An exploration of joint LIDAR and multiangle polarimeter aerosol retrieval capabilities using the GRASP algorithm and OSSE data derived from the GEOS model

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Aerosol remote sensing from polarimetry

- According to the most recent IPCC report, the largest radiative forcing uncertainty stems from aerosols and their interactions with clouds and the Global Climate Observing System (GCOS) aerosol retrieval accuracy goals (e.g. $\Delta\tau = \pm 0.03 \pm 0.1\tau$) are still generally unmet.

- Space-based polarimetry can improve aerosol retrieval capabilities and many new, more capable space-based sensors will be launched in next decade (e.g. 3MI, MIAI, HARP2 and spexOne on PACE, DPC, A-CCP, etc.).

- A significant number of theoretical polarimetry studies (Mishchenko and Travis (1997), Knobelspiesse et al. (2012), Xu et al. (2016), et.) have given greater insight into the potential of polarimetric aerosol retrievals.

- However, many of these studies are performed under relatively straightforward conditions with limited exploration of retrieval modeling and assumption errors or orbital sampling biases.

- Little work has been done on potential of joint polarimeter-LIDAR retrieval

Generalized Retrieval of Aerosol and Surface Properties (GRASP) provides flexibility in observation configurations

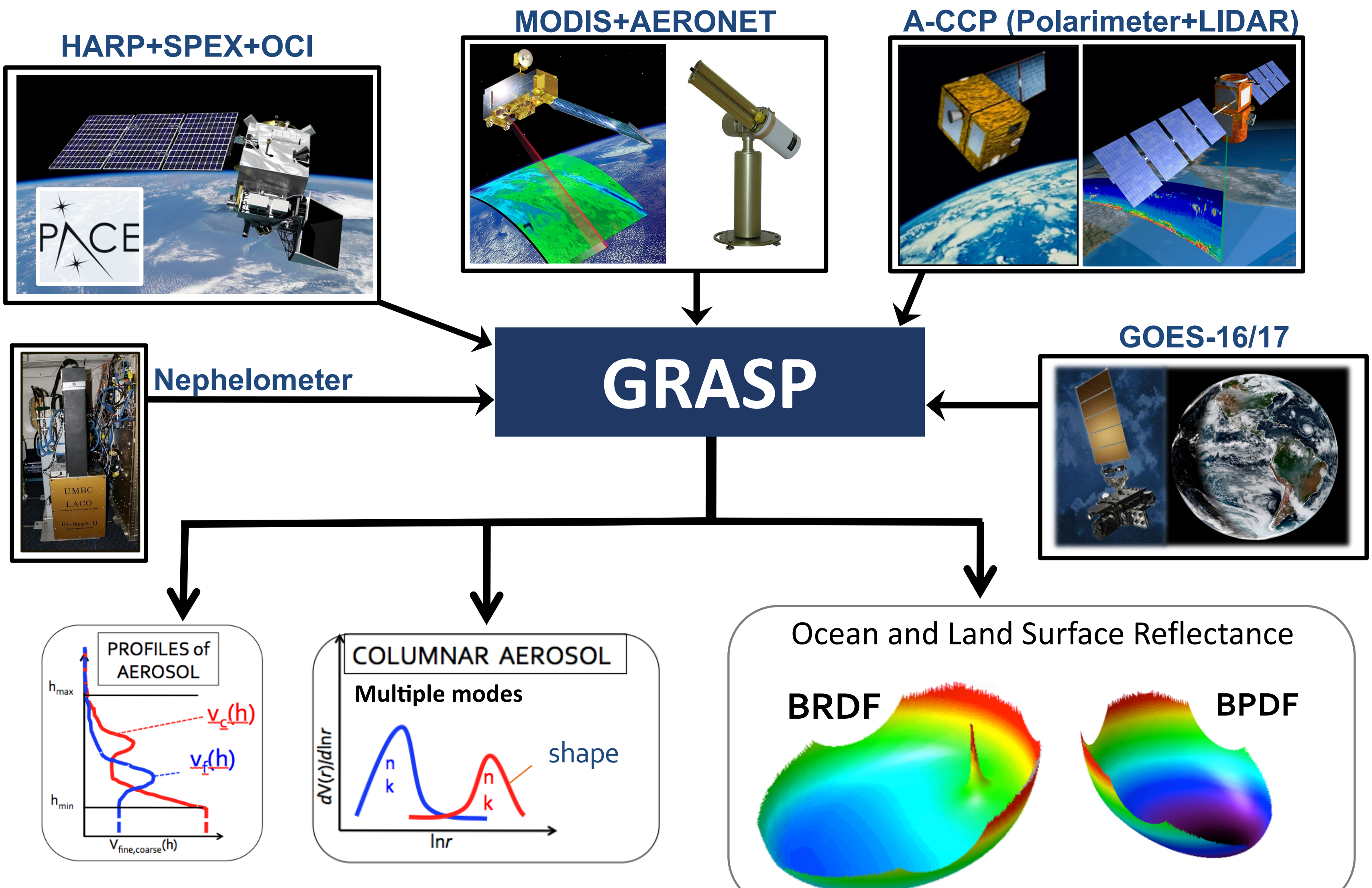


Figure adapted from **Dubovik et al. (2014),** *SPIE Newsroom*

GRASP algorithm structure and forward model

Forward model can be run independently and is:

- fast, accurate and contains precomputed spheroid single scattering tables
- consistent with itself → no unwanted modeling errors in retrieval simulations

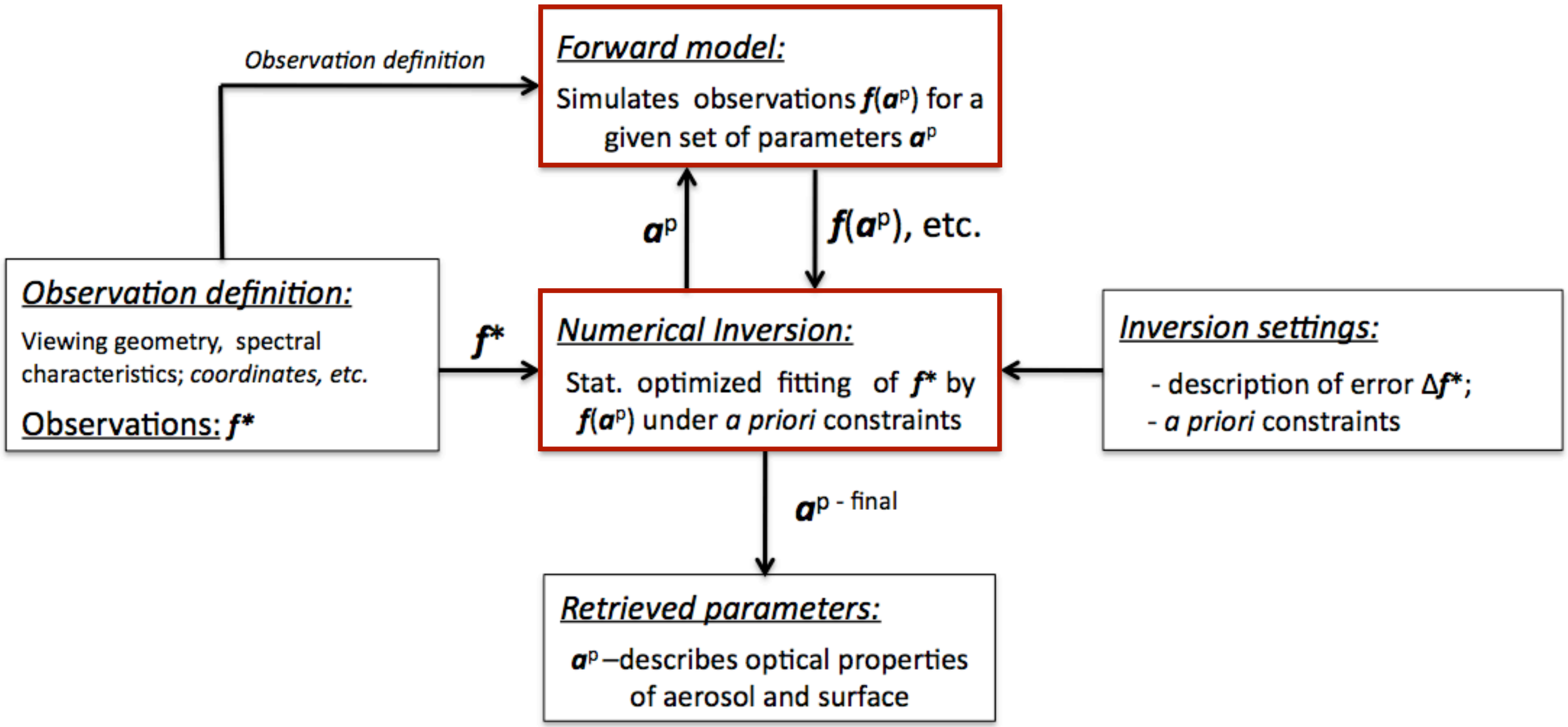
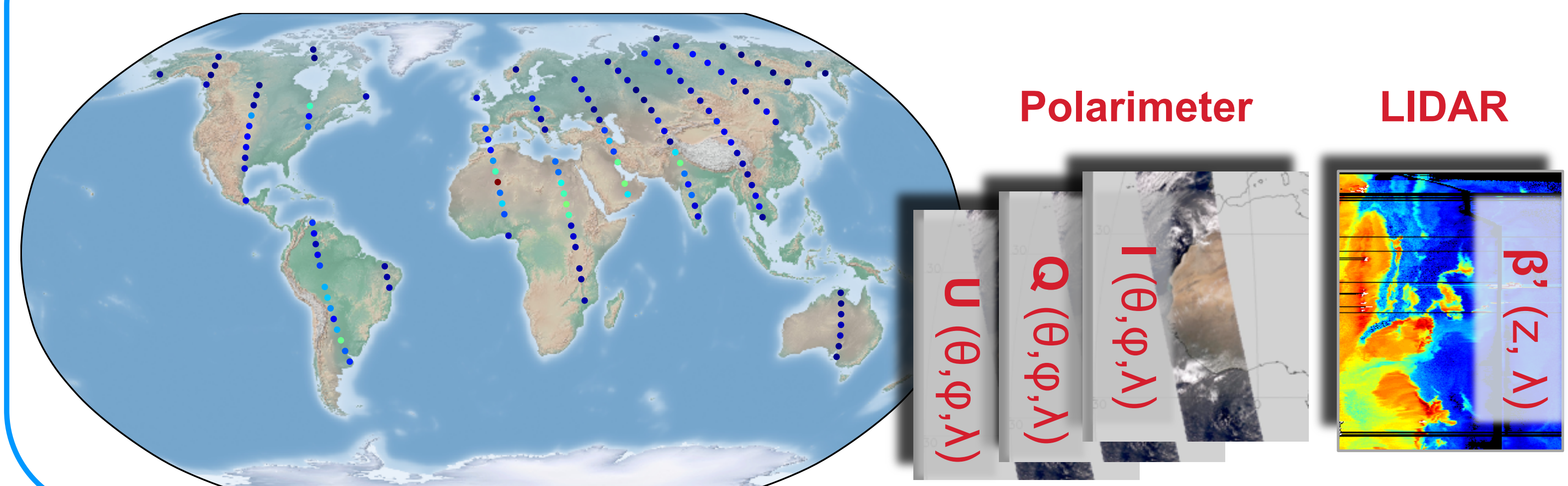


Figure adapted from
Dubovik et al. (2011), *AMT*, 4:975–1018

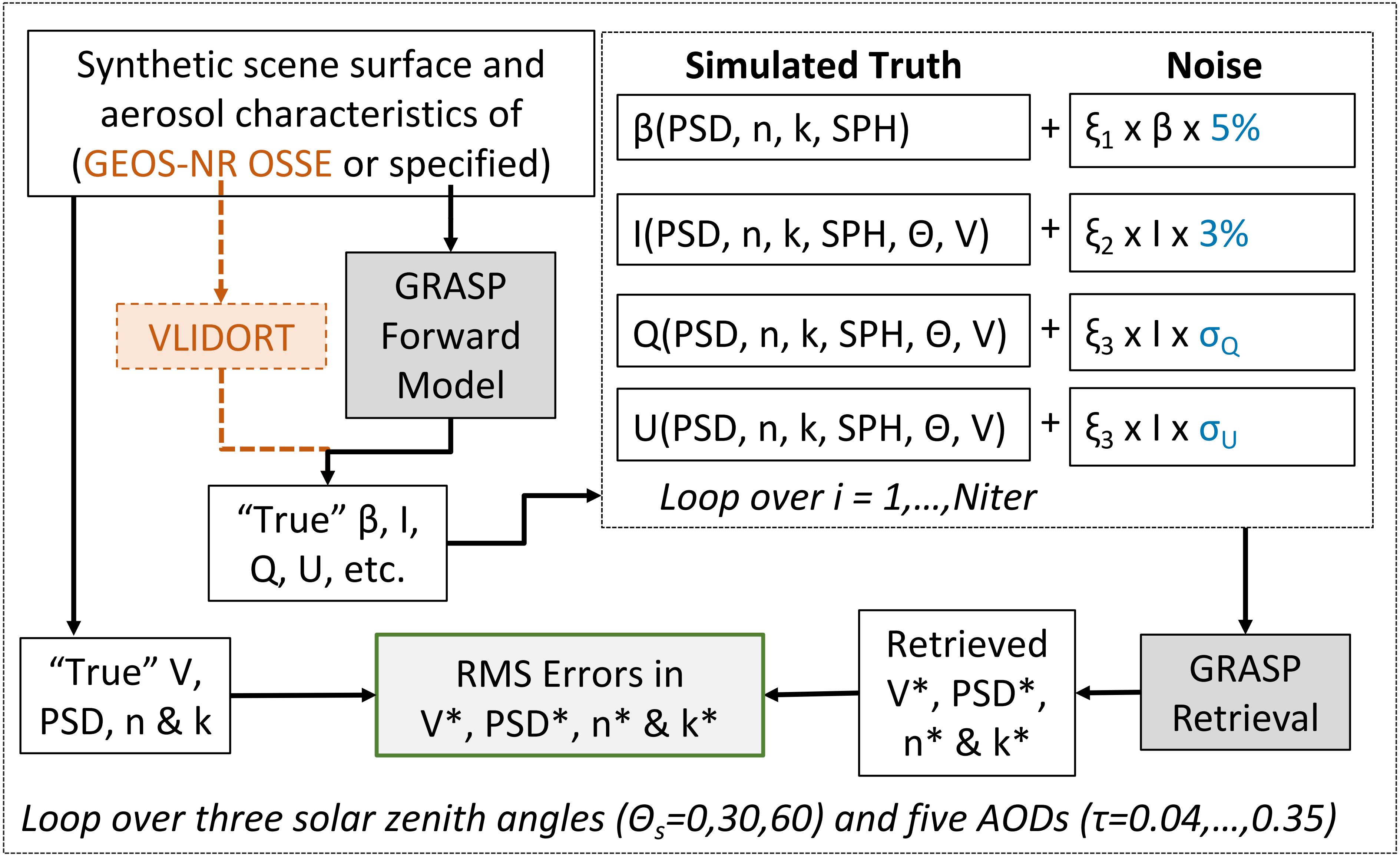
Goddard Observation System Simulation Experiment (OSSE) Simulated

- **Current status of retrieval testbed**
  - Synthetic OSSE polarimetric and LIDAR observations for arbitrary satellite orbits are generated using surface and aerosol fields from GEOS-5 Nature Run
  - VLIDORT (OSSE RT code) and GRASP forward models generally agree to ~0.3%.
    - Lots of work… (reconciling, Rayleigh depolarization correction, surface model, etc.)

Simulated OSSE data: I, Q, U & Lidar profiles along satellite orbit



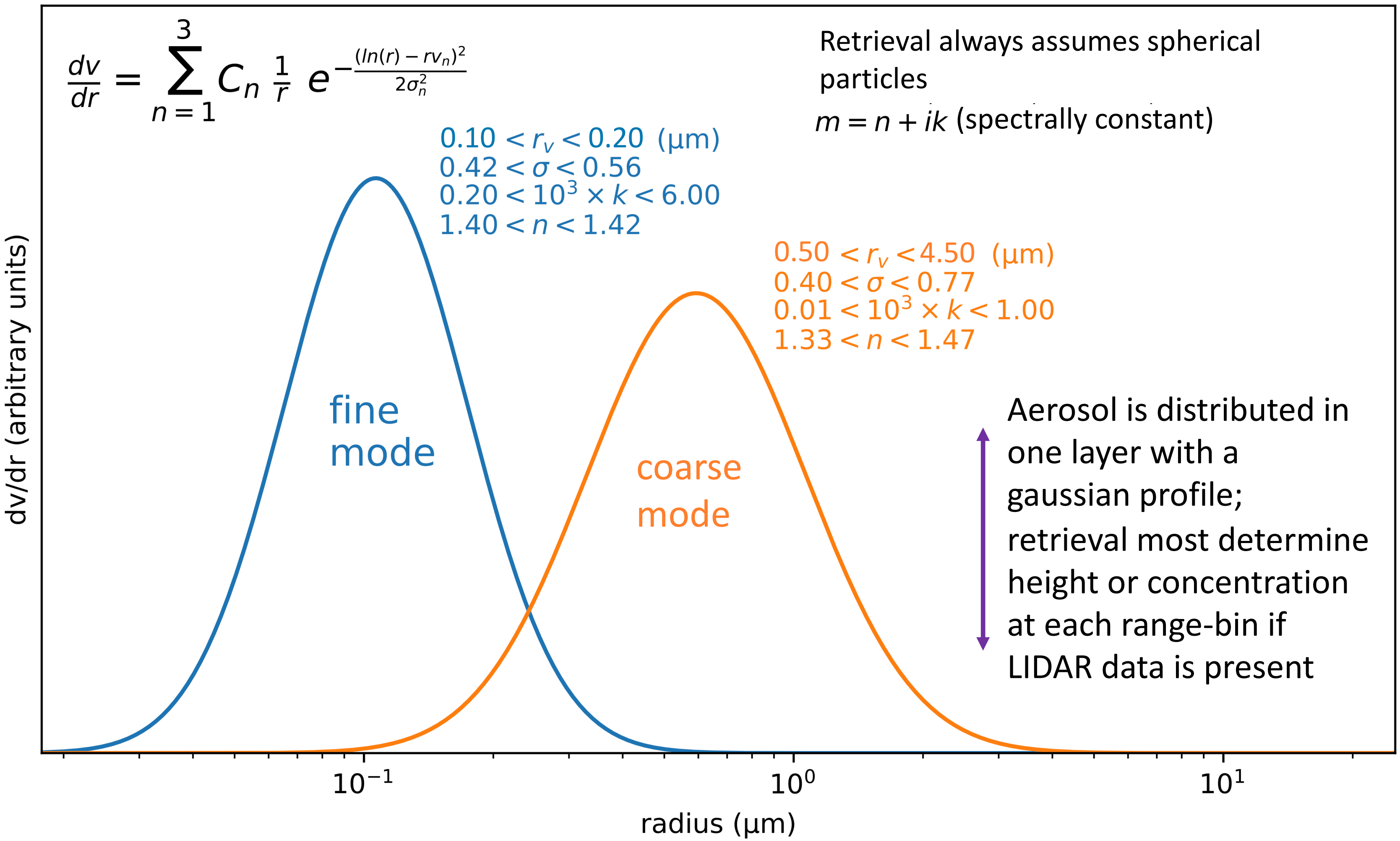
Monte Carlo Retrieval Simulation Framework



σ_Q and σ_U are chosen so that σ_Q/σ_U=Q/U and ***σ_{DoLP} = 0.5%***

Example case using a bimodal aerosol layer

- Retrieval aerosol model is bimodal w/ separate coarse & fine refractive indices
- Simulated "Truth" also bimodal with properties chosen at random from the retrieval search space show below for each viewing geometry and AOD
- Cox-Munk ocean surface set V=7m/s in forward model, V is retrieved w/ aerosol



Retrieval studies performed on three separate simulated instruments:

Radiometer

Top-of-atmosphere measurements of intensity at **10 angles** evenly spaced over ±57 degrees with **6 wavelengths spanning 0.44 µm to 2.2 µm** (ΔI/I = 3%)

Polarimeter

Radiometer configuration but with **additional measurements of q and u** (ΔDOLP = 0.5%).

Backscatter LIDAR

Attenuated **backscatter from space at 532nm and 1064nm** over 45 log-space altitude bins ranging from 100 m to 20 km (Δβ = 0.5%).

Polarimeter simulation example case

Generally, LIDAR+Polarimeter has most sensitivity followed by polarimeter alone and then intensity only radiometer

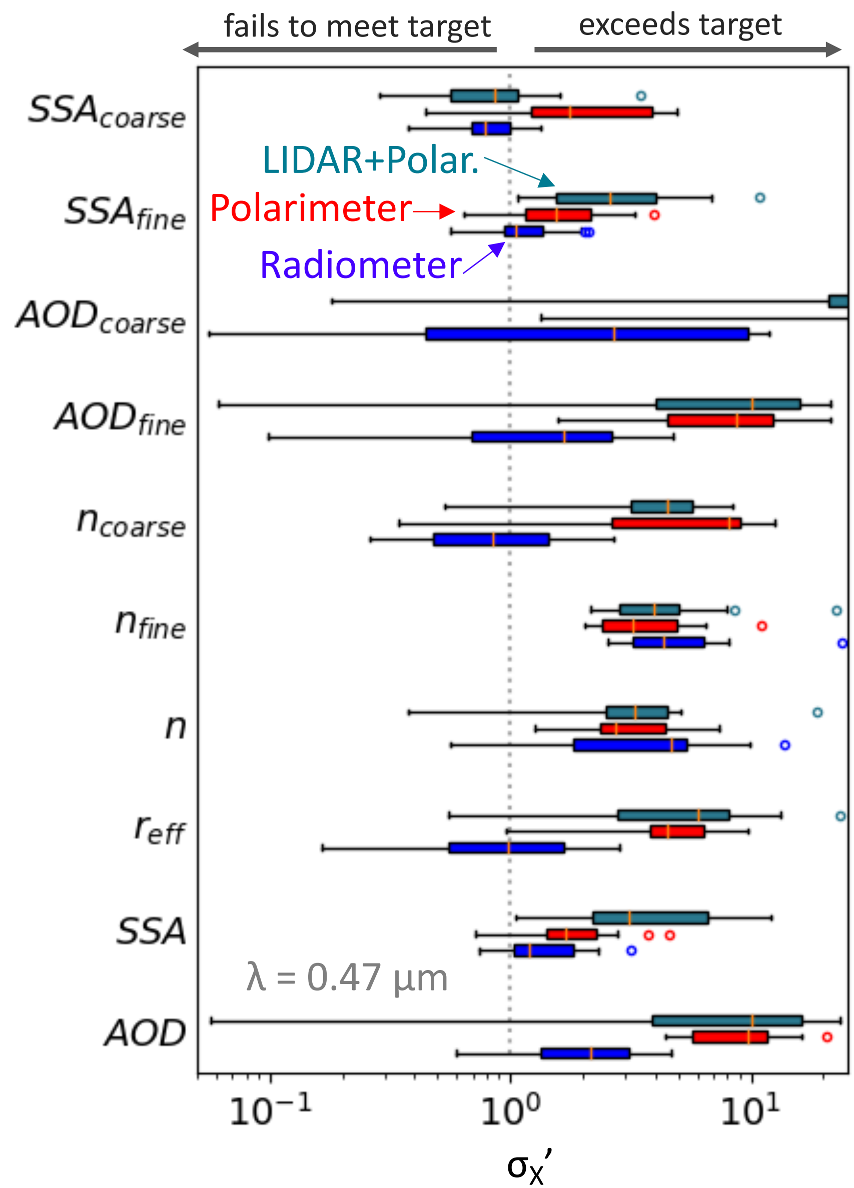
$$\sigma_X' = \sigma_X \Big/ \sqrt{\frac{1}{N}\sum_{n=1}^{N}(X - X_n')^2}$$

Simulation "Truth" (X); Retrieved Value on n[th] trial (X_n'); Target Uncertainty (σ_X)

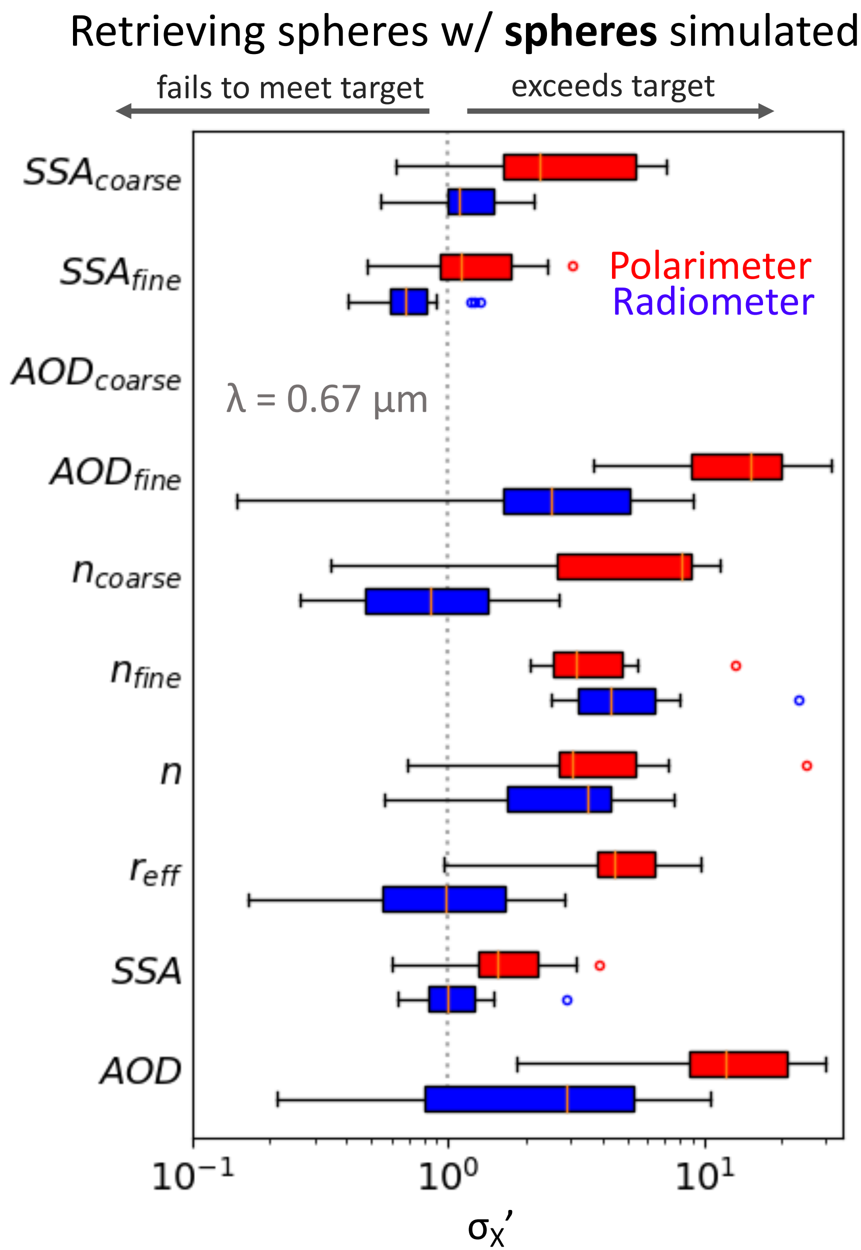
n = 0,1,2,…,56 trials per cases over 15 cases (840 retrievals per architecture)

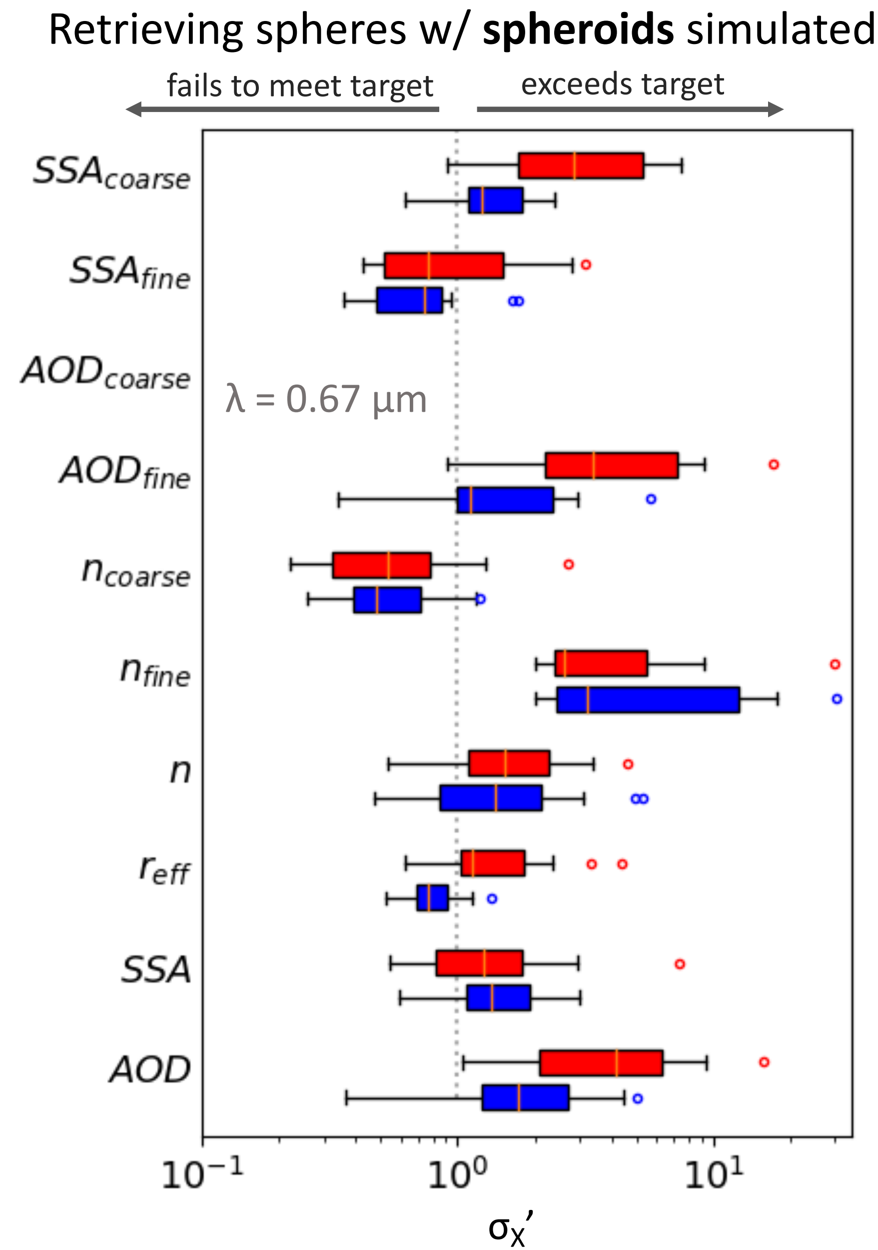
Geophysical Variable (GV)	Target Uncertainty
Total Aerosol Optical Depth	$\sigma_\tau = 0.02 + 0.05\,\tau$
Single Scattering Albedo	$\sigma_{SSA} = 0.02$
Aerosol Effective Radius	$\sigma_{reff} = 0.2\, r_{eff}$
Real Refractive Index	$\sigma_n = 0.02$

The total, fine and coarse mode σ_X all use the same target uncertainty values

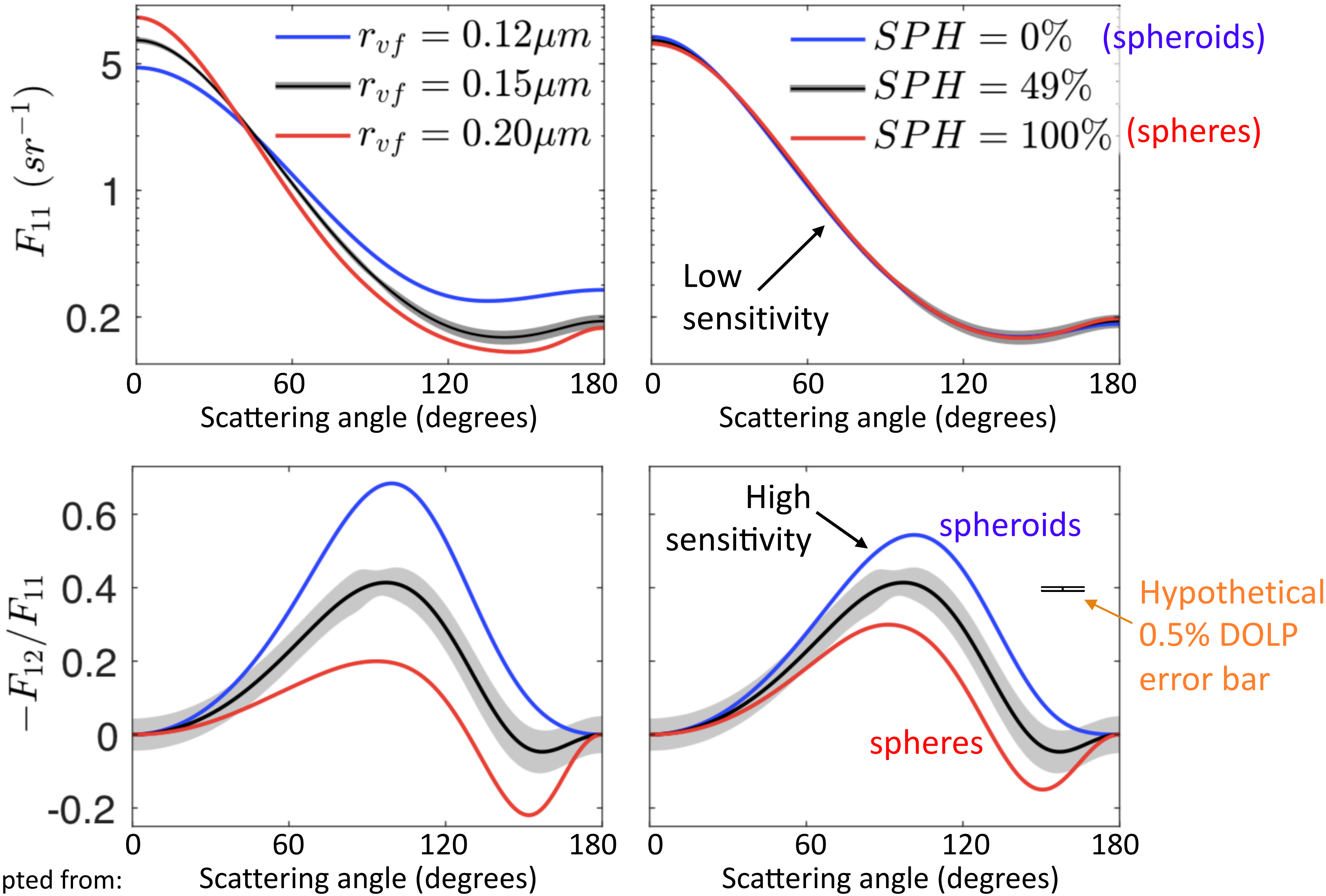


Simulating incorrect shape assumptions in retrievals





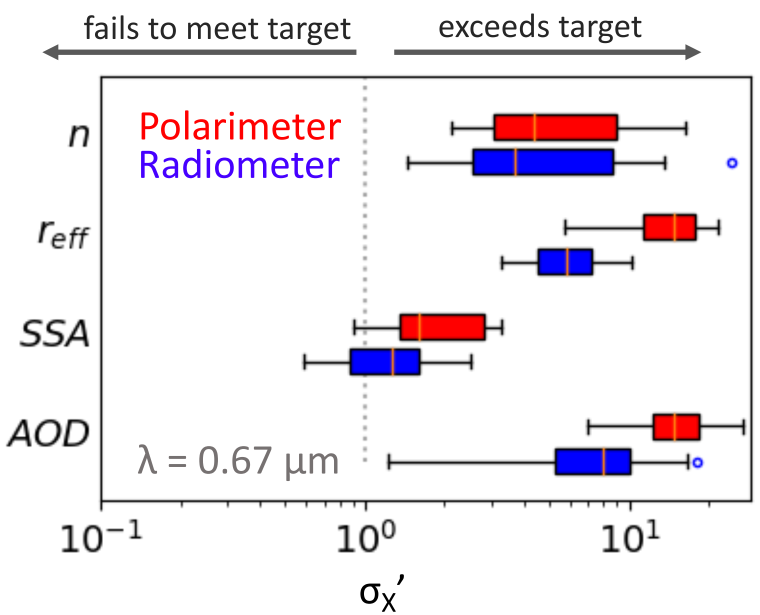
Fine mode angular scattering: spheres vs spheroids



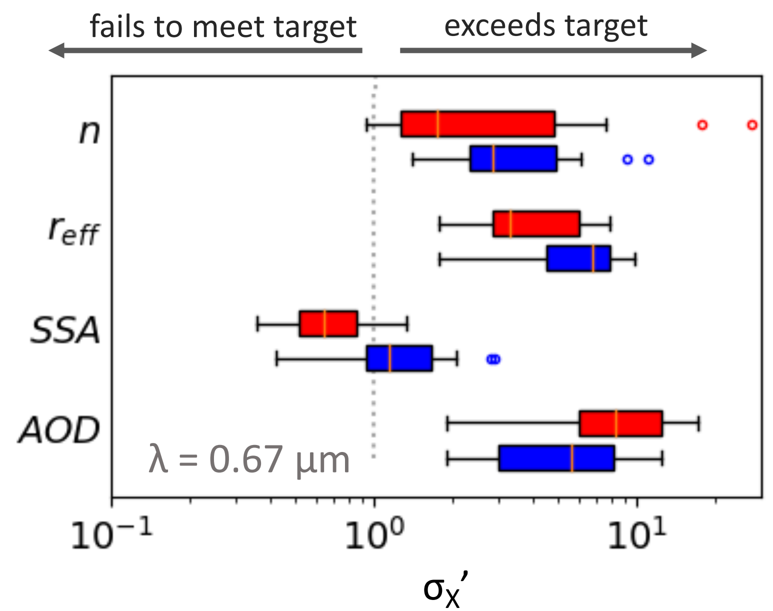
Adapted from: *Espinosa et al, (2019)*

Shape effects in scene with only fine mode aerosol

Retrieving spheres w/ **spheres** simulated



Retrieving spheres w/ **spheroids** simulated



Assuming spheres in the presence of fine mode spheroids has limited impact on radiometer retrievals but significantly degrades polarimeter retrieval. In many cases the radiometer now outperforms the polarimeter.

Summary

Conclusions:

- We can estimate retrieval sensitivities for various instruments combinations (polarimeter, LIDAR, etc.) using ensembles of pre-specified or GEOS Nature Run derived surface and aerosol properties

- Incorrectly assuming spherical particles degrades polarimetric retrieval quality more than inversion of only intensity
  - This is particularly true for a fine mode dominated aerosol

Future Work:

- Retrievals of GOES-NR OSSE simulations, explore limitations beyond pixel level uncertainties

- Explore retrieval accuracies under other modeling errors, including other particle morphologies, size distribution shapes, number of refractive indices, instrument error model, etc.