Comparison of Cassini UVIS reflectance spectra of Saturn's rings to compositional models

Todd Bradley

August 13, 2014

Overview

Review of Chandrasekhar-Granola bar model

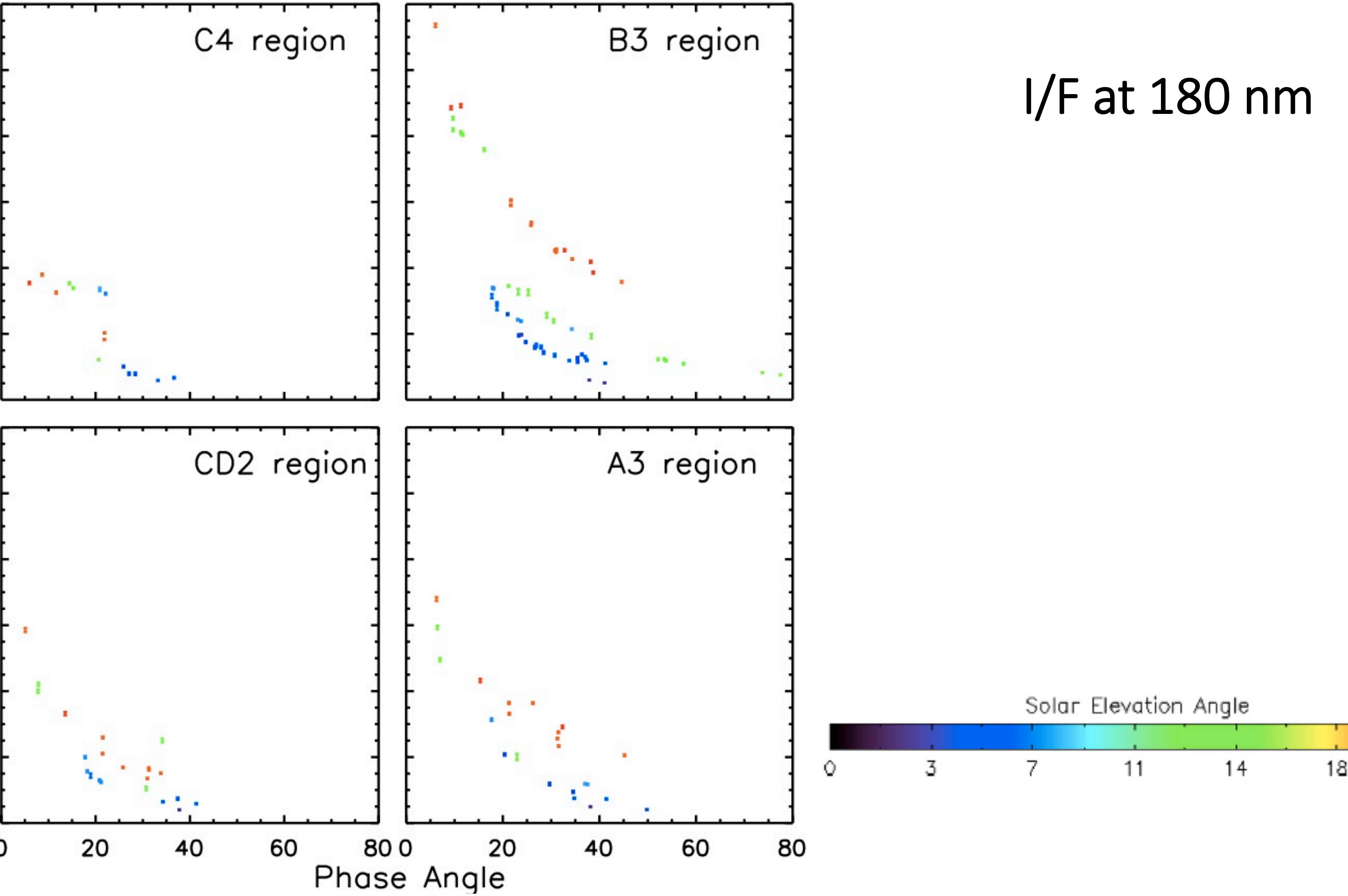
Compare FUV ring spectra to two-component compositional models

- Van de Hulst – Hapke model
- Shkuratov model

Use two different mixing models

- Linear mixture of optical constants
- Discrete water ice and contaminant grains (add single scattering albedos)

I/F at 180 nm


C4 region
B3 region
CD2 region
A3 region
0
20
40
60
80
Phase Angle
Solar Elevation Angle
0
3
7
11
14
18

Model discretely averaged spectra using Chandrasekhar-granola bar model

$$\frac{I}{F} = A_B * P * \frac{\mu_o}{4(\mu + \mu_o)}\left[1 - \exp(-\tau_n / \mu)\exp(-\tau_n / \mu_o)\right]$$

$$T = \exp(-\tau_n / \mu)$$

$$= \frac{\left[S/W - H/W \left|\sin(\phi - \phi_{wake})\right| \cot B\right]}{S/W + 1} \exp(-\tau_{gap} / \mu)$$

$$T_o = \exp(-\tau_n / \mu_o)$$

$$= \frac{\left[S/W - H/W \left|\sin(\phi_o - \phi_{wake})\right| \cot B'\right]}{S/W + 1} \exp(-\tau_{gap} / \mu_o)$$

Assume power law phase function (Dones et al. 1993)

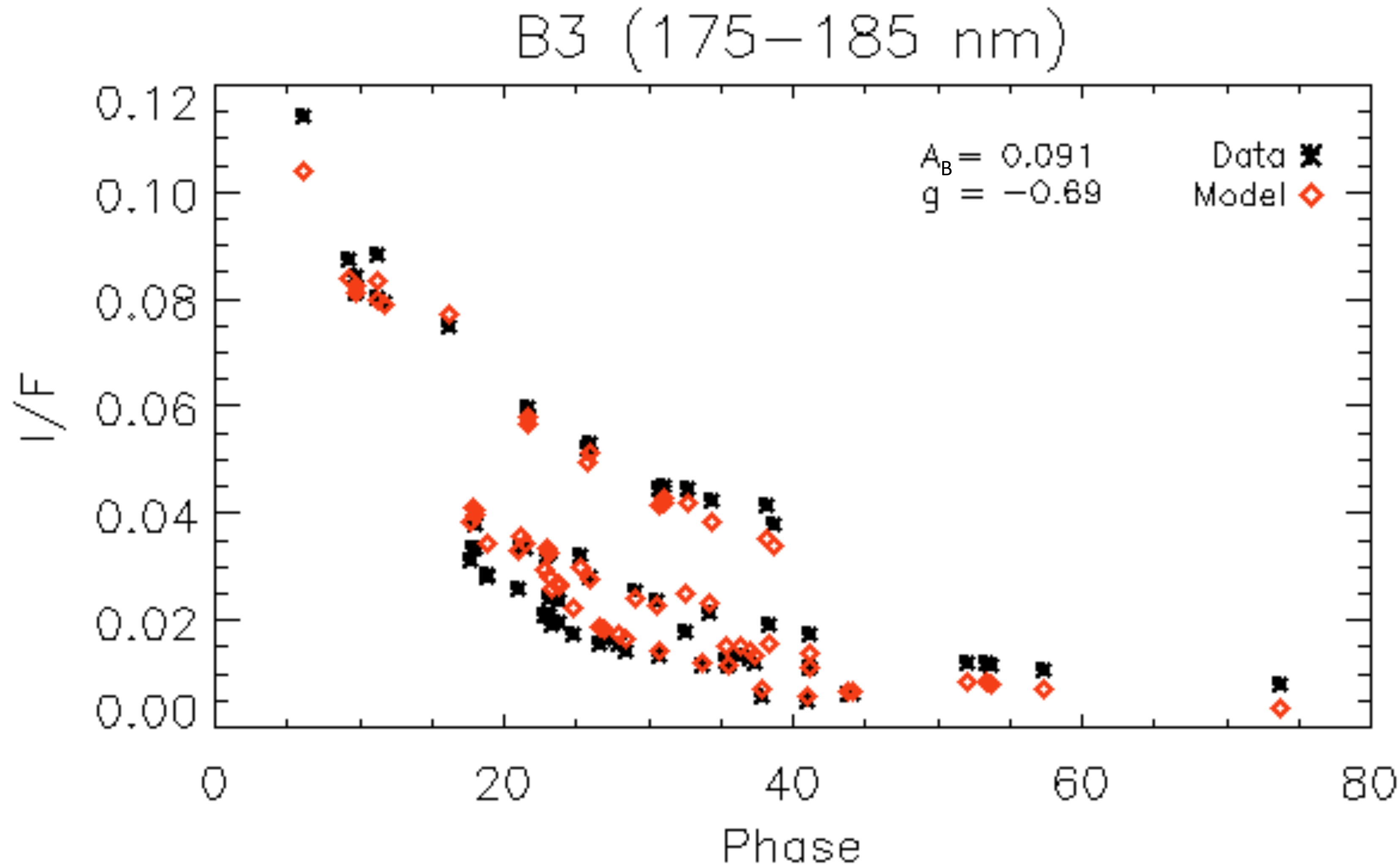
$$P = C_n(\pi - \alpha)^n$$

$$g = -\frac{1}{2}\int_0^{\pi} P(\alpha)\cos\alpha\sin\alpha d\alpha$$

Minimize D

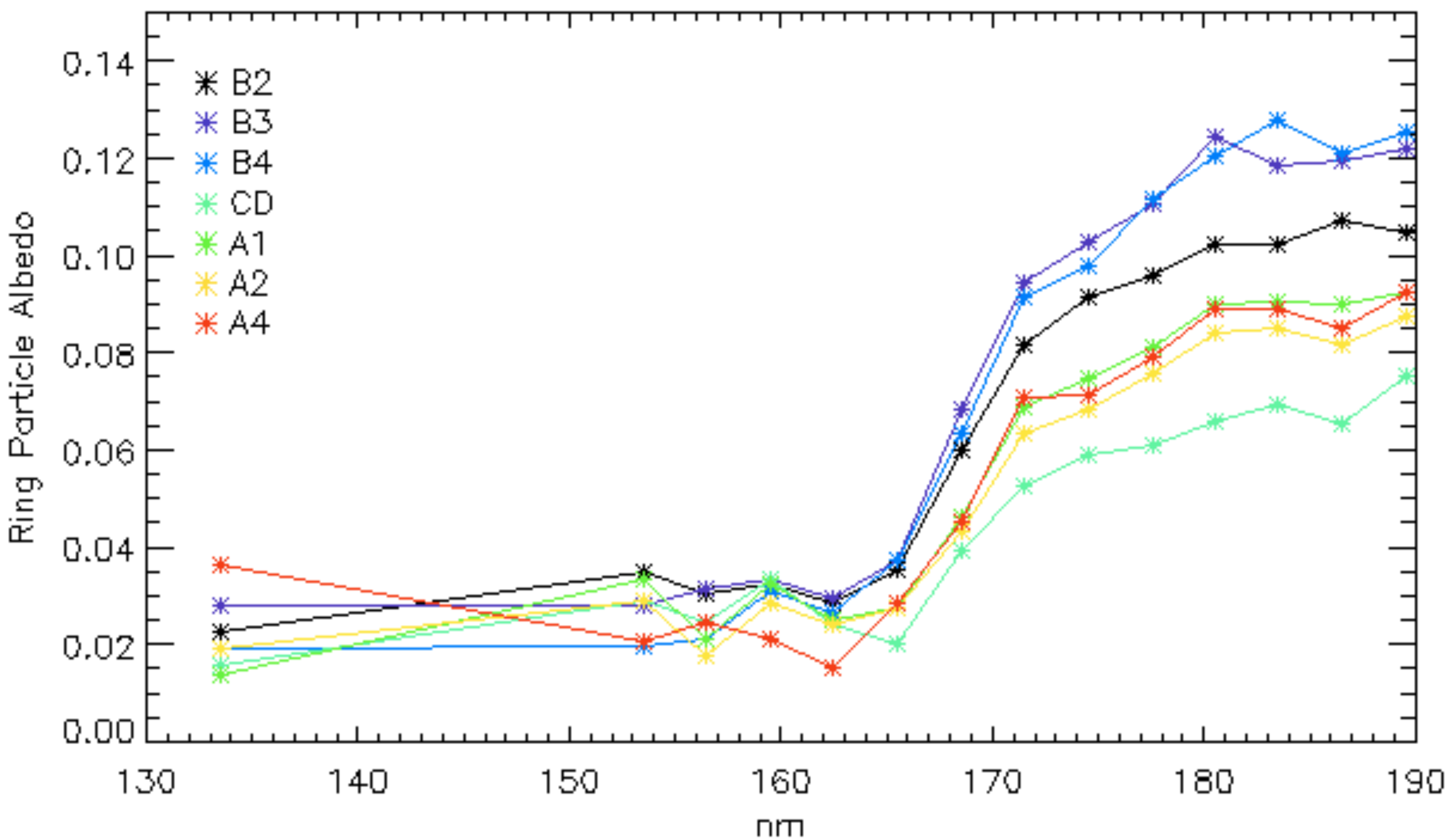
$$D = \frac{1}{n}\sum_{i=1}^{n}(d_i - m_i)^2$$

Where i = 1 to n is over a range of phase angles and free parameters are A_B, d is the measured I/F, and m is the model I/F



B3 (175–185 nm)
A_B = 0.091
g = −0.69
Data
Model
I/F
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
20
40
60
80
Phase

Ring Particle Bond Albedo



Van de Hulst – Hapke Model

Cuzzi and Estrada (1998) used Van de Hulst to relate A_B to ϖ

$$A_B = \frac{(1-S)(1-0.139S)}{1+1.17S} \quad \text{where } S = \sqrt{\frac{1-\varpi}{1-\varpi g}}$$

g = regolith grain anisotropy parameter

$$\varpi = Q_s = S_e + (1-S_E)\frac{1-S_I}{1-S_I\Theta}\Theta \qquad S_E = \frac{(n-1)^2+k^2}{(n+1)^2+k^2} + 0.05 \quad , \quad S_I = 1 - \frac{4}{n(n+1)^2}$$

$$\Theta = \frac{r_i + \exp\left(-\sqrt{\alpha(\alpha+\varsigma)}\,2d_i/3\right)}{1 + r_i\exp\left(-\sqrt{\alpha(\alpha+\varsigma)}\,2d_i/3\right)} \quad \text{where } r_i = \frac{1-\sqrt{\alpha/(\alpha+\varsigma)}}{1+\sqrt{\alpha/(\alpha+\varsigma)}}$$

n and *k* are the optical constants, d is the grain diameter, $\alpha = 4\pi k/\lambda$ and ς is the internal scattering coefficient

Shkuratov Model

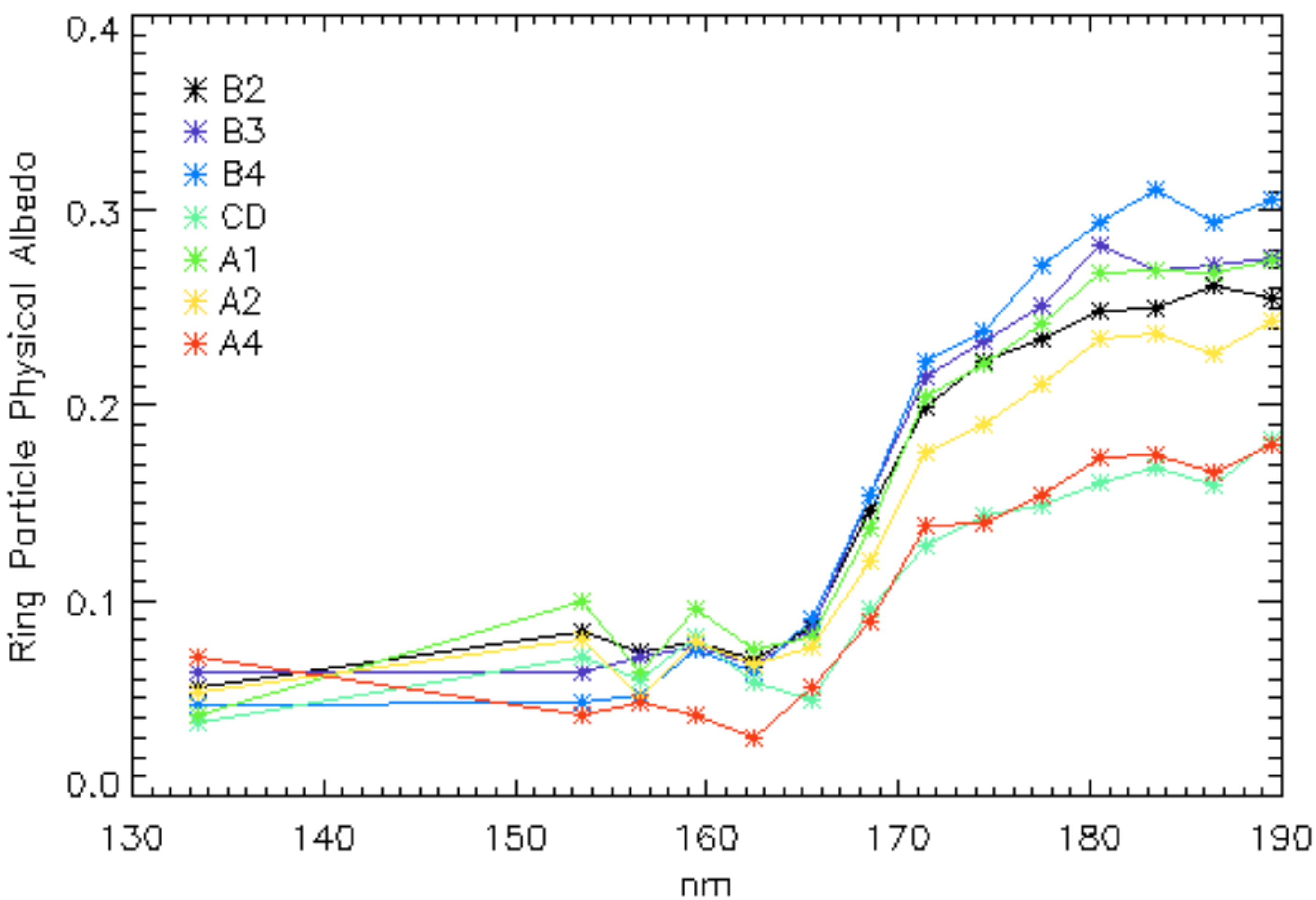
- Requires geometric (physical, A_p) albedo
- Ratio of brightness of a body at g = 0 to the brightness of a perfect Lambert disk of the same radius and at the same distance as the body but illuminated and observed perpendicularly
- Previously I derived ring particle bond (spherical, A_s) albedos and ring particle phase functions

$$A_p = \frac{A_s}{q} \qquad q = 2\int_0^{\pi} \Phi(g)\sin g\, dg$$

Φ(g) is integral phase function, i.e. the relative brightness of a body at phase angle g normalized to its brightness at 0°phase angle.

q = phase integral

Ring Particle Geometric Albedo



Bond albedo corrected to 0° pha
using retrieved ring particle pha
functions

Try Two Different Two Component Mixtures

Water Ice and Triton Tholin (irradiation of 0.999:0.001 N2:CH4; bulk substance: $C_3H_5N_4$

Linearly add optical constants and get one single scattering albedo; a single regolith grain is a well mixed combination of components (Cuzzi and Estrada, 1998)

$$n_i = (1 - f_e) n_{io} + f_e n_{ie}$$

$$n_r = (1 - f_e) n_{ro} + f_e n_{re}$$

Separate grains for each component. Calculate single scattering albedo for each. Add together.

$$\varpi = \frac{\varpi_{H_2O} + \varepsilon \varpi_X}{1 + \varepsilon}, \qquad \varepsilon = \frac{\mu_x}{\mu_{H_2o}} \frac{\rho_{H_2o}}{\rho_x} \frac{D_{H_2o}}{D_x}$$

μ = bulk density, ρ = solid density, D = size
Assume ρ is same for both (Hapke, 1993)

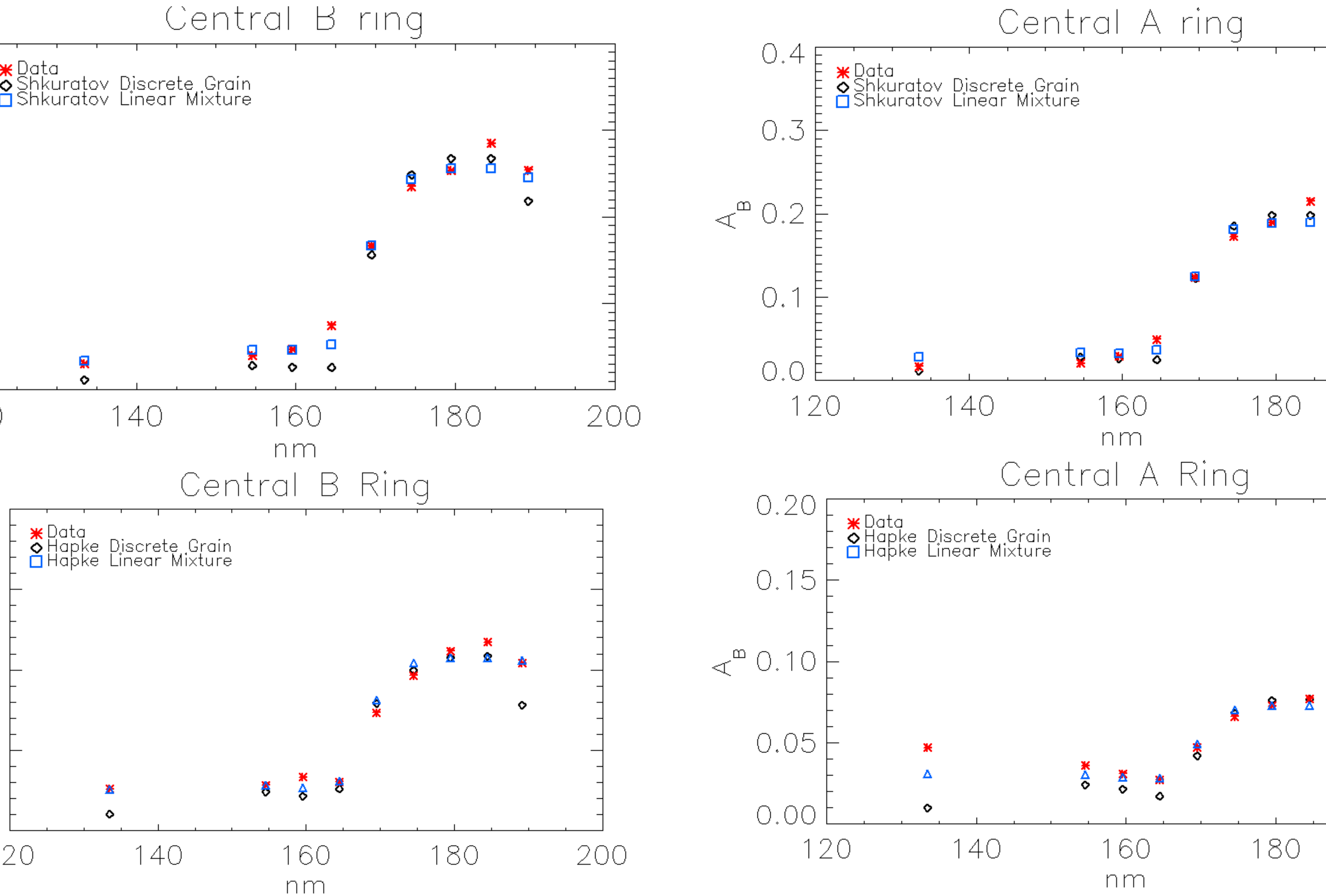
Free Parameters in Models

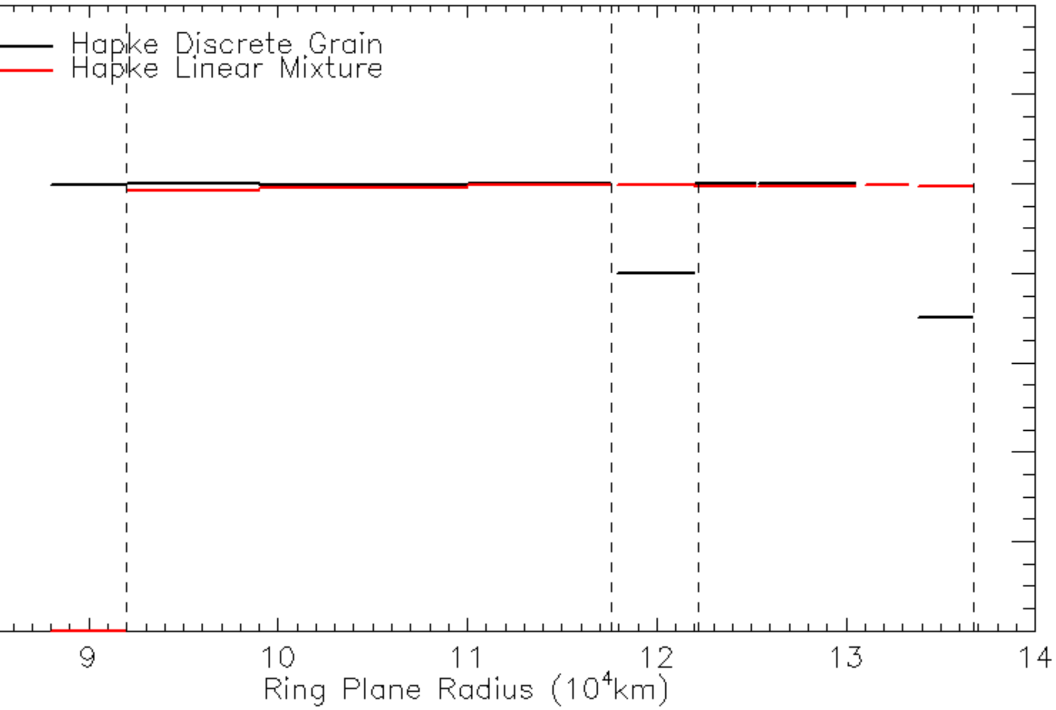
Shkuratov Discrete Grain:
1. Water ice grain diameter
2. Contaminant grain diameter
3. Fraction of water ice
4. Porosity
5. Regolith grain asymmetry parameter

Shkuratov Linear mixture:
1. Water ice grain diameter
2. Fraction of water ice
3. Porosity
4. Regolith grain asymmetry parameter

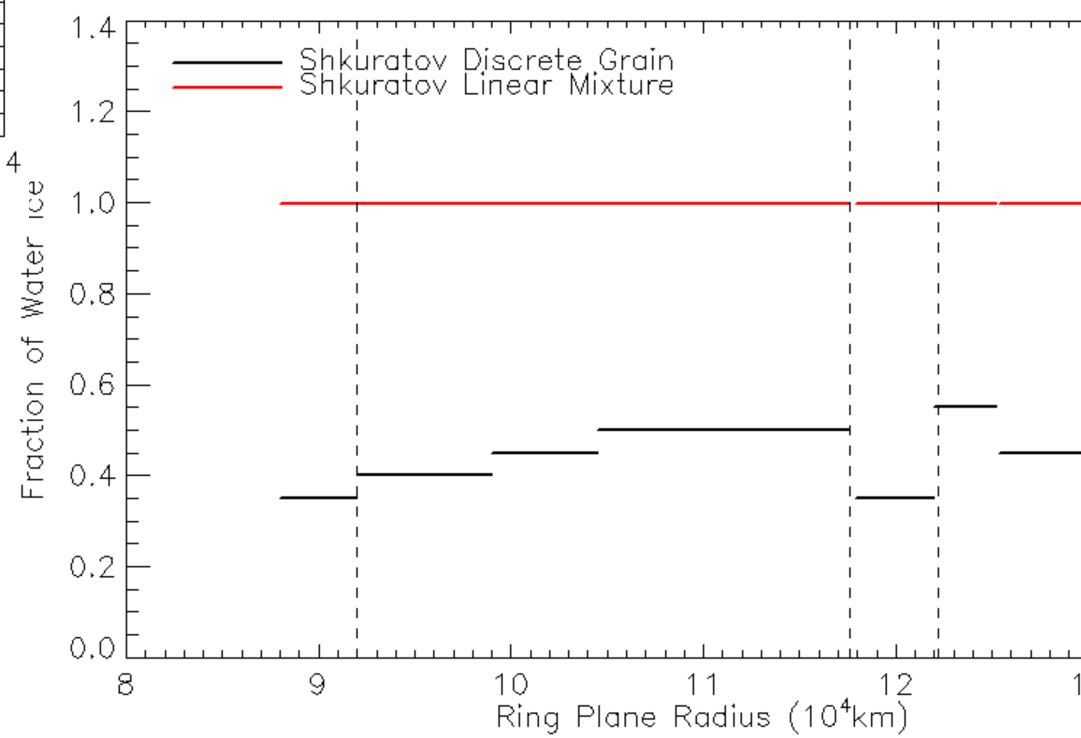
- Hapke Discrete Grain
    1. Water ice grain diameter
    2. Contaminant grain diameter
    3. Fraction of water ice
    4. Regolith grain asymmetry parameter

- Hapke Linear Mixture
    1. Water ice grain diameter
    2. Fraction of water ice
    3. Regolith grain asymmetry parameter


Central B ring
Data
Shkuratov Discrete Grain
Shkuratov Linear Mixture
140
160
180
200
nm
Central A ring
0.4
0.3
0.2
0.1
0.0
A_B
Data
Shkuratov Discrete Grain
Shkuratov Linear Mixture
120
140
160
180
nm
Central B Ring
Data
Hapke Discrete Grain
Hapke Linear Mixture
20
140
160
180
200
nm
Central A Ring
0.20
0.15
0.10
0.05
0.00
A_B
Data
Hapke Discrete Grain
Hapke Linear Mixture
120
140
160
180
nm



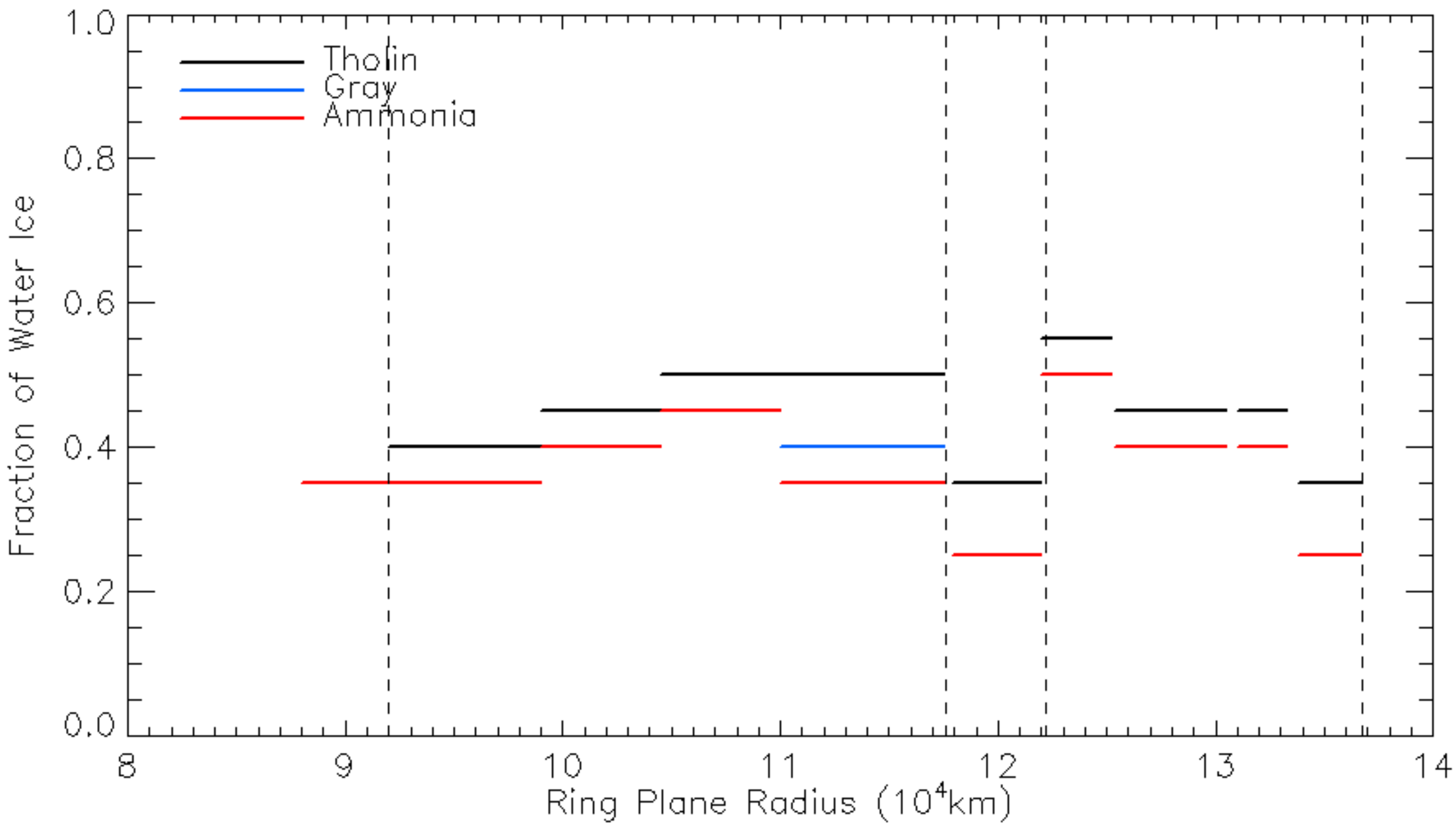
Hapke water ice fractions are near 1 for both mixtures



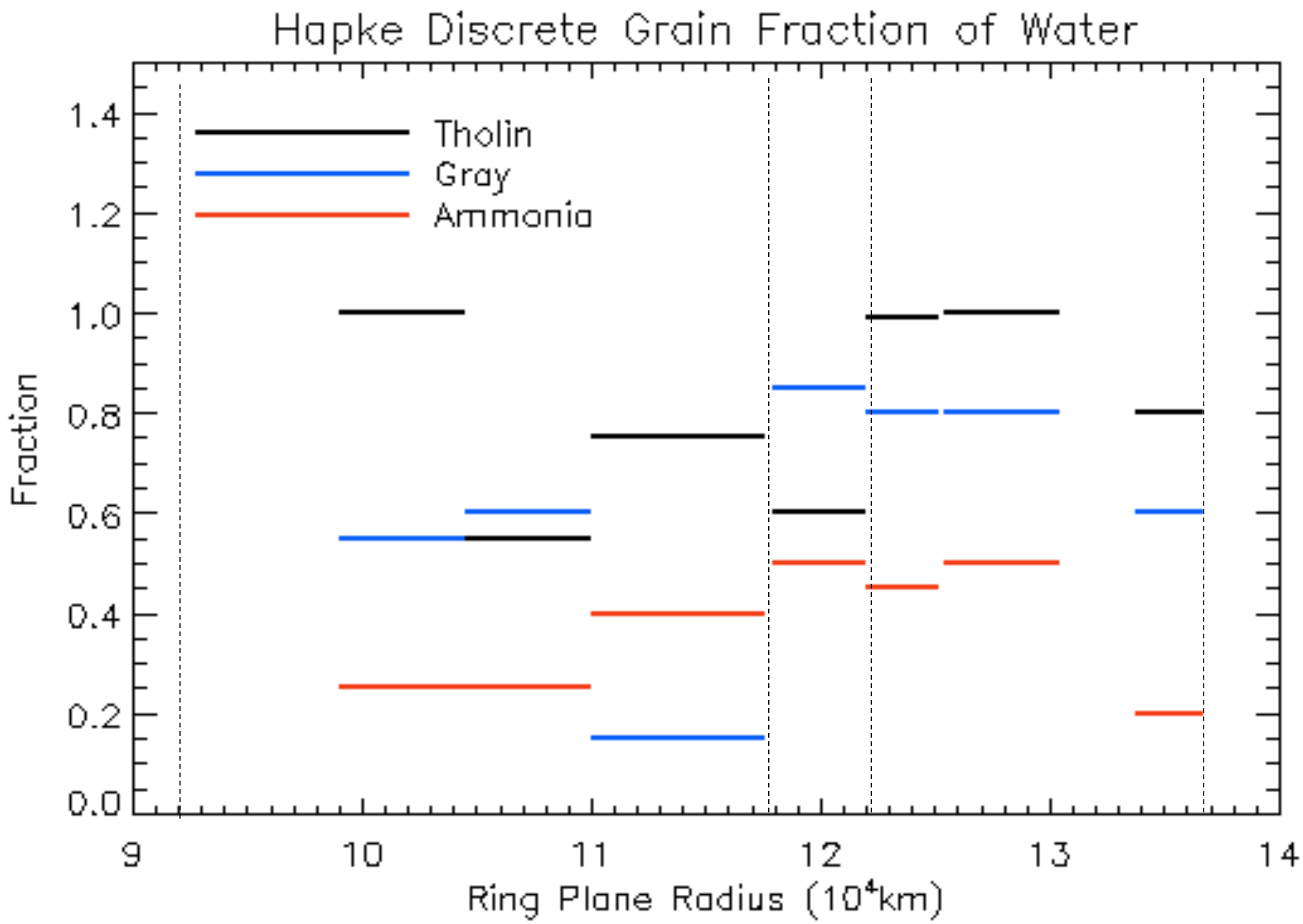
tov linear mixture water ice fraction is ~ 1

hough the fraction seems low, the shape of the ce abundance across the rings seems to make or the discrete grain model

Shkuratov Discrete Grain Water Ice Fraction



Hapke Discrete Grain Water Ice Fraction



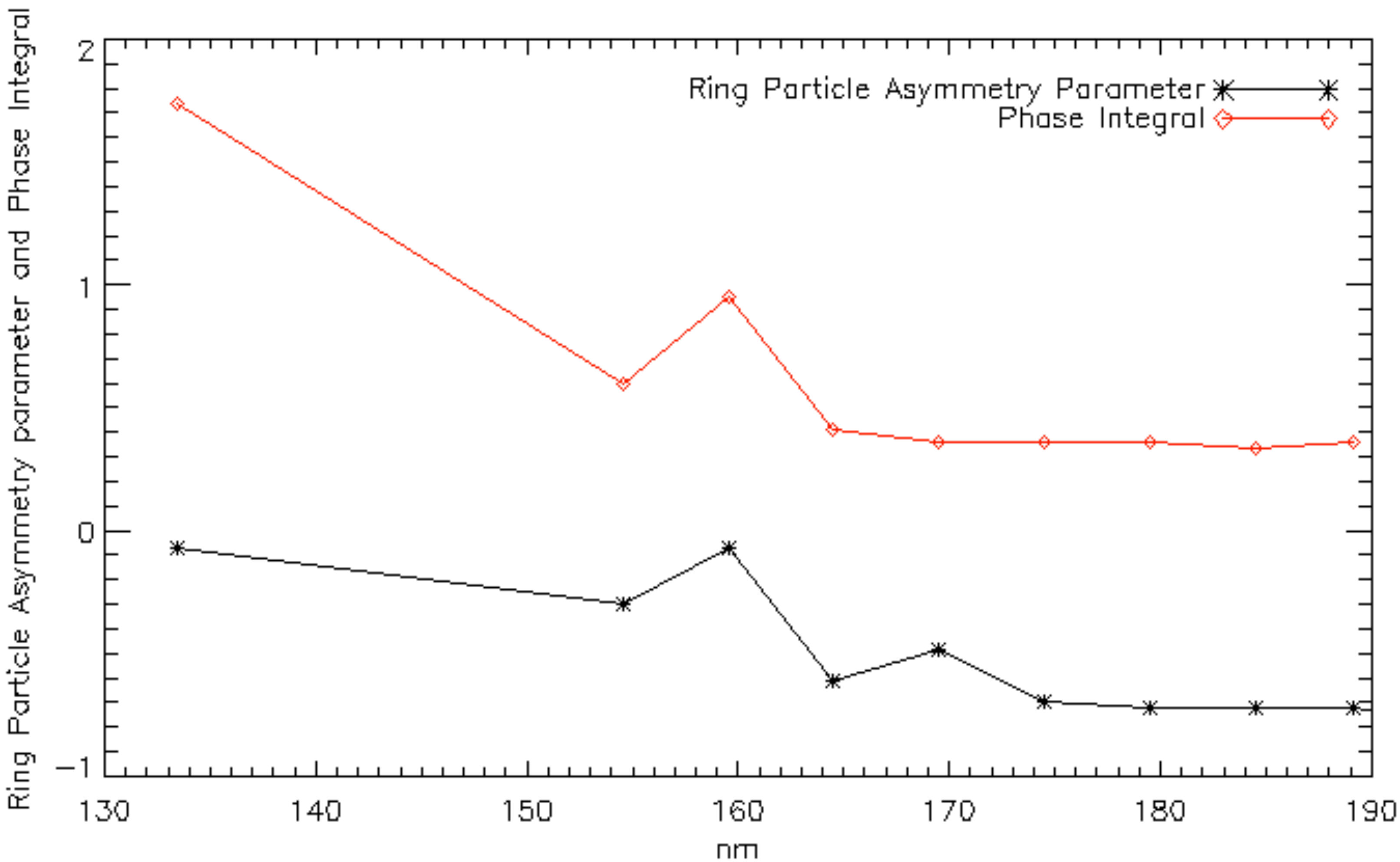
Explanation

Shkuratov model uses retrieved ring particle albedo

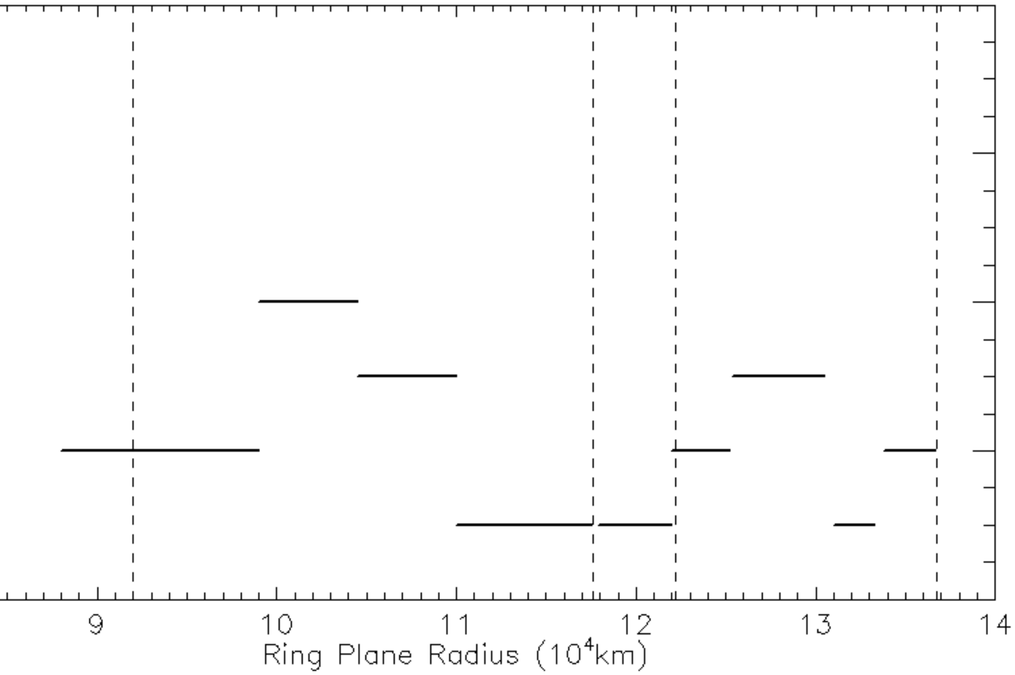
This suggests that the ring particle structure, whatever that is, significantly affects scattering properties of rings

Discrete grains may be “seen” at very short wavelengths

31 Region

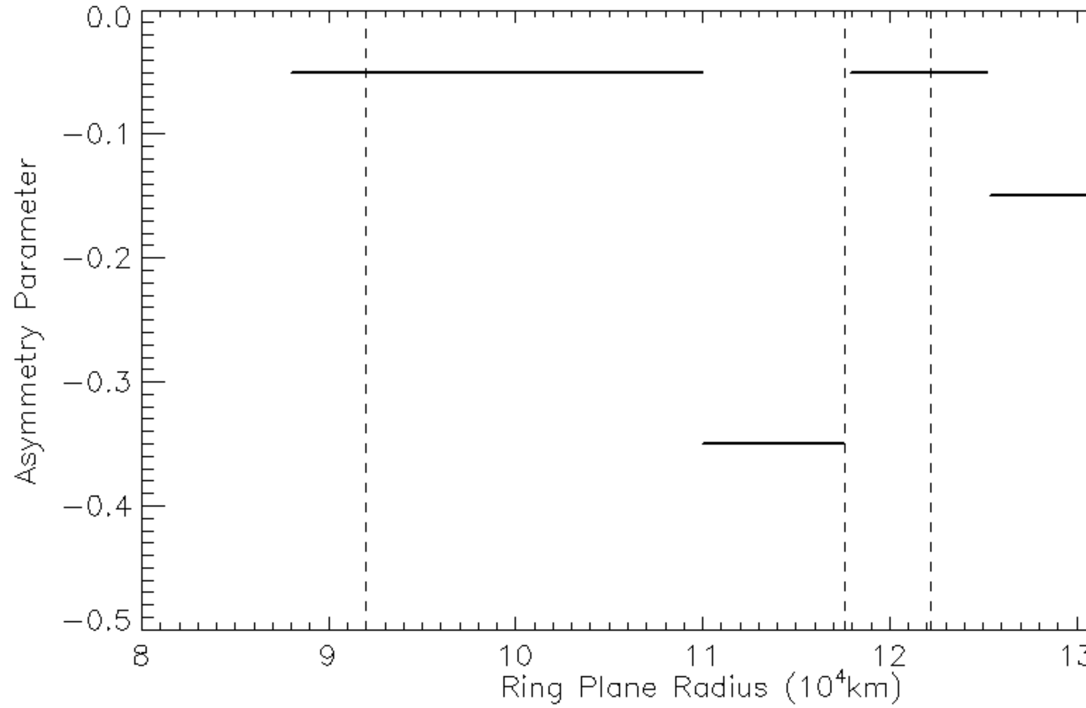


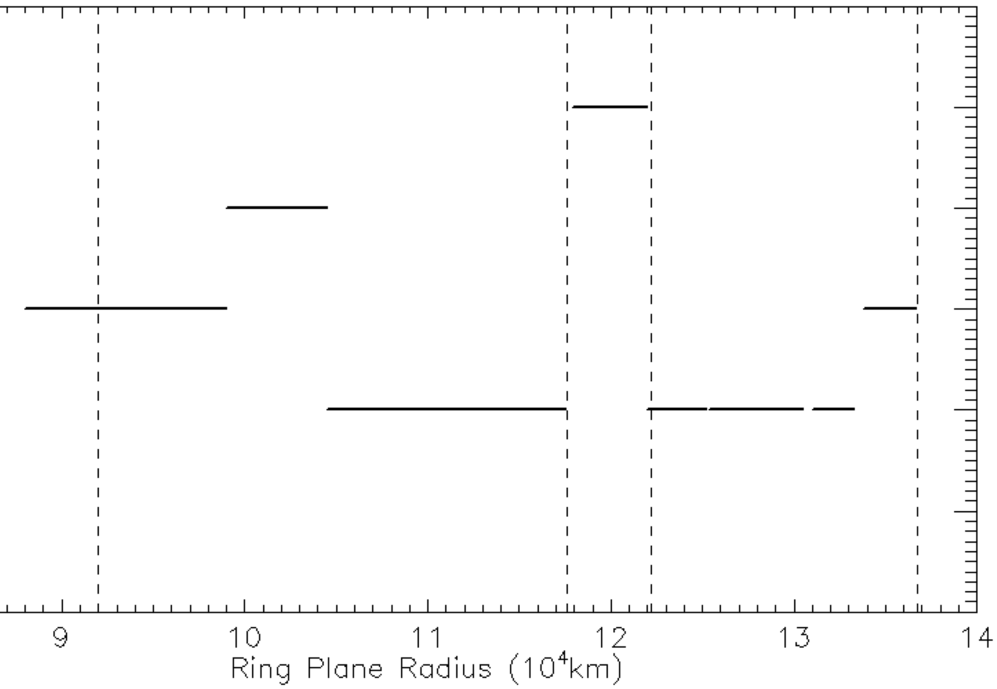
Ring Particle Asymmetry Parameter
Phase Integral
Ring Particle Asymmetry parameter and Phase Integral
2
1
0
−1
130
140
150
160
170
180
190
nm



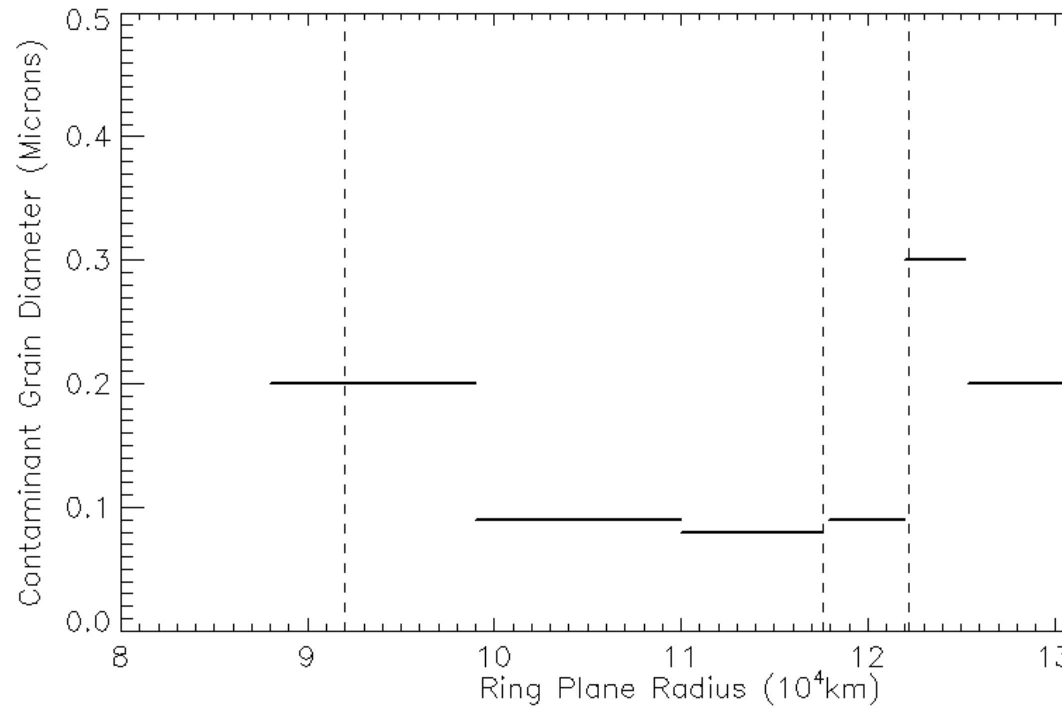
Porosity

Grain Asymmetry Parameter





Water ice grain diameter



ontaminant grain diameter

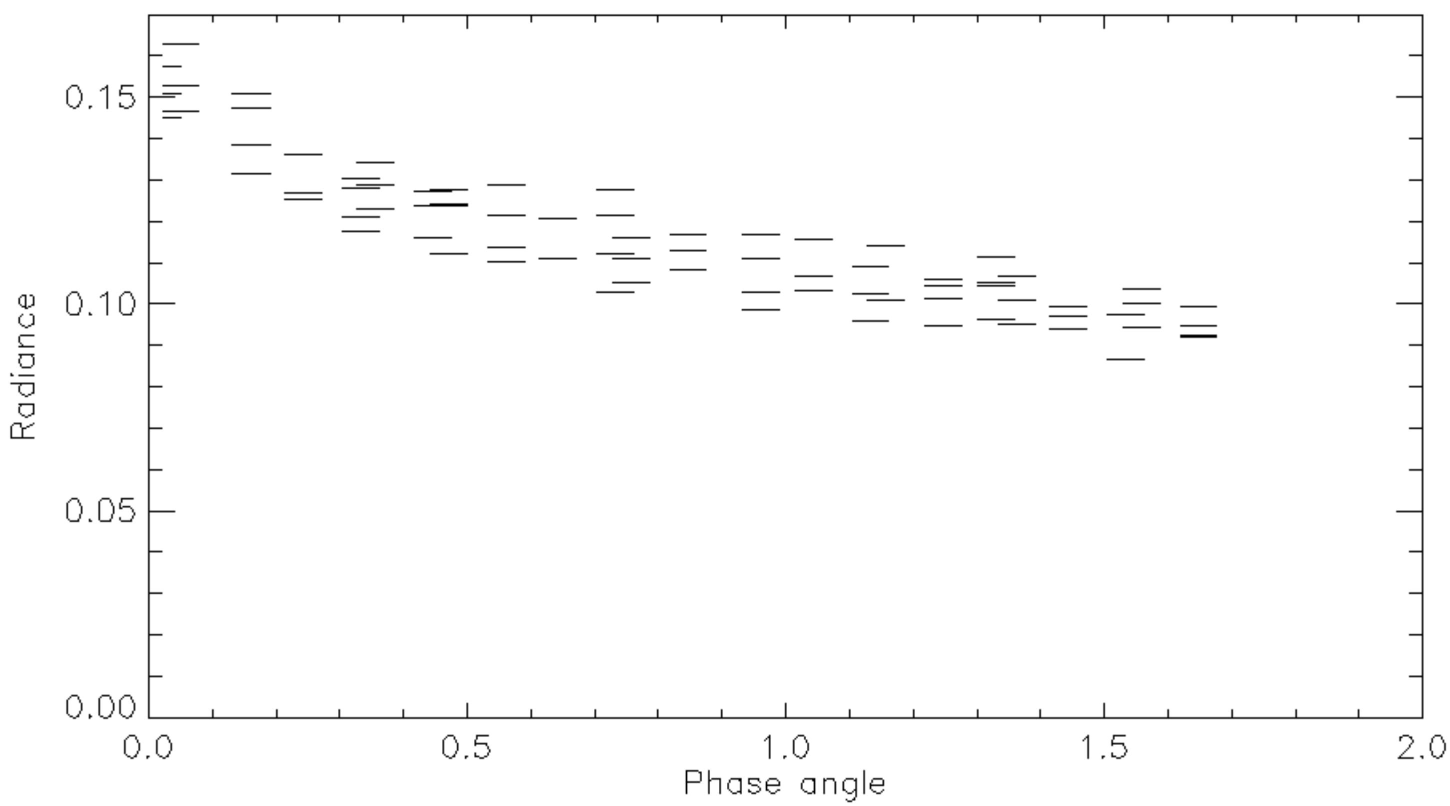
Current Research Efforts

Need to learn more about the morphological properties of the rings

Try to get something out of opposition effect

Try shape models such as a discrete dipole approximation

Observation of central B ring near 0° phase angle



Questions/Discussion