Light scattering by structurally complex lunar dust grains

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Why model light scattering?

To **characterize** the dust dispersed in the lunar environment
(either naturally or due to human activity)

Grain physical properties can be inferred from scattering:

- Intensity → 1^{st} order information on particle size.
- Polarization → particle size and morphology

Dust environment observables can be linked to **optical depth, dust scale height, grain size and morphology**.

Who or what benefits from accurate scattering models?

LCROSS, LRO, LADEE, etc.

Generally, any future remote sensing system designed to detect dust in orbit, at the surface, in habitat, etc. including missions to other airless bodies.

Light scattering models

No general solution to the Maxwell equations.

Mie solution ("Mie theory"):

> <u>Spherical and homogenous particles</u>
> Is the standard model (Analytical, easy to implement)

Numerical methods:

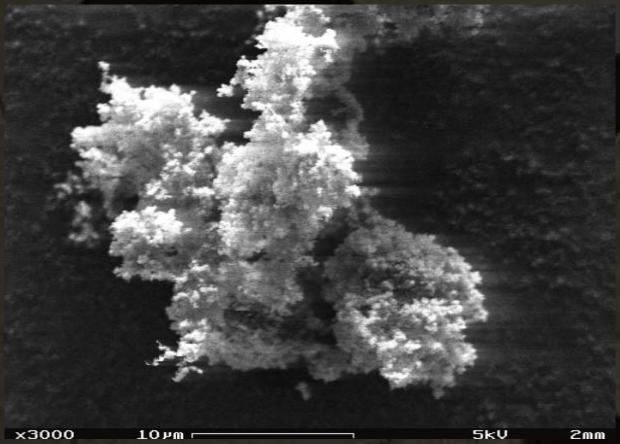
> Among which the **Discrete Dipole Approximation** (DDA)
>
> Continuum target approximated by an array of interacting dipoles ("coupled dipoles" approximation)
>
> Allows for simulation of scattering by <u>targets of arbitrary geometries and composition</u>.
>
> Limitations from computational cost.
> (Physical constraints on numerical resolution).

Structurally complex dust grains

Separated lunar dust grains morphology:

* Micron size +: typically irregular grains.
* Sub-micron: small aspect ratios: **relevance of non-spherical grain models?**

Sub-micron particulates are highly cohesive.



Typical microsilica aggregate

Exist mainly as aggregates
or as “parasites” onto larger grains.

Unless non-trivial separation processes are at work
(as in the laboratory.)

Lunar conditions increase particulates cohesion

Hard vacuum: inter-particle distances are reduced.
Reduced gravity: reduced load and therefore flowability.

Methodology

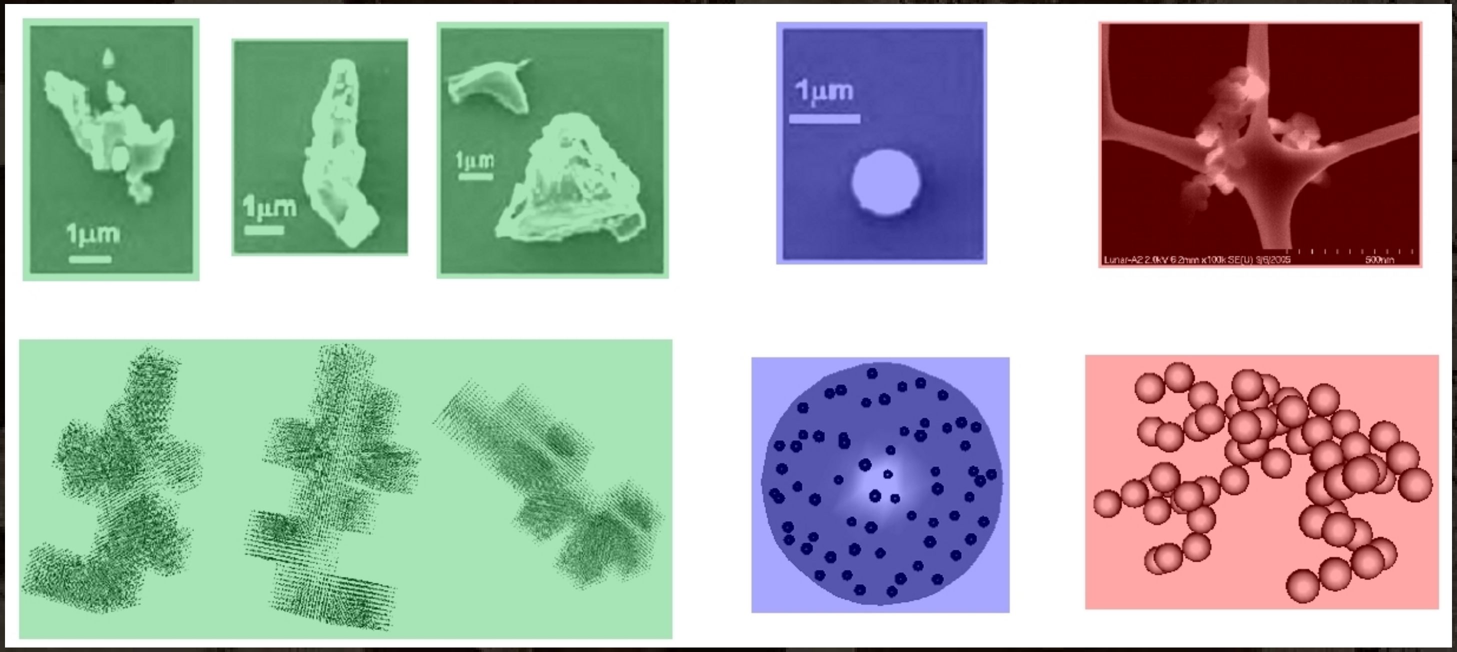
Pathway:

- Numerically model **individual dust grain:** Virtual Lunar Simulant;
- Compute **single grain scattering** signatures;
- Simulate **scattering by dust distribution**, as would be observed by optical instruments;
- **Validate** model; laboratory measurements;
- Support **interpretation of mission data** and **instrument design**.

Single grain modeling

Morphology:

Scanning Electron micrographs
(Park et al. 2006, Greenberg et al. 2007)



Numerical models
("Virtual Lunar Simulant")

Composition:

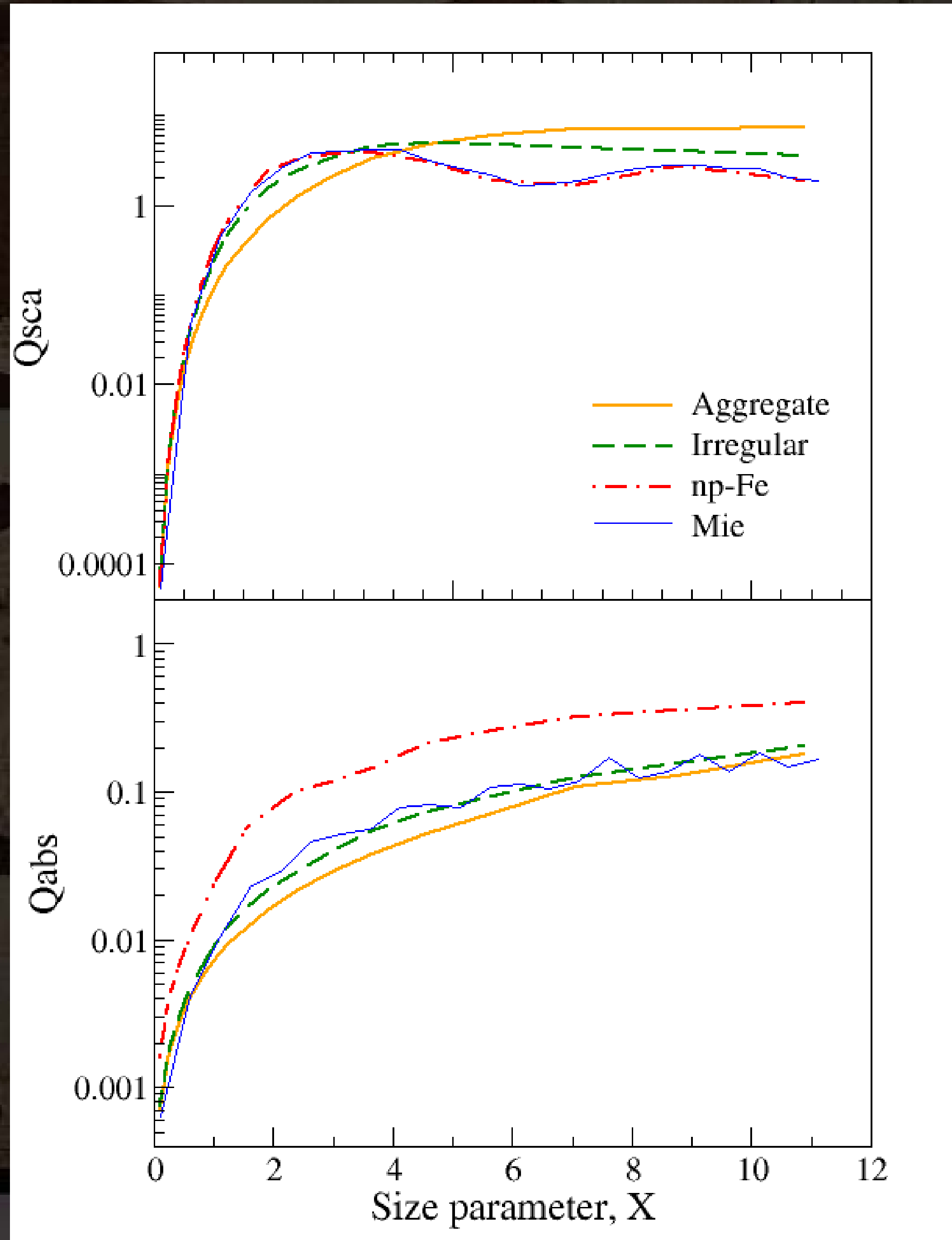
Index of refraction: silicate, no wavelength dependence.
Nano-scale Iron inclusion.

Single grain: scattering efficiencies

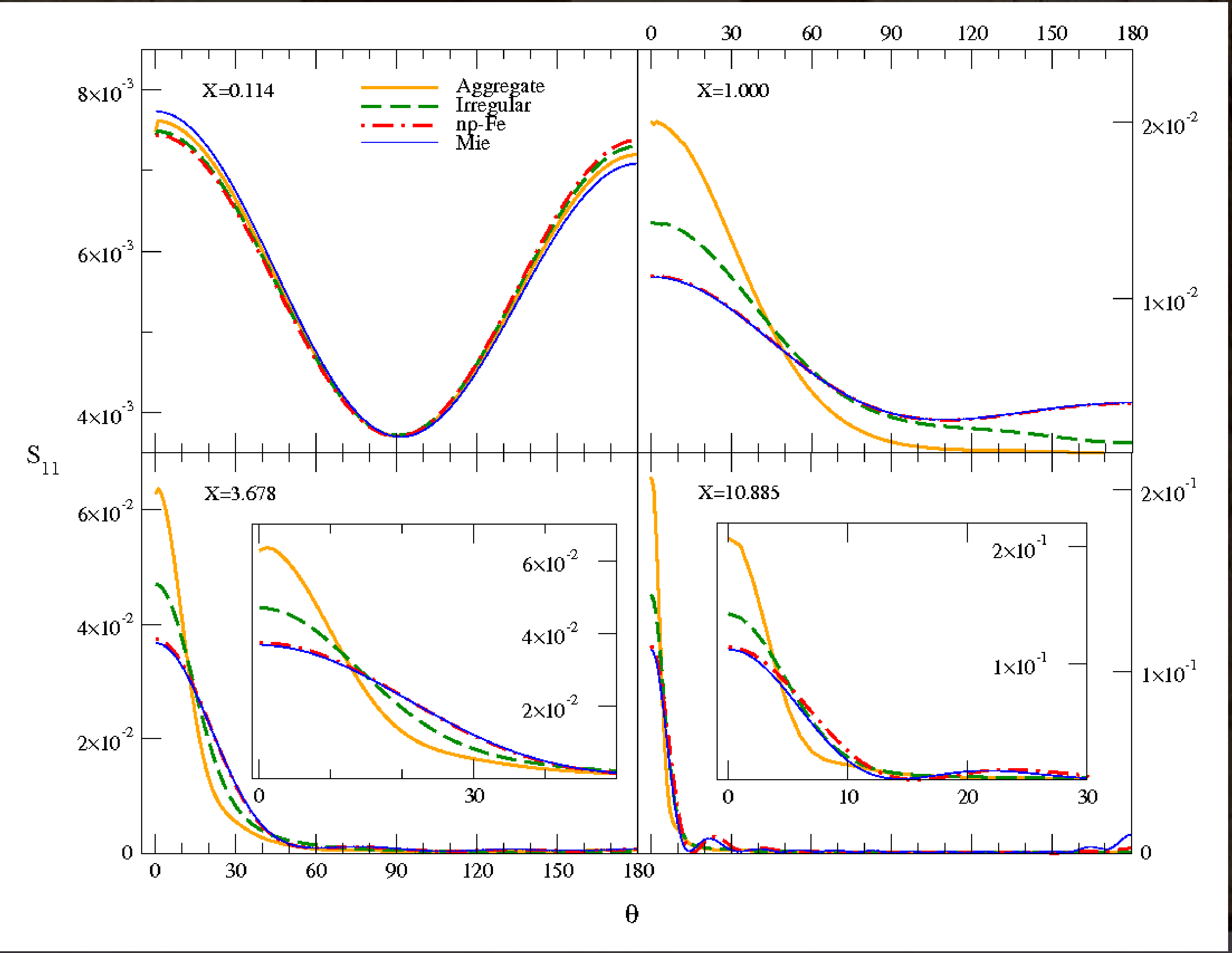
Efficiencies
$Q_{sca/abs}=C_{sca/abs}/\pi a^2$

Size parameter:
$X=ka=2\pi a/\lambda$

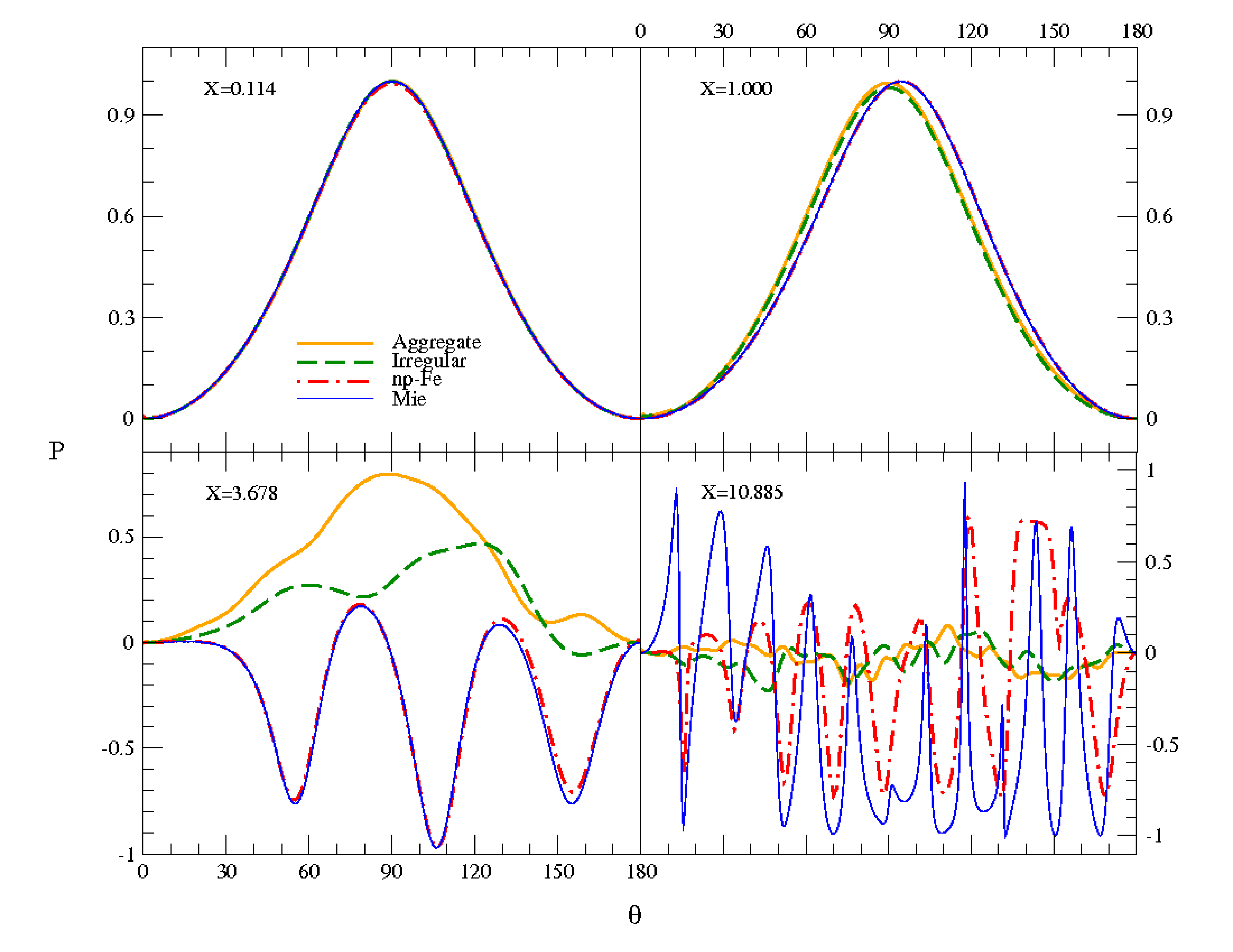
$X=10$
If $\lambda=628nm$
then $a=1\mu m$



Single grain: scattered intensity



Single grain: polarization



Radiative transfer model

NMSU scattering code, developed and operated by Dave Glenar;

Developed to simulate measurement by the LADEE UVS;

Models spectral intensities and polarization of sunlight scattered by dust, using an assumed dust vertical distribution, dust optical properties and instrument observing configuration.

Objectives:

Quantify **linkages** between **measured scattered light** and dust **physical properties and distribution**;

Define optical measurements that are **diagnostic** of dust properties;

Better **understand the limitations** of optical scattering measurements;

Guide the design of optical instruments designed to measure the lunar dust environment.

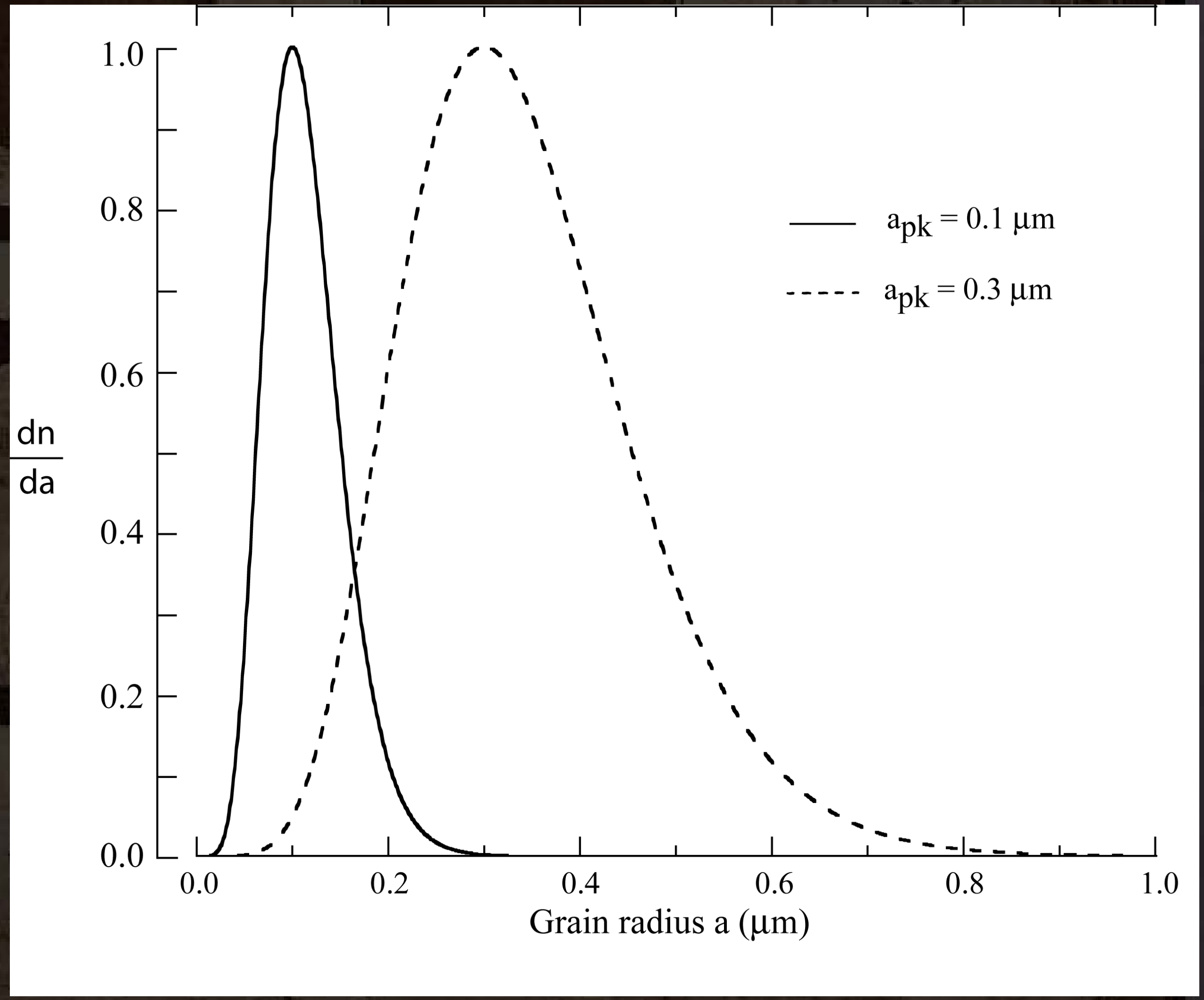
Size distribution

Hypothetical size distribution:

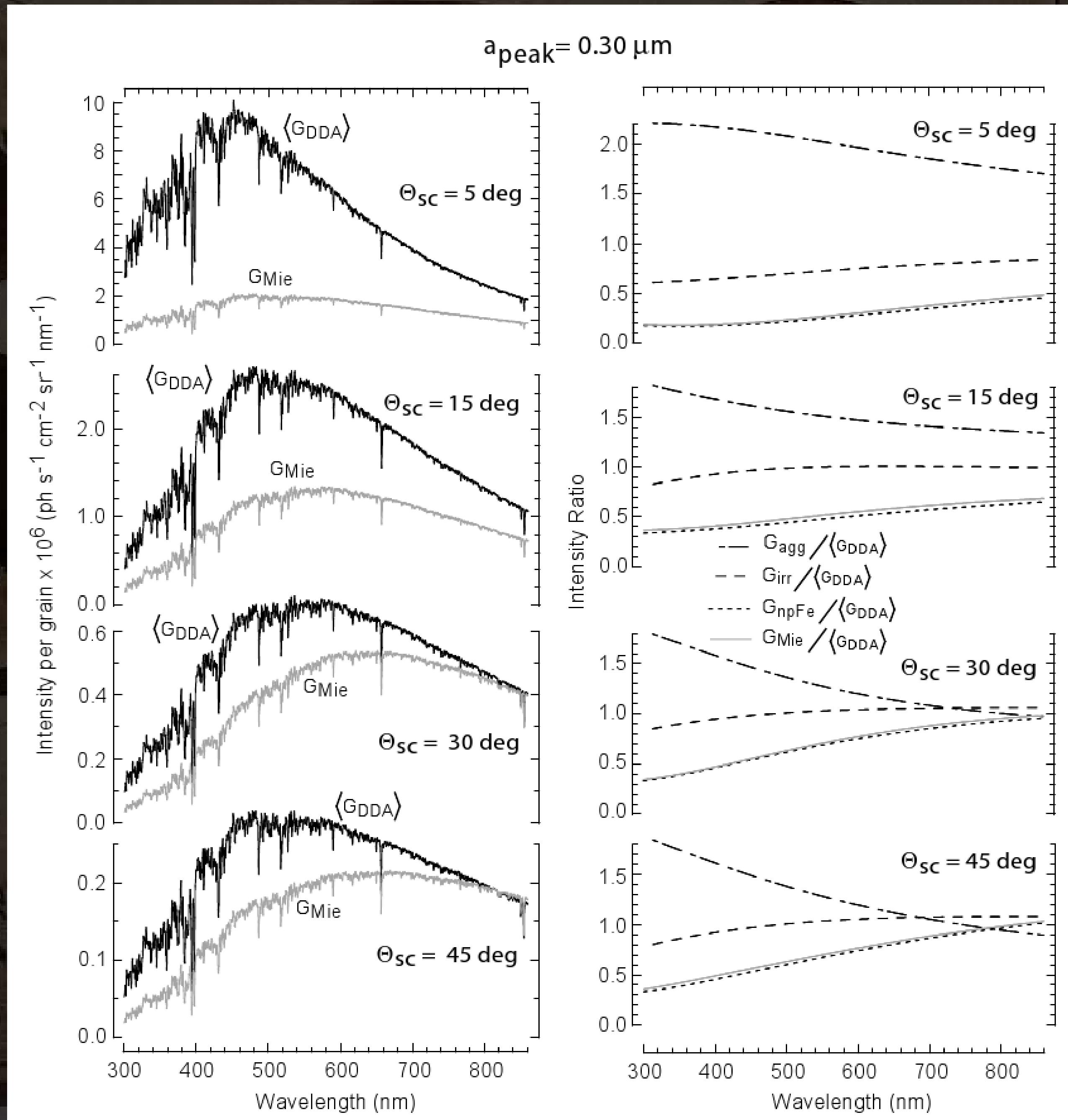
Gamma distribution (typical cloud and dust aerosols model)

Equal part-by-volume mixtures of the three grain models shown earlier.

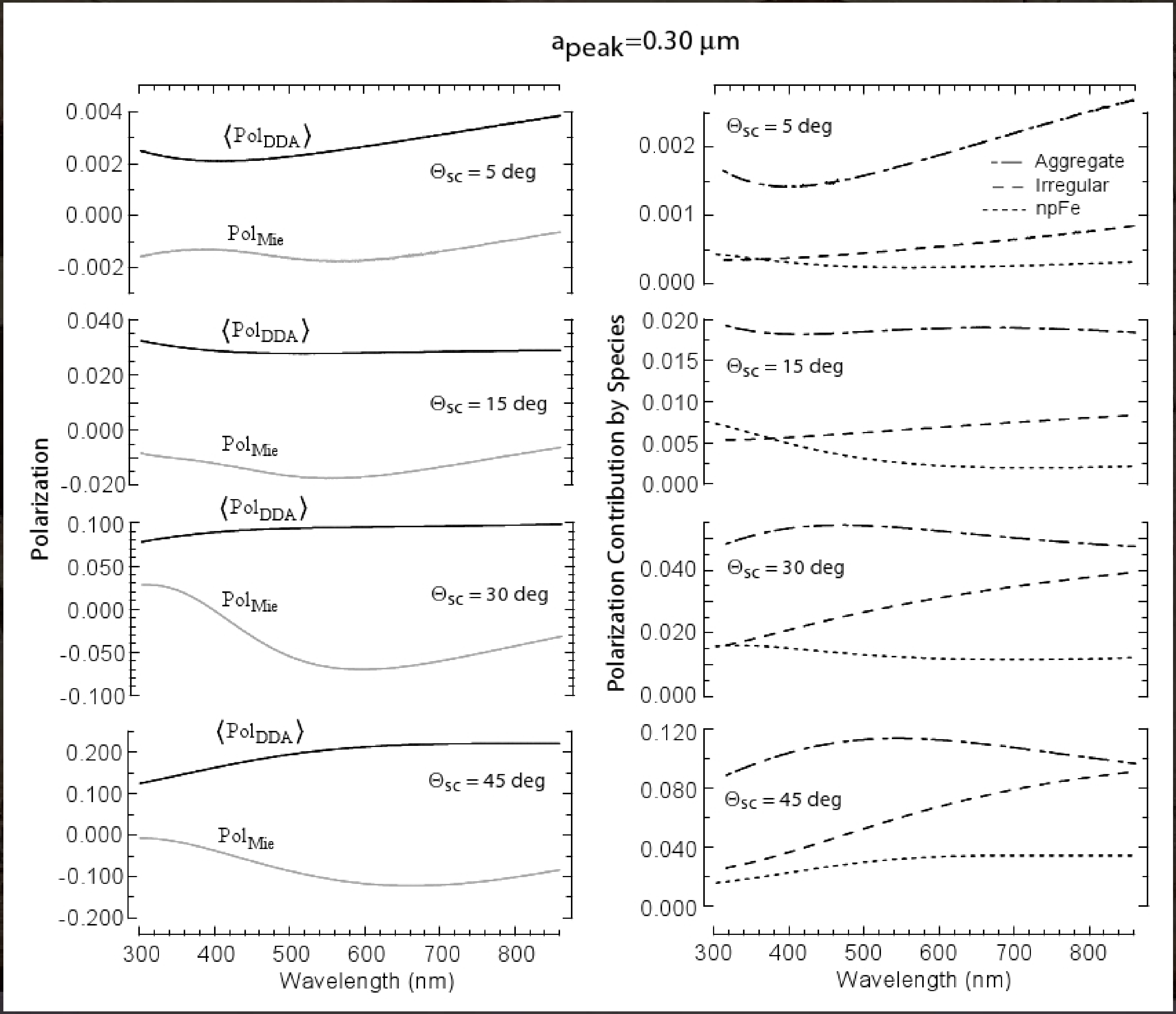
Peak at 0.3 micron in this demonstration.



Scattered Intensity



Polarization



Conclusions & future developments

Interpreting data based on Mie can lead to significant errors.

Results presented are a demonstration of models and team capabilities.

Major applications:

- Mission data interpretation.
- Provide input for instrumentation design
  (in orbit, at the surface, LIDAR, weather stations, etc.)

Upcoming improvements:

- Populate particle zoology. (Virtual Lunar Simulant)
- Define morphology dependent size distributions.
- Realistic dust density distributions.