# Fractal aggregates of sub-micron-sized grains in the young planet-forming disk around IM Lup


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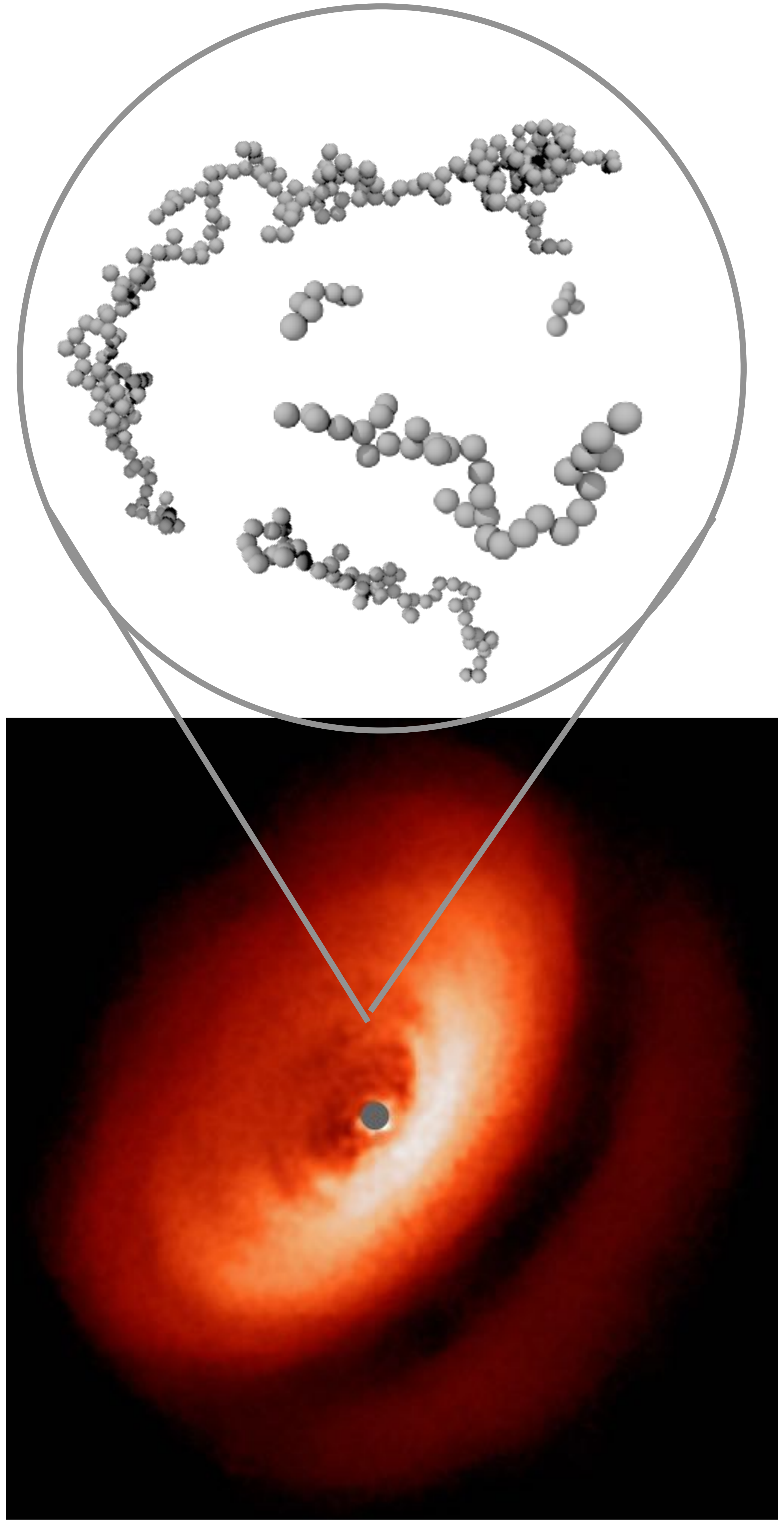
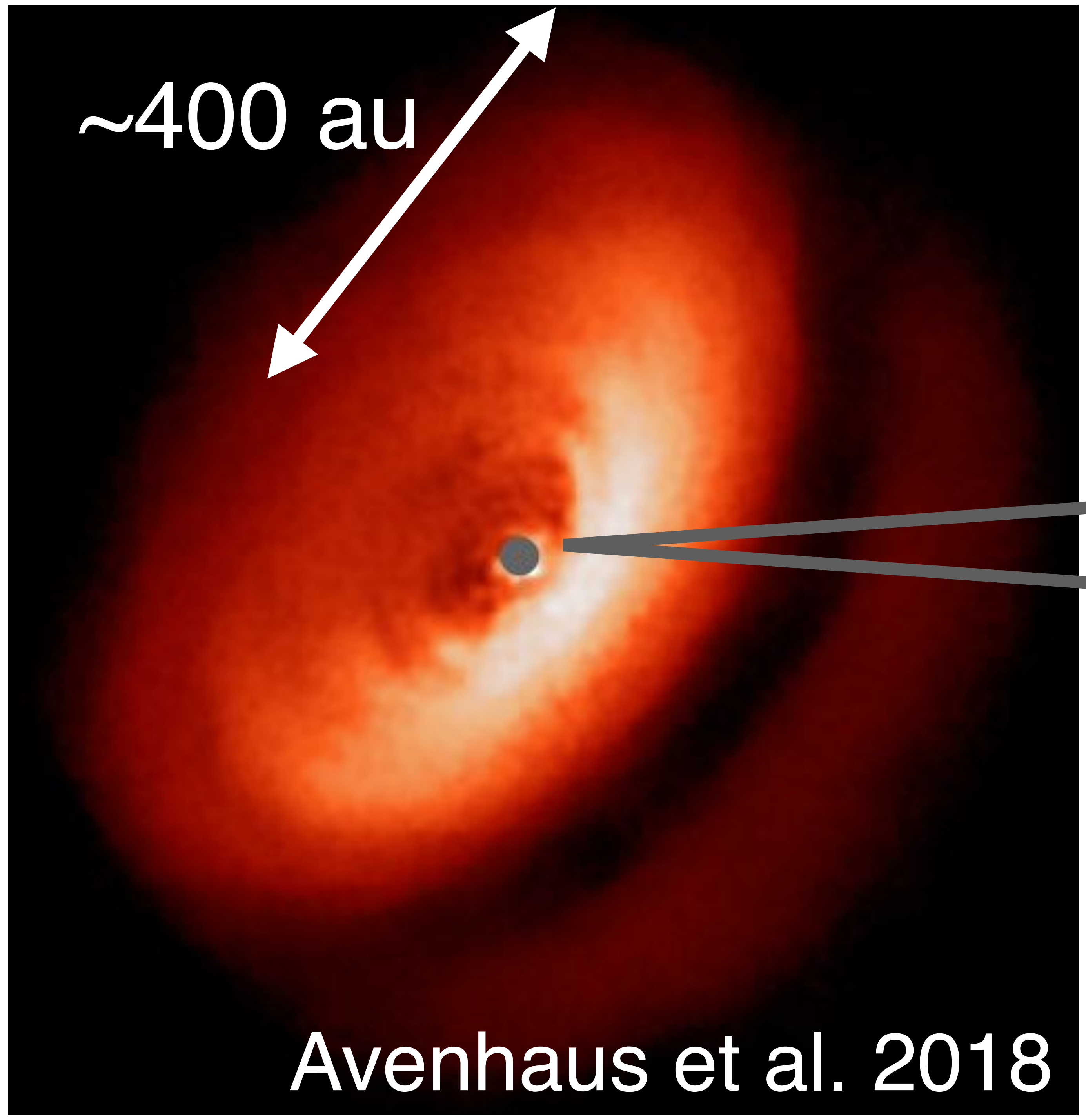
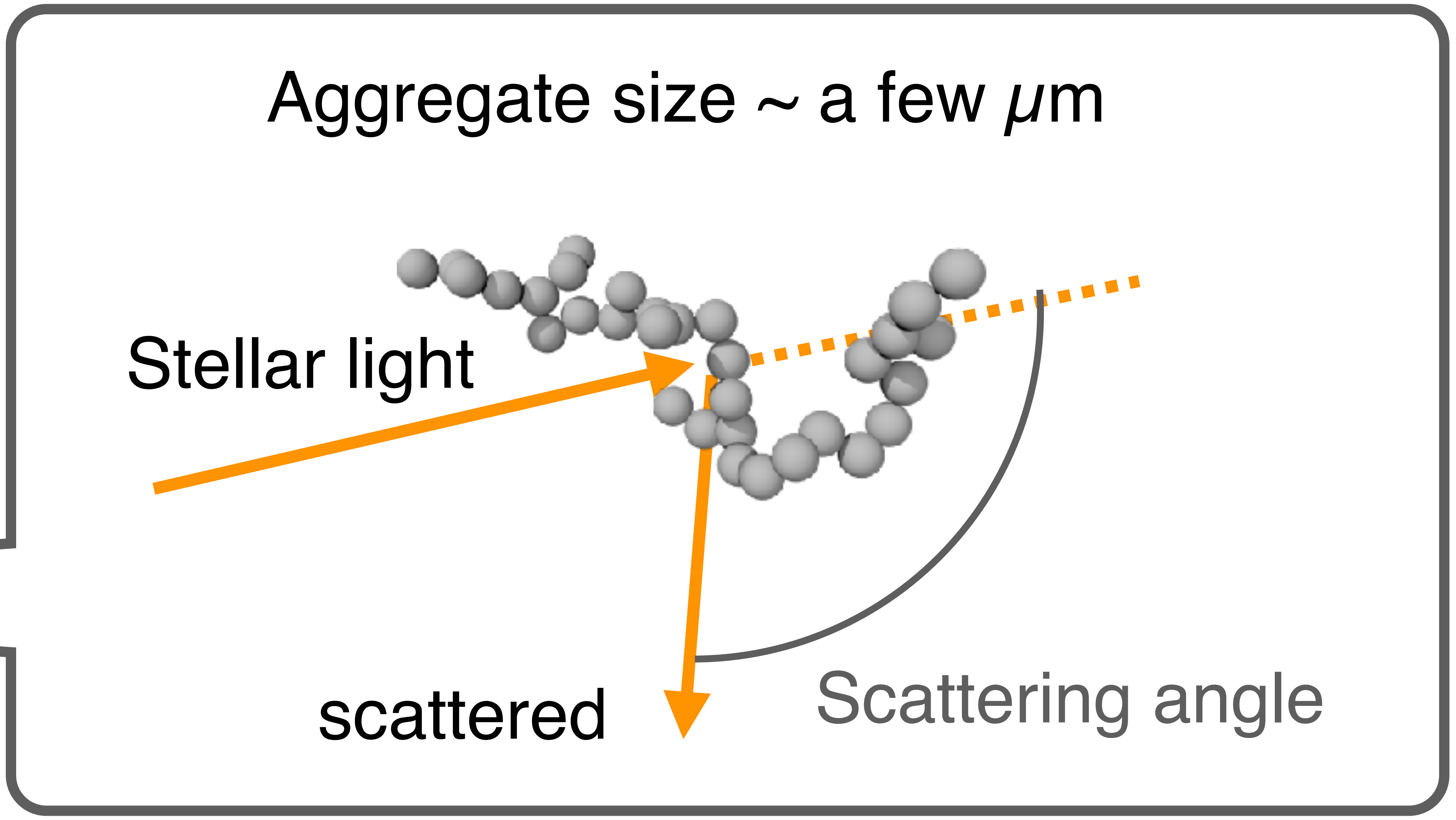
Carsten Dominik (University of Amsterdam)

# Near-IR scattered light of the IM Lup disk

Near-IR scattered light image
by VLT/SPHERE
(polarized intensity)



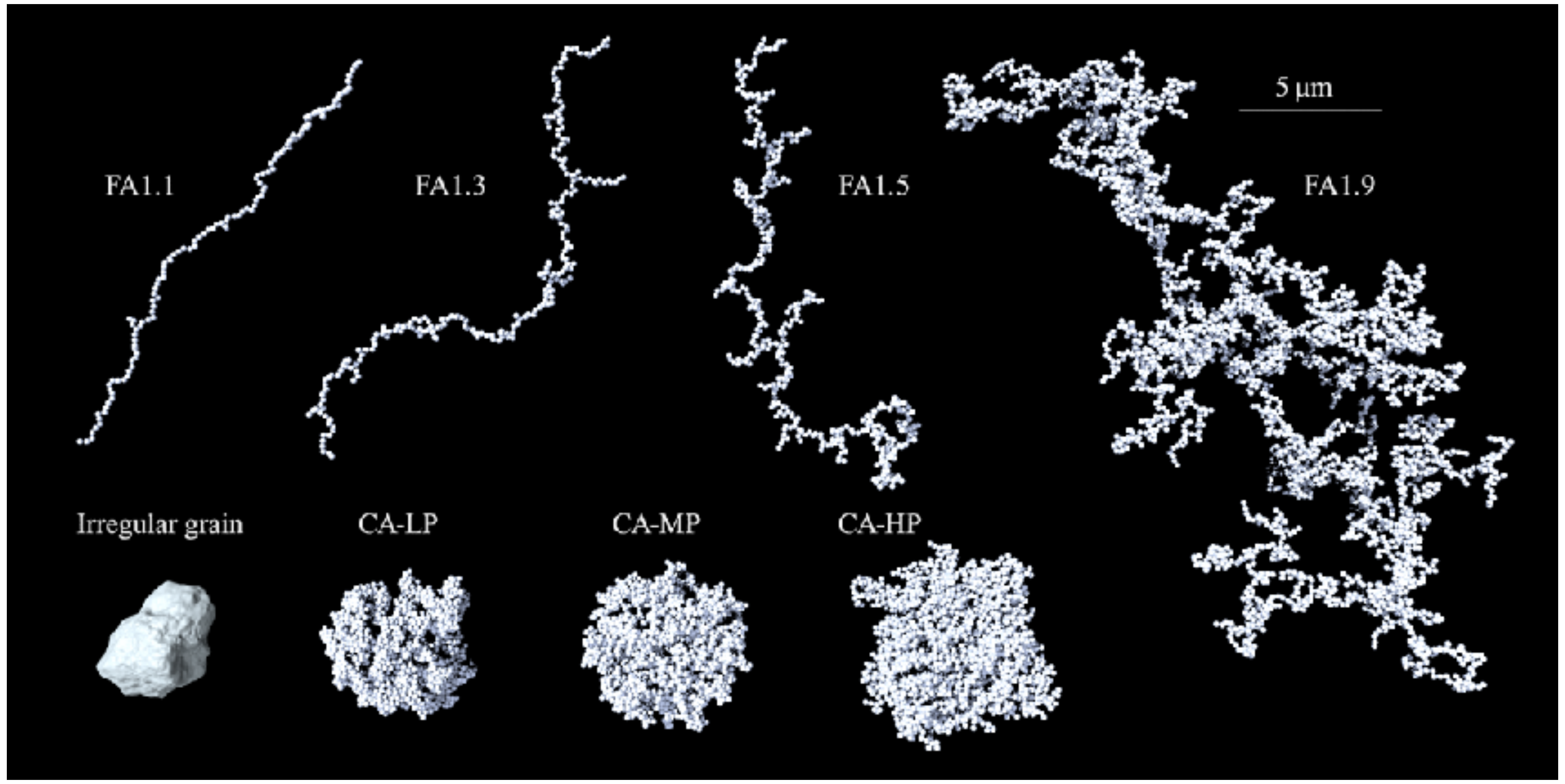




**What do the scattered light images tell us about dust properties?**

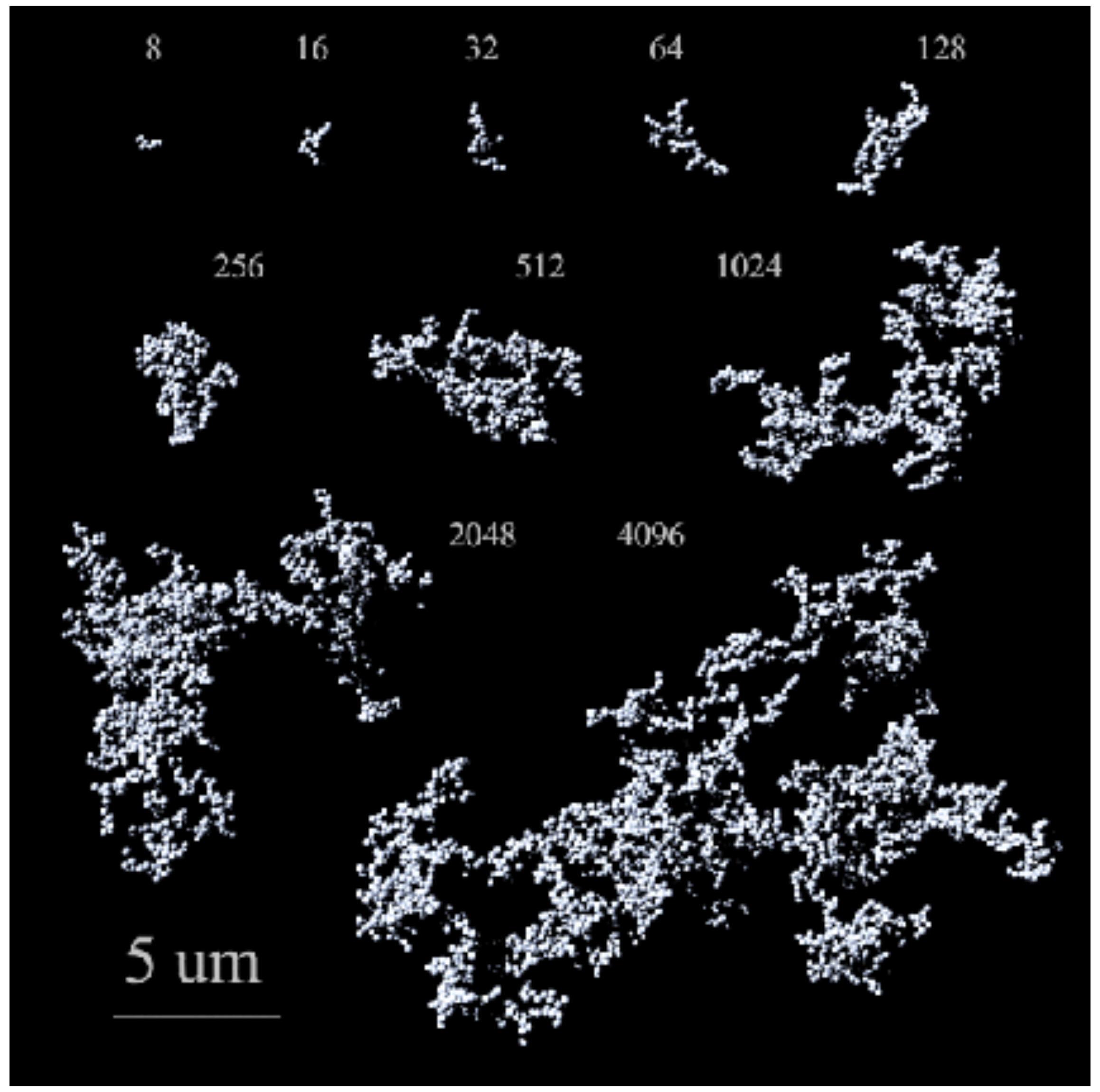
# Light scattering database: AggScatVIR

*Tazaki et al. (2023)*
*Tazaki and Dominik (2022)*

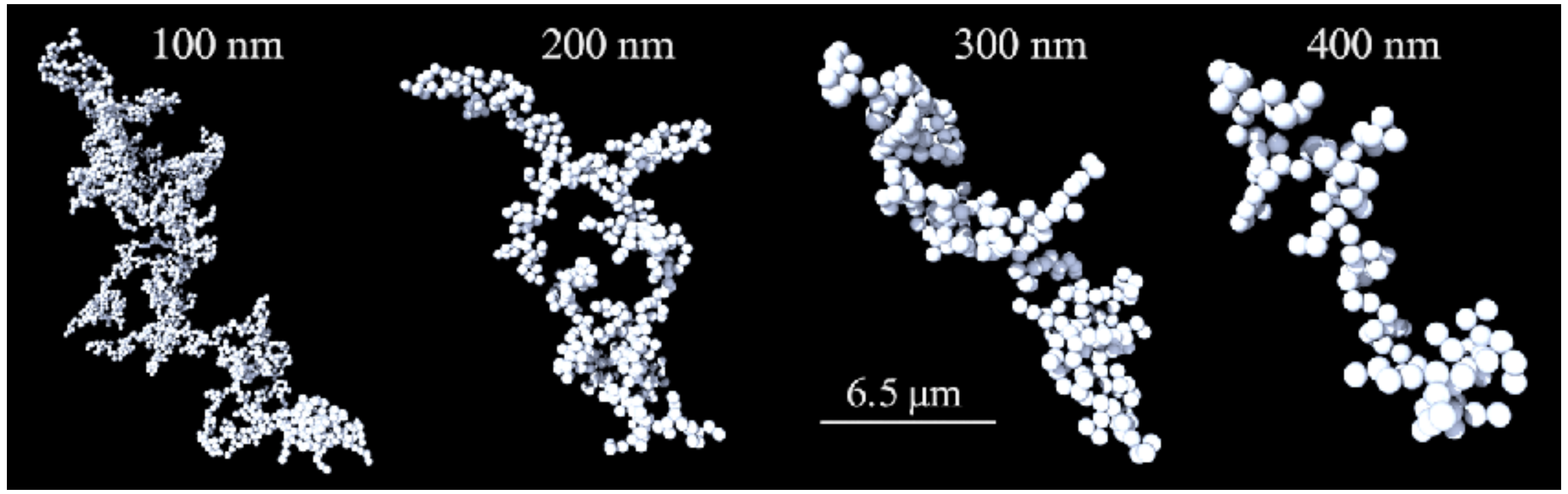
## Particle shape models (8 types)



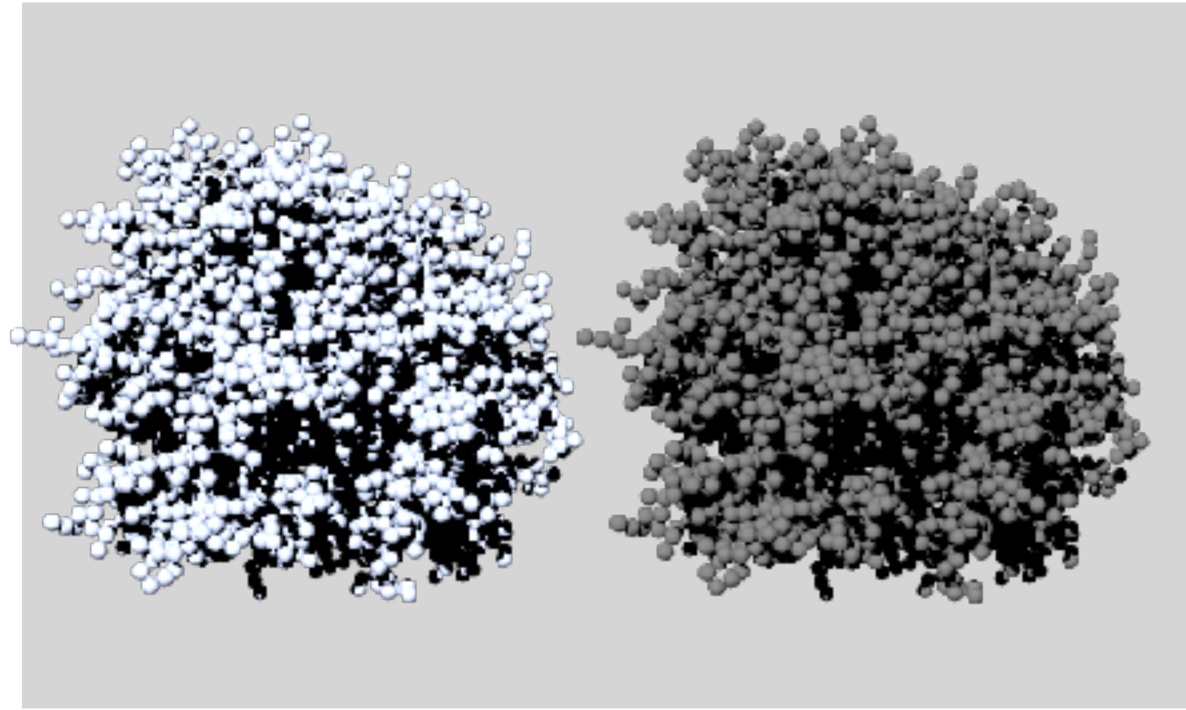

## size distribution




## Different monomer radius (0.1, 0.2, 0.3, 0.4 µm)




## Two compositions



**360 sets of dust models**

Light scattering simulations:

- T-matrix method
  with MSTM code v3.0
  Mackowski & Mishchenko 2011
- DDA with ADDA
  Yurkin & Hoekstra 2011

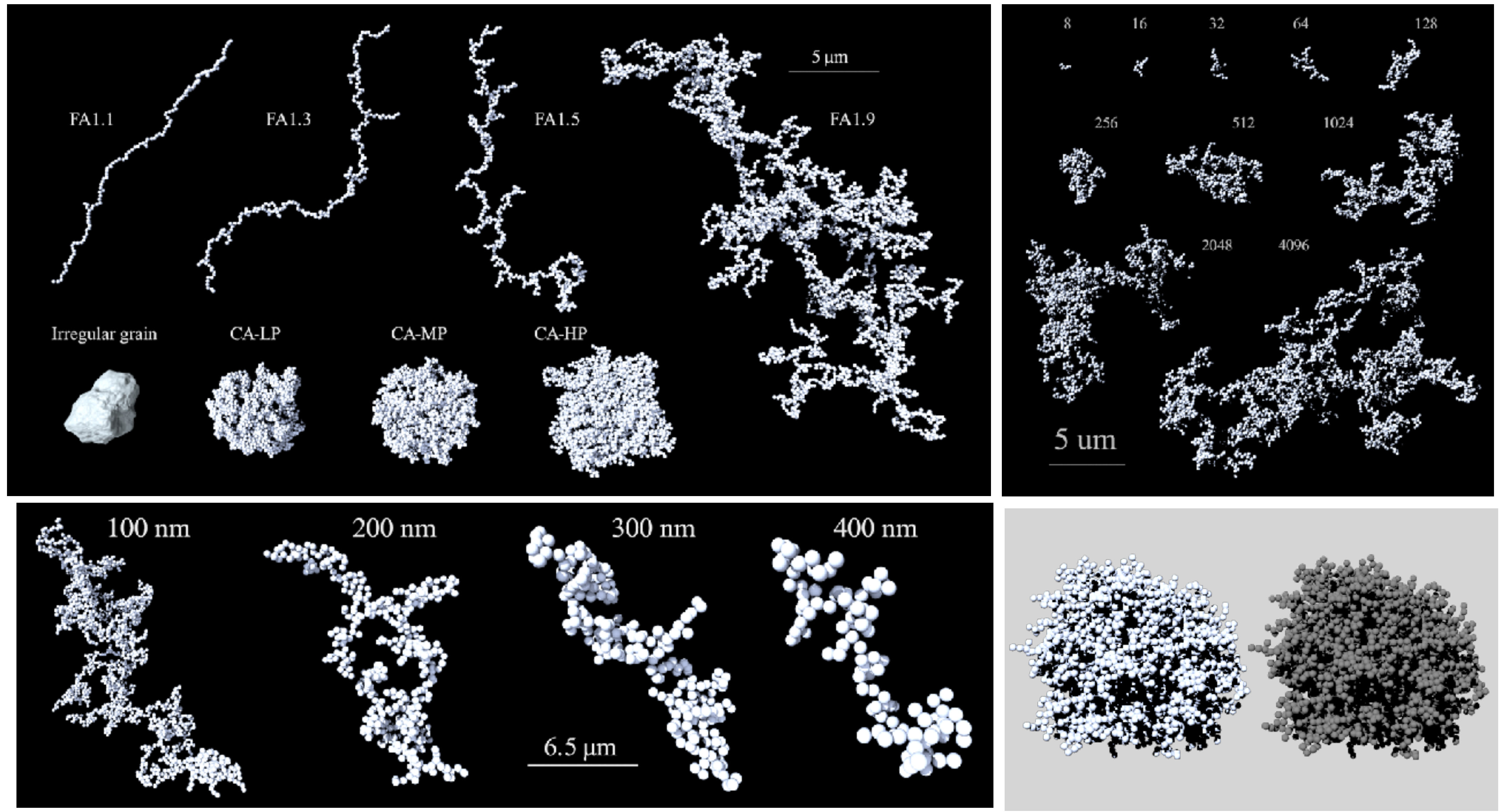
Random Orientation

Dust composition:

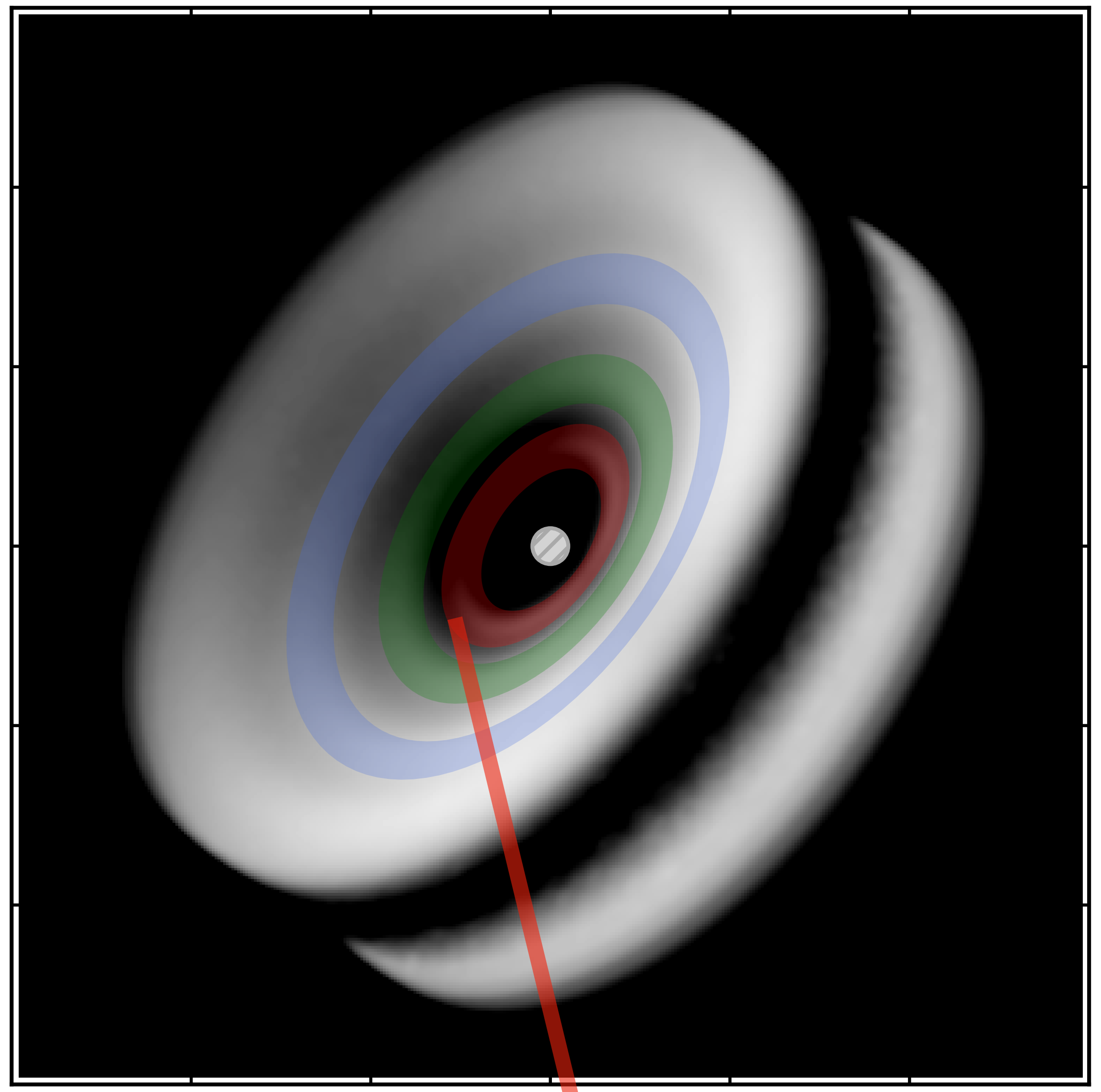
- High albedo model
  carbon form: refractory organics
  i.e. DSHARP like; Birnstiel et al. 2018
- Low albedo model
  carbon form: amorphous carbon
  i.e. DIANA like; Woitke et al. 2016

# Radiative transfer simulations of the disk

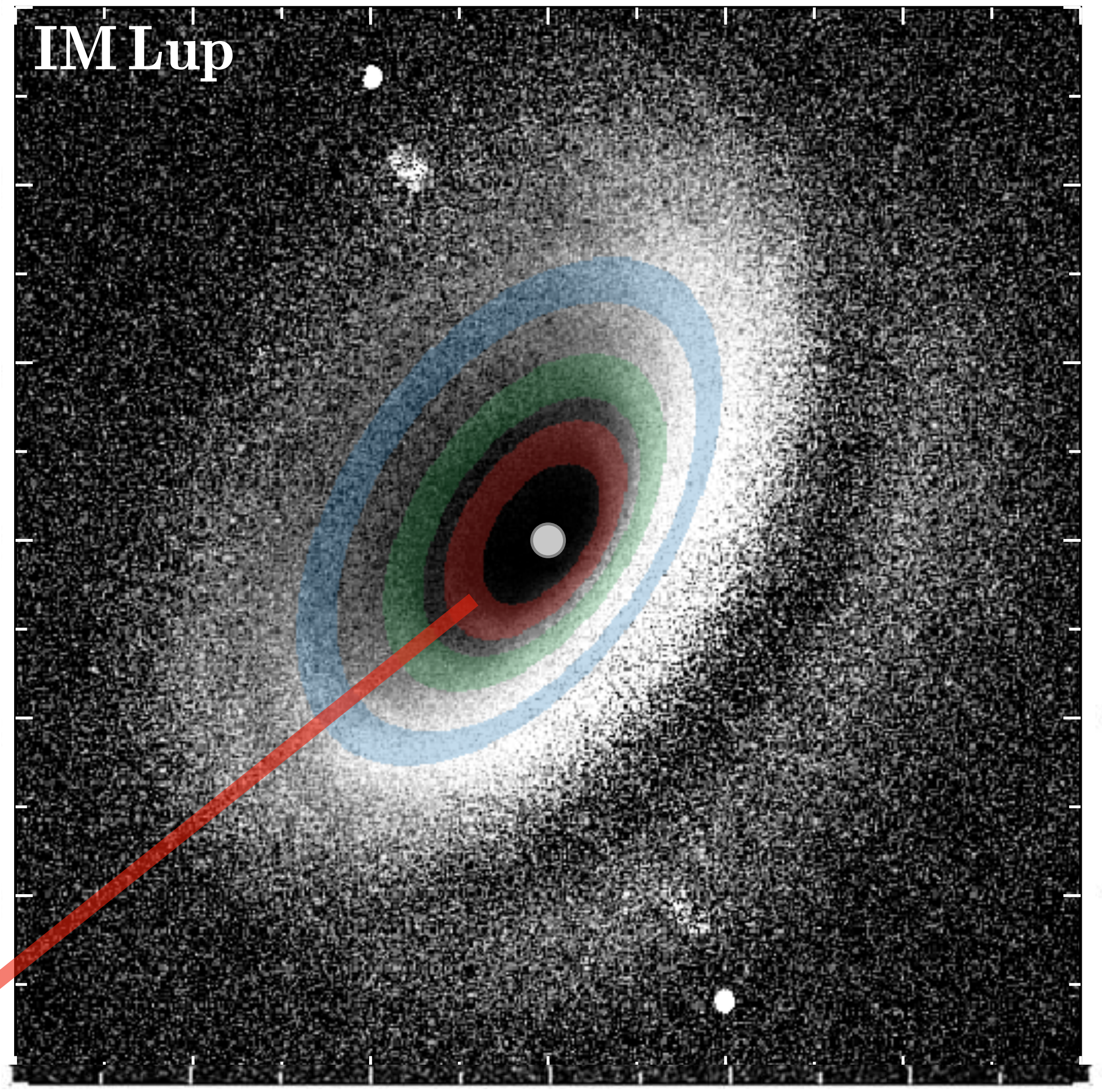
Dust scattering database




Radiative transfer
(RADMC-3D; Dullemond+12)



VLT/SPHERE
(Avenhaus+18)

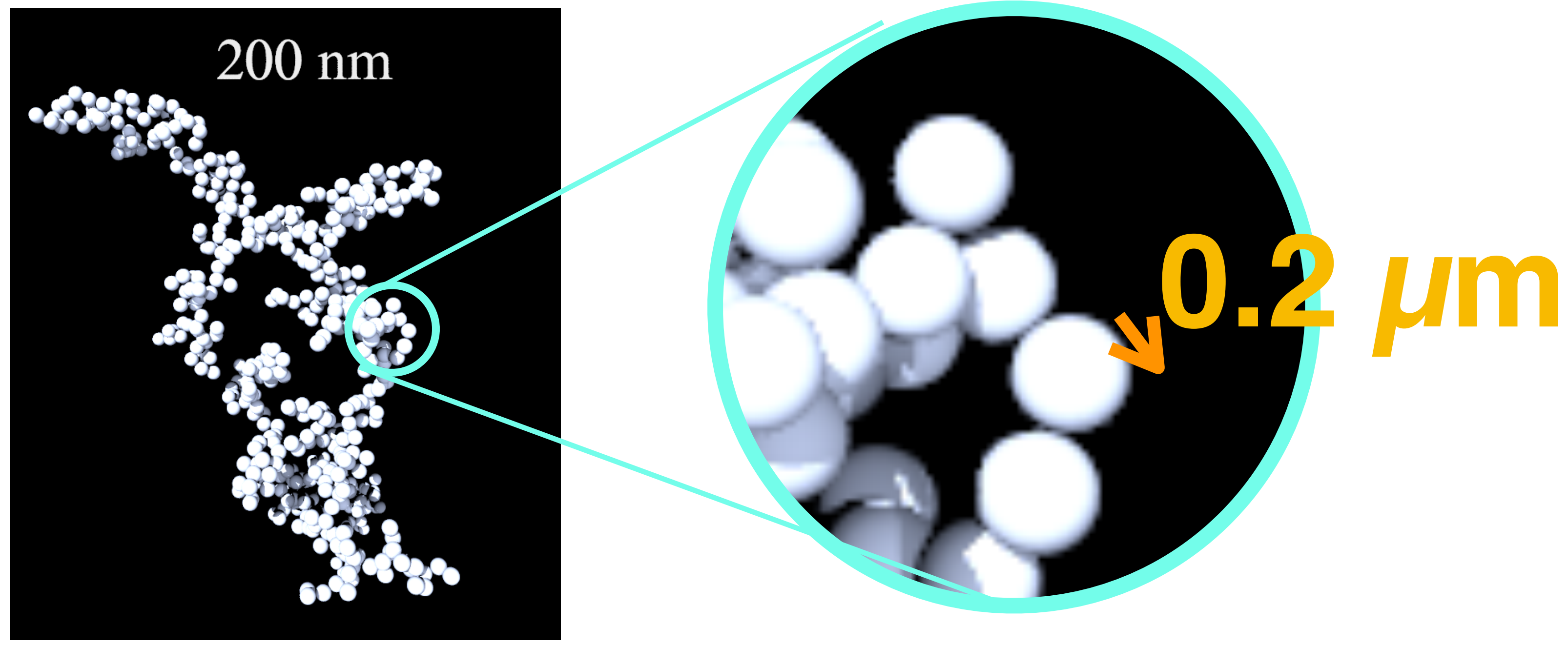


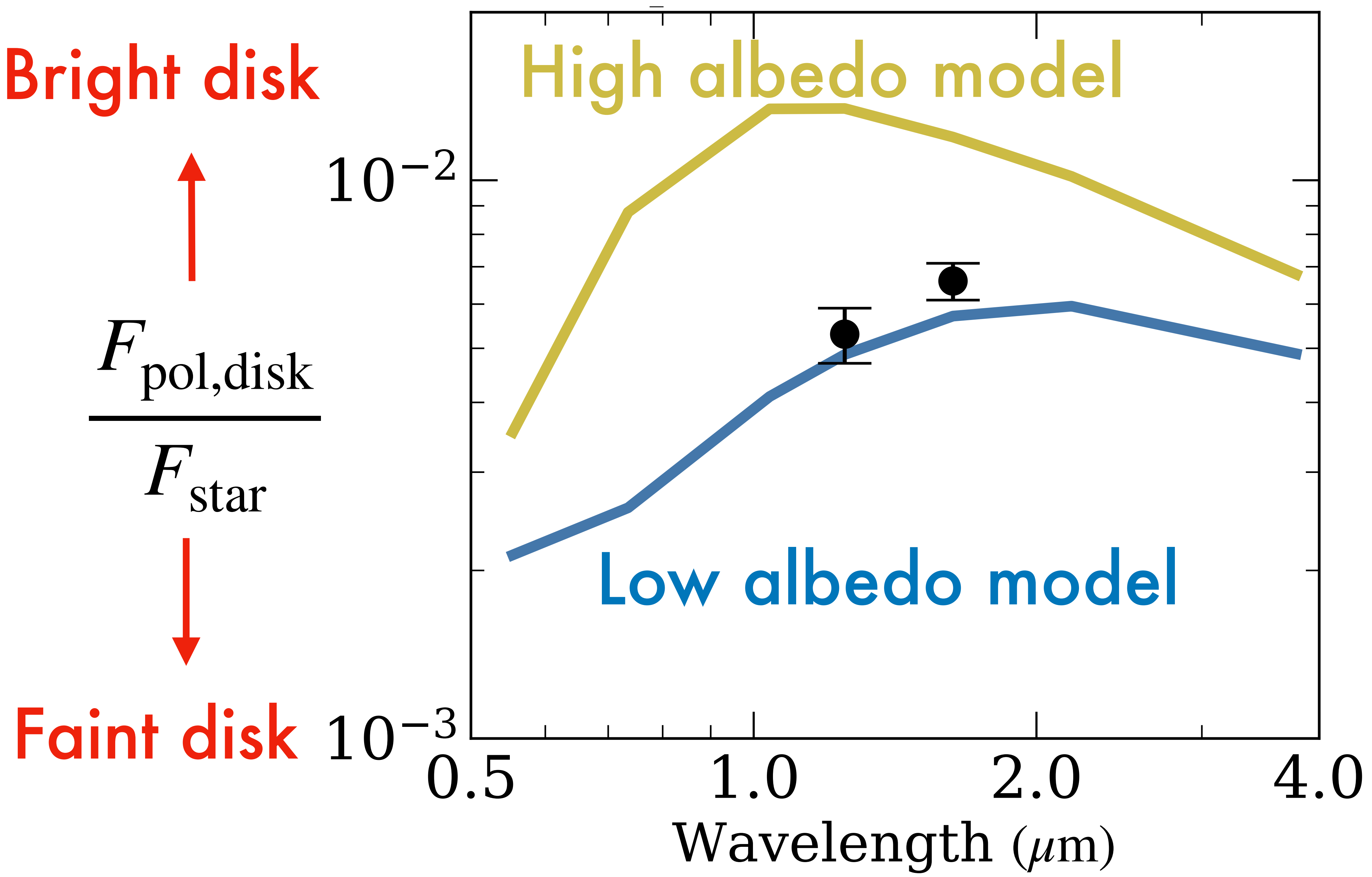

Disk model:
- Disk geometry (Avenhaus+18)
- Dust mass (fiducial: Zhang+2021)
  (another parameter)

- Disk polarized flux
- Scattering angle dependence of polarized intensity at 90 au, 150 au ('polarization phase function')

# Low albedo vs. high albedo composition

*Type: Fractal aggregates (Df=1.9; BCCA)*
*Size: $a_{min}$=2$a_{mon}$, $a_{max}$=6.5 μm, p=−3.5*
*Monomer radius: 0.2 μm*



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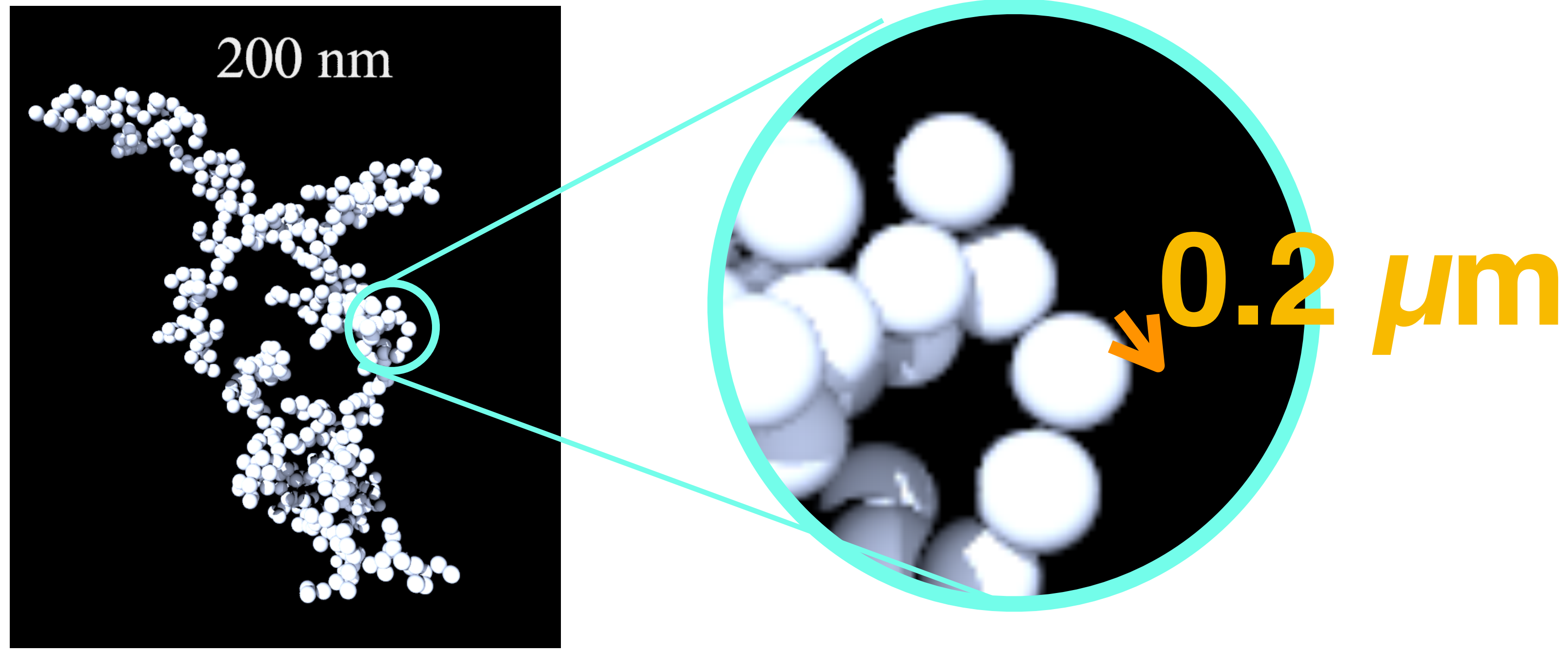
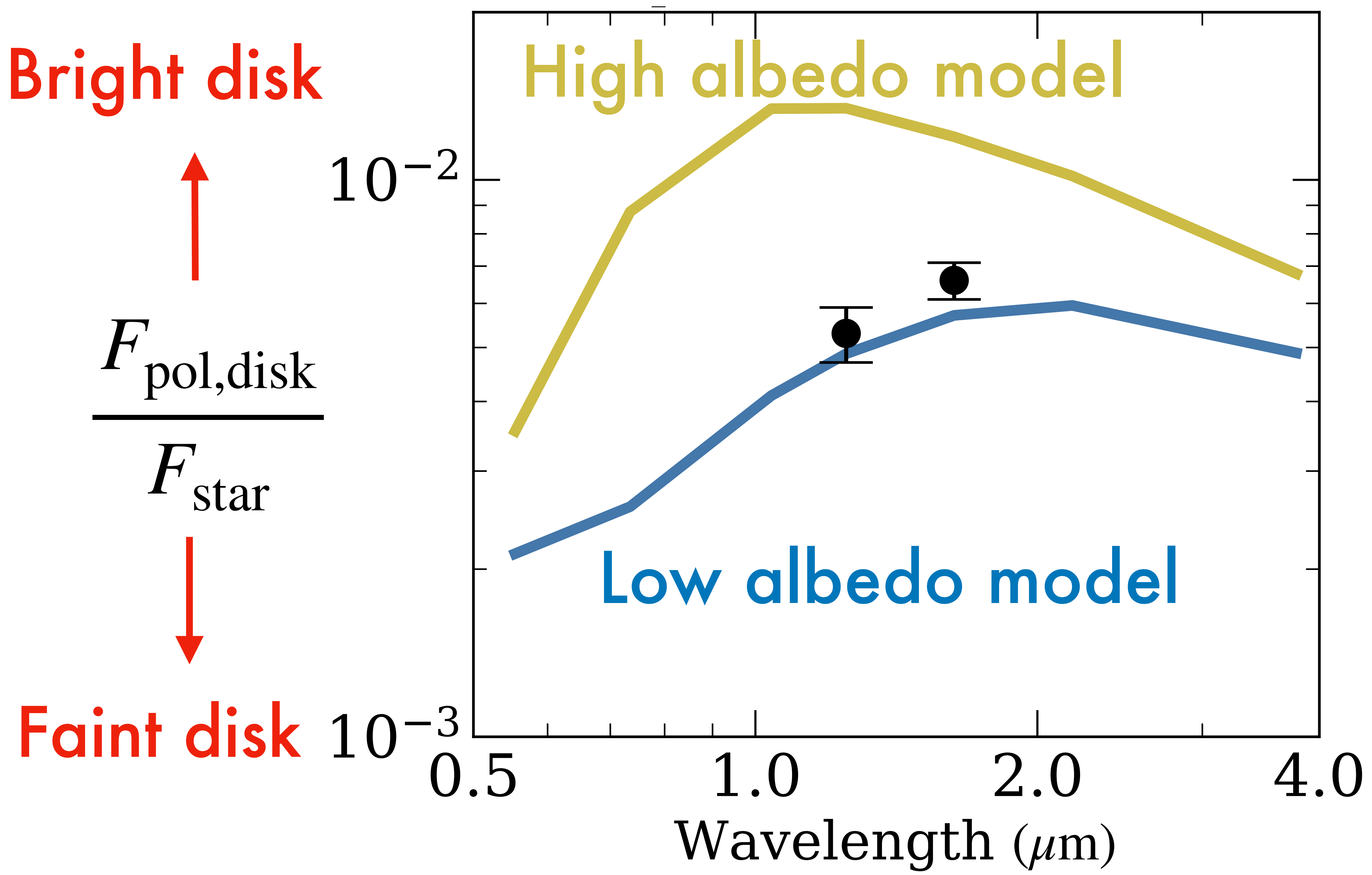
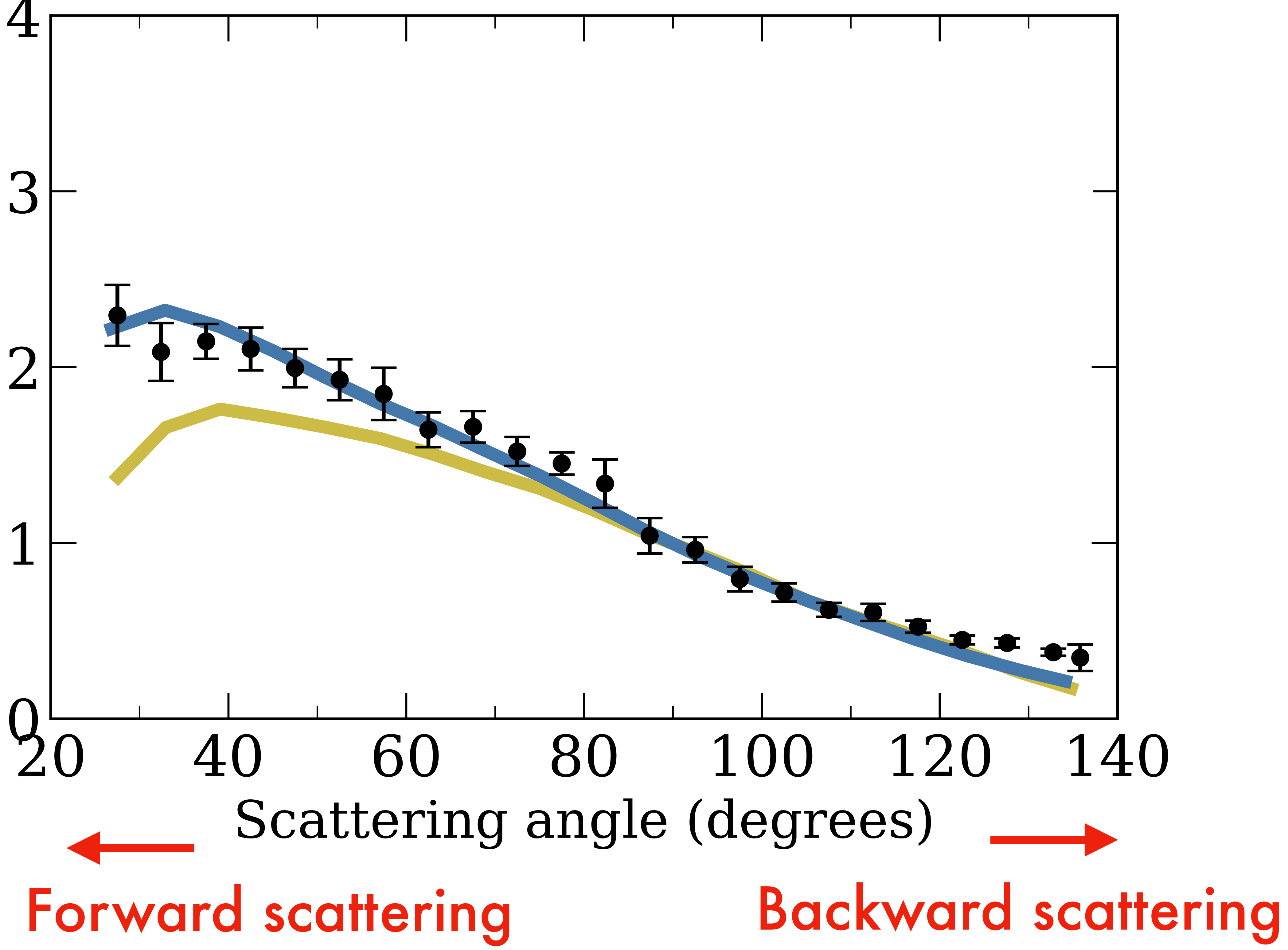


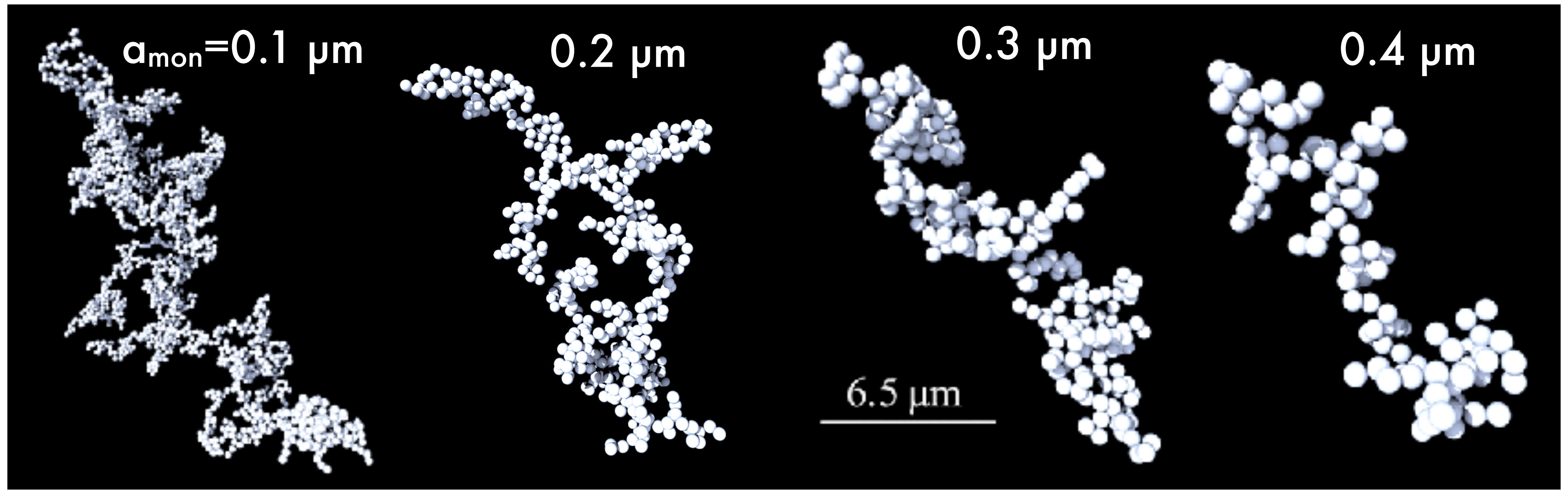

Low-albedo model is favored!

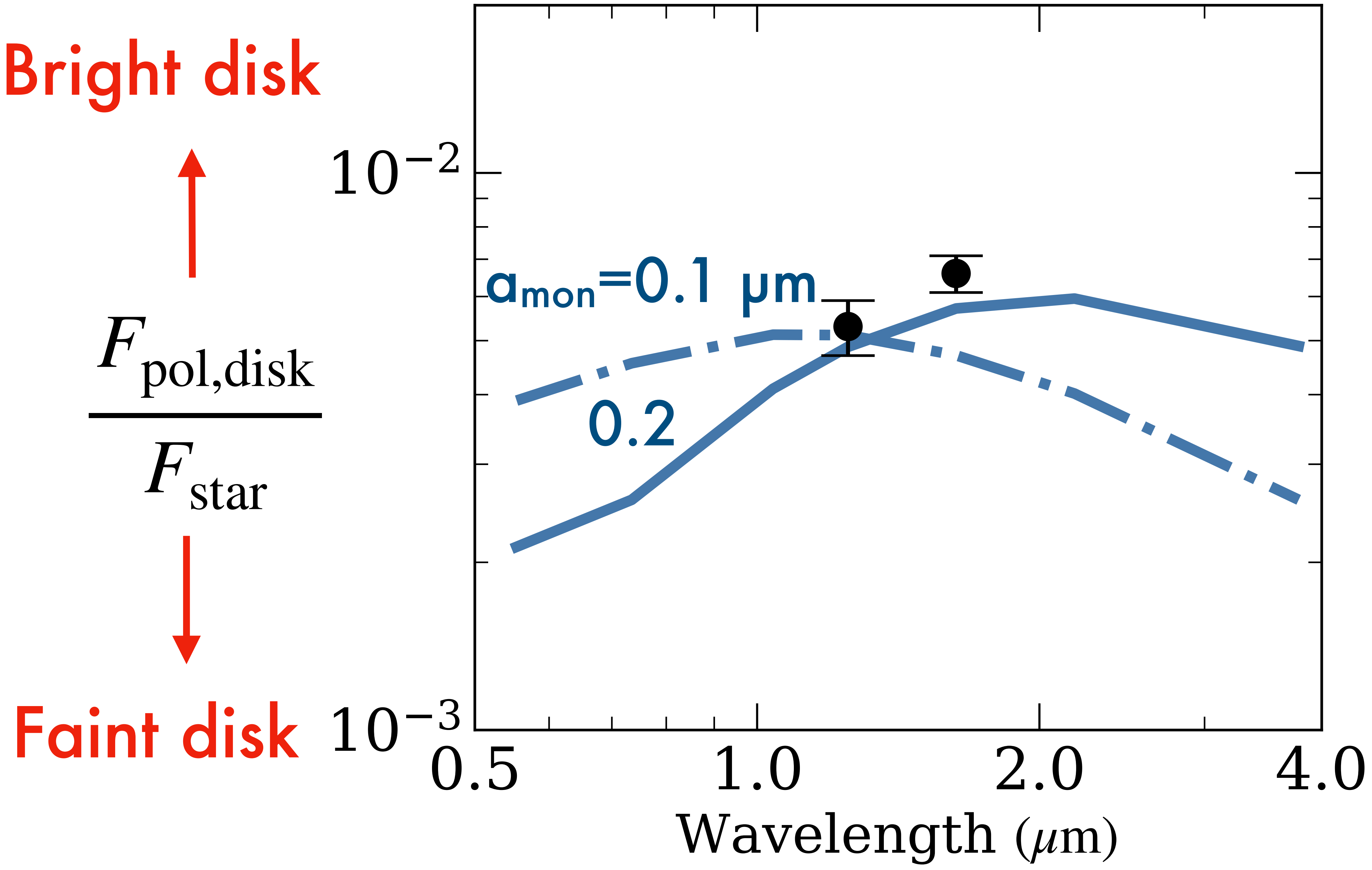
Polarization phase function (normalized to 90°)



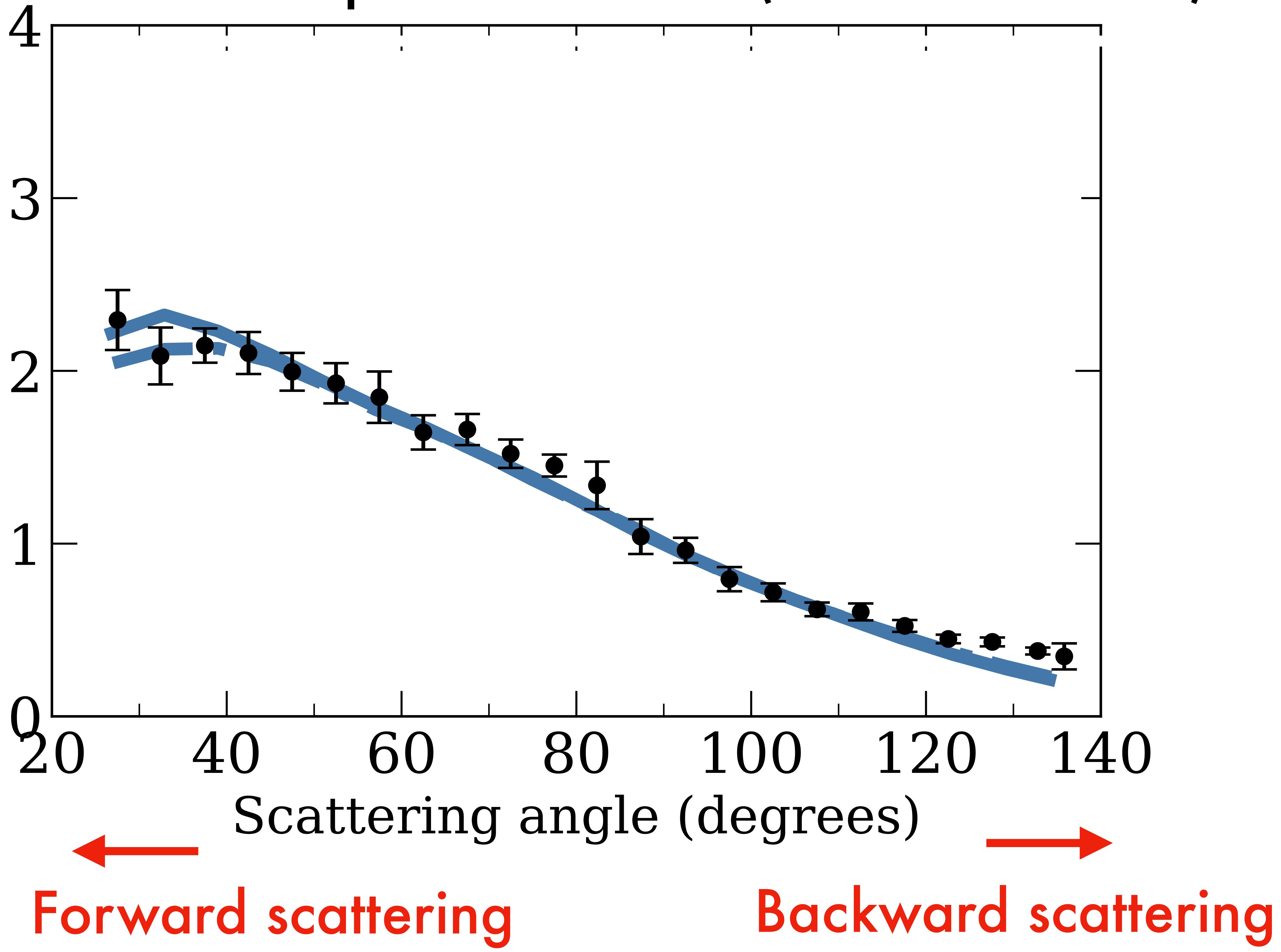
# How large are the monomers?

*Type: Fractal aggregates (Df=1.9; BCCA)*
*Size: $a_{min}$=2$a_{mon}$, $a_{max}$=6.5 μm, p=−3.5*
Composition: *Low albedo*



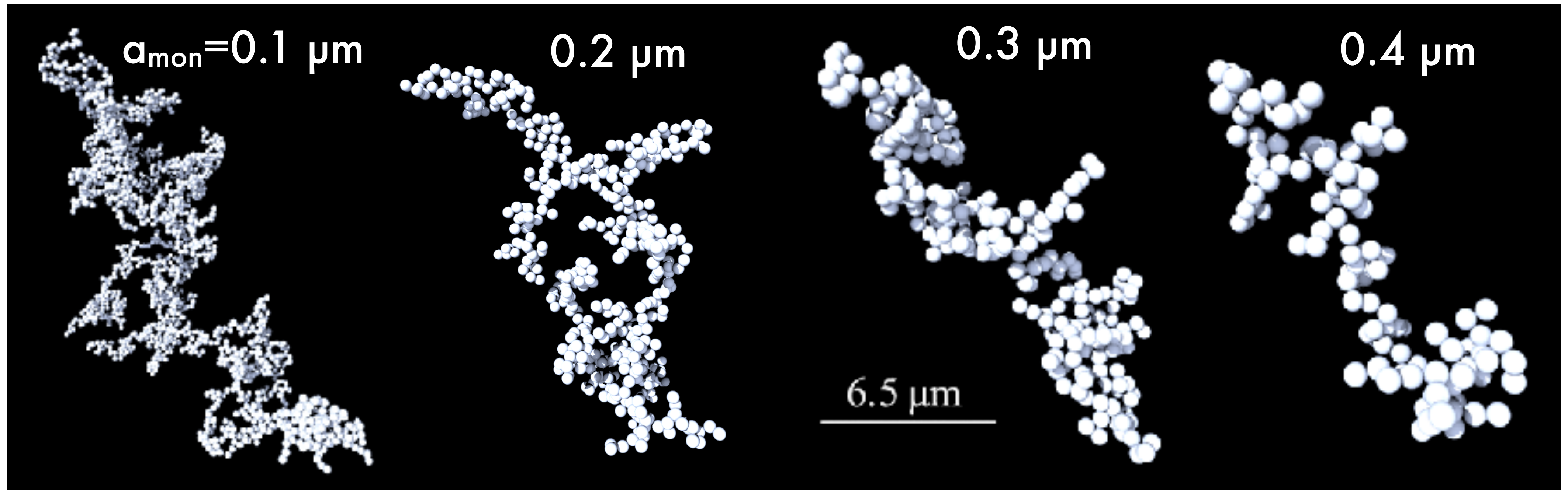




Polarization phase function (normalized to 90°)



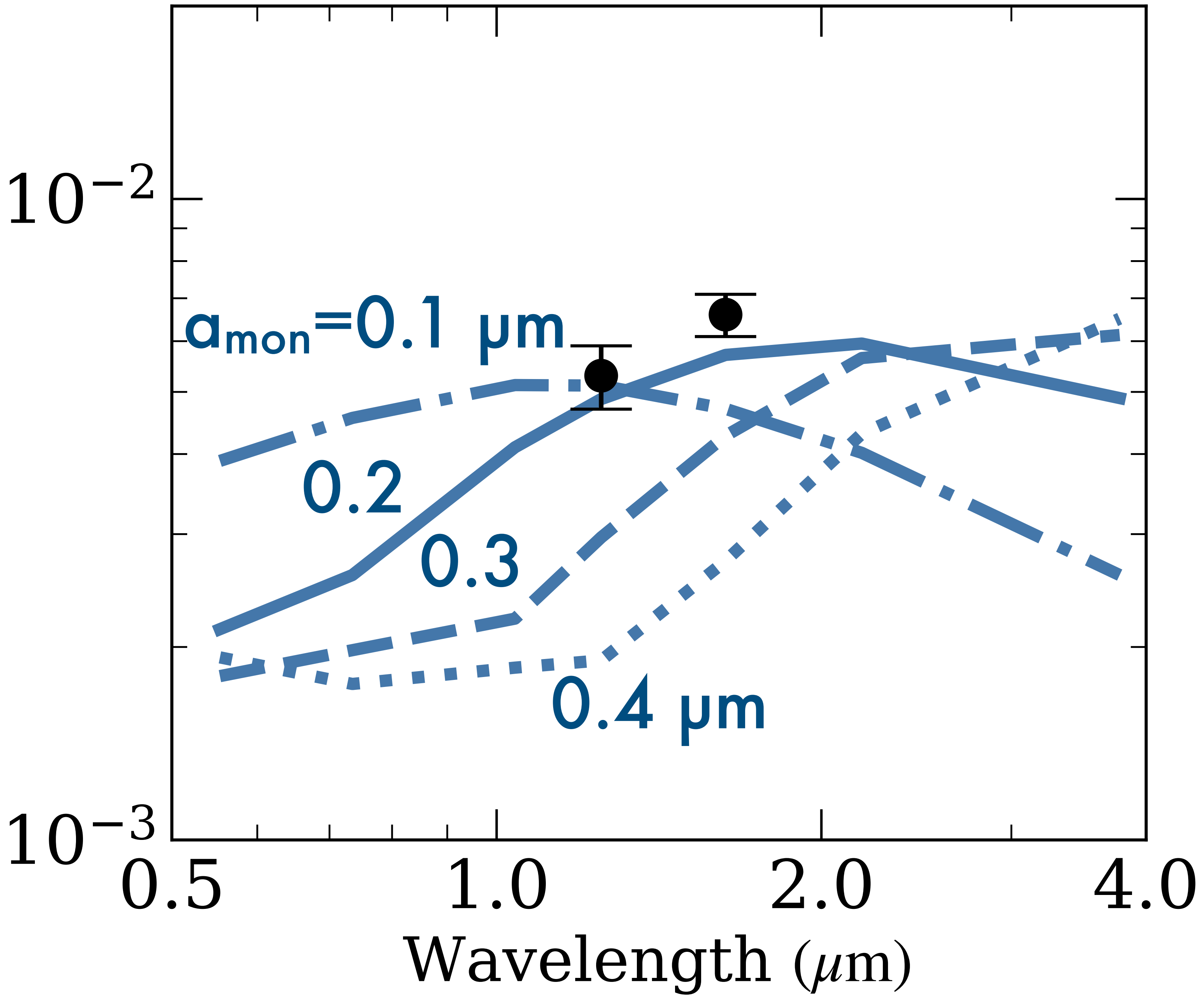
# How large are the monomers?

*Type: Fractal aggregates (Df=1.9; BCCA)*
*Size:* $a_{min}=2a_{mon}$, $a_{max}=6.5$ μm, $p=-3.5$
Composition: Low albedo



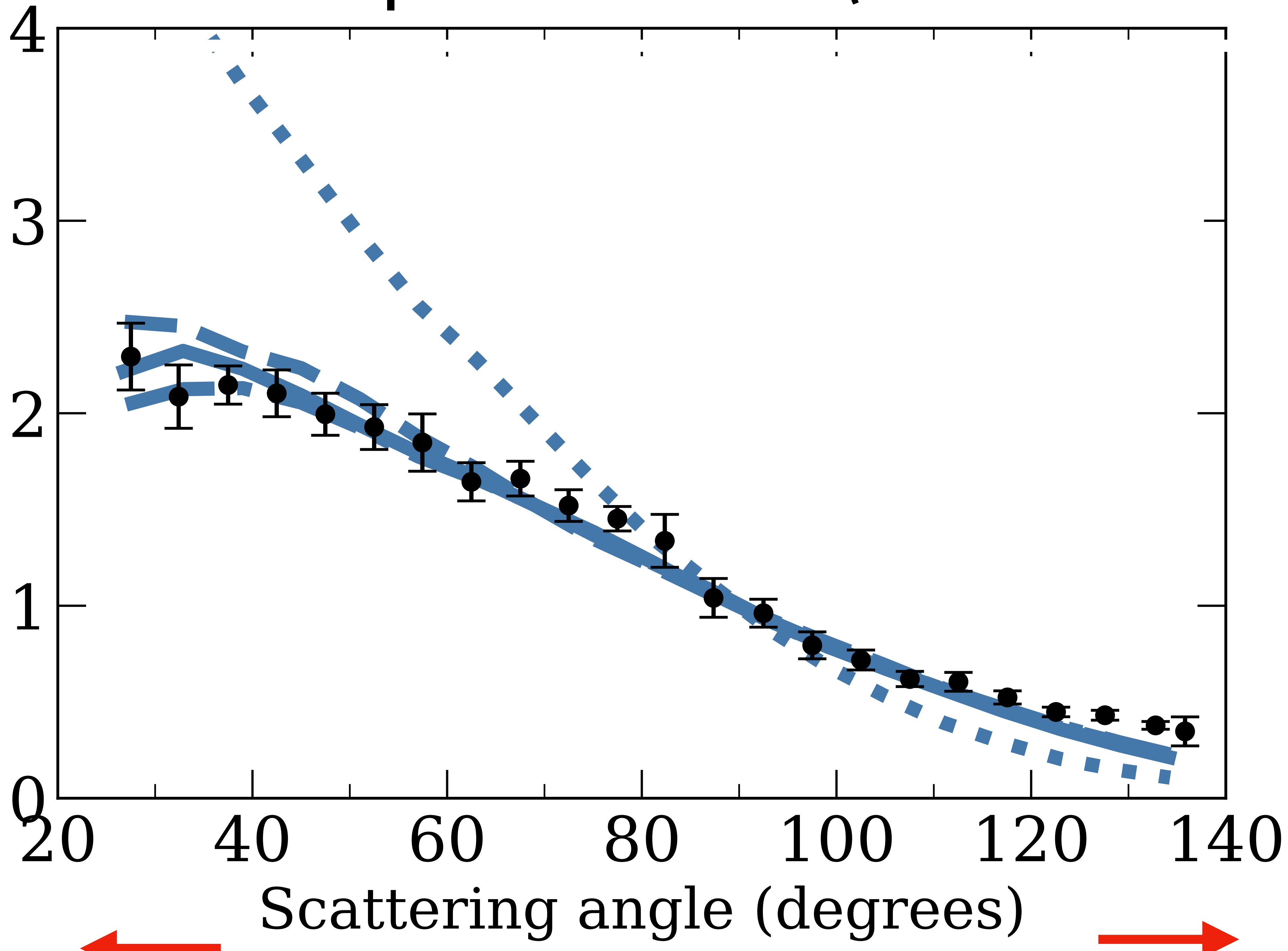

Bright disk

Faint disk




$\frac{F_{\rm pol,disk}}{F_{\rm star}}$

Polarization phase function (normalized to 90°)



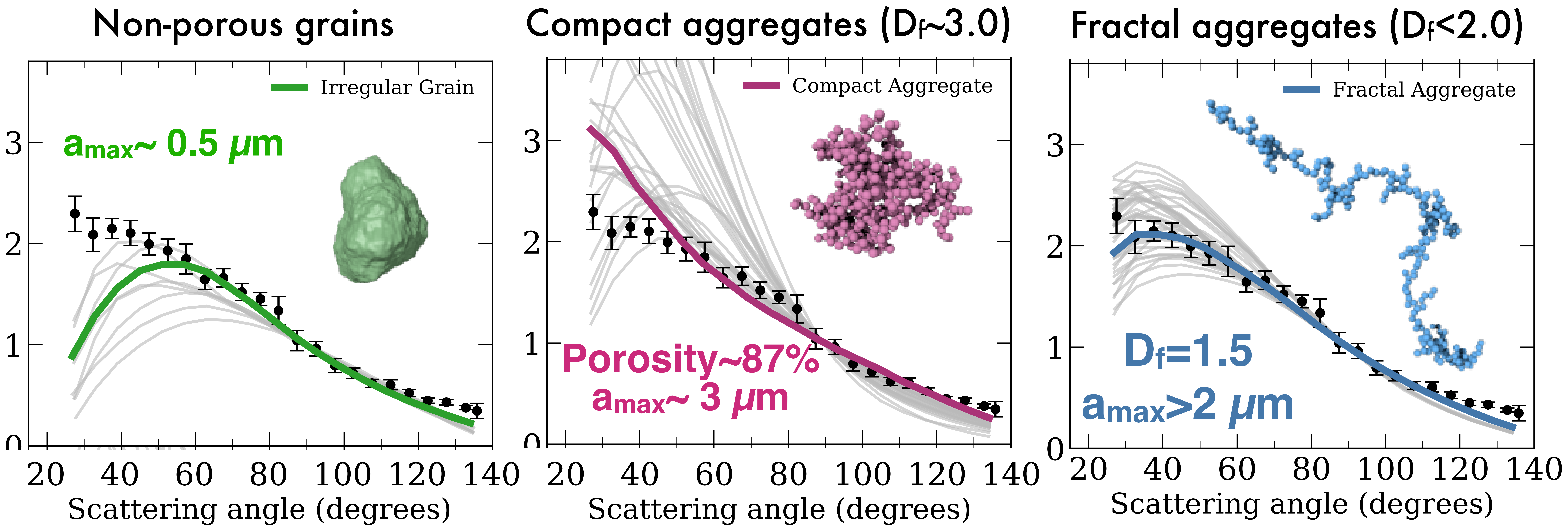

Forward scattering

Backward scattering

**Monomer radius of ~0.2 μm is favored!**

# Fractal dust aggregation in IM Lup

H-band Polarization phase function at 90 au (normalized to 90°)
(Fitting was performed simultaneously at the H- and J-bands data)




The best solution is fractal aggregates with fractal dim. $D_f$=1.5 and >2 μm.

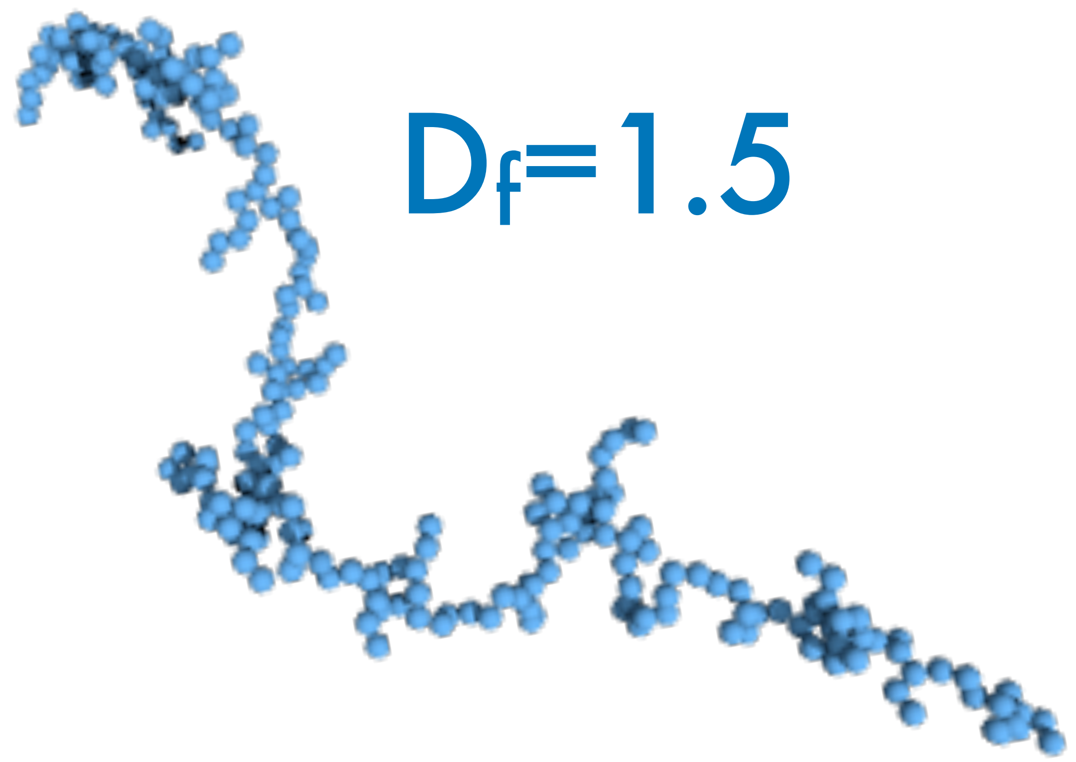
# Are we observing primordial coagulation?

- Brownian motion produces low-dimension fractal aggregates!
  Blum et al. 2000, Krause & Blum 2004, Paszun & Dominik 2006

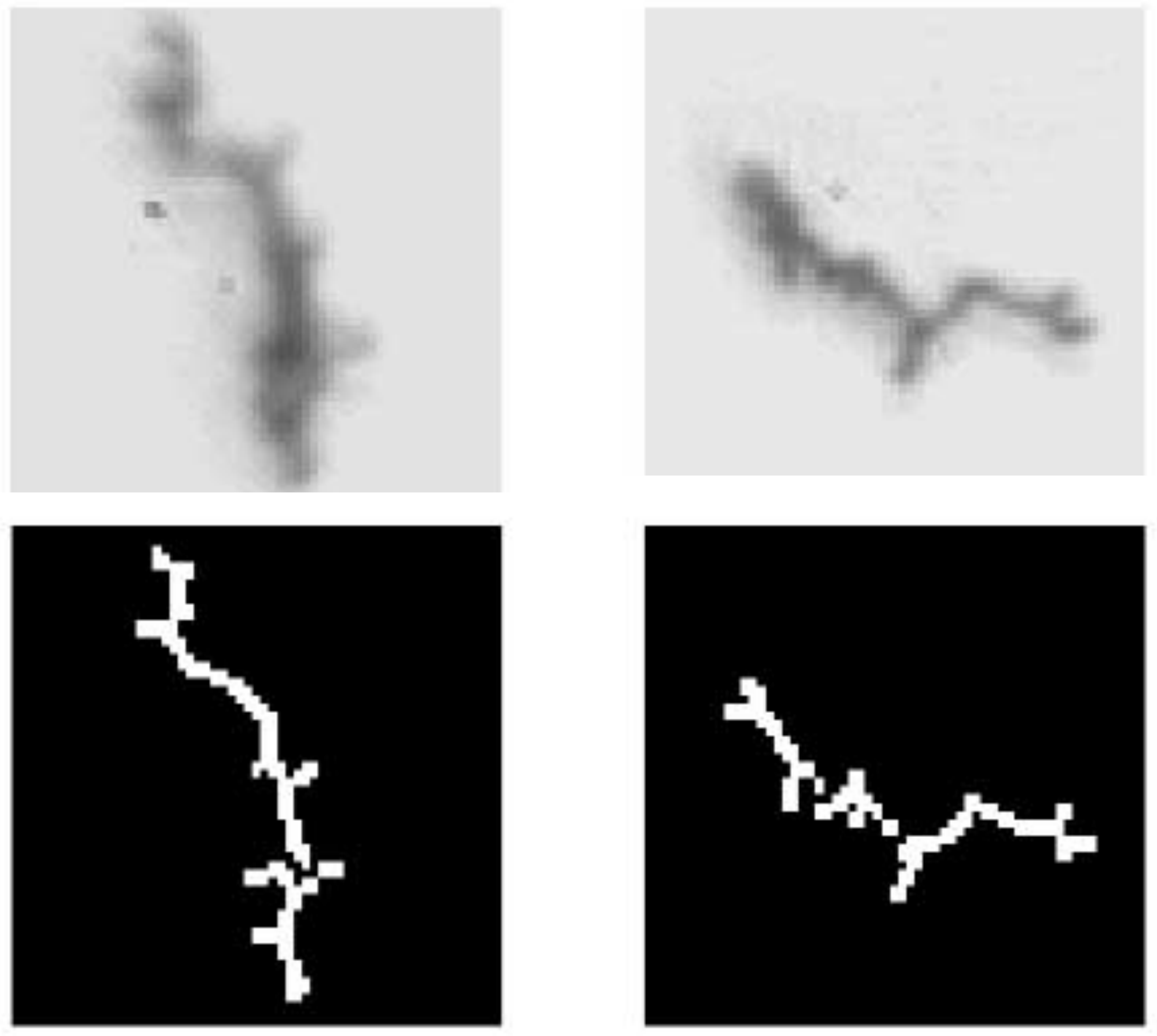
$$D_\mathrm{f} \sim 1.1 - 1.46$$

- The earliest phase of dust coagulation is likely driven by Brownian motion.

**We speculate that we witness the earliest phase of dust coagulation in the IM Lup surface !?**




Microgravity experiments



Blum et al. 2000

# Summary

We have studied the polarization phase function of the IM Lup disk. Our results suggest that dust particles are

- fractal aggregates with Df~1.5 and >2 *μ*m,
- with a monomer radius of ~0.2 *μ*m,
- made of the low-albedo material.

Are we observing the very first moment of planet formation?!

*Tazaki, Ginski, and Dominik (2023, ApJL, 944, L43)*