Understanding Effective Diameter and Its Application to Terrestrial Radiation in Ice Clouds

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ASR Atmospheric System Research

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Common Parameterization Approach for Ice Optics

1. Calculation of single ice crystal optical properties from electrodynamic theory, geometric optics and "bridging" parameterization.

2. Integrate (1) over selected ice particle size distributions (PSDs) to obtain PSD optical properties.

3. Relate PSD optical properties to PSD effective diameter (D_e) and ice water content (IWC) => parameterization

Caution: For step 3 to be valid, D_e and IWC must uniquely define the PSD optical properties, regardless of PSD shape. How valid is this assumption?

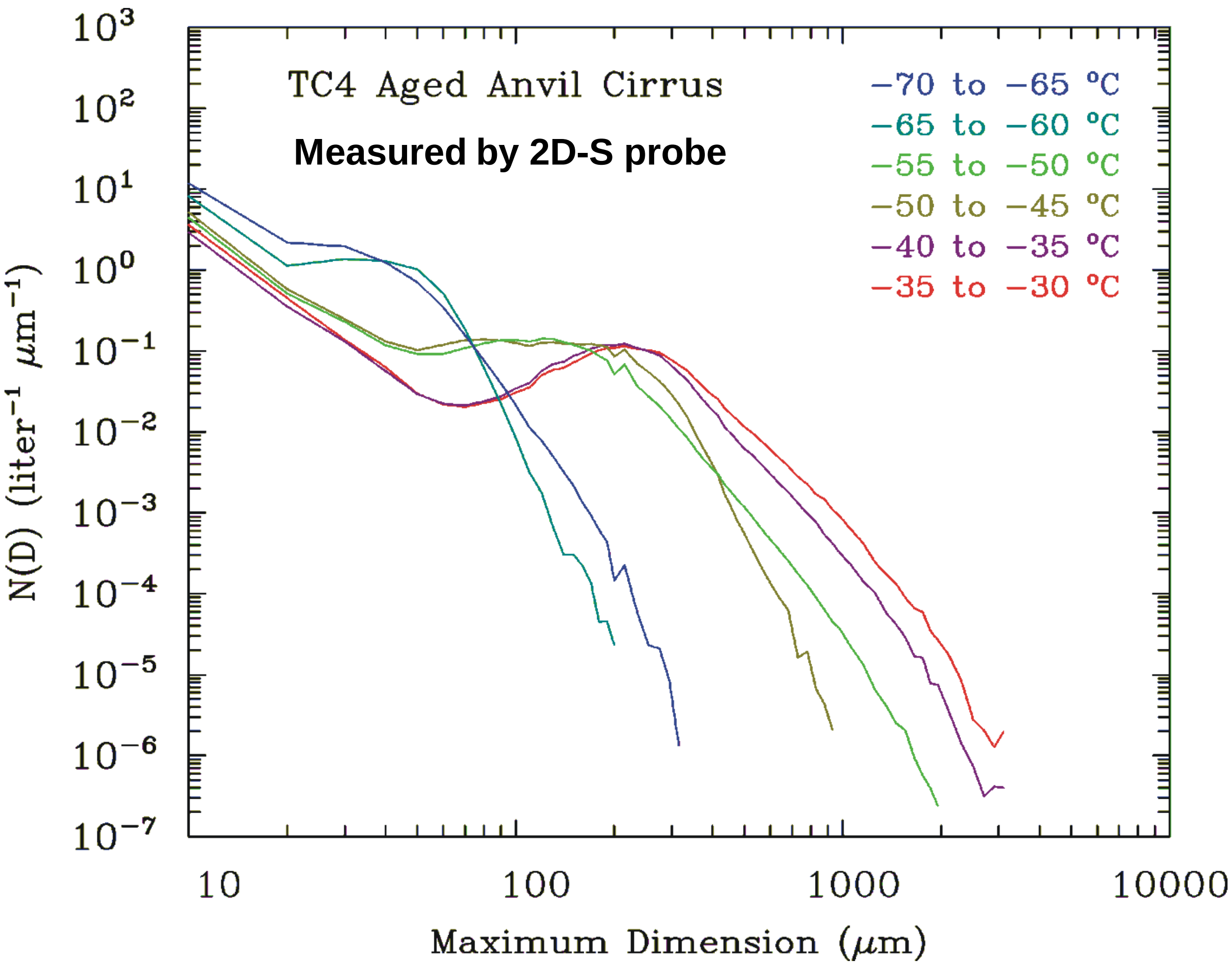
MORE TO CONSIDER

1. Recent research shows that historical PSD measurements suffered from small ice particle artifacts due to shattering of ice particles on the probe inlet tube.

2. Improvements in probe design and electronic detection of shattered ice appear to have removed most of the shattering artifacts. Peak concentrations of small ice crystals are often 10^2 times lower than historical PSD measurements indicate.

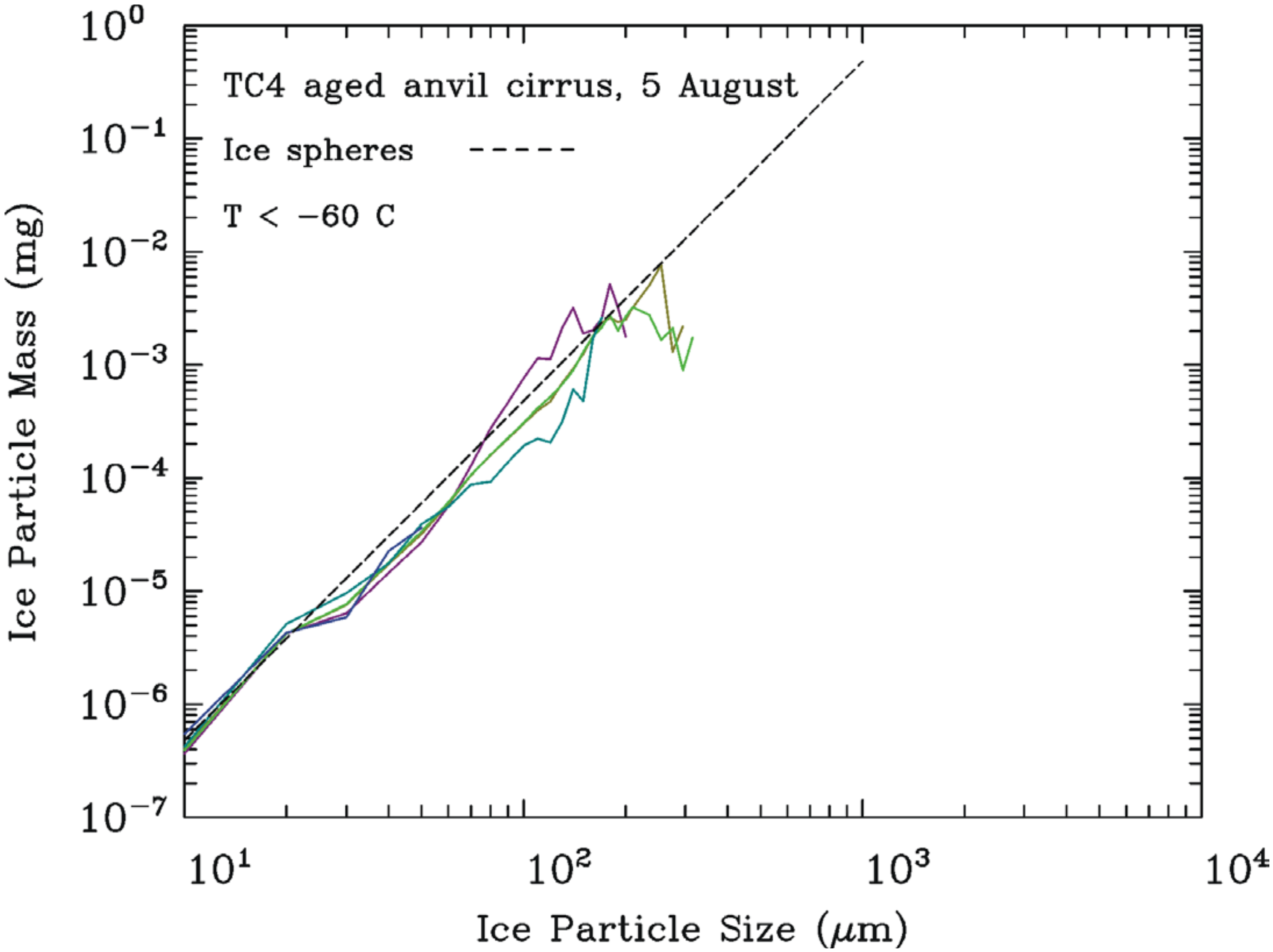
3. What effect, if any, will this change in PSD shape have on parameterized optical properties?

Experiment: Select a 2D-S measured PSD (less shattering) and compare its optical properties with PSD having the same D_e but attributes of historical PSD.

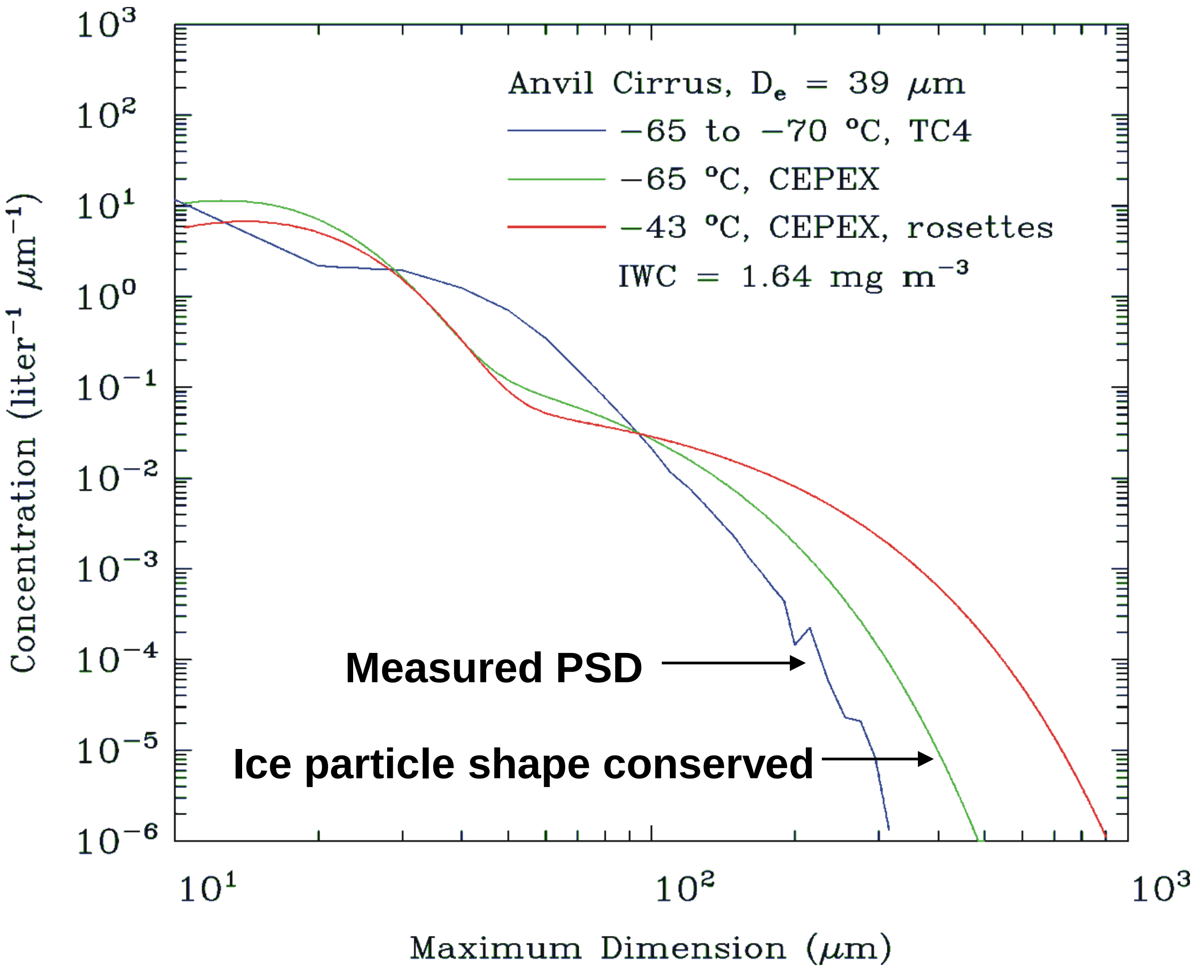


Conserve ice particle shape while changing PSD shape

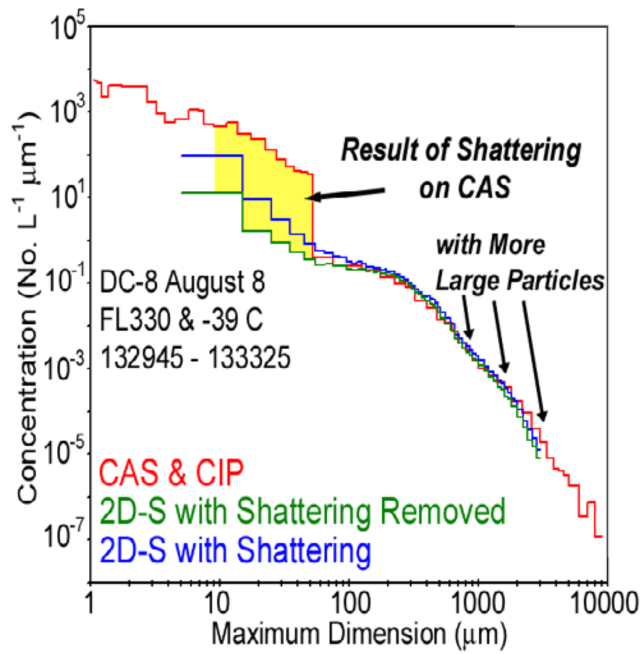
Derive m-D and A-D power laws from 2D-S data to conserve particle shape



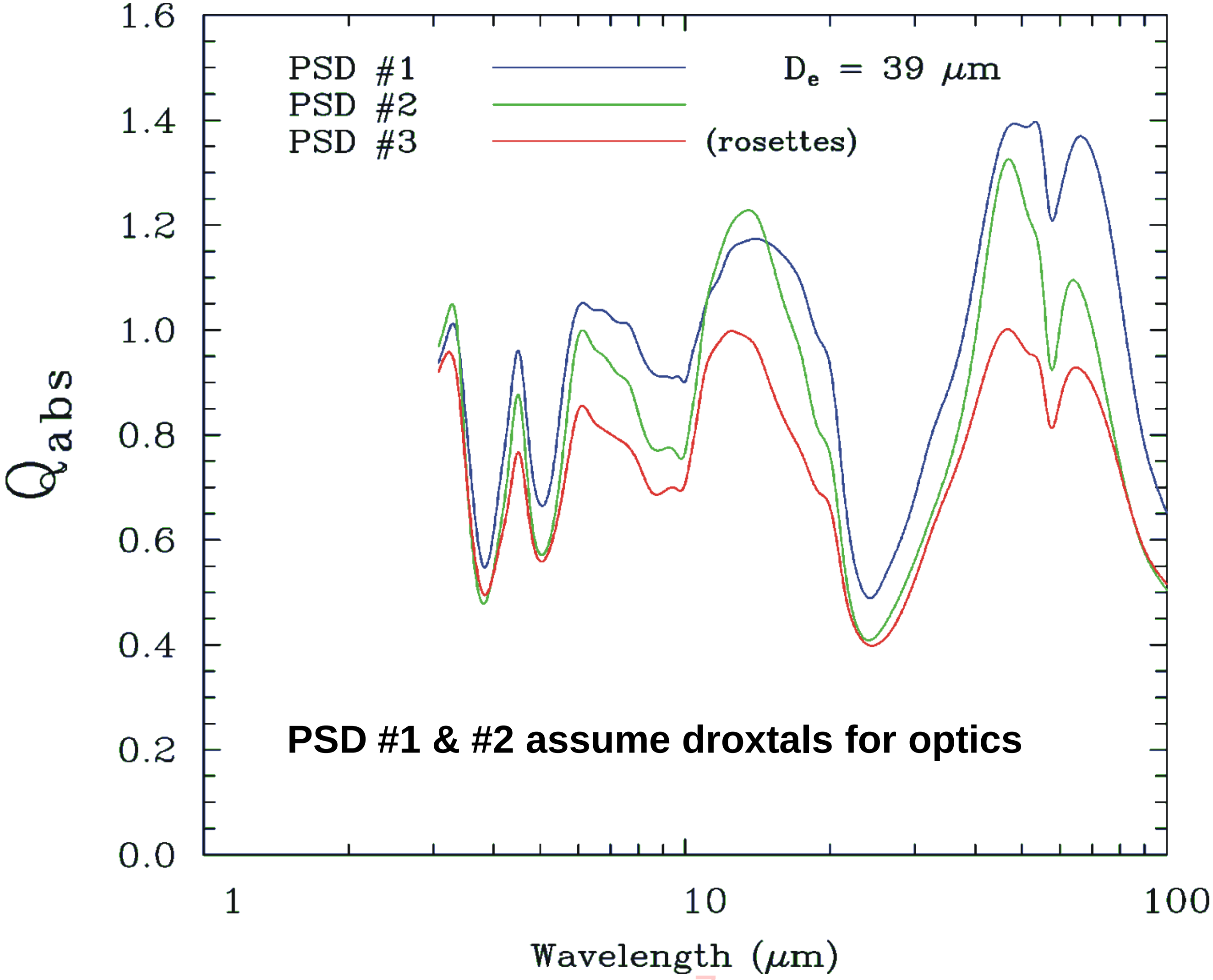
Changing the ice crystal shape changes the PSD for constant D_e (red curve).



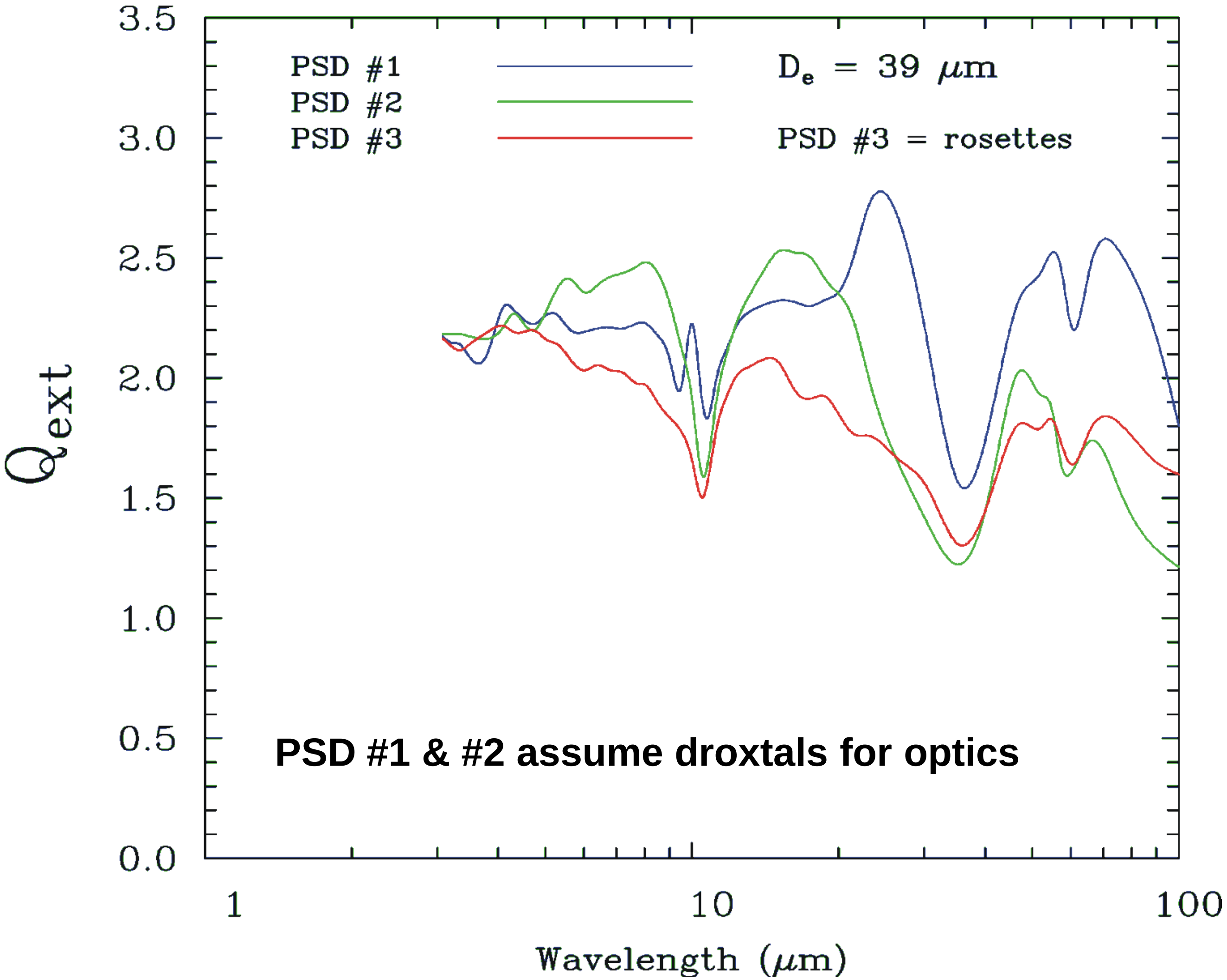
Shattering often increases small crystals by 10^2



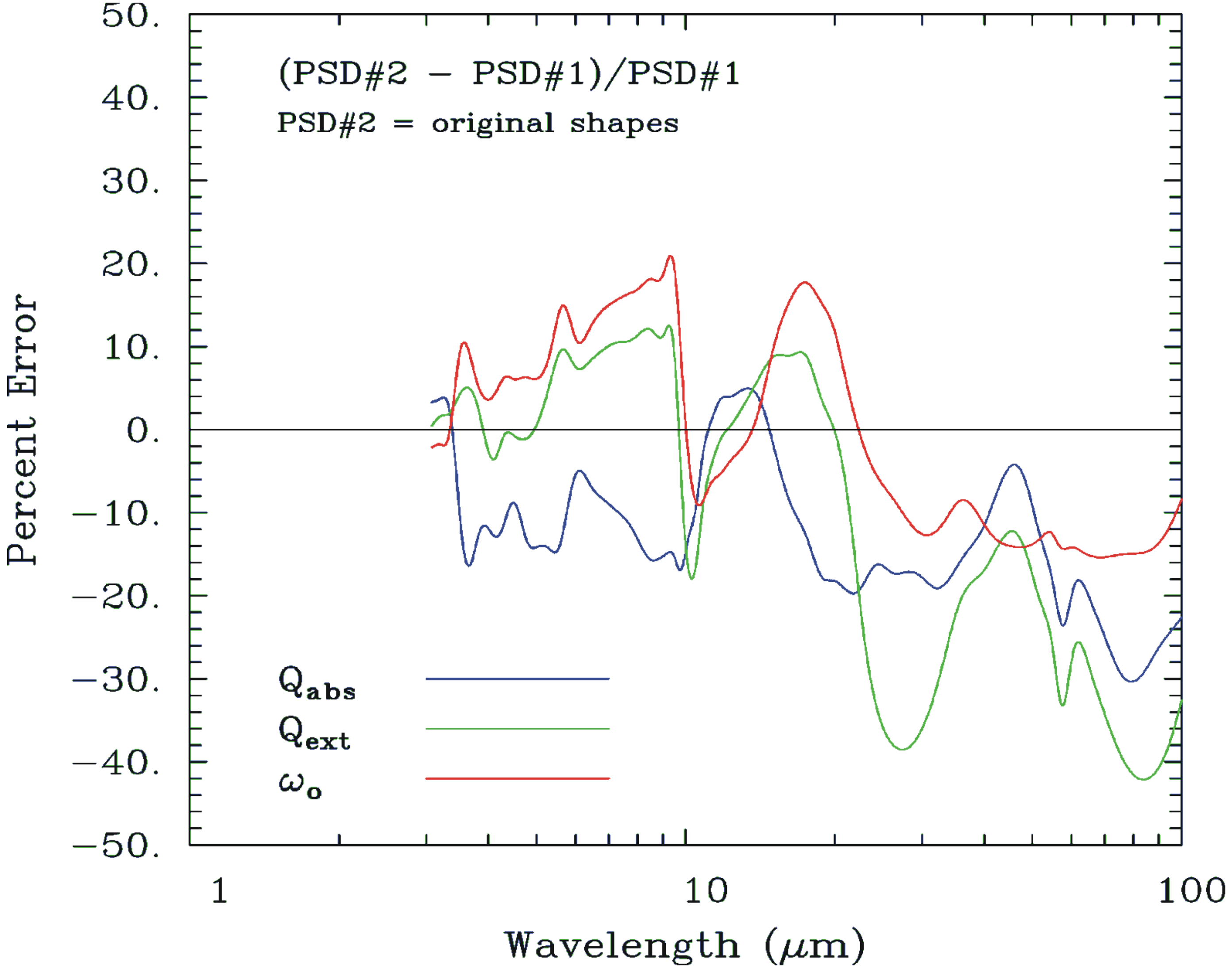
Calculate optical properties for (1) measured PSD; (2) altered PSD with same particle shapes; (3) altered PSD with bullet Rosettes. All use ice optics database of Yang et al. (2005).



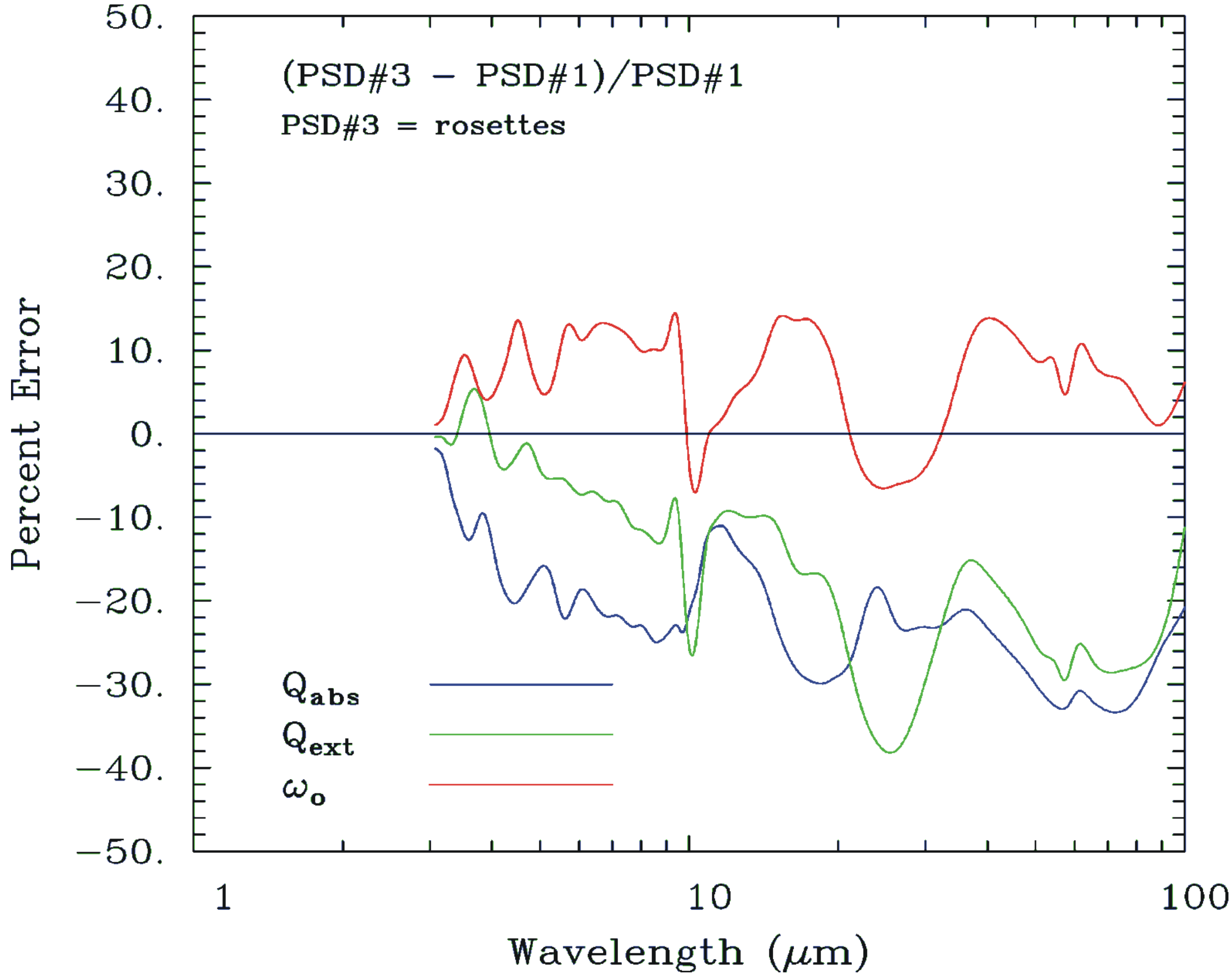
Extinction efficiencies for (1) measured PSD; (2) altered PSD with same particle shapes; (3) altered PSD with bullet rosettes.



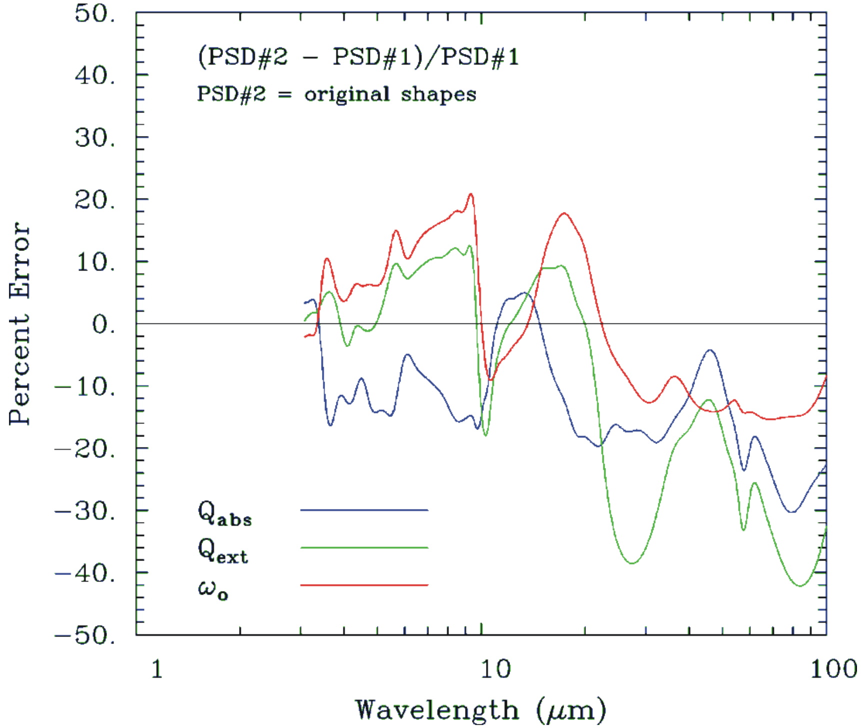
Errors when only PSD shape changes and ice particle shapes remain constant.

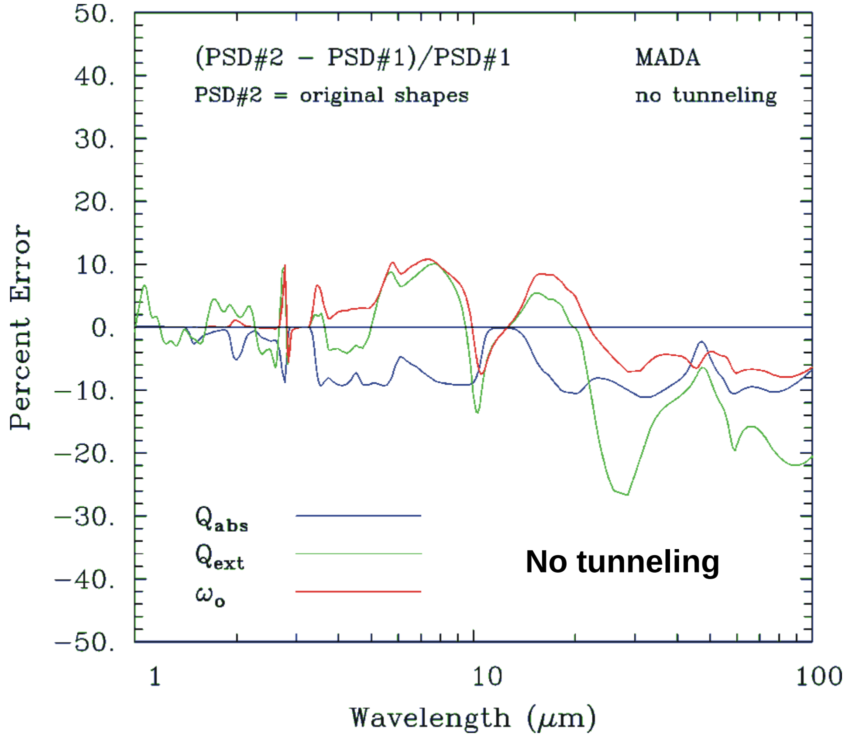


Errors when both PSD shape and ice particle shape change



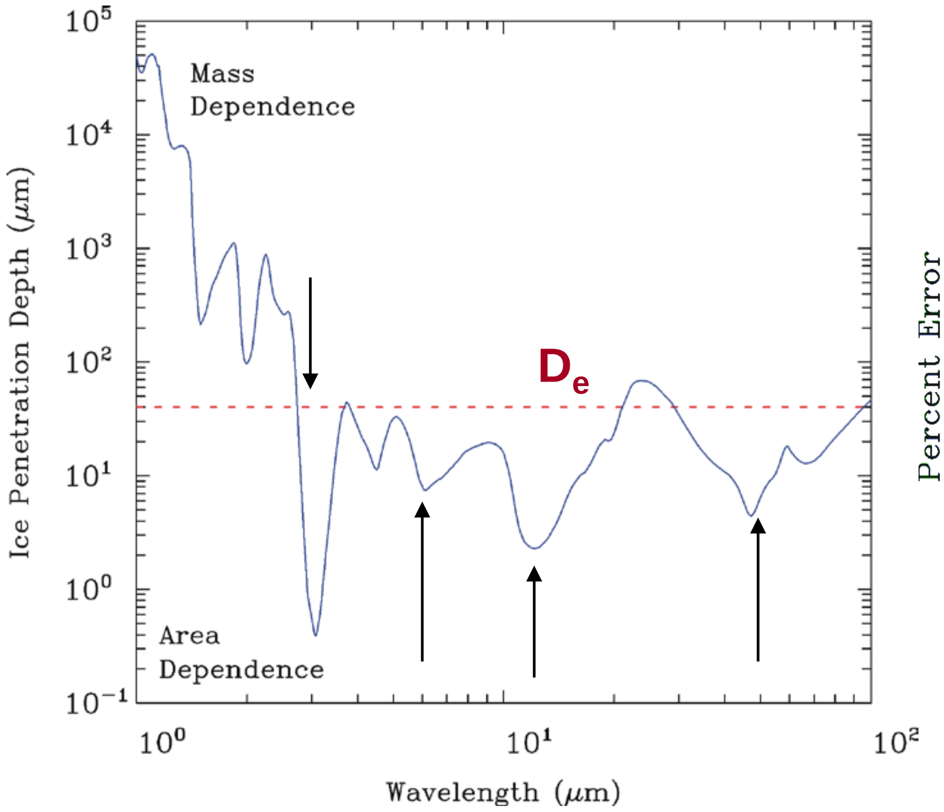
Physical Processes Responsible for Ice Optics Dependence on PSD Shape at Constant D_e

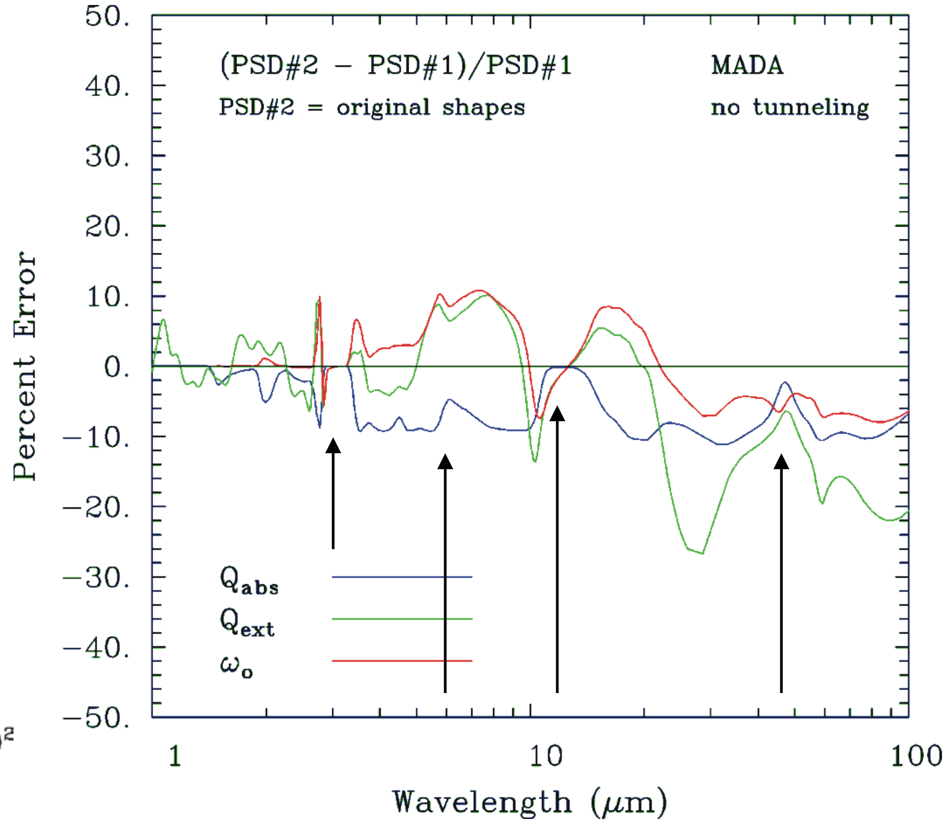


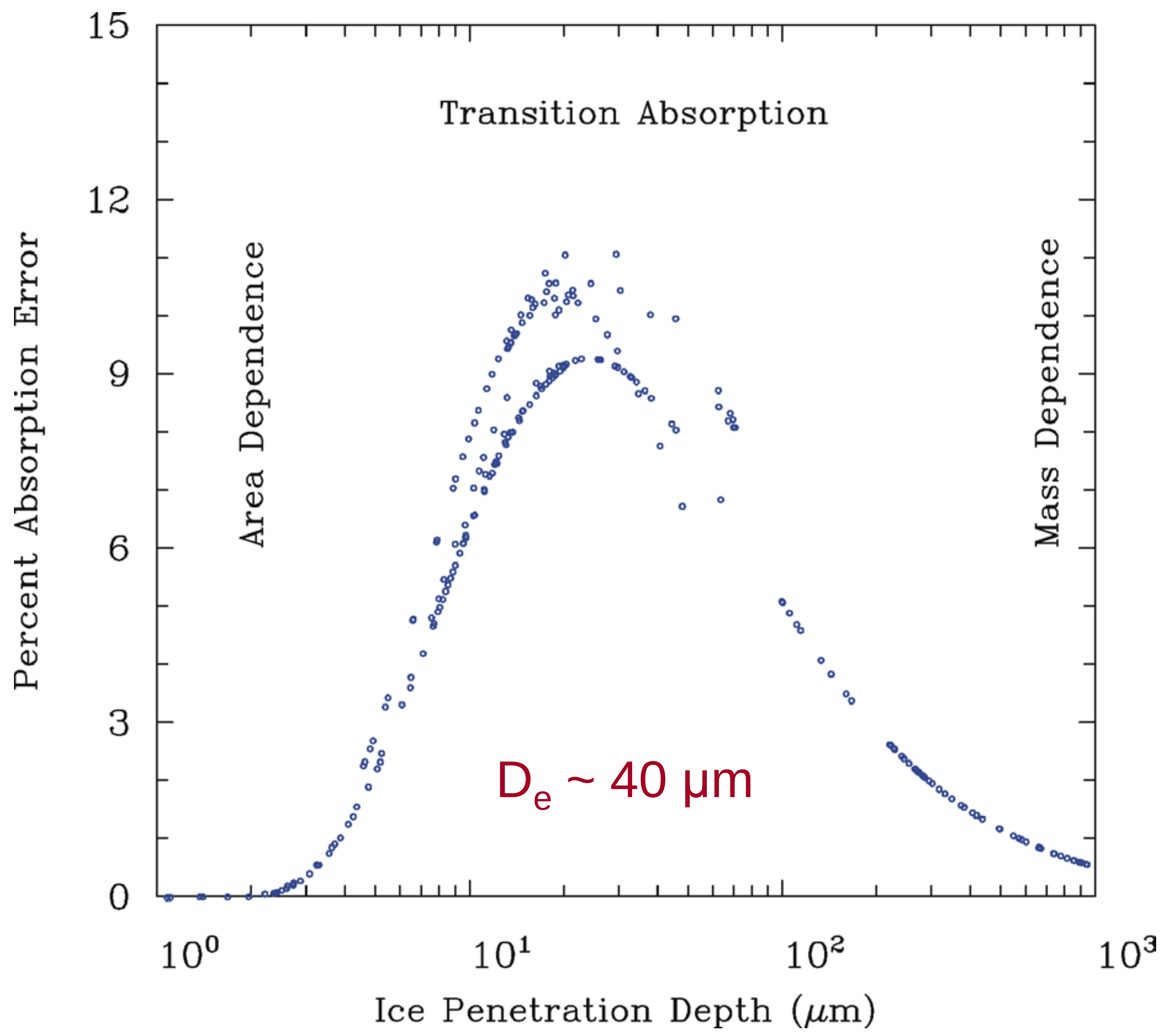


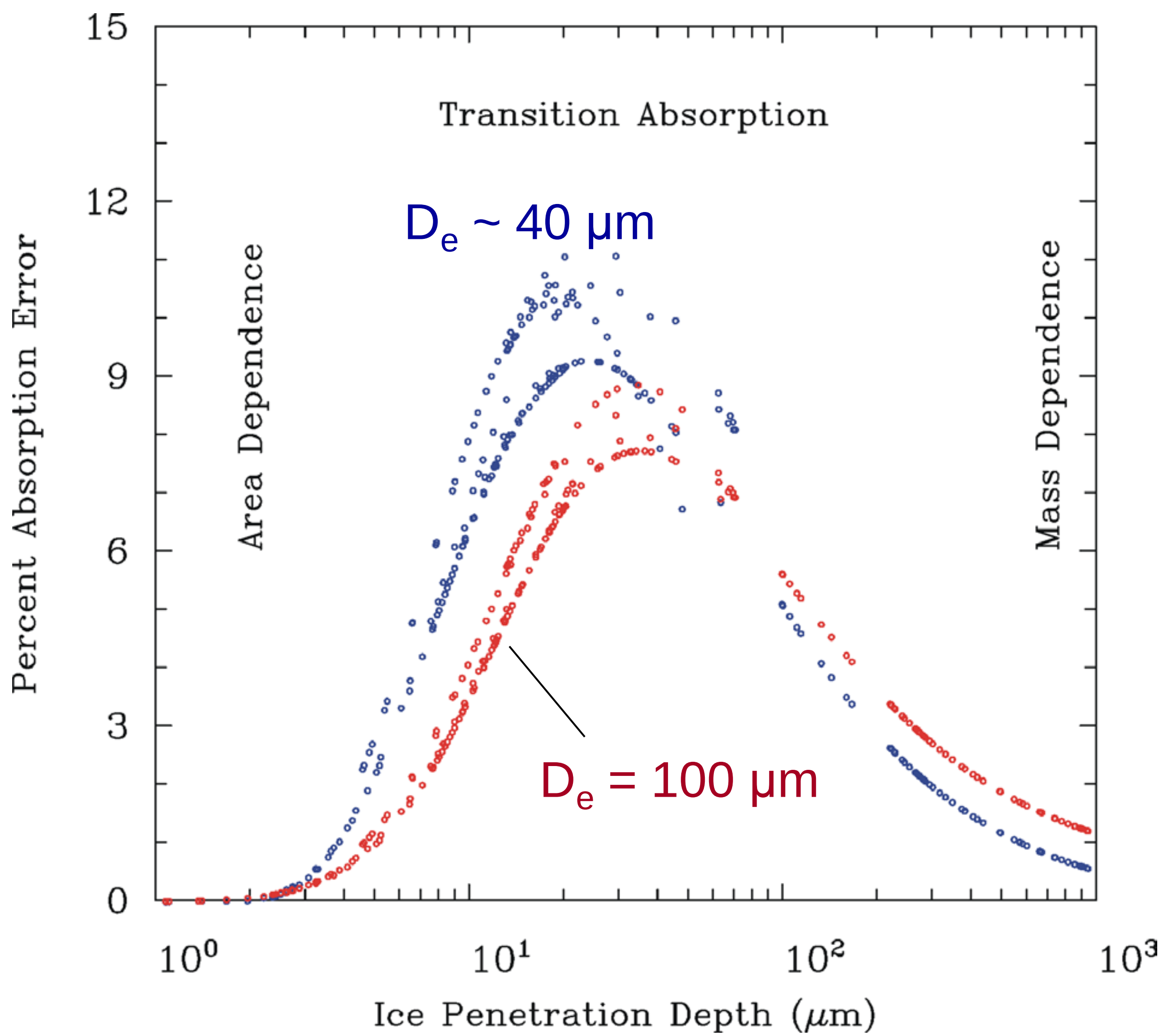
Up to ½ or more of the error can be due to differences in tunneling contributions. But where does the other error come from?

Area dependent, mass dependent, and transition absorption






Transition Absorption
Area Dependence
Mass Dependence
Percent Absorption Error
Ice Penetration Depth (μm)
15
12
9
6
3
0
10^0
10^1
10^2
10^3
D_e ~ 40 μm



Maximum error when penetration depth ~ ½ to ⅓ D_e

CONCLUSIONS

1. Changes in PSD shape alone (while holding D_e and particle shape constant) substantially affects IR ice optical properties.

2. For constant D_e, changing the ice particle shape assumption further changes the PSD shape, which further changes optical properties relative to the reference (i.e. measured) PSD.

3. "Transition absorption" and absorption by tunneling depend on the PSD shape in addition to D_e and IWC.

4. Some GCMs treat terrestrial radiation using ω_o while others use emissivity (related to Q_{abs}). Errors for both quantities vary rapidly with wavelength and may introduce significant errors into both the magnitude and spectral dependence of fluxes.

5. Recent, more reliable PSD measurements may prove useful in revising existing ice cloud optics parameterizations.

CONCLUSIONS (continued)

6. Between 100 and 1000 µm wavelength, for the same D_e and IWC, PSD extinction efficiencies and coefficients can vary by a factor of 2 or 3 (Mitchell et al. 2002). This should be considered when proposing retrieval algorithms using the MMCR.

The success of D_e in cloud optics suggests this photon path concept should be found in optics theory:

$Q_{abs} \approx 1 - \exp(-4 \pi n_i d_e / \lambda)$, where $d_e = V/A$.

For $n_i d_e / \lambda << 1$ (often true for liquid water clouds), absorption cross-section $C_{abs} = A\, Q_{abs} = 4 \pi n_i V/\lambda$.

For $n_i d_e / \lambda > 1$, $C_{abs} \approx A$ (often true for ice clouds in IR).

Working hypothesis: When $C_{abs} \Rightarrow A$, D_e looses its skill in predicting cloud optical properties.