Polarized Optical Properties of Dust Aerosols: Lessons learned from modeling simulations and the Amsterdam-Granada Laboratory Measurements

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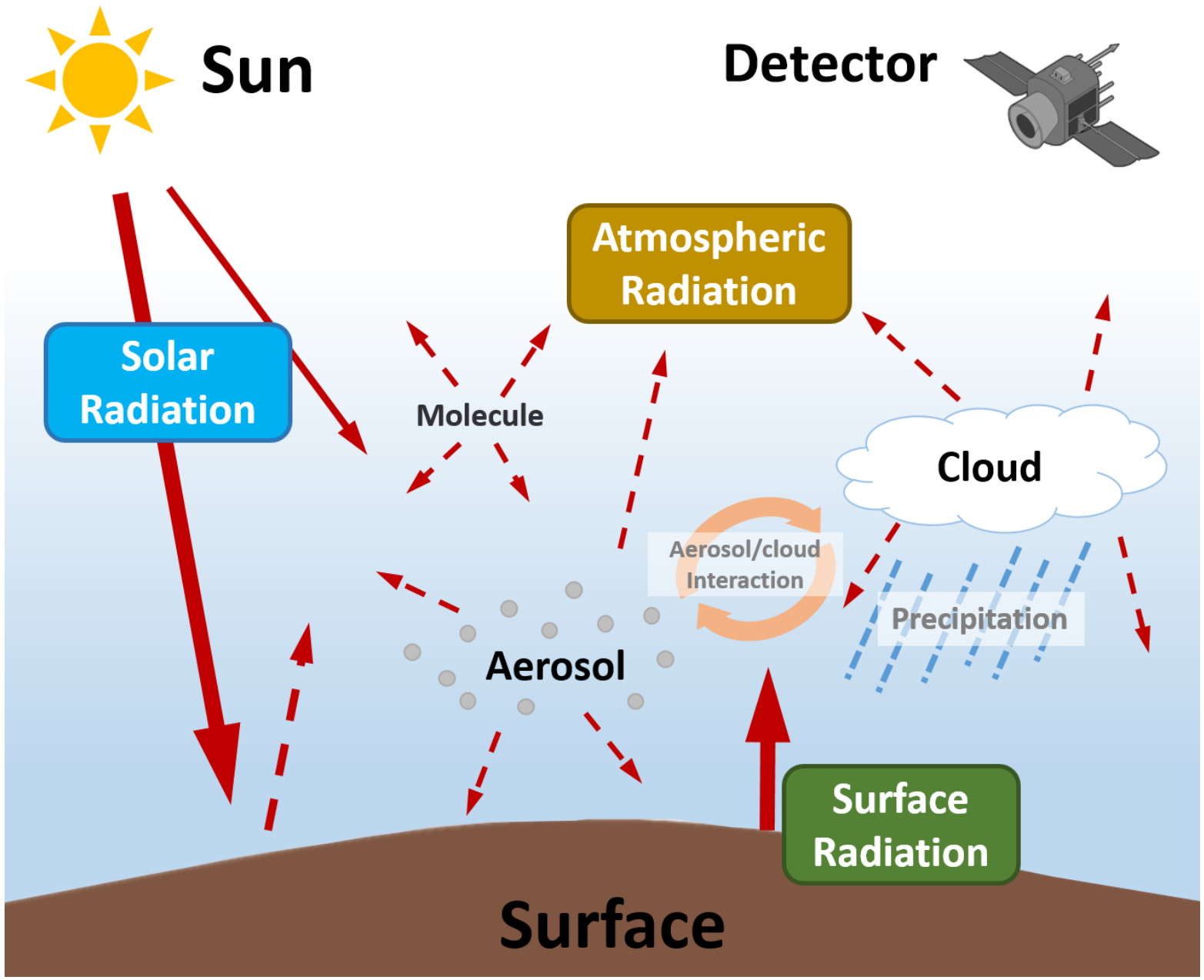
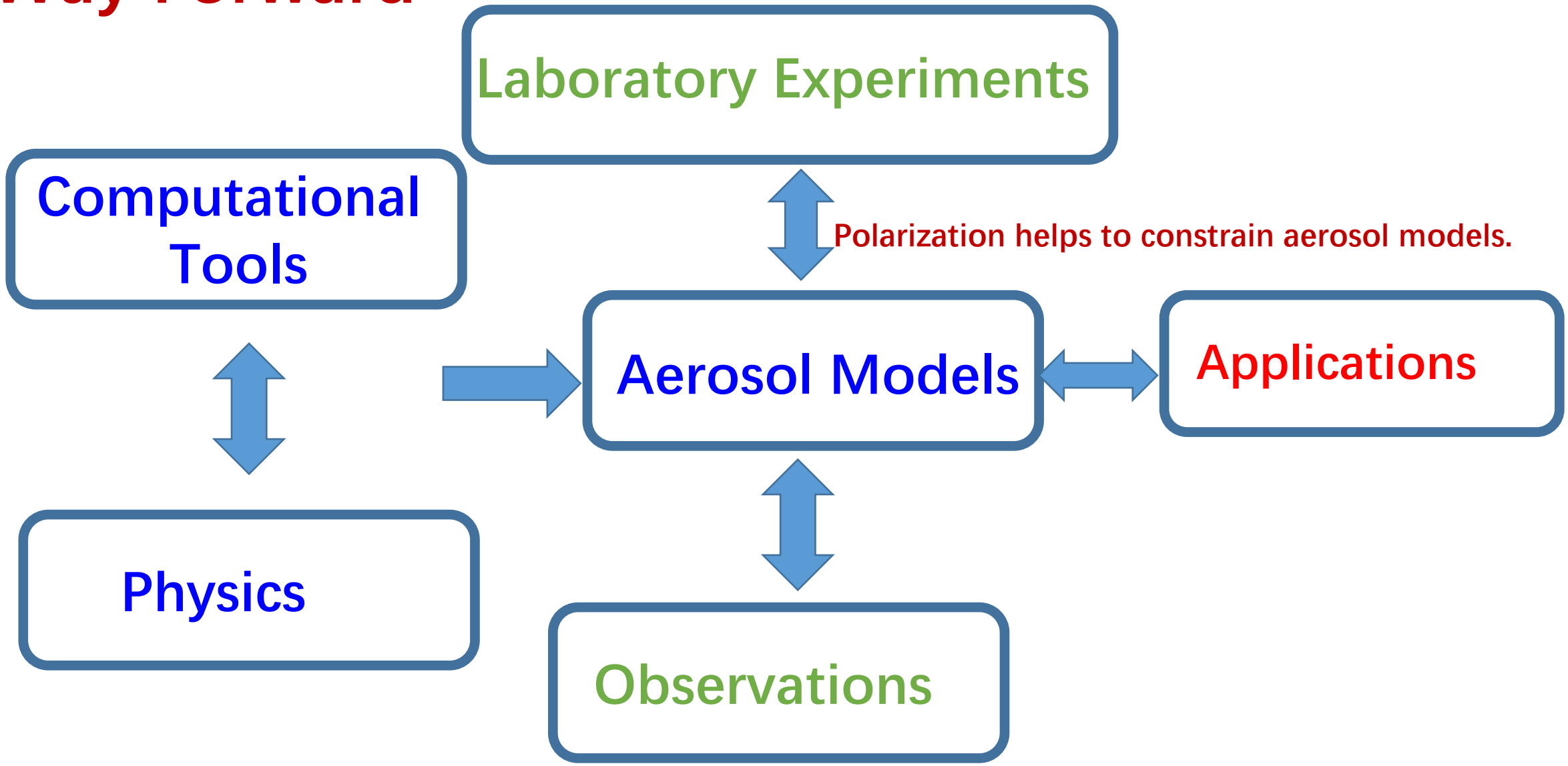
APOLO Workshop, Lille, France
November 5, 2019


Sun
Detector
Atmospheric Radiation
Solar Radiation
Molecule
Cloud
Aerosol/cloud Interaction
Precipitation
Aerosol
Surface Radiation
Surface

Critical Issues in Developing Aerosol Models

- **Tools**: **Accurate and efficient** computational methods to compute the optical properties of non-spherical aerosol particles.
- **Physics**: **Physical mechanism/interpretation** on how particle microphysics affects electromagnetic wave scattering.
- **Constraints**: constrain **"suitable"** models for atmospheric radiative transfer simulations/applications

Way Forward

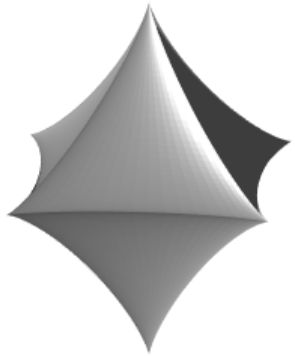

Laboratory Experiments
Computational Tools
Polarization helps to constrain aerosol models.
Aerosol Models
Applications
Physics
Observations

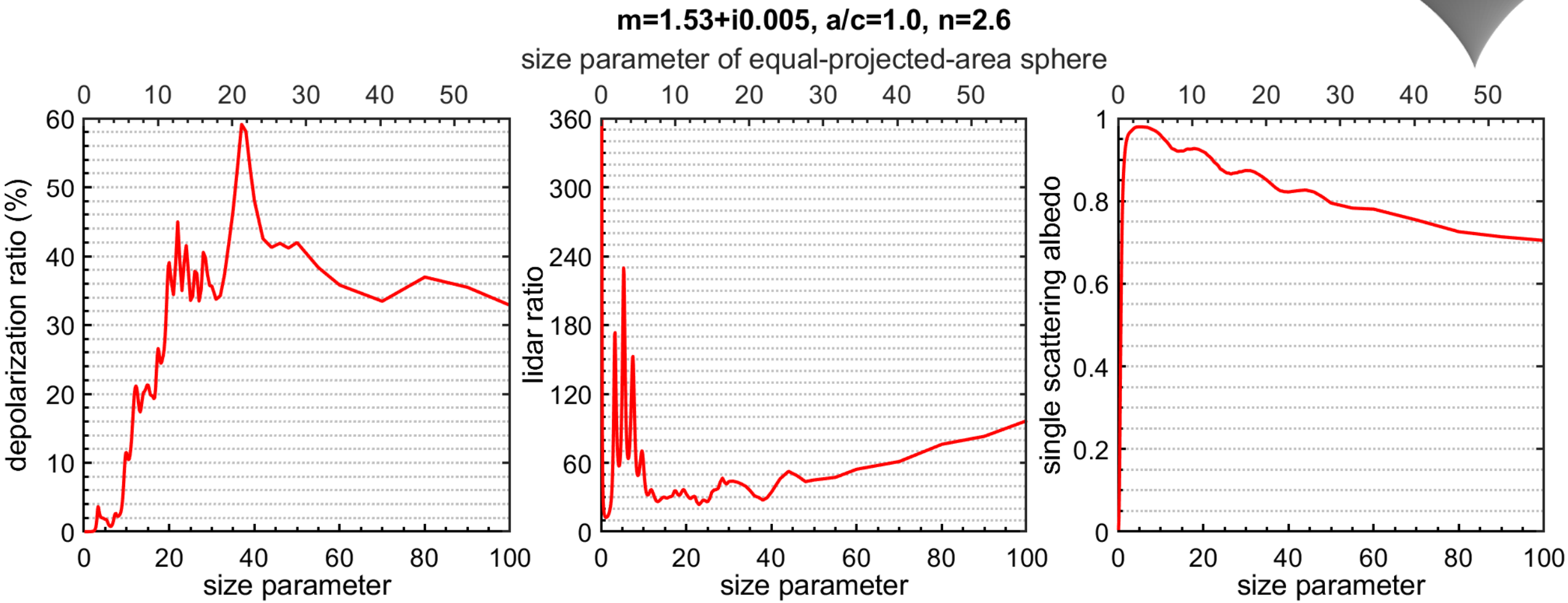
Invariant imbedding T-matrix

- Arbitrary shaped and inhomogeneous particles (flexibility)
- Analytical random orientation average (accuracy and efficiency)
- Particle size parameter up to geometric-optics domains (applicability)

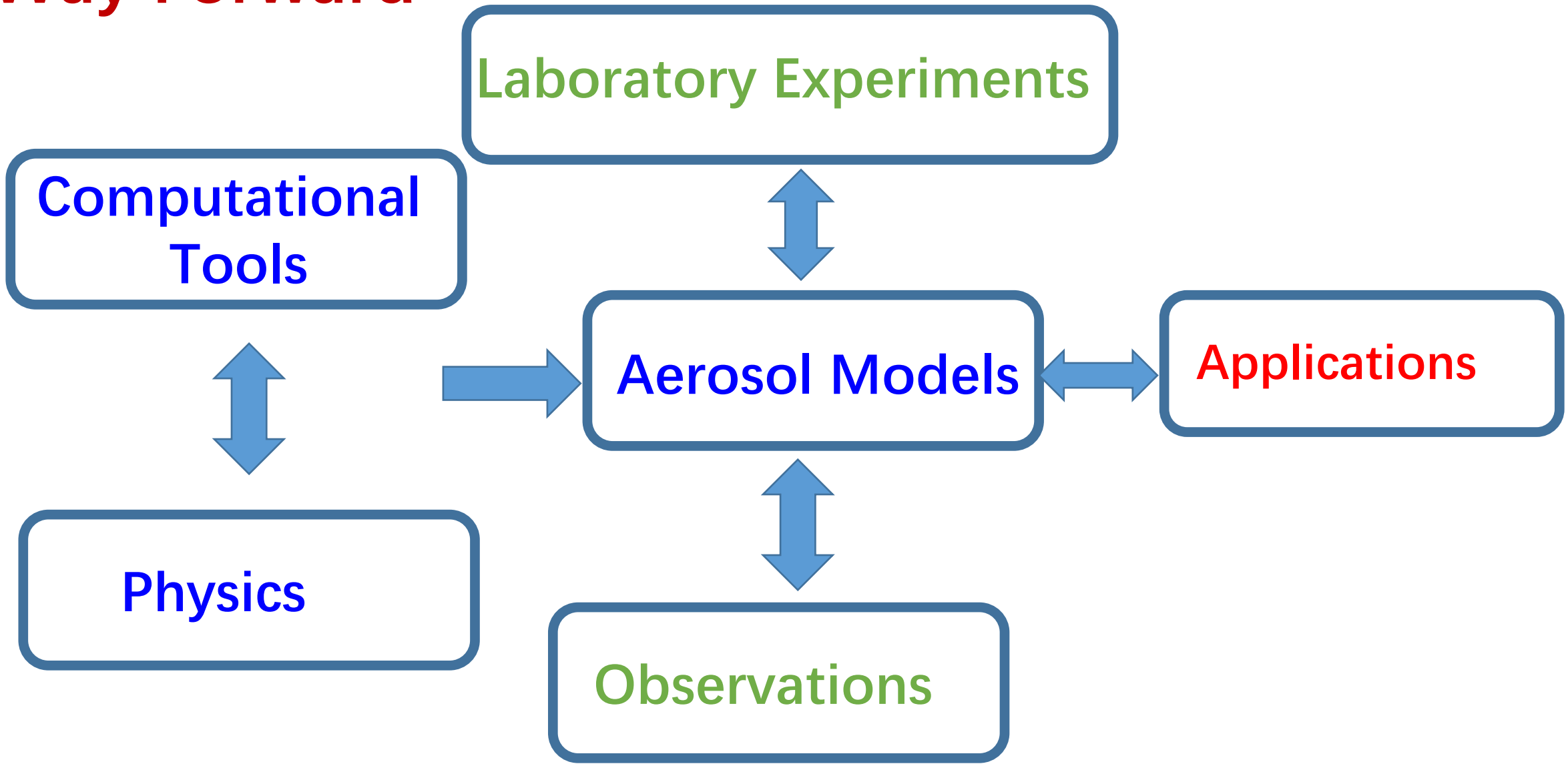
Extensive simulations with size parameter upto 100

Superspheroid





Way Forward


Laboratory Experiments
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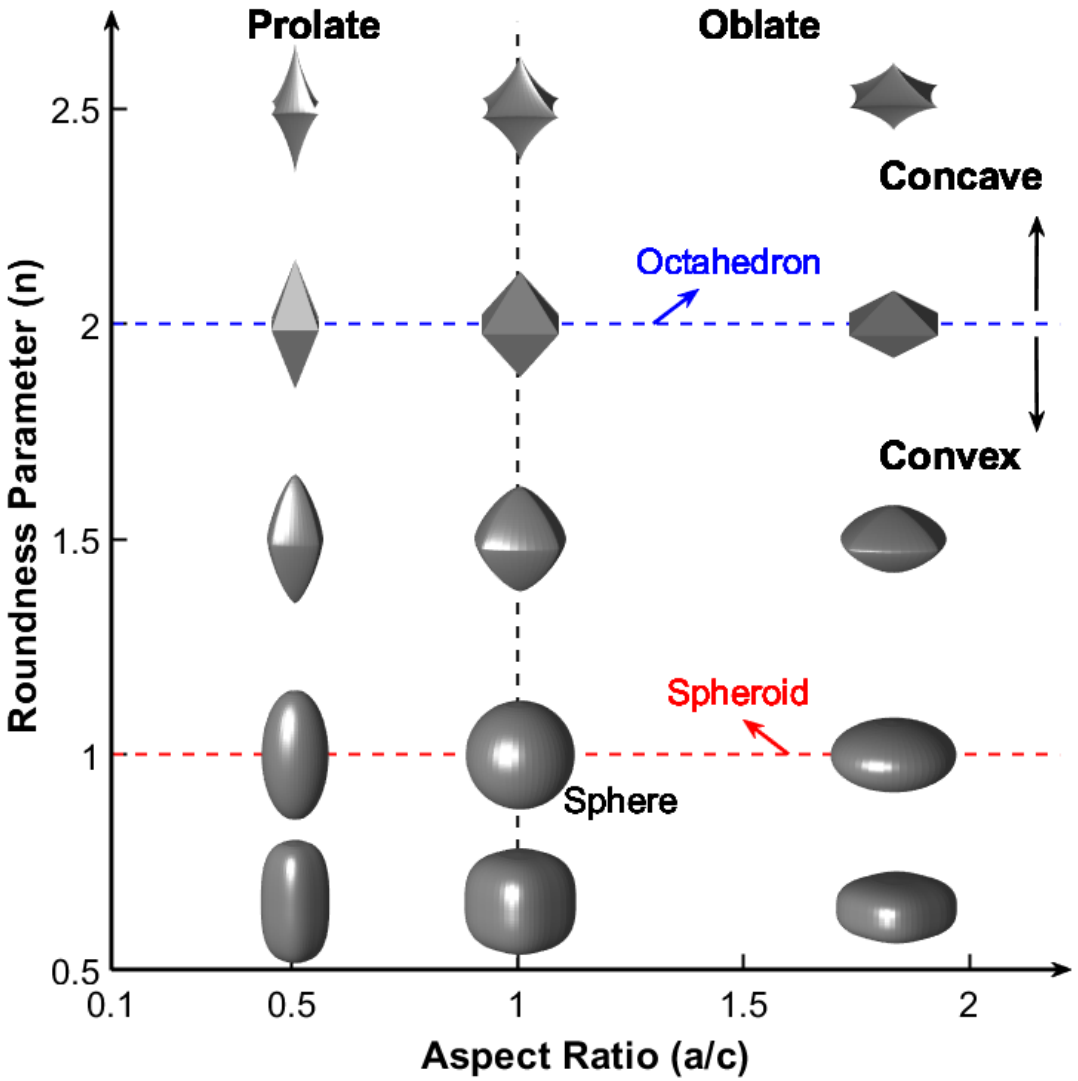
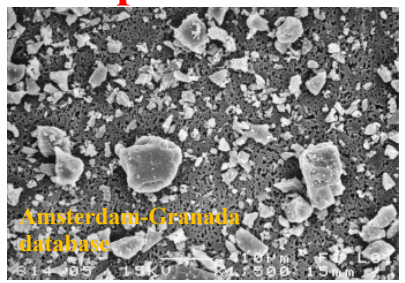
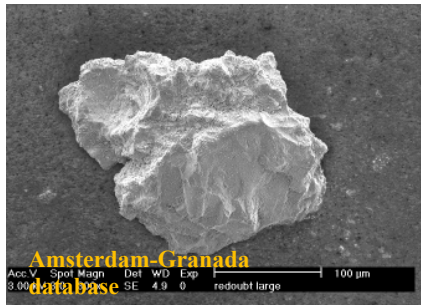
Super-spheroidal Space

$$\left(\frac{x}{a}\right)^{2/n} + \left(\frac{y}{a}\right)^{2/n} + \left(\frac{z}{c}\right)^{2/n} = 1$$



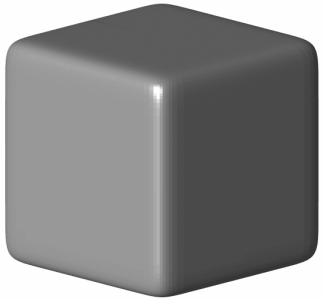
Feldspar

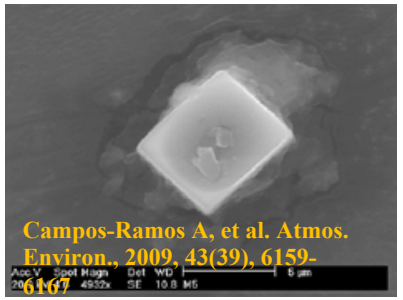




Volcanic ash

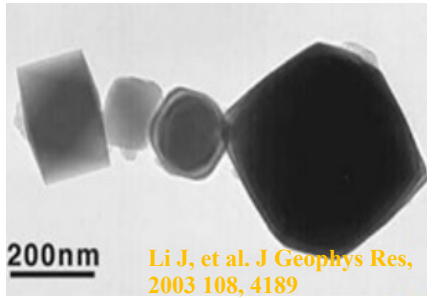
n=0.15





Sodium chloride

Sea salt



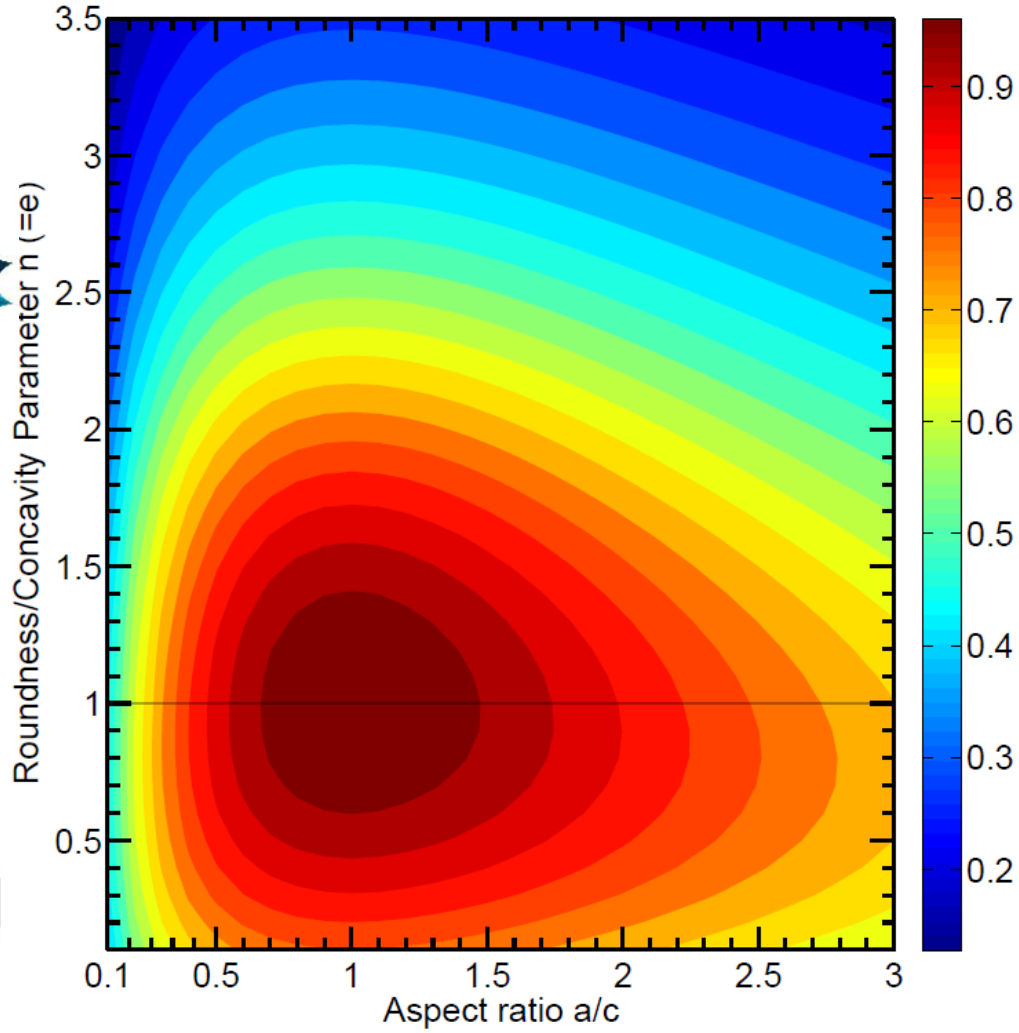
Why more freedom is useful?

S=average projected ar

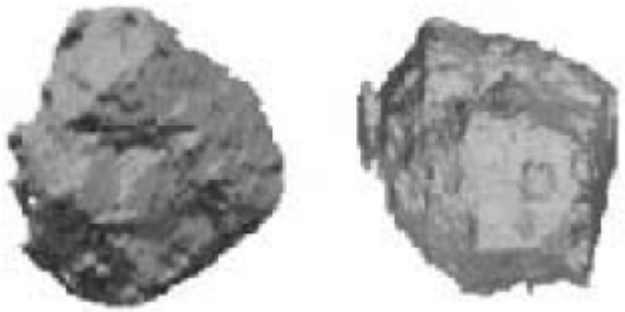
V=volume of a particle

$$\mathrm{SI} = \frac{3V}{4\pi(S/\pi)^{3/2}}$$

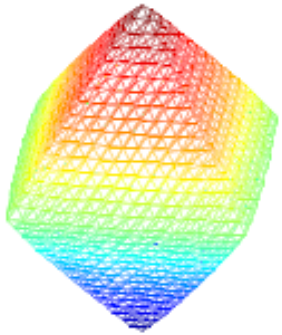
SI=1 for a sphere



Stereogrammetry

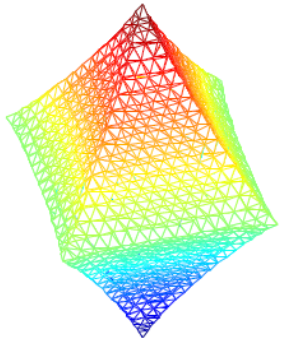


SI=0.67

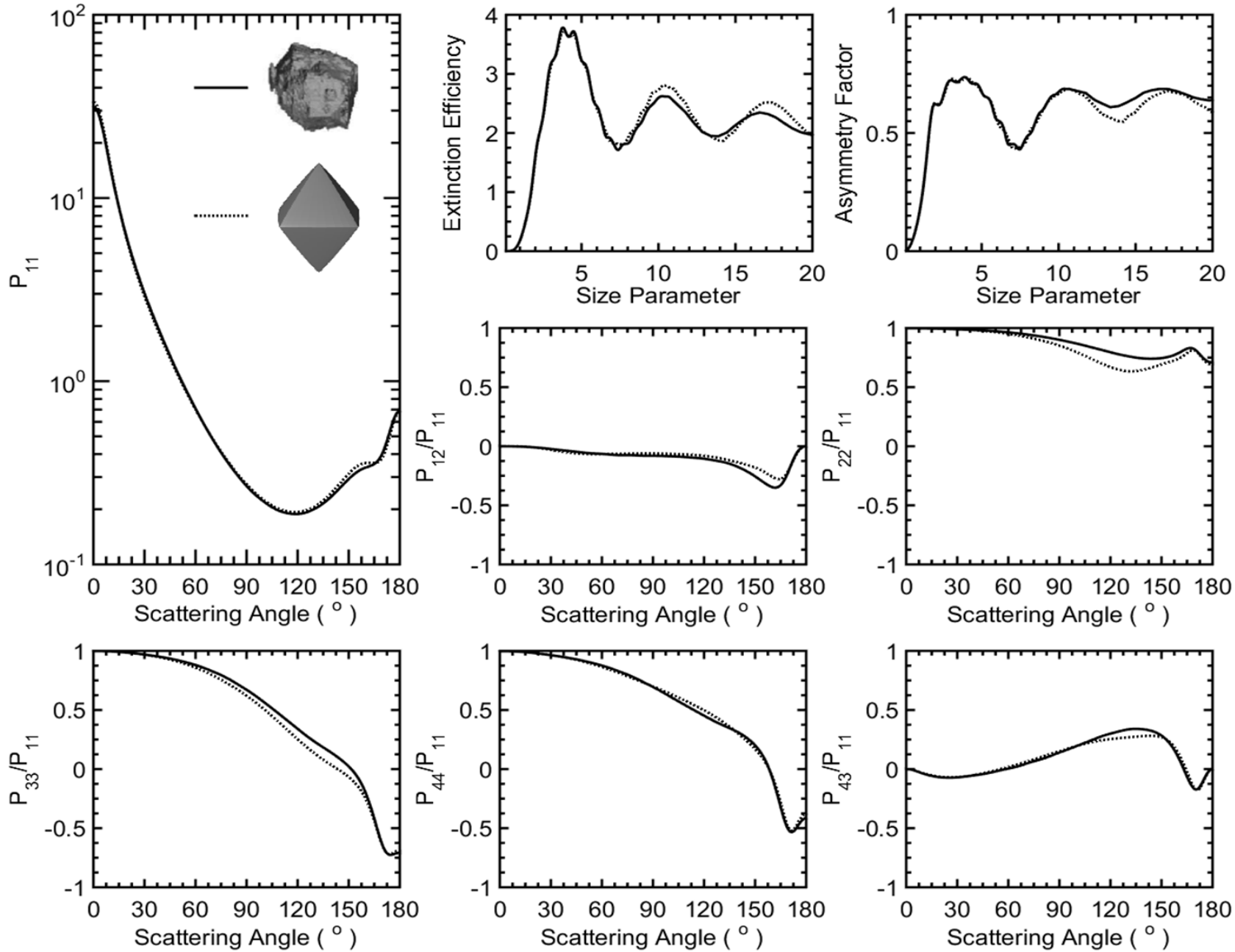


volume, projected area, aspect ratio

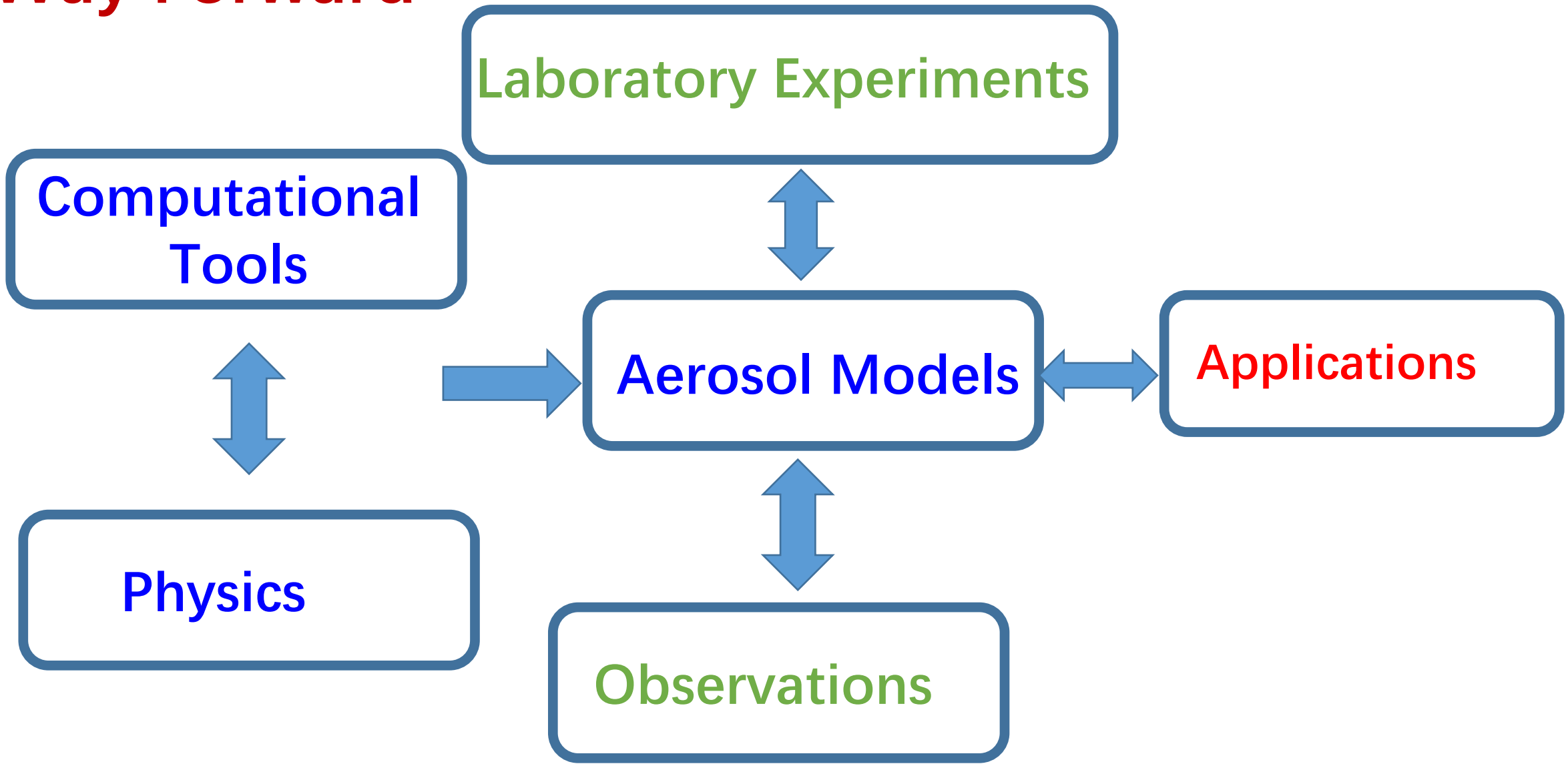
SI=0.82



(Image from Lindqvist, et al., 2014)


P11
Scattering Angle (o)
Extinction Efficiency
Size Parameter
Asymmetry Factor
Size Parameter
P12/P11
P22/P11
P33/P11
P44/P11
P43/P11

Way Forward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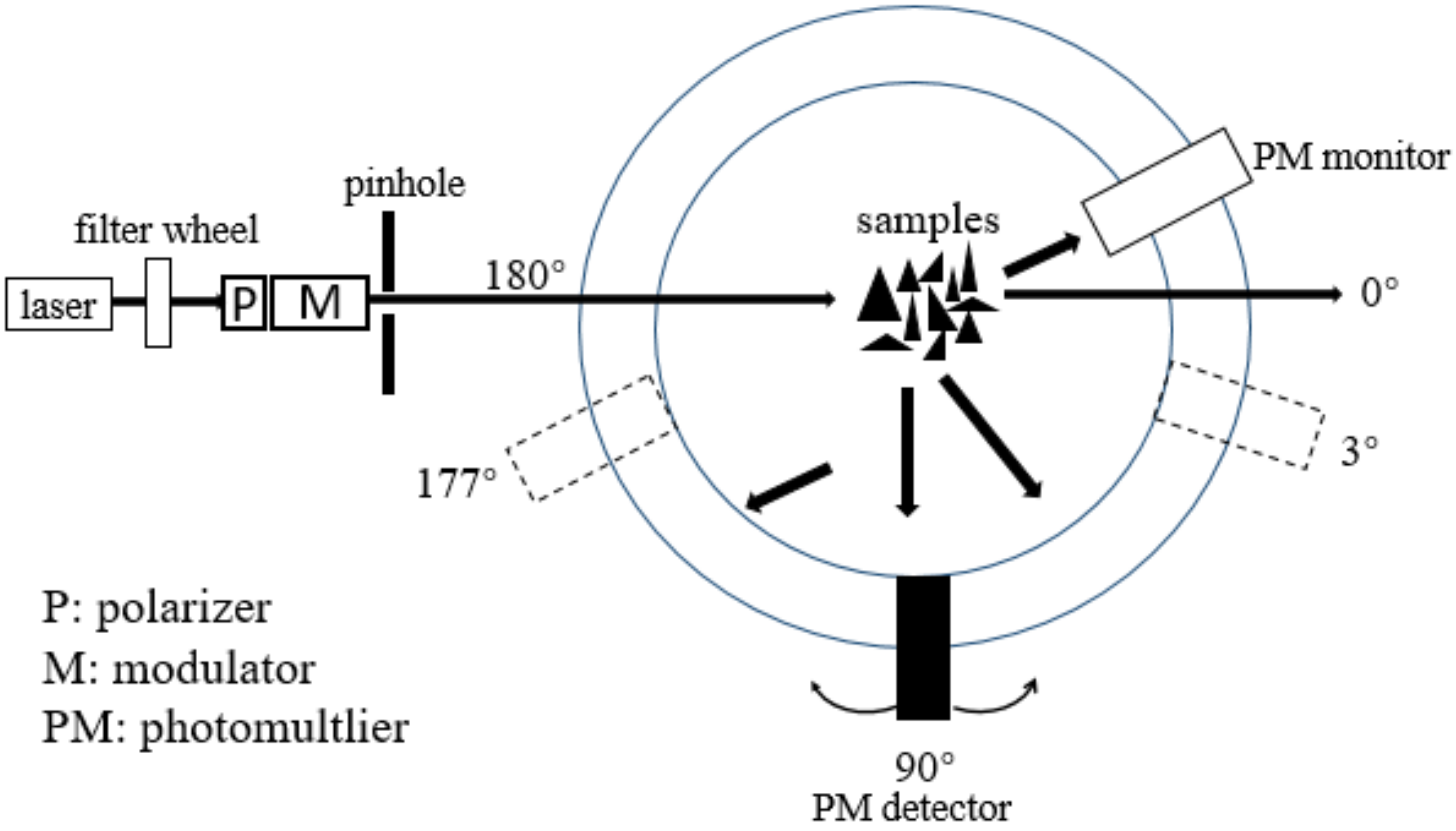
Laboratory Measurement



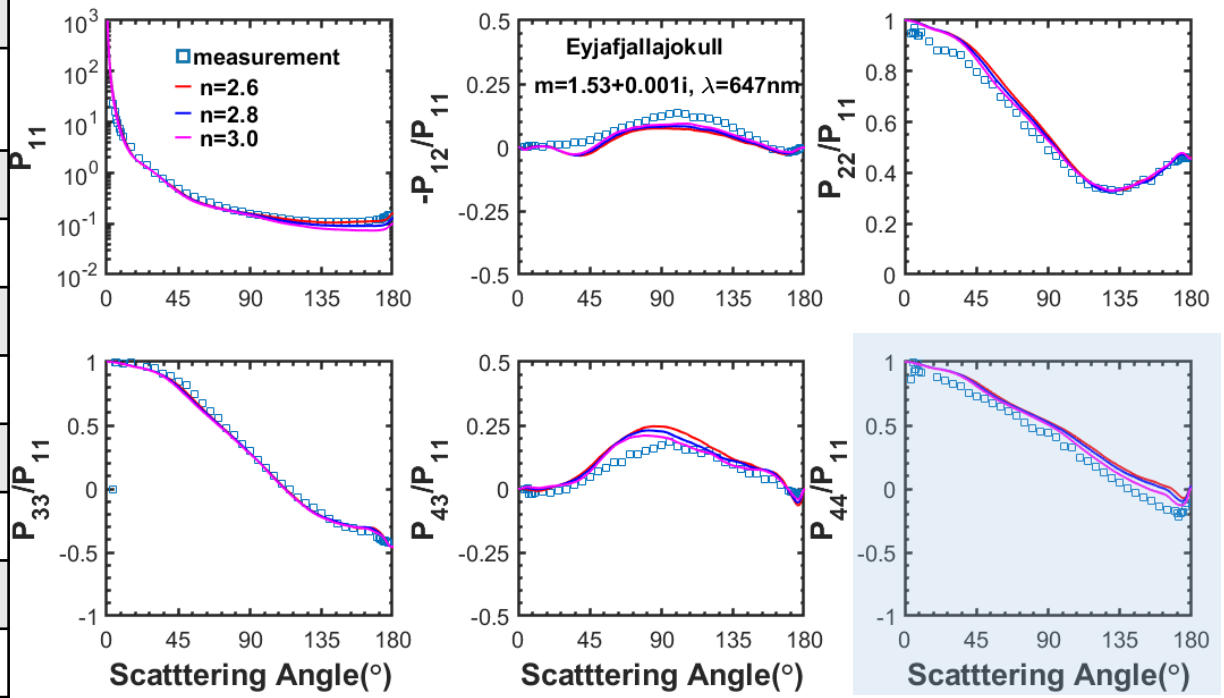
Schematic overview of the experimental light scattering apparatus (e.g., Amsterdam-Granada).

❶ P_{44} :A straight line

Sample (21)	R_{eff}/μm	v_{eff}	Re(m)	Im(m)
Volcanic ash(Eyjafjallajokull)	7.8	2.9	1.43-1.59	0-0.004
Volcanic ash(Puyehue)	8.6	2.2	1.48	0.00027
Cosmic analogs(Basalt)	6.9	7.0	1.52	0.00092(488nm) 0.001(647nm)
Cosmic analogs(JSC-1A)	15.85	2.28	1.65	0.003
Cosmic analogs(JSC0)	29.5	1.1	1.5	0.01(488nm) 0.001(647nm)
Cosmic analogs(JSC200)	28.1	1.2	1.5	0.01(488nm) 0.001(647nm)
Quartz	1.3	2.3	1.54	0
Volcanic ash(Pinatubo)	3.0	12.3	1.5-1.6	0.001-0.00001
Volcanic ash(Loken)	7.1	2.6	1.5-1.6	0.001-0.00001
Olivine S	1.3	1.8	1.62	0.00001
Olivine M	2.6	5.0	1.62	0.00001
Olivine XL	6.3	6.8	1.62	0.00001
Volcanic ash (Mnt St. Helens)	4.1	9,5	1.48-1.56	0.0018
Volcanic ash (Redoubt A)	4.1	9.7	1.48-1.56	0.0018
Volcanic ash (Redoubt B)	6.4	7.6	1.48-1.56	0.0018
Volcanic ash (Spurr Ashton)	2.7	4.9	1.48-1.56	0.0018
Volcanic ash (Spurr Anchorage)	4.8	8.8	1.48-1.56	0.0018

46 Aerosol Samples from the Amsterdam-Granada Light Scattering Database (Volten et al., 2006; Muñoz et al., 2012)

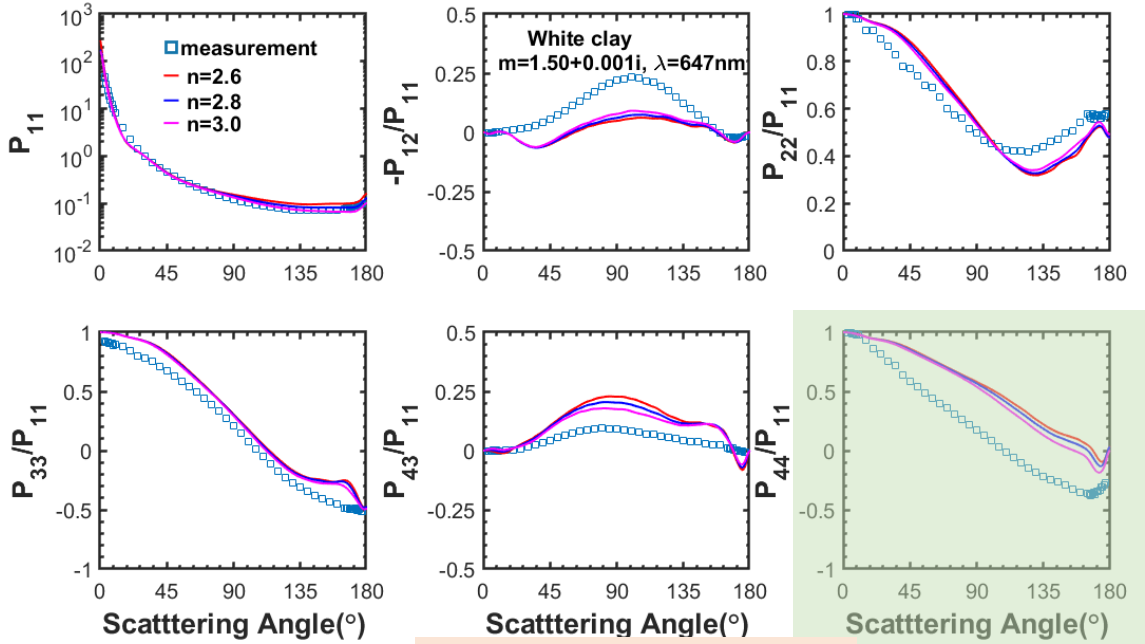
Sample	R_{eff}/μm	v_{eff}	Re(m)	Im(m)
Volcanic ash (Spurr Gunsight)	3.5	8.2	1.48-1.56	0.0018-0.02
Forsterite initial	1.8	5.4	1.63	0
Forsterite washed	3.3	4.7	1.63	0
Martian analog (palagonite)	4.5	7.3	1.5	0.0001-0.001



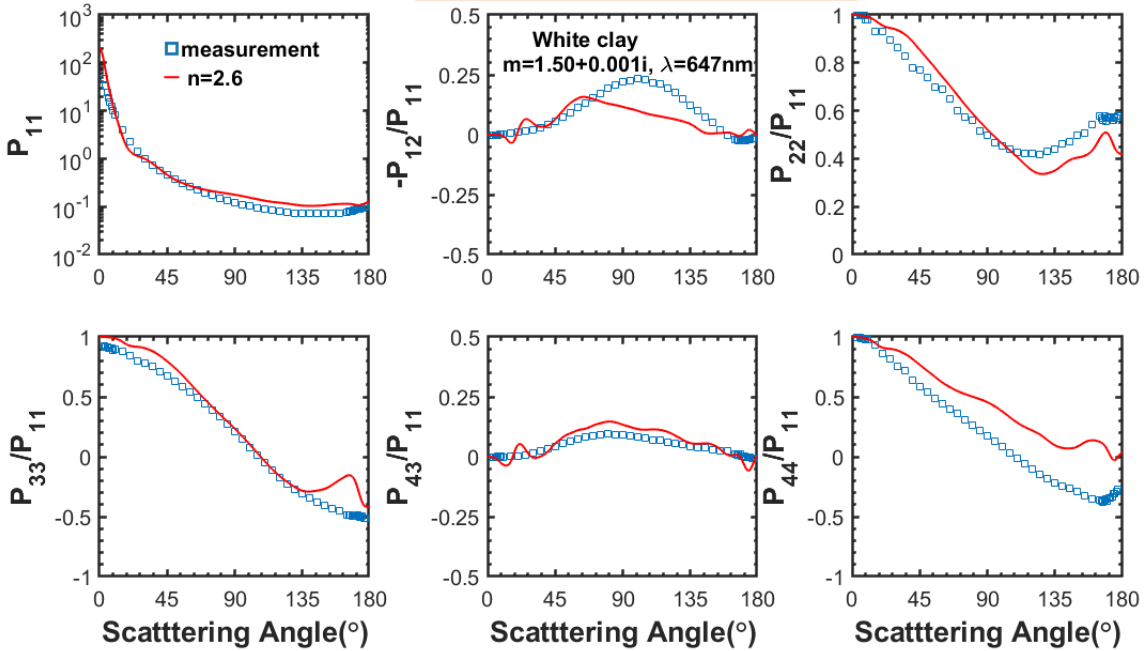
Note. The r_{eff} is the effective radius; v_{eff} is the variance; Re(m) and Im(m) are the real part and the imaginary part of the estimated refractive index, respectively.
*These samples have been investigated in Merikallio et al., (2011).

❷ P_{44} :Concave

Sample (11)	Reff/μm	veff	Re(m)	Im(m)
White clay	2.6	0.7	1.5-1.7	0.00001-0.001
Green clay-Granada	2.3	1.1	1.5-1.7	0.00001-0.001
Cosmic analogs(Calcite)	3.3	4.9	1.485-1.655	0
Montmorillonite	2.8	1.2	1.52	0.001
Red clay	1.5	1.6	1.5-1.7	0.001-0.00001
Loess	3.9	2.6	1.5-1.7	0.001-0.00001
Sahara	8.2	4.0	1.5-1.7	0.001-0.00001
Olivine L	3.8	3.7	1.62	0.00001
Green clay-Amsterdam	1.55	1.4	1.5-1.7	0.001-0.00001
Hematite	0.4	0.6	3.0	0.1-0.01
Sahara sand (Libya)	124.75	0.15	1.5	0.004

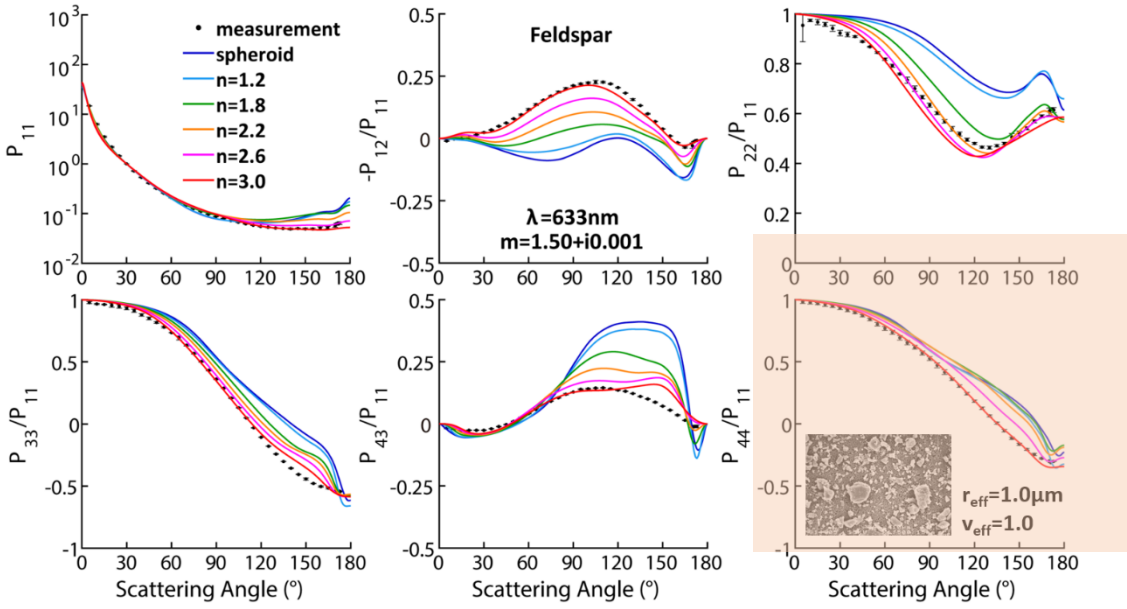


imhomogeneity



❸ P_{44} :Convex

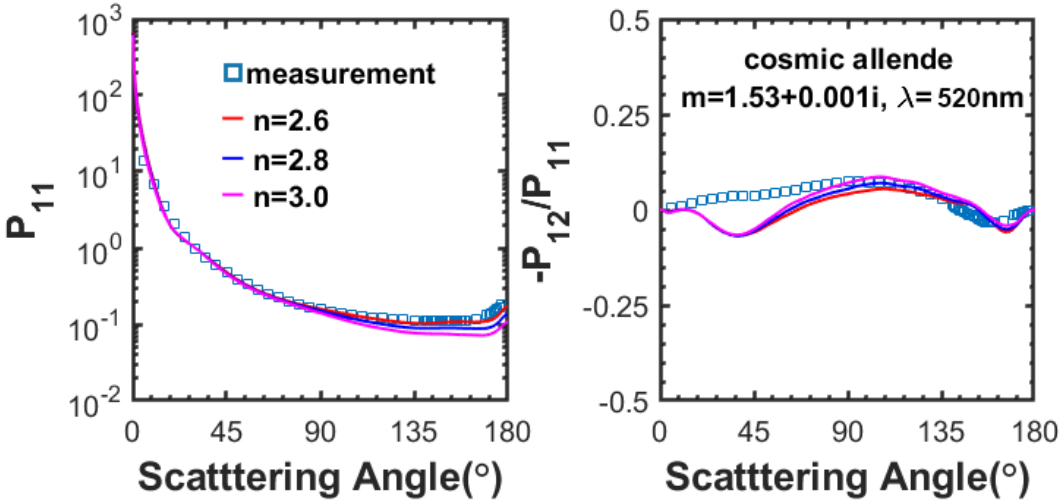
Sample (5)	Reff/μm	veff	Re(m)	Im(m)
feldspar	1.0	1.0	1.5-1.6	0.001-0.00001
allende	0.8	3.3	1.65	0.001
Volcanic ash (Spurr Stop 33)	14.4	6.6	1.48-1.56	0.0018-0.02
Forsterite small	1.3	3.1	1.63	0
Fly ash	3.65	10.9	1.5-1.7	i0.001-0.00001



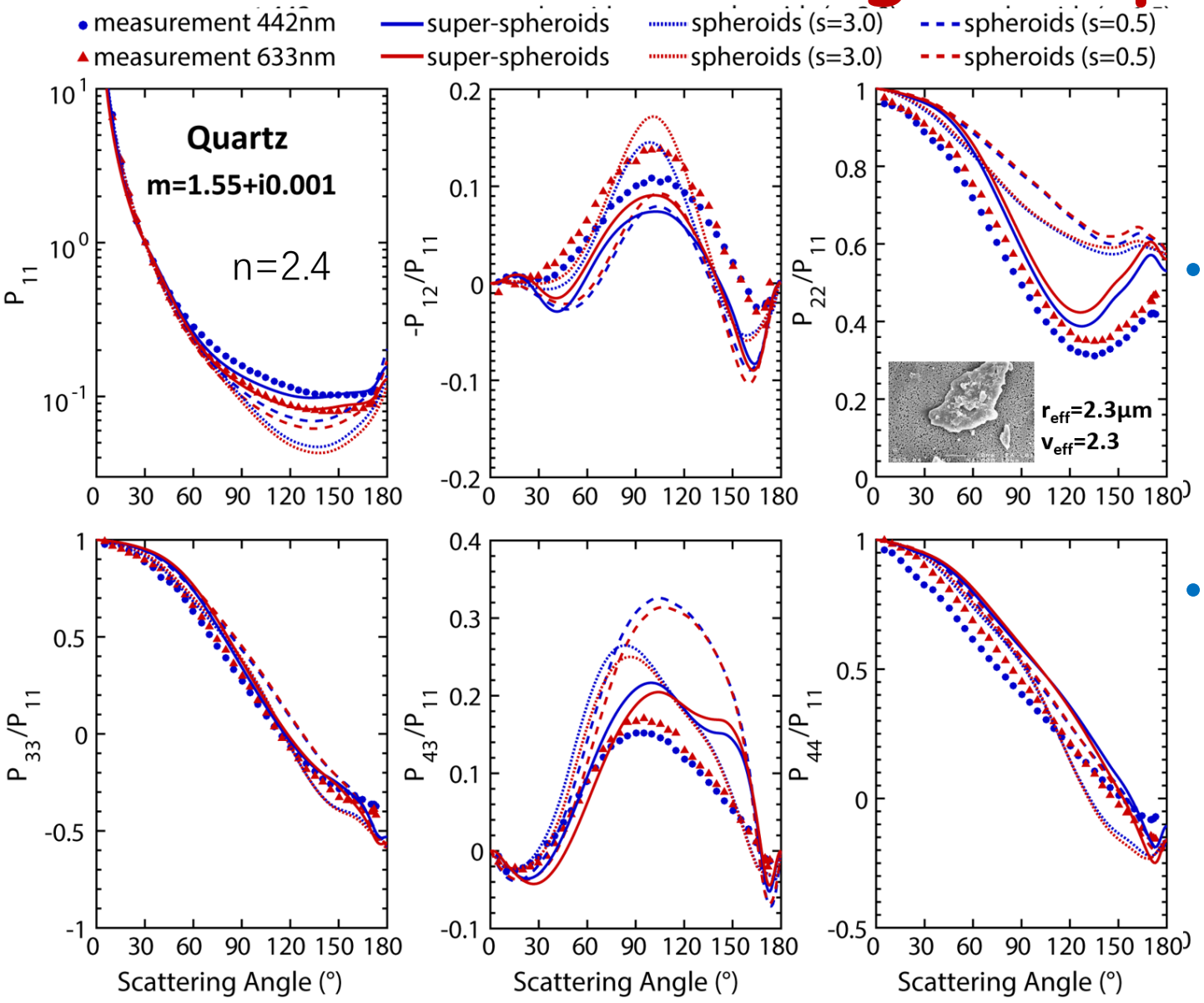
Lin ,W., et al., *Journal Geophysical Research: Atmospheres*, 2019

Only two measured elements P_{11} , P_{12}

Sample (9)	Reff/μm	v_{eff}	Re(m)	Im(m)
Cosmic analogs (Allende)	2.63	3.43	1.65	0.001
Cosmic analogs (DaG521M)	8.68	2.44	1.65	0.001
Cosmic analogs (DaG521S)	3.58	1.97	1.65	0.001
Cosmic analogs (Enstatite)	3.71	3.14	1.58	0.00001
Cosmic analogs (OlivineS)	3.29	1.04	1.62	0.00001
Cosmic analogs (FRO95002M)	3.92	2.72	1.65	0.001
Cosmic analogs (FRO99040M)	5.90	3.09	1.65	0.001
Cosmic analogs (FRO99040S)	3.68	1.73	1.65	0.001
Volcanic ash (EI Chichon)	3.2	5.4	1.5-1.6	0.001



Wavelength Dependence

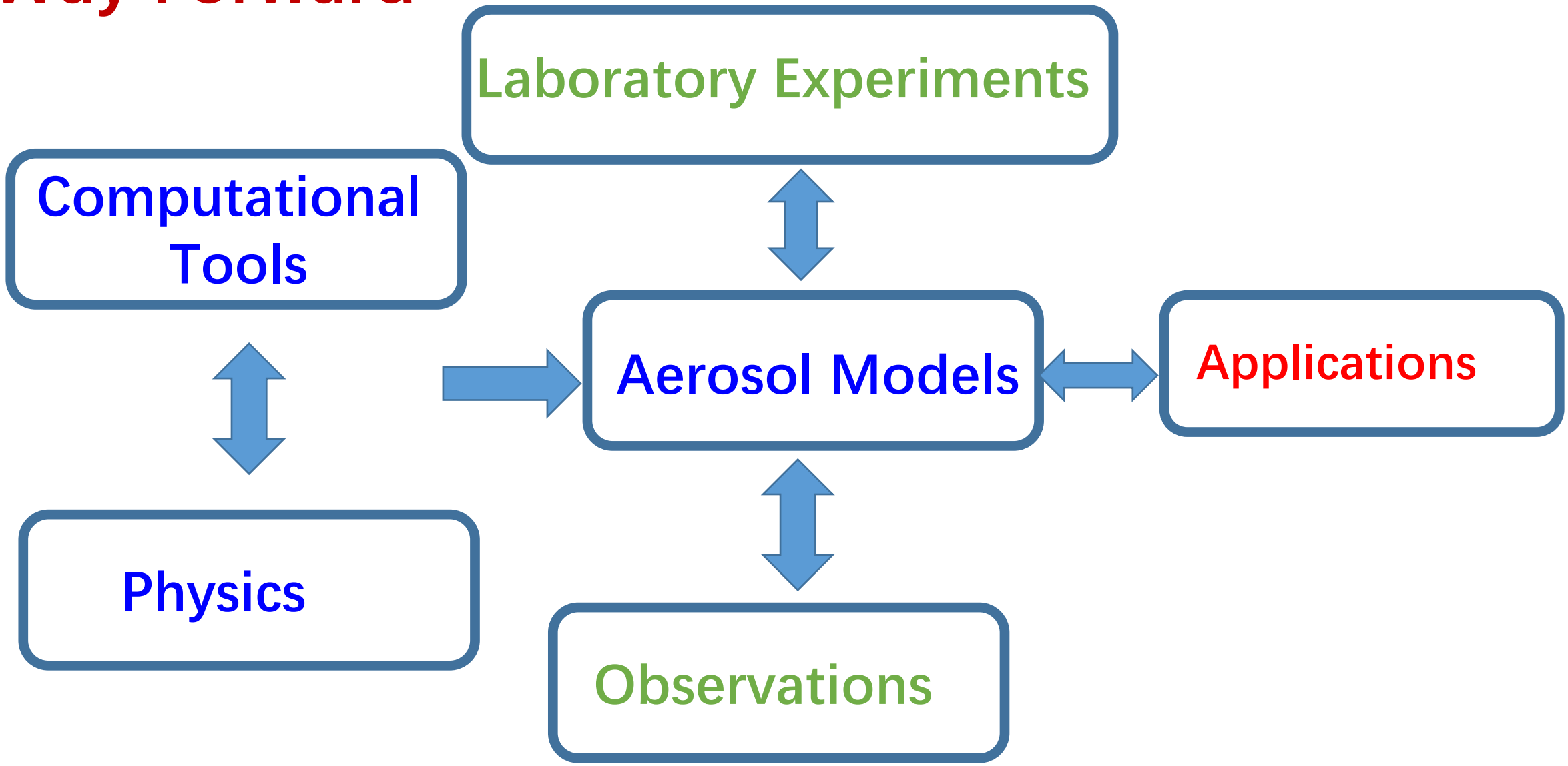


Lin ,W., et al., *JGR*, 2018

Super-spheroid: equi-probable shape distribution
Spheroid: power-law shape distribution

- Super-spheroids are much better than spheroids to simulate the wavelength dependence of scattering matrix.
- Super-spheroids with constrained roundness parameters appear to be much better than spheroids even though extreme aspect ratios of spheroids are considered.

Way Forward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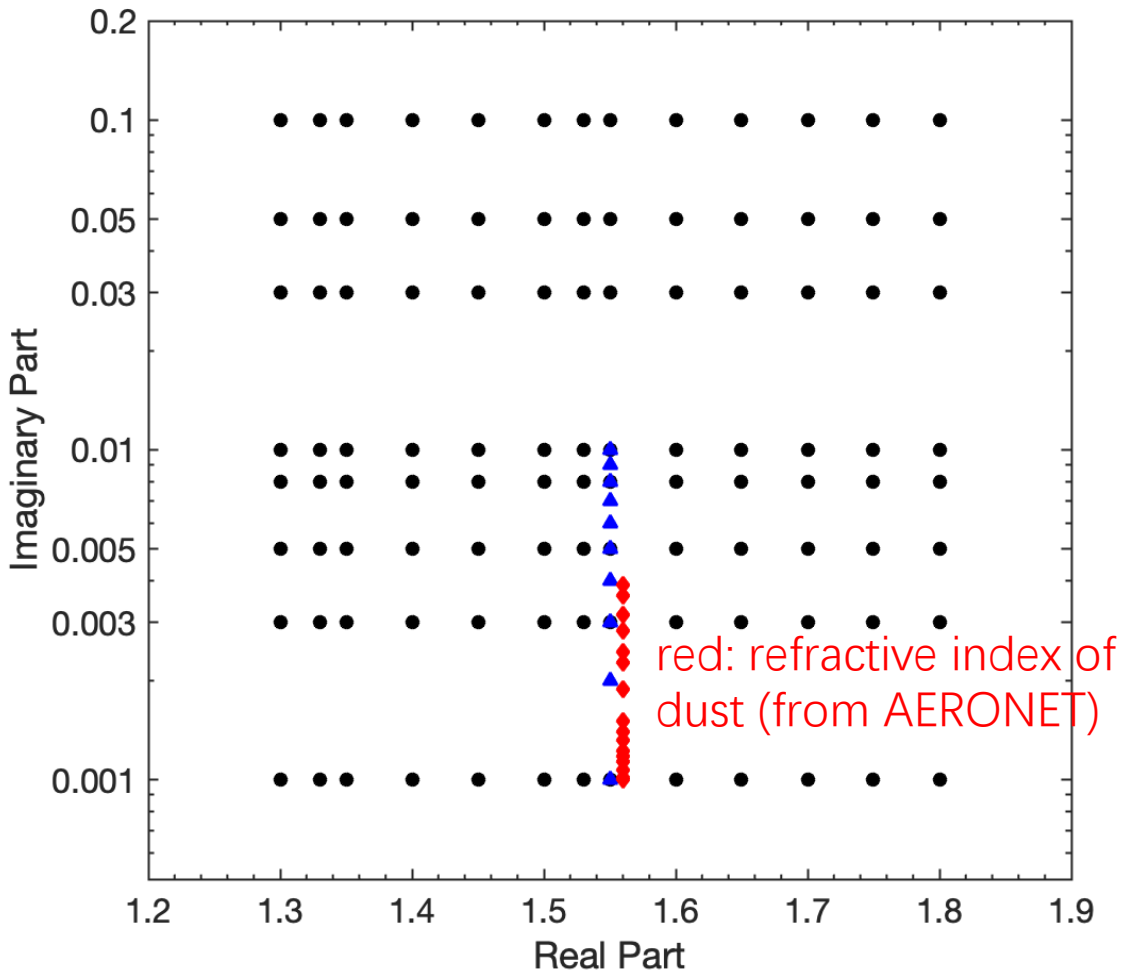
Database

Refractive Index

$m_i \backslash m_r$	1.30	1.33	1.35	1.40	1.45	1.50	1.53	1.55	1.60	1.65	1.70	1.75	1.80
10^{-7}	√	√	√	√	√	√							
0.001	√	√	√	√	√	√							
0.003	-	-	-	√	√	√							
0.005	√	√	√	√	√	√							
0.008	√	√	√	√	√	√							
0.01	√	√	√	√	√	√							
0.03	√	√	√	√	√	√							
0.05	√	√	√	√	√	√							
0.1	√	√	√	√	√	√							



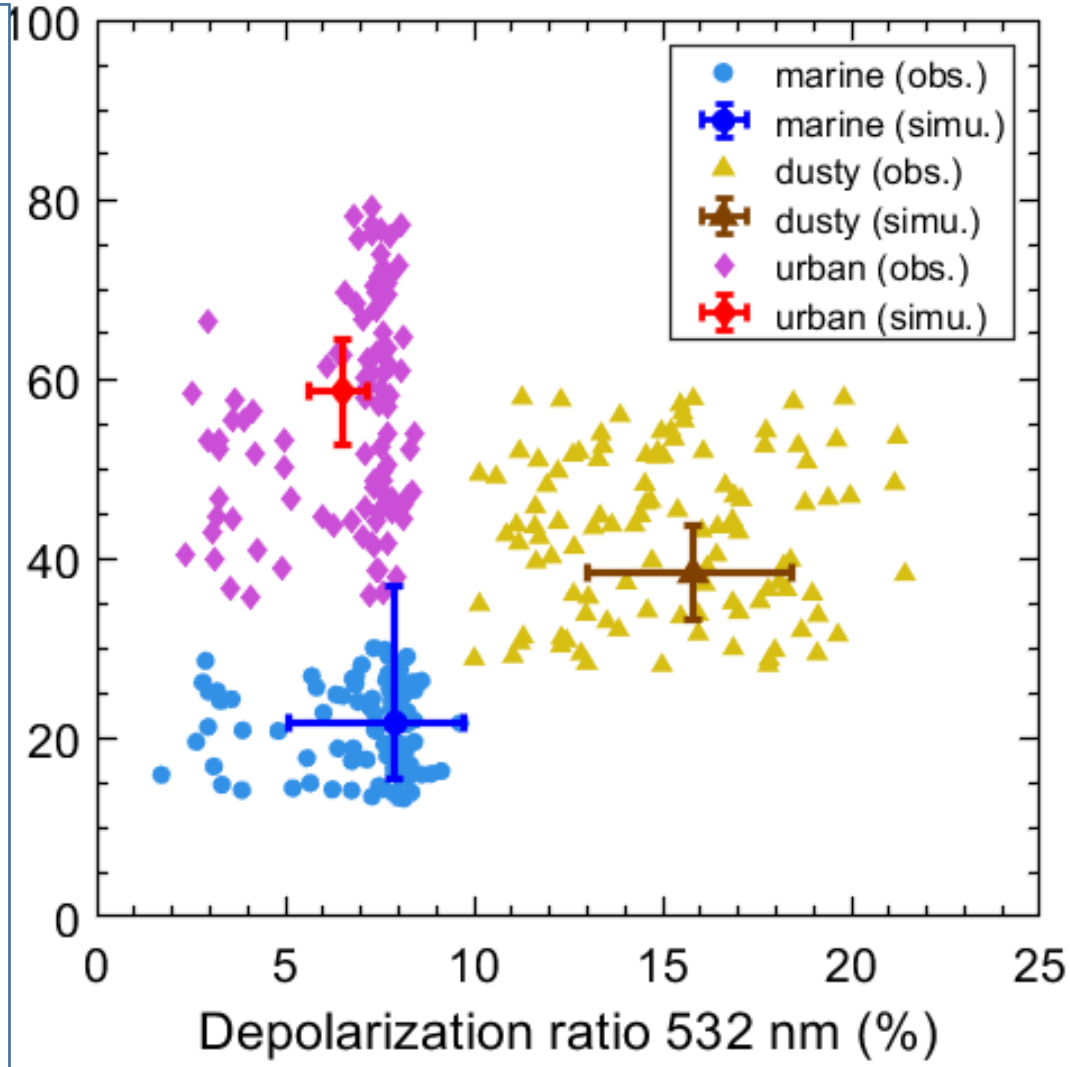
Database

Shape Parameter											
Aspect ratio (a/c)	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.8	2.0
Roundness parameter (n)	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0

Size Parameter and Computational Method				
$2\pi a/\lambda$ $2\pi c/\lambda$	0.1~50/100	50~70	70~100	100~1000
Method	II-TM	IGOM (II-TM)	IGOM (II-TM)	IGOM

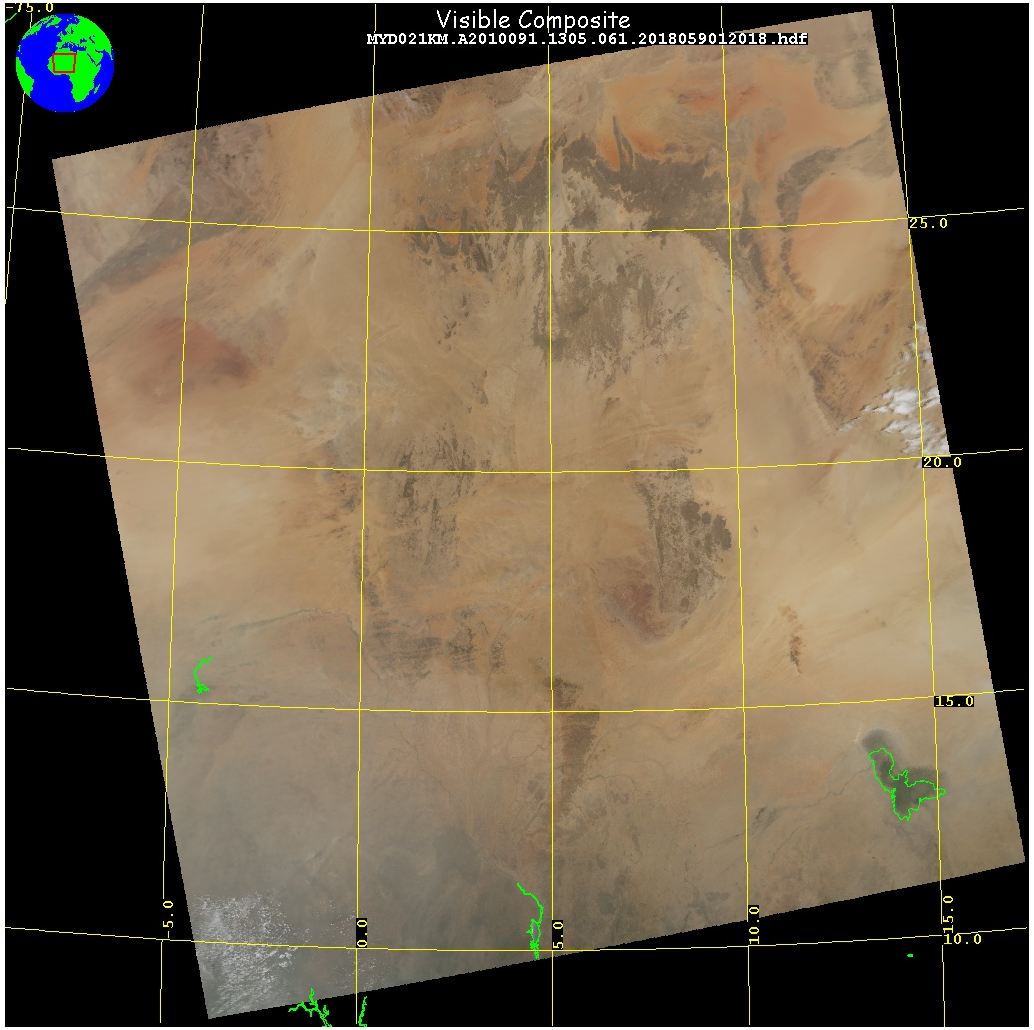
LiDAR Aerosol Classification

Courtesy to: Prof. Dong Liu

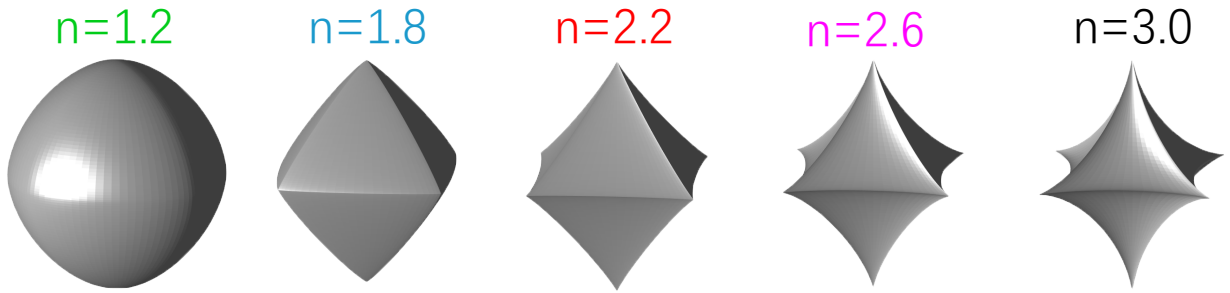


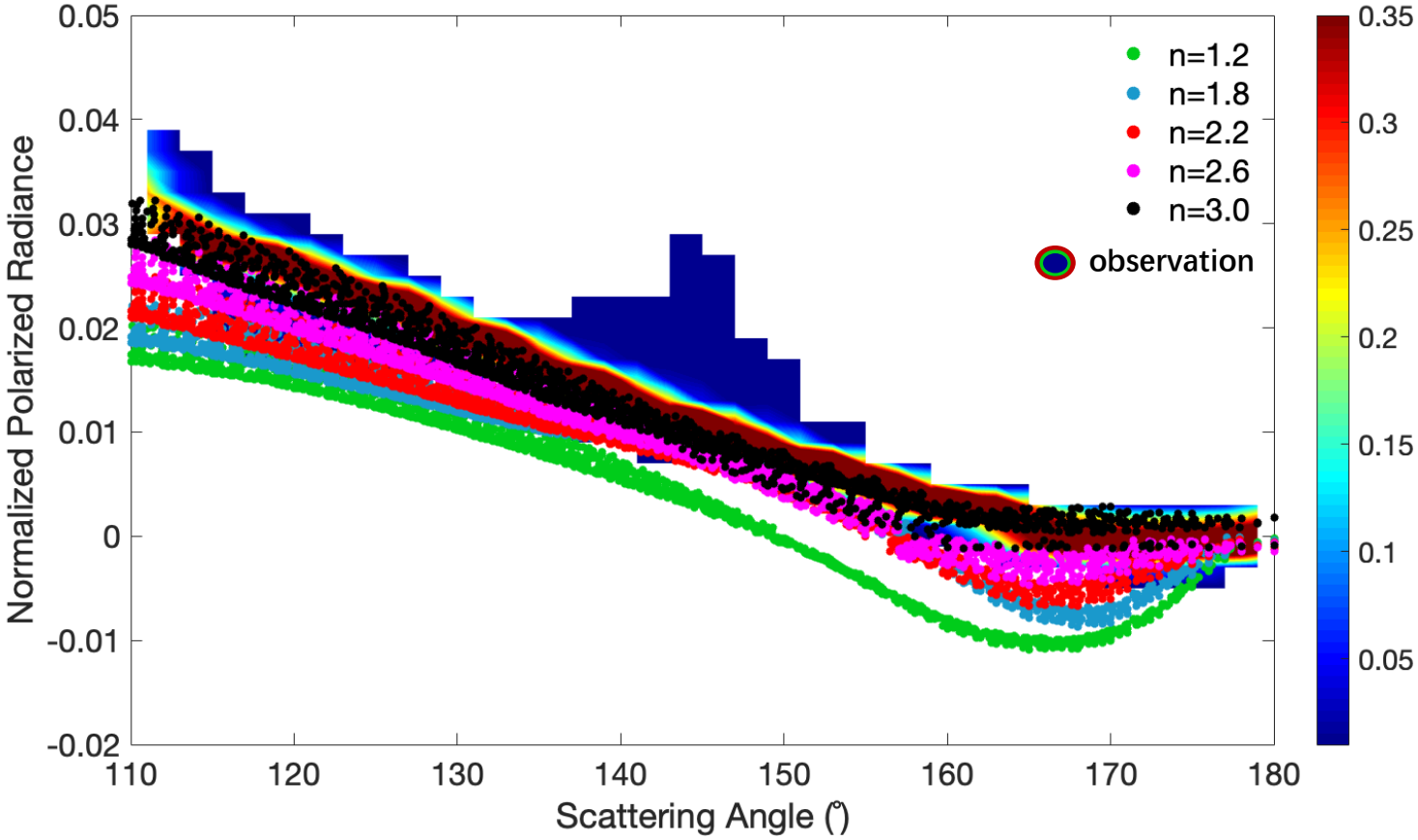
POLDER: Simulation VS Observation

Saharan dust (April 1st, 2010)

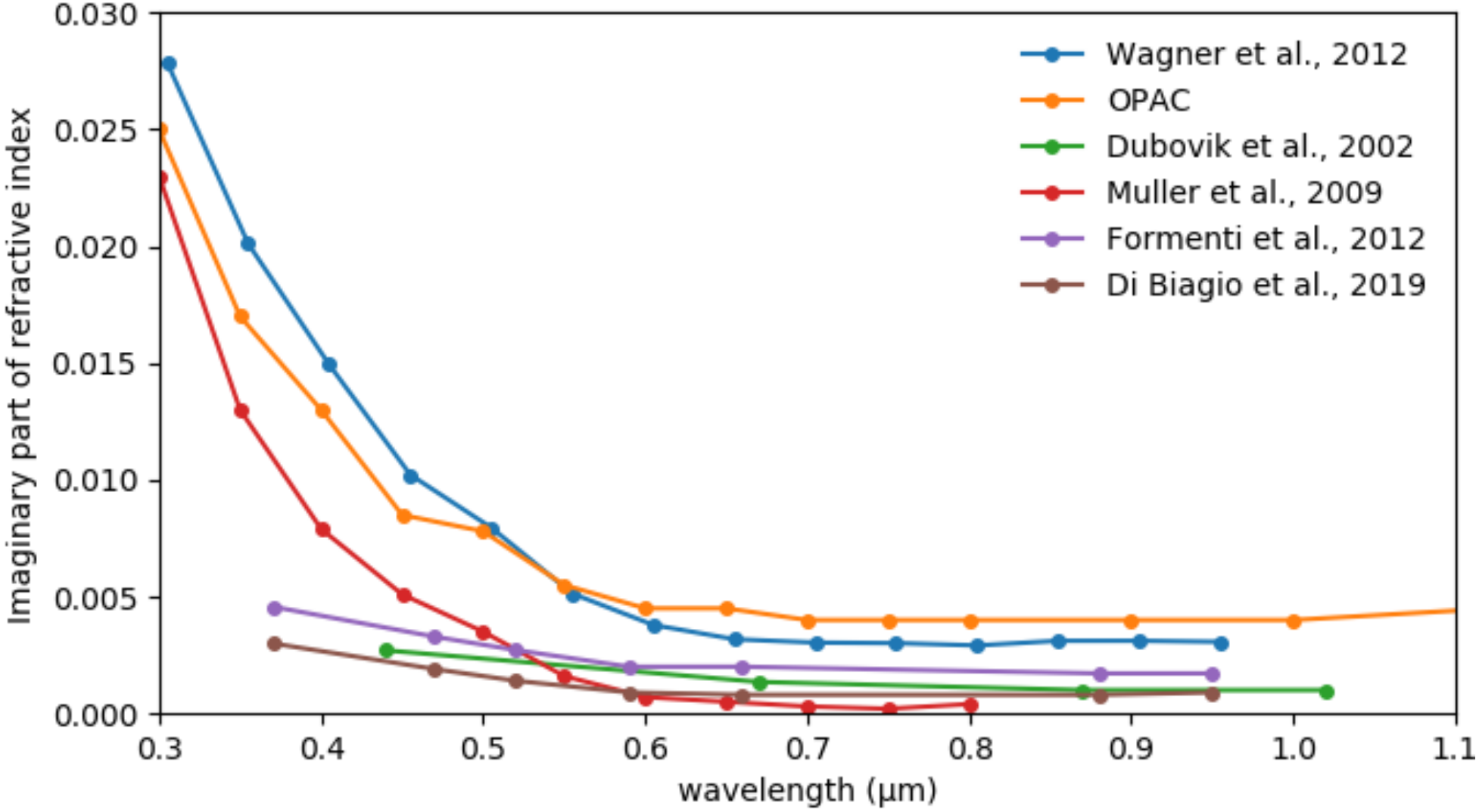


From: https://ladsweb.modaps.eosdis.nasa.gov/

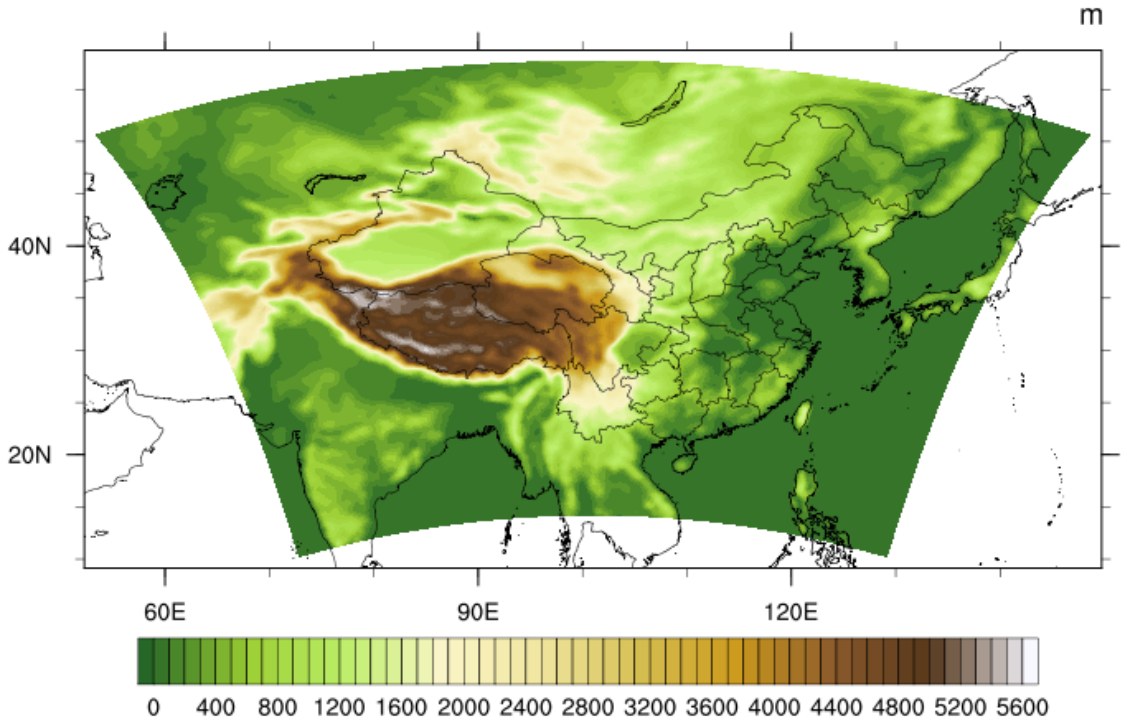




Dust Shortwave Absorption Impact



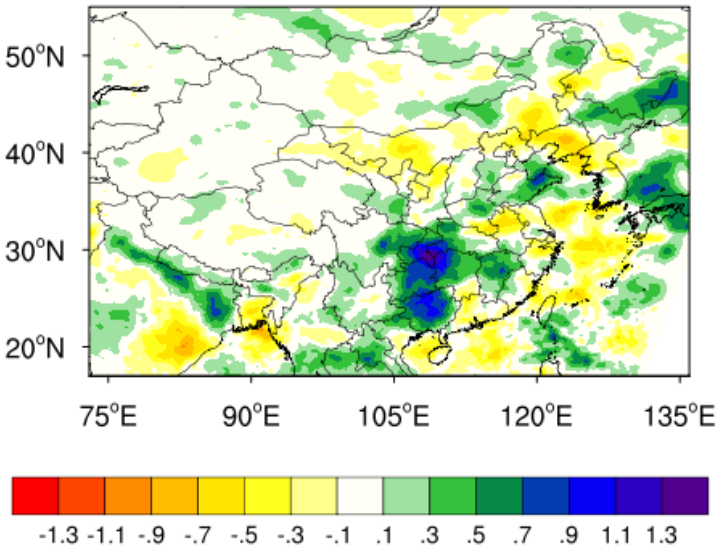
WRF-Chem

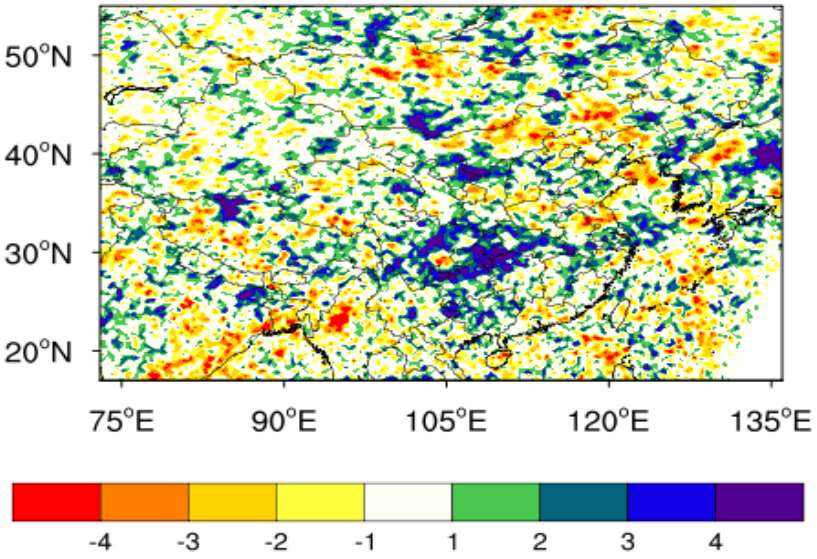


- Grid 36km, 35 Layers
- 2006/4/1-9/1
- Lin, Grell-Freitas, RRTMG, YSU, Noah
- uoc dust(shao2004)
- fdda

Strong absorption – weak absorption

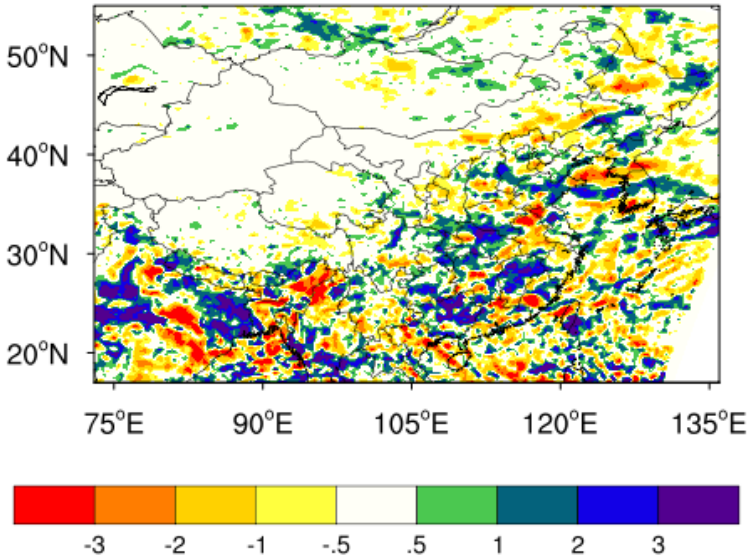
Column Water Vapour（mm）

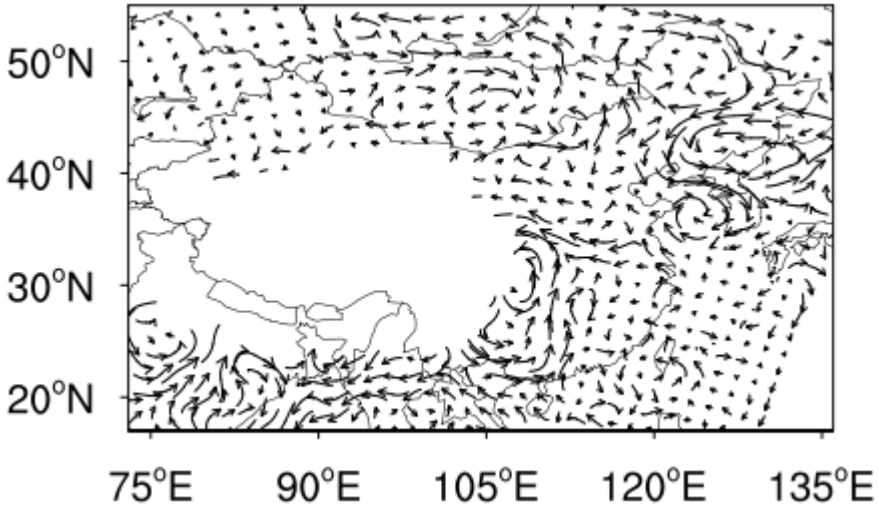




Cloud amount（%）

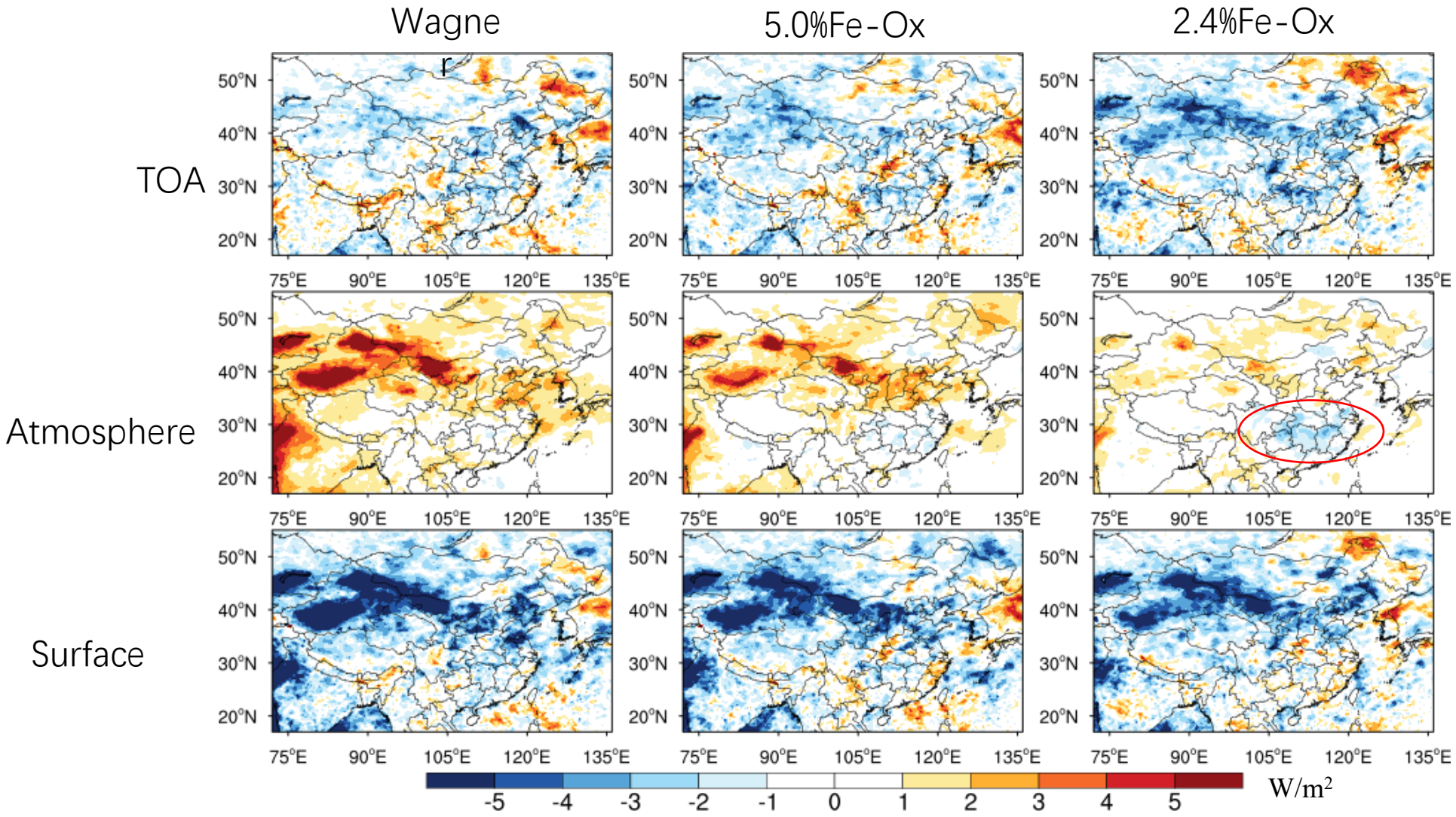
Precipitation（mm/day）





700hPa wind field

Dust direct radiative effect (summer)

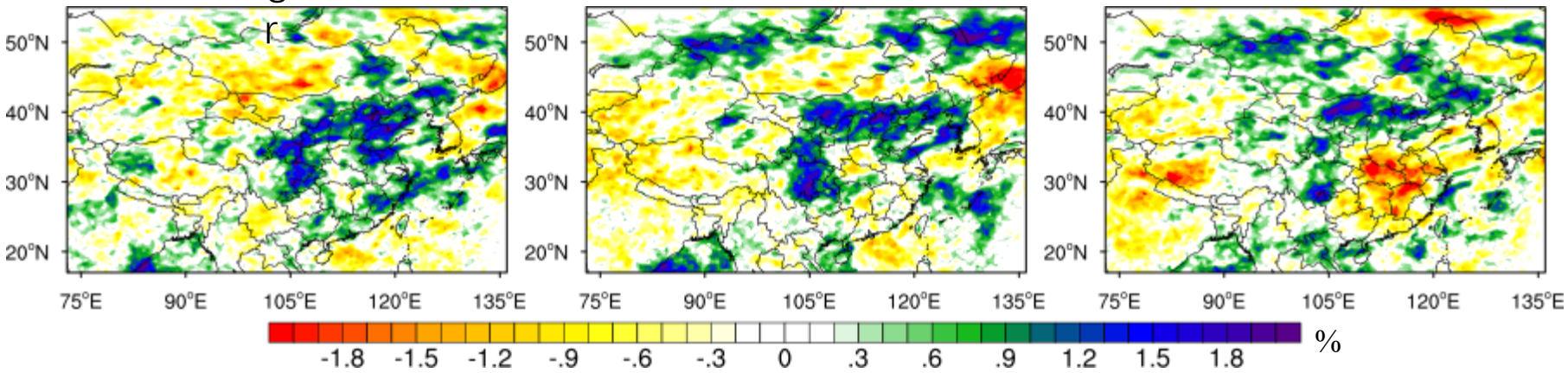


Wagner

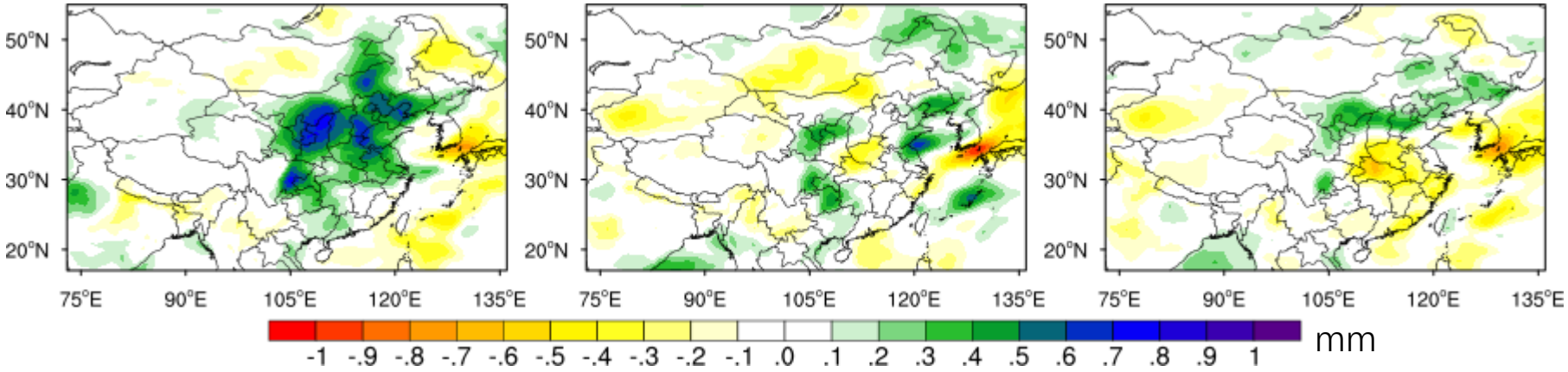
5.0%Fe-Ox

2.4%Fe-Ox

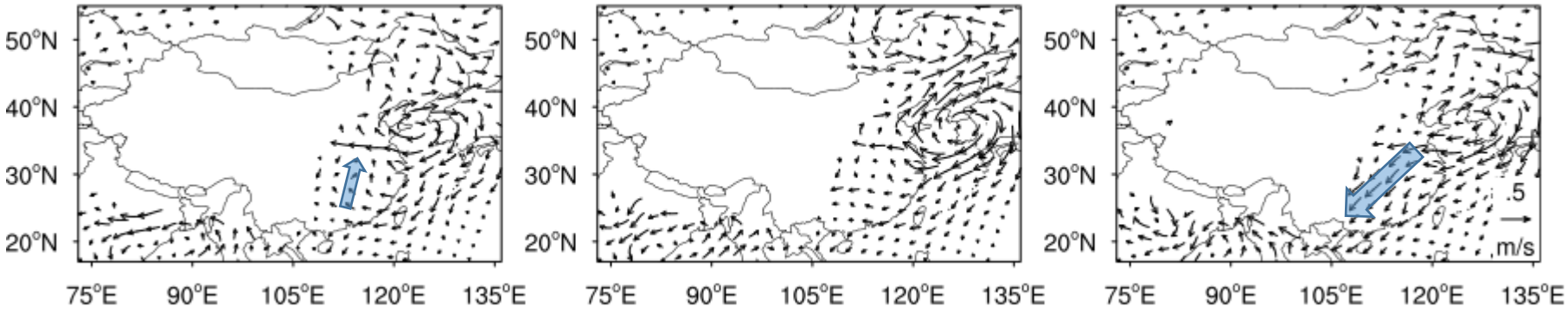
Cloud Amount Change



Precipitation Change



Wind Field Change (850 hPa)



Summary

- Fundamental progress has been made to compute the optical properties of aerosol particles: **T-matrix**
- Due the technical advances, the aerosol modeling approach has been extended from the conventional models (spheres and spheroids) to current **super-spheroidal models**
- Extensive comparisons have been made between modeling simulations and the Amsterdam-Granada Laboratory Measurements.