experimentally.

Furthermore, some papers have reported numerical investigation of metallic arrays or particles covered by nematic LCs. But all of these works neglect the anchoring phenomenon at the interface of LC molecules and glass substrates, or consider that a weak anchoring condition is met.

On the contrary, in this work, we theoretically study strong anchoring effects on the localized surface plasmon resonance (LSPR) peak position of an ordered gold nanoparticles array deposited on a glass substrate. LSPR peaks are theoretically found by computing extinction spectra using the FDTD method.

A schematic of the setup is depicted on Fig. 1. Strong anchoring is considered at the lower and upper interface of LC cell. By comparing the results of weak and strong anchoring using different structure parameters, the contribution of the LC anchoring effect on LSPR tunability can be checked.

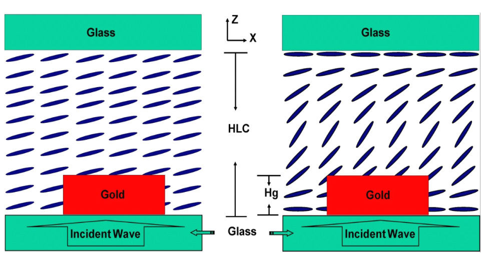

Fig. 1 : schematic of the structures

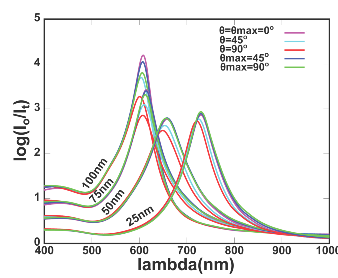

Fig. 2 : extinction spectra

In conclusion, we have investigated the LSPR shift of gold nano-structures embedded in a LC cell as a function the optical axis orientation of the LC molecules by taking anchoring effects into account. We have shown that these effects strongly reduce the LSPR tunability, but that modifications to the nano-structures shape or LC height could efficiently compensate it. Further work is required to fully optimize the configuration in order to get significant and usable shifts.

Analysis of 3D morphology of normal and cancerous prostate cells and their effect on diffraction images

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Keywords: cell morphology, light scattering, diffraction imaging

How to quantify and rapidly measure the morphological differences in normal cells and their cancerous counterparts is a long-standing issue. Here we will present a study of 3D morphology between a normal type of prostate epithelial cells (PCS) and a prostate cancer cell line (PC3) with the goal to develop a rapid method of cell assay for early detection of prostate cancers through test of blood or urine samples. In addition, we have performed diffraction imaging measurement of these cells with a flow cytometry method to investigate the correlations between morphological features and the texture features of the diffraction image data.

Confocal image stacks were acquired of PCS and PC3 cells in suspension between glass slides after double staining of the nucleus and mitochondria with fluorescent dyes. Each cell was randomly selected from an imaging sample and a total of 40 cells were imaged for each cell type. Software has been developed to reconstruct the 3D structures of the cells form the fluorescent image stacks. For quantitative analysis we extracted 31 morphological parameters for all cells in the three groups based on the voxels of 0.070μm sides in the x-y plane and 0.073μm side along the z-axis. Comparison of these parameters show that the main difference among these two cell types lie in the nucleus with the nucleus-to-cell volume ratio equal to 43.1% for the PCS and 55.7% for the PC3 cells. We then performed angle-resolved measurement of light scattering with a diffraction imaging flow cytometer to acquire one pair of cross-polarized diffraction images per imaged cell. By controlling the polarization direction of the incident light, we found the new flow cytometry method can accurately classify these two types of prostate cells which may be attributed to their difference in the nuclear structure.

Note: the name of the person who will make the actual presentation is underlined.

Retrieval of aerosol microphysical properties from AERONET measurements of polarimetric skylight radiance

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Keywords: AERONET, polarization, aerosol microphysical properties, optimal estimation

Atmospheric aerosols play an important role in the Earth-atmosphere energy budget by reflecting and absorbing solar radiation and indirectly through their effect on microphysical properties and lifetimes of clouds. Quantification of such radiative effects in current climate models remains a large source of uncertainty, due in no small part to poor knowledge of aerosol microphysical properties and burdens on a global basis. With more than 200 sites round the world, the AERONET (Aerosol Robotic Network) continues to provide aerosol products of optical depth, size, and refractive index that are retrieved from measurements of Sun and sky radiance [*Holben et al*., 1998; *Dubovik and King*, 2000]. While polarization contains essential information on aerosol sizes and refractive indices [*Mishchenko and Travis*, 1997], the potential of AERONET polarization measurements has not been fully exploited in this regard.

We present a new approach to invert aerosol properties from AERONET solar and sky measurements for the 440, 675, 870, and 1020 nm bands, as well as additional polarization measurements at 870nm. The approach aims to retrieve 22 aerosol loading and microphysical parameters for a bi-modal aerosol size distribution; these include aerosol columnar volume, effective radius, effective variance, and spectral complex refractive index. From these retrieval parameters, one can derive aerosol single scattering properties that are required for aerosol climate-effect studies. The retrieval algorithm is based on a linearized vector radiative transfer model VLIDORT [*Spurr*, 2006], plus linearized Mie and T-Matrix codes [*Spurr et al.*, 2012], in combination with an iterative optimal estimation method [*Rogers*, 2000]. We use the algorithm to investigate the information content as part of the retrieval procedure, in order to quantify theoretically the available information in the measurements and the uncertainties in the retrievals based on *a priori* constraints and measurement error characterization. Additionally, we also consider the uncertainty in the radiative transfer calculation due to errors in the assumed surface reflectance.

In the poster, we show the calculated information content in the measurements with and without the inclusion of polarization, and also the corresponding theoretical error in the retrieved parameters and derived single scattering properties. The results clearly indicate the improvement in aerosol property characterization resulting from the use of additional polarization measurements. We also present a suite of real retrieval results for a number of case studies based on AERONET sites in Beijing, Lille, and Capo Verde.
Note: the name of the person who will make the actual presentation is underlined.

Measuring the Void: Scattering by a cylindrical annulus

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Keywords: Scalar waves; Electromagnetic scattering; Lorenz-Mie theory; Energy extinction

Consider a monochromatic plane wave scattering from an infinitely long homogeneous and isotropic cylindrical annulus with outer radius r_1 and inner radius r_2. Let ϵ_1 denote the permittivity of the space surrounding the cylindrical annulus and let ϵ_2 denote the permittivity of the cylindrical annulus itself, $r_2 < r < r_1$. Let us refer to the region of space inside the cylindrical annulus as the "cylindrical void" and ask what effect the cylindrical void has on the scattered field(s) outside the cylindrical annulus. If one were to *experimentally* investigate this, one would do the following:

(a) measure the total field $V^{(1)}(r,\theta)$ outside the cylindrical annulus ($r > r_1$);

(b) measure the total field $U^{(1)}(r,\theta)$ outside an identical "host cylinder;" i.e., a cylinder of radius r_1 and permittivity ϵ_2;

(c) compute the difference between the two fields in (a) and (b):

$$W^{(\mathrm{sca})}(r,\theta) = V^{(1)}(r,\theta) - U^{(1)}(r,\theta).$$

Following the above procedure, $W^{(\mathrm{sca})}(r,\theta)$ contains the effect that the cylindrical void had on the scattered field. In this talk, we show that $W^{(\mathrm{sca})}(r,\theta)$ can be approximated by the scattered field produced by the cylindrical void when a plane wave from a region of space with a permittivity of ϵ_2 is incident on it. This approximation holds if the "screening effect" of the cylindrical annulus is properly accounted for, and if the cylindrical void is sufficiently small. We refer to this approximation as the *screened cylindrical void* (SCV) approximation. The SCV approximation is first developed in a physically intuitive manner, and then in a mathematically rigorous manner. The generalization of the SCV approximation to the case when the cylindrical void is non-concentric with the host cylinder is also discussed. Furthermore, we discuss the rate, denoted by $\mathbb{W}^{\mathrm{ext}}$, at which the energy is extinguished (depleted) by the cylindrical void from the total field outside the host cylinder, and physically interpret the terms contained in $\mathbb{W}^{\mathrm{ext}}$.

Note: The preferred mode of presentation is **oral**.

P3
Poster Session

(June 20th, 5:35 PM)

Light scattering of discrete random media slab with fractal particles

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Keywords: light scattering, discrete random media, *T*-matrix method, fractal

Light scattering in discrete random medium have attracted much more attention in various fields in recent years, it has many applications in the field such as biomedical engineering, environmental monitoring and air pollution control etc. Mostly used models in light scattering in discrete random medium layer involve the light scattering of spheres. Several researchers have been devoted to the scattering by non-spheres particles in random medium. All researches are based on the wave radiation transmission theory in random medium, and the Monte Carlo method is usually used in numerical simulation. In this paper we are studied the transmission characteristics of aerosol particles composed with discrete random distributed non-spherical fractal particles. *T*-matrix method was used to numerically describe the light scattering properties of a single fractal aggregate particle in the media. The method of establishing scattering phase function database of fractal particles in different scattering angles and azimuth angles is established. The dependence of the radius and the number of elementary particles, incident wavelength on the time of establishing the database is analyzed. Factors affecting the transmission characteristics of clusters aerosol are also discussed. The results show that the influence of the fitted method of phase function on the transmission characteristics is significant. For the transmission characteristics of a layer with random oriented non-spherical particle aerosol, using H-G phase function method for spherical particles by volume equivalence or area equivalence will lead too large errors. Numerical experimental results with the transmission characteristics of fractal aerosol slab by using improved Monte Carlo method provide a useful way in dealing with the problems in the case of multiple scattering by discrete random media.

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Efficient simulation of dynamics of nonspherical particles in optical tweezers

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Keywords: optical tweezers, optical torque, *T*-matrix method

The *T*-matrix method provides an efficient method for calculating forces and torques in optical tweezers, where a tightly focused laser beam is used to trap and manipulate microscopic dielectric particles. The ease of repeated calculations of scattering by the same particle under different illumination allows the force and torque to be calculated for different positions and orientations within the trapping beam, using the same *T*-matrix. However, when there are many degrees of freedom, such as with the trapping of non-spherical particles, where even a rotationally symmetric particle results in five degrees of freedom, or multiple particles with $3N$, or $6N$ if non-spherical, degrees of freedom, calculation of the force and torque over all degrees of freedom remains a very computationally intensive task. A solution to this difficulty is to model the dynamics of the particle or particles within the optical trap. This requires modeling the motion of the particle subject to optical and other forces.

The dominant non-optical force is viscous drag. The time constant at which terminal speed is approached is about 1μs, and the terminal speed is typically under 100μ/s, so it can be assumed that the particle always moves at terminal velocity. That is, we can solve the equation of motion $F = -Dv$, where F is the optical force, D is the drag coefficient, and v is the velocity, rather than $F = ma$ (where F would be the *total* force). It is important to include Brownian motion, both translational and rotational, since this will prevent the particle from remaining in an unstable equilibrium or a local minimum of the potential. In addition, Brownian motion is important in the dynamics of particles within real optical traps.

We discuss the use of such dynamic simulation to determine features of optical traps, such as equilibrium positions and orientations, spring constants, and trap strengths. We also consider other forces, such as hydrodynamic coupling between translation and rotation, thermophoresis, and drag due to convective flow.

Latitude dependence of ice cloud particle roughness and habit

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Keywords: ice cloud, polarization, roughness

The microphysical properties of ice clouds are still relatively poorly understood, including the degree of surface roughening which may be present and the shape of the ice crystals within the cloud. Many satellite retrieval algorithms use one ice model to retrieve ice cloud properties on a global scale, but ice microphysics can vary greatly depending on the source of the ice cloud, which is often a function of latitude. This study investigates the degree of roughening and shape of ice particles within ice clouds by using polarized reflectance measurements from the PARASOL (Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar) satellite. Simulations of polarized reflectance are performed using a vector adding-doubling radiative transfer (RT) model with different levels of surface roughening and different ice shapes, and the results are compared with PARASOL observations sorted by latitude. In general, compact aggregates with roughened surfaces compare well with polarized reflectance observations from the tropics, while more pristine shapes with roughened surfaces compare well with observations in the midlatitudes and polar regions.

Averaging of Scattering Characteristics in 2D Diffraction Problem Related to Multiple Bodies Based on Pattern Equation Method

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Keywords: 2D diffraction problem, pattern equation method, multiple scattering, averaging of scattering charcteristics

In order to simplify the presentation of procedure of averaging, a 2D diffraction problem was considered. As the method of solution to the problem stated, the Pattern Equation Method (PEM) was used. Earlier, this method had already been applied to solve 2D and 3D wave diffraction problems, both for scalar and vector cases. Until recently the procedure of averaging of scattering characteristics was not considered in the frame of PEM. It should be mentioned that, for this purpose, the T-Matrix Method (TMM) is currently being used, which is applied to obtain the averaged scattering characteristics both of a single particle and a group of bodies.

Generalization of the PEM enabling us to average wave scattering characteristics in 2D diffraction on a single cylinder of arbitrary section with impedance boundary condition at the interface has been obtained relatively recently. The comparison of two procedures for averaging – within the frame of the PEM and the TMM as well as of numerical results of calculations of averaged characteristics, such as scattering pattern, integral scattering cross section, etc., was carried out.

In this paper we outline the procedure of averaging of scattering characteristics over the incident angles in the PEM for a 2D wave diffraction problem on multiple bodies with impedance boundary condition at the interface. Averaged scattering characteristics for a finite group of similarly shaped bodies (circle, ellipse, superellipse, multifoil) were studied with regard to their different arrangements relative to each other and various body sizes. The results of calculations have demonstrated that an averaged scattering pattern of several bodies randomly arranged around the central body is close to the averaged scattering pattern of the central body under certain conditions. Besides, it was numerically confirmed that an averaged integral scattering cross section of a group of scatterers shall be equal to the sum of averaged integral scattering cross sections of individual reflectors comprising this group when the distances between the scatterers are much larger than their sizes and wave length, so, there is virtually no interaction between the scatterers.

Laboratory simulations of asteroidal surfaces by polarization measurements and comparison to remote observations

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Keywords: laboratory experiments, linear polarization, regolith, asteroid, meteorite

Sunlight scattered by asteroidal surfaces is partially linearly polarized. The polarization depends on the physical properties of the particles (size, refractive index, structure), and varies with the geometry of observations (phase angle) and wavelength. The polarization phase curves of asteroids with a bell-shaped positive branch and a shallow negative branch are typical of irregular particles. The polarization maxima are observable only for near-Earth objects, while observations of main belt asteroids are limited to relatively small phase angles, mainly in the negative branch. The polarimetric phase curve parameters allow a classification into various types [1], which are similar to the spectral classification. They also provide information on, e.g. the bulk surface albedo by the slope at inversion and a two parameters empirical function [2]. Observations of NEA objects are expected in the near future to better characterize their surface properties [3].

The determination of the parent bodies of most classes of asteroids still remains a puzzling question. It is thus of interest to compare the properties of some meteorites to their potential progenitors. Powdered meteorites in different size distributions deposited on a surface are used as regolith analogues of their parent body. Such work is in progress with the PROGRA^2 experiment (http://www.icare.univ-lille1.fr).

First, we present the instrumental set-up for the laboratory work on surfaces and explain how we use also microgravity measurements on clouds of the particles to infer the size influence on the polarimetric phase curves. Second, we present some results for meteorites and finally we compare the phase curves parameters to the observational results of asteroids to tentatively infer some physical properties of the regoliths [4].

We acknowledge CNES and ESA support for the microgravity flights and experimental work

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Added value of 3MI SWIR observations and overall performance study with the GRASP algorithm

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*Keywords:*3MI, GRASP, inversion, aerosol properties

The Multi-Viewing Multi-Channel Multi-Polarization Imaging mission (3MI) is a high performance new generation radiometer dedicated to aerosol characterization for air quality, climate monitoring, and atmospheric chemistry.

The 3MI will provide multi-spectral (from 388 to 2130 nm), and multi-angular (10 to 14 views) images of the Earth outgoing radiance for aerosol load and aerosol microphysical properties retrieval. The satellite is a direct descendant of POLDER/PARASOL missions(3 instruments since 1996), but in contrast to them provides wider channels range including measurements in shortwave infrared spectrum to ensure more accurate and robust aerosol composition retrieval.

The present study supported by CNES addressed the added value of 3M SWIR observations as well as overall 3MI performance. The GRASP[1] (Generalized Retrieval of Aerosol and Surface Properties) developed during last years at LOA is a statistically optimized algorithm. It performs multi-variable fitting of all available angular observations (sets of 3MI synthetic measurements) and provides a robust retrieval of complete aerosol properties including information about aerosol particle sizes, shape, absorption and composition (complex refractive index). The overall algorithm performance for deriving detailed aerosol properties from 3MI was studied. Additionally, the added value of Short-Wavelength Infrared (SWIR) measurements was tested with GRASP using different combinations of typical aerosols and surfaces. The influence of SWIR channels was presented and discussed.

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The diurnal cycle of cloud top properties and thermodynamic structure from the Atmospheric Infrared Sounder

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Keywords: infrared, hyper-spectral, cloud thermodynamic phase, optical depth, effective diameter, cloud top, diurnal cycle, temperature and water vapor vertical structure

The new cloud products from the upcoming Version 6 release of the NASA-Aqua Atmospheric Infrared Sounder (AIRS) include cloud thermodynamic phase, cirrus cloud optical thickness, and cirrus cloud effective diameter. A complete re-processing of the decade-long AIRS record is in progress and includes the new cloud parameters in addition to existing geophysical products. A significant observing strength of the AIRS instrument is the lack of dependence on solar illumination that enables high latitude and nighttime sampling. In this paper, we will discuss processes that have a strong component of variability across the diurnal cycle, with an emphasis on (but not limited to) tropical convection in the Maritime Continent. Using these unique observations, we will show that the diurnal cycle appears more clearly in the optical thickness and effective diameter parameters compared to the cloud frequency and effective emissivity. The relationship of cloud properties to the diurnal cycle of temperature and water vapor structure will also be described. Significant diurnal signals are also observed in cloud thermodynamic phase over and near continents, including the prominent subtropical stratocumulus regimes and in extra-tropical orographic cirrus. The key role that light scattering research advances have played in enabling the research community to exploit the hyper-spectral radiances of AIRS will also be discussed and highlighted.

Note: the name of the person who will make the actual presentation is underlined.

Database of the Mueller matrices for light scattered by hexagonal ice particles

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Keywords: scattering matrix, ice crystal, cirrus cloud

Cirrus clouds consisting of ice crystals play essential role in the radiation budget of the Earth and, consequently, in climate. Therefore the optical and microphysical properties of cirrus clouds are widely studied both theoretically and experimentally. In particular, the most comprehensive experimental data concerning the optical properties of cirrus clouds are obtained from the space lidar CALIPSO. Theoretical calculations of the optical properties are mainly worked out within the geometric-optics approximation by means of some ray-tracing codes. Though such numerical data for the Mueller matrices of the ice crystals are presented in several databases, they do not include the backward scattering direction that is just detected in lidar measurements.

The main feature of our database is that it presents the Mueller matrices of the hexagonal ice crystals for backscattering. These matrices are calculated within the physical-optics approximation. They are obtained in the case of both randomly and preferably oriented crystals for the input parameters corresponding to the CALIPSO lidar. In particular, we consider two wavelengths: 0.532µm and 1.064 µm and two lidar tilts: 0.3° (initial tilt) and 3° off nadir (present tilt). For the quasi-horizontally oriented hexagonal plates, the plate diameters run from 10 µm to 1000 µm and their maximum tilt is varied between 0° and 15°. Also the database includes the Mueller matrices of quasi-horizontally oriented hexagonal plates and columns obtained within the geometric-optics approximation for arbitrary scattering angles. These data are helpful for taking multiple scattering of light into account.

Proof of scalar and vectorial radiative transfer equations from electromagnetic theory; physical meaning of additional terms.

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Keywords: scalar radiative transfer, vectorial radiative transfer, electromagnetic scattering, distributed particles, optical dispersion.

The Radiative Transfer Equation (RTE) [1-3] is commonly used in different domains of physics (astrophysics, oceanography, biomedical imaging,...) and can model light interactions with particles randomly distributed in a homogeneous medium. Historically, RTE is built from phenomenological arguments based on local energy balance in a referent volume. Recently, a new approach has been developed that establishes the link between Maxwell's equations and the RTE [4]. A new form of the RTE, called Vector Radiative Transfer Equation (VRTE) [4,5], takes into account the states of polarization of the fied by means of Stokes formalism. This latter relies on two new variables: Stokes vector and Muëller-Stokes matrix. However, proof by electromagnetic model is based on hypotheses to obtain formulation of RTE or VRTE. There are the three following important assumptions: the first is to consider the medium as static (time derivative smaller than pulsation), the second is to focus only on propagating waves (far-field optics) and the third is to consider media with a weak extinction parameter (scattering prevails).

In the present study, we present a more general proof of RTE and VRTE that does not need the first and second limiting assumptions. Compared to the previous formulations, our approach introduces extra-terms, the consequences of which are briefly discussed. In particular, in the presence of dispersive medium, they are related to the spatial and time evolutions of wave packet envelop. Critical parameters governing the envelope are the group velocity, the group velocity dispersion (GVD) and Third Order Dispersion (TOD): their impact is analyzed and connection of RTE with SVEA (slowly varying envelop approximation) is discussed.

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Enhancement of atmospheric aerosol characterization by GARRLiC algorithm: accounting for polarimetric observations

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Keywords: aerosol, remote sensing, photometer, lidar, polarization

Currently, most of experiments pursuing comprehensive characterization of atmosphere include coordinated observations by both lidar and radiometers in order to obtain important complimentary information about aerosol properties. The passive observations by radiometers from ground are mostly sensitive to the properties of aerosol in total atmospheric column and have very limited sensitivity to vertical structure of the atmosphere. Such observations are commonly used for measuring aerosol optical thickness and deriving the information about aerosol microphysics including aerosol particles shape, size distribution, and complex refractive index. In a contrast, lidar observations of atmospheric responses from different altitudes to laser pulses emitted from ground are designed to provide accurate profiling of the atmospheric properties. The interpretation of the lidar observation generally relies on some assumptions about aerosol type and loading. Here we present GARRLiC algorithm (Generalized Aerosol Retrieval from Radiometer and Lidar Combined data) that simultaneously inverts co-incident lidar and radiometer observations and derives a united set of aerosol parameters. Such synergetic retrieval is expected to result in additional enhancements in derived aerosol properties because the back-scattering observations by lidar add some sensitivity to the columnar properties of aerosol, while radiometric observations provide sufficient constraints on aerosol type and loading that generally are missing in lidar signals.

GARRLiC is based on AERONET algorithm adapted for the inverting combined observations by radiometer and multi-wavelength elastic lidar observations with possibility to account for polarimetric observations made by photometer. It is expected that spectral changes of back-scattering signal obtained by multi-wavelength lidar at different altitudes provide some sensitivity to the vertical variability of aerosol particle sizes. In order to benefit from this sensitivity, the algorithm is set to derive not only the vertical profile of total aerosol concentration but it also differentiates between the contributions of fine and coarse modes of aerosol. The detailed microphysical properties are assumed height independent and different for each mode and expected to be derived as a part of the retrieval. Thus, GARRLiC retrieves vertical distributions of fine and coarse aerosol concentrations as well as the size distribution, complex refractive index and single scattering albedo for each mode. It is expected that additional information from polarization measurements will increase the accuracy of the retrievals, compared to intensity-only inversions, affecting fine mode refractive index and coarse mode shape estimations.

The potential and limitations of the method are demonstrated by the series of the sensitivity tests. Possibility of applying the method to lidar polarization observations is discussed.

Contribution to the characterization of optical properties of atmospheric sand and soot with the instruments PROGRA2

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Key words: polarization, brightness, soot, sand, atmosphere

Polarization and brightness curves as function of scattering angle produced by soot and sand samples were studied at λ = 632.8 nm and 543.5 nm using PROGRA2 instruments (Propriétés Optiques des Grains Astronomiques et Atmosphériques). Soot and sand samples were studied while levitating in a cloud and also when deposited on a surface. The soot samples are generated under different combustion conditions, thus affecting their optical properties.

No significant effect of the wavelength used during the experiment was detected with soot samples. At the opposite a wavelength effect was noticed with sand samples. An obvious difference is noticed between results obtained with deposited particles and levitating particles for all the studied samples.

The amplitudes of polarization produced by soot differ significantly depending on the primary particle diameter and on size distribution. In fact the amplitude of polarization decreases when the primary particle diameter increases. While the amplitude of polarization increases when the particle diameter increases. On the other hand the curves of brightness produced by soot samples show a similar behaviour between each other that differ from those produced by the sand samples.

The application of these results will be discussed, in particular for remote sensing measurements of planetary atmosphere and surface.

The data base obtained with PROGRA2-VIS and –SURF is available at http://www.icare.univ-lille1.fr/progra2/indexeng.html

Radiative-transfer coherent-backscattering computations for close-packed spherical volumes of scatterers

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Keywords: electromagnetic scattering, particulate media, coherent backscattering, radiative transfer

We extend the radiative-transfer coherent-backscattering computations (RT-CB) for plane-parallel and spherical media of scatterers (Muinonen, Waves Random Media, 14, 365, 2004; Muinonen & Videen, JQSRT 113, 2385, 2012) to close-packed spherical volumes of scatterers. We start by generating geometrical aggregates of spherical volumes with the help of a ballistic particle-cluster aggregation algorithm. Within the spherical volumes, we place single scatterers with pre-defined single-scattering albedos, Mueller scattering matrices, Jones scattering amplitude matrices, and pre-defined volume density, constituting a diffusely scattering medium with known extinction mean-free-path length. For such aggregates of spherical volumes, we run RT-CB computations and obtain Mueller scattering matrices that, in addition to coherent backscattering, account for the shadowing effects among the spherical volumes. In the limit of large numbers of spherical volumes, the present approach provides a realistic multiple-scattering model for a planetary regolith. We describe the first results from these computations (e.g., sharpening of the opposition effects and negative polarization surges near backscattering) and offer tentative comparisons to the astronomical observations of atmosphereless Solar System objects.

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Characterization of Deep Impact ejecta dust particles

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Keywords: comet dust, Deep Impact, computer modeling

In July 2005, Deep Impact space mission reached comet Tempel 1 and the spacecraft released an impactor that collided with the comet nucleus. The collision produced a large ejecta cloud with material excavated from the comet nucleus. The surprisingly thick cloud completely obscured the impact crater and cast a shadow on the surface of the comet nucleus. Analysis of the images taken by the Deep Impact Medium Resolution Instrument showed that the shadow had a complex structure, thus revealing variations in optical thickness within the cloud. Over a few seconds of image data, the brightness distribution within the shadow changed with time, reflecting density and/or compositional variations of the dust in the ejecta cloud.

We model the scattering of sun light by the ejecta cloud to reproduce the shadow structure and its change with time. The modeling is based on the 3D radiative transfer code HYPERION[1]. Following [2], the ejecta cloud is presented as an oblique, hollow cone. The cone is populated with dust particles whose properties, primarily line-of-sight column and single scattering albedo, we adjust to get the best fit to the characteristics of the shadow. The variations in the properties of the dust that we study most likely reflect variations of the structure and composition of the nucleus of Comet Tempel 1, thus providing us an insight into the comet interior.

The work is supported by a grant from the NASA Planetary Mission Data Analysis Program.

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Observation of ice clouds from ground-based lidar over Lille: methodology and first results

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Keywords: cirrus clouds, contrails,lidar.

Cirrus clouds play an important role in regulating the earth's energy budget through their interactions with solar and terrestrial radiation. Their structures are complex because they are composed of ice particles in myriad shapes and sizes. For the study of cirrus clouds, many lidar systems are adapted for monitoring, especially thin cirrus due to their ability to profile the vertical structure of clouds.

The LOA(Laboratoire d'Optique Atmospérique) has a ground-based station for atmospheric observation. A platform located on the roof of the laboratory is equipped with a 532 nm lidar and passive remote sensing instruments. Since 2007, the LOA has developed an automated processing system and a database for the study of aerosols. The next goal is to use these database for developping a climatology of cirrus and contrails.

First results are presented and discussed on cirrus clouds detected over Lille. We describe the methodology that will be applied to detect ice clouds (cirrus, contrails), and to determine their physical properties using the instruments that are in the plateform of LOA(lidar, infrared radiometer, sky_imager).

Spectroscopic measurements of meteorite samples at visible to near-infrared wavelengths

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Keywords: reflectance spectroscopy, meteorites, asteroids, principal component analysis, radiative-transfer

The composition of asteroids sets significant constraints on Solar System evolution. With the exception of a few flyby and sample-return missions to asteroids, ground-based low-resolution spectroscopy of asteroids at the visible and near-infrared wavelengths is the main source of information on asteroid compositions. The interpretation of asteroid spectra is closely tied with surface structure. Asteroid surfaces are usually covered with regolith, which is a mixture of mineral grains ranging from micrometers to centimeters in size. The inverse problem of deducing the characteristics of the grains from the scattering of light (e.g., using photometric and polarimetric observations) is extremely difficult. Spectroscopy of meteorites can be a complementary source of information considering that unweathered meteoritic “falls” are almost pristine samples of their parent bodies.

We have measured reflectance spectra (350-2500 nm with a zenith angle of reflection range of ±60 degrees) of centimeter-size pieces of 18 different meteorites (an example of the meteorite spectra is presented in Fig. 1). The measurements were carried out with the Finnish Geodetic Institute Field Goniospectrometer (FIGIFIGO) (Suomalainen et al., Sensors 9, 2009). Principal Component Analysis (PCA) was performed on the spectra. The analysis results in distinct groups of undifferentiated ordinary chondrites and differentiated achondrites. Our measurements expand the database of reflectance spectra of 26 meteorites obtained by Paton et al. (JQSRT 112, 2011). The spectra of meteorites found in both data sets are consistent. Furthermore we offer a phenomenological radiative-transfer model for the measurements. Our intent is to further expand the database of meteorite spectra in the future.

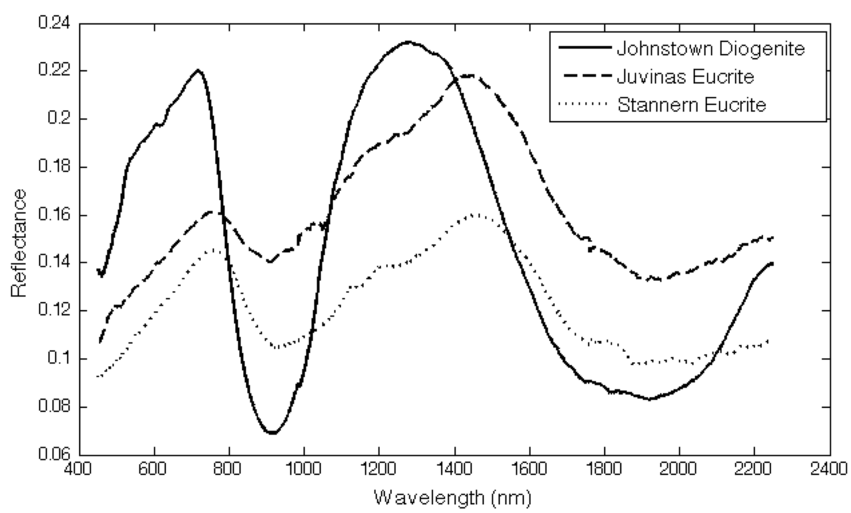

Figure 1. Measured spectra of three HED-meteorite samples

An exact formula for Fraunhofer diffraction by randomly oriented ice crystals in cirrus cloud

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Keywords: Fraunhofer diffraction, Ice crystals, Cirrus

This communication deals with Fraunhofer diffraction by an ensemble of independent ice crystals which are randomly oriented. These crystals are of assorted shapes. There is no restriction on the shape of each crystal. That concerns in particular cirrus clouds.

It is shown that light flux density in the Fourier plane is azimuth-invariant and varies as $1/\sin^4 \theta$, where θ is the angle of diffraction.

The analytical formula proposed is exact. The key point of this study is conservation of electromagnetic energy.

Comparison of discrete exterior calculus and discrete dipole approximation for electromagnetic scattering

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Keywords: electromagnetic scattering, discrete exterior calculus, discrete dipole approximation

We compare two methods for solving the scattering problems numerically. The first method is the discrete dipole approximation (DDA), which is a well-known technique in the context of light scattering, see, e.g., [1]. The other approach is based on the discrete exterior calculus (DEC), which provides the properties and calculus of differential forms in a natural way at the discretization stage [2]. By using this technique, we discretize both the electric and magnetic fields, i.e., the whole Maxwell's system. The focus of this research is comparing the DEC with the DDA to validate the method and to assess the properties in practice.

Our DEC-based method is developed for solving three-dimensional time-harmonic problems in domains of size 10–100 wavelengths. We overcome the challenges of solving large-scale indefinite systems, arising from the time-harmonic problems, by returning to the time-dependent equations. Essentially the time-harmonic solution can be reached by simple time integration. Nevertheless, such an asymptotic approach suffers from poor convergence in particular for large wave numbers and complicated domains. Thus, we accelerate the convergence rate by using the exact controllability technique. A natural quadratic error functional is the squared energy norm of the system, allowing to minimize the cost by the conjugate gradient method operating in Hilbert spaces. The approach has a reasonable asymptotic computational cost.

Combining the exact controllability method with the DEC provides a promising alternative for solving the general Maxwell equations. One of the advances of such an approach is that the energy norm is a weighted L^2-norm, implying that the discrete quadratic functional we minimize is spanned by a diagonal mass matrix. Thus, the proposed conjugate gradient algorithm operating in a purely L^2-type Hilbert space does not need any preconditioning which is verified by numerical results.

There are certain advantages of utilizing the DEC. Firstly, the DEC is an exact method, but still very flexible. For instance, curved shapes such as spheres can be applied in sufficiently high accuracy within the DEC framework. The DEC-based discretization of the simulation domain is relatively flexible, because efficient cubical elements can be combined with arbitrary-shaped well-centered elements. Secondly, the implemented asynchronous time-stepping makes the simulation efficient at every point of the geometry. Benefits of the DEC-based approach include also implementability for parallel computers and multicore processors.

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Characterizing the Mid-Infrared Spectral Effects of Dust Coated Surfaces: *Implications for In Situ and Remote Sensing Observations of Mars*

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Keywords: remote sensing, particulate media, radiative transfer, single and multiple scattering

On the Martian surface, one of the most common complicating factors in the acquisition and interpretation of thermal infrared spectroscopic measurements (TIR; ~200 to 2000 cm^{-1}) is that caused by dust. Dust is ubiquitous on the Martian surface. Identifying and characterizing the effects caused by dust is imperative to properly correct TIR datasets not only of Mars but also of other planetary bodies. The effects attributable to dust in TIR datasets are different depending on where the dust is located (e.g. whether on instrument mirror surfaces, rocks and soils, or suspended in the atmosphere), on the amount of dust present, as well on how close the dust particles are to each other. Fully accounting for the effects of dust is crucial for the interpretation of surface mineralogy, which is necessary to determine current and past processes on planetary surfaces.

The effects attributed to atmospheric dust and of thick mantles of dust on rock and soil surfaces have been extensively studied [*e.g.* 1-3]. Although their effects can make remote compositional characterization more difficult, they are relatively well understood and simple to identify in TIR datasets. These investigations did not investigate thin dust coatings (< ~5 μm) and considered them to be negligible.

Recently however, thin mantles of dust (< ~5 μm) have been recognized as the cause of an unexpected spectral contribution that dominates many of the *in-situ* measurements of rocks and soils taken by the Miniature Thermal Emission Spectrometer (Mini-TES) instruments on the Mars Exploration Rovers (MER) [3-5]. The magnitude and extent of the effects caused by thin mantles of dust have not been studied in detail and little is understood of the radiative and thermophysical properties that govern their behavior. If not corrected, the additional contribution to the spectra caused by thin mantles of dust greatly hinders mineralogical interpretation of rock surfaces [3]. These effects have only been identified in Mini-TES data, but they are likely to be present in TIR spectroscopic measurements of other Solar System bodies.

Our goal is to combine laboratory measurements and modeling to characterize the spectral effects of dust coatings in thermal infrared (TIR) measurements of planetary surfaces and their implications for the interpretation of remote sensing and in situ measurements of Mars. Particular focus is given to the effects caused by thin mantles of dust. Laboratory measurements are used to reproduce and quantify these effects, whereas radiative transfer modeling (two/four stream) is used to better understand the underlying physics responsible for the spectral effects observed in spacecraft and laboratory measurements. Preliminary modeling efforts and laboratory measurements show spectral behavior similar to that seen in Mini-TES data. By characterizing the spectral behavior of dust coatings including the potential for thermal contrast between the dust and the substrate, it will be possible to more clearly interpret TIR spectra of rocky surfaces.

A summary of the recognized dust coating effects observed in TIR spectral measurements with preliminary data from our modeling and laboratory efforts will be presented.

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A 3D polarized Monte Carlo spaceborne LIDAR system simulator for investigating cirrus inhomogeneities effects on their retrieved optical properties

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Keywords: LIDAR system, tridimensional radiative transfer, polarization, Monte Carlo, cirrus, simulation

LIDAR is a powerful tool for deriving the cirrus properties. The main difficulty to overcome is the significant extinction of the LIDAR beam in its path through the cloud as one must take into account multiple scattering. Actually, the "apparent" backscatter estimated by the LIDAR system from the "basic LIDAR equation" is not equal to the "true" backscatter of the cirrus when multiple scattering is omitted. The cirrus properties are also assumed to be horizontally homogeneous at each level into and around the LIDAR system footprint. Our objective is to quantify the effects of cirrus inhomogeneities represented by 3D spatial fluctuations of extinction on the apparent backscatter and on the apparent depolarization ratio measured by CALIOP/CALIPSO.

We are developing a 3D polarized LIDAR system simulator. Early results show that effects of horizontally random spatial fluctuations of cloud extinction on the apparent backscatter seem to be negligible but not on the apparent depolarization ratio. In order to generalize these early results, our LIDAR simulator must be improved and compared with other LIDAR simulators. Sensitivity tests will be carried out not only with academic cloud models, but also with realistic fluctuations of cirrus extinction provided by the synthetic cloud generator (3DCLOUD) developed at the Laboratoire de Météorologie Physique, and with different ice crystals shapes.

Poster

The scattering properties of spherical particles coated with epsilon near zero (ENZ) materials

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Keywords: Mie scattering, epsilon near zero (ENZ) materials

The materials with epsilon near zero (ENZ) like low loss noble metals Ag and Au at infrared and optical frequencies or some semiconductors near their plasma frequencies are under significant attention of researchers [1]. As shown in the article [2] the peculiarities of epsilon near zero materials revealed new features and the singularity in Mie scattering theory, where the dielectric properties of the scattering uniform spherical particles and surrounding medium are considered in the epsilon near zero limits. The scattering theory for coated spheres is generalized when particles shell, cores and surrounded medium are considered in the epsilon near zero limits. The simultaneous zeros of dipole electric and dipole magnetic polarization coefficients and consequently the condition of near invisibility for coated particles are investigated. The possibility to achieving the magnetic dipole resonances and significant effective permeability for aggregate of particles coated with ENZ materials is demonstrated.

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SENSITIVITY OF INVERSION-DERIVED AEROSOL PROPERTIES TO THE OBSERVATION GEOMETRY OF GROUND-BASED SUN/SKY-RADIOMETERS

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We have carried out a sensitivity study of the inversion-derived aerosol optical properties to the geometrical configuration of the ground-based sky radiometer observations, in particular principal plane and almucantar observation, since these are the geometries used in the AErosol RObotic NETwork (AERONET). First, several parameters have been analyzed for both geometries by means of simulations: scattering angle range, aerosol vertical distribution, surface reflectance, instrument pointing errors and finite field of view. Synthetic spectral radiance observations were calculated using the Dubovik et al. (2000) forward model and aerosol climatology values from three AERONET sites: Mongu (Zambia) for biomass burning aerosol, Goddard Space Flight Center (Maryland-USA) for urban aerosol and Solar Village (Saudi Arabia) for desert dust aerosol. The test results show that almucantar retrievals are in general more reliable than principal plane retrievals, with respect to the investigated error sources. Two advantages of almucantar geometry may be responsible for this: the symmetry between its left and right branches and the constant optical air mass in the measurements. The first one allows minimizing the effects of sky inhomogeneities (mainly clouds) and pointing errors; the second one makes almucantar observations nearly independent of the aerosol vertical distribution. However almucantar retrievals present instabilities at short solar zenith angles, due to the reduction of the scattering angle range that results in reduction of information content. Second, the study was completed with the investigation of differences in almucanatar and principal plane retrievals in real data from three key AERONET sites: Mongu (biomass burning), Beijing (urban) and Solar Village (desert dust). This analysis shows overall consistency between near-simultaneous principle plane and almucantar retrievals, being all identified differences within AERONET estimated uncertainties. Desert dust is the aerosol type in which larger discrepancies were found. The size distribution differences are generally under 10% (0.1μm<r<5μm) but outside this size range they can be as large as 50%. For the single scattering albedo and the imaginary part of refractive index, the differences are typically under 0.01 and 0.002 respectively. The real part of the refractive index showed differences about 0.01 for biomass burning and urban aerosol and 0.03 for desert dust.

An accurate and flexible parameterization for shortwave optical properties of ice crystals

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Keywords: ice crystals, parameterization, single scattering albedo, asymmetry parameter

We present a simple, yet accurate parameterization that provides the single-scattering albedo (ω) and asymmetry parameter (*g*) of ice crystals for any combination of volume, projected area, aspect ratio and microscale roughness at any wavelength in the shortwave. Unlike existing parameterizations, this scheme is flexible enough to obtain ice crystal optical properties that are consistent with any assumptions about ice crystal mass (equivalent to bulk volume), projected area and aspect ratio used in modern cloud and climate model ice microphysics schemes to parameterize the fall-speed and capacitance of particles. Similar to previous parameterizations, our scheme makes use of geometric optics approximations and the observation that optical properties of complex, aggregated ice crystals can be well approximated by those of single hexagonal crystals with varying size, aspect ratio and microscale roughness. We show that ω is largely determined by the particle aspect ratio and the newly defined absorption size parameter, which is proportional to the ratio of imaginary part of refractive index to the wavelength and the ratio of particle volume to projected area. The dependence of ω on absorption size parameter and aspect ratio is parameterized using a combination of exponential, log-normal and polynomial functions. The variation of *g* with aspect ratio and microscale roughness is parameterized for one reference wavelength using a combination of several polynomials. Subsequently, a newly determined semi-empirical relation is used to scale the parameterized *g* to provide values appropriate for other wavelengths. Also, a correction for the dependence of the ray-tracing asymmetry parameter on single-scattering albedo is proposed. In total, the parameterization scheme consists of only 88 coefficients. The scheme is tested for a large variety of hexagonal crystals in several wavelength bands from 0.2 to 4 micron, revealing absolute errors in both ω and *g* generally below 0.015. We will show that, in general, the resulting errors in cloud reflectance and transmittance are below 1%. Finally, some practical applications of the parameterization scheme are highlighted.

Preferred presentation mode: Oral

Light scattering by innermost coma in Comet 81P/Wild 2: Implication to the *Stardust* findings

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Keywords: electromagnetic scattering, cometary dust, discrete dipole approximation, particulate media

The low abundance of refractory carbonaceous material in samples collected by *Stardust* at its closest approach to the comet 81P/Wild 2 nucleus (about 240 km) was completely unexpected [1]. Carbon is an essential component of organic material, which is thought to be formed in the interstellar medium. Comets presently observed in the solar system are believed to be remnants of planetesimals that contained organic materials and/or amorphous carbon and are expected to preserve pristine material of the interstellar medium.

Polarimetric imaging of comets provides evidence that different types of dust are present in different regions within the cometary coma. For instance, the innermost coma produces a strong negative polarization of up to −6%, which is called the *circumnucleus polarimetric halo* [2]. The halo is typically a few thousand kilometers across that is much smaller than the size of the whole coma. Such a circumnucleus polarimetric halo also was found in comet 81P/Wild 2.

We investigate the mechanism governing the phenomenon of the strong negative polarization with the discrete dipole approximation (DDA) and the model of irregularly shaped agglomerated debris particles. In our modeling we take into account the size polydispersity of agglomerated debris particles so it is similar to what was measured *in situ* in comets. We compute light scattering by agglomerated debris particles at various degrees of material absorption and found that the strong negative polarization in the innermost coma ultimately suggests the lack of highly absorbing materials. However, most carbonaceous materials are highly absorbing; therefore, our finding implies the depletion in the innermost coma of such materials. We draw attention that this finding is consistent with the *Stardust* findings.

We emphasize that the circumnucleus polarimetric halo that produces a strong negative polarization is only a small part of the whole coma. The degree of linear polarization in other parts of the coma is much less negative. Moreover, some features, such as cometary jets, do not reveal any negative polarization at all [2]. This feature can be interpreted in terms of high abundance in carbonaceous materials. Note, more detailed report of the present research can be found in [3].

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