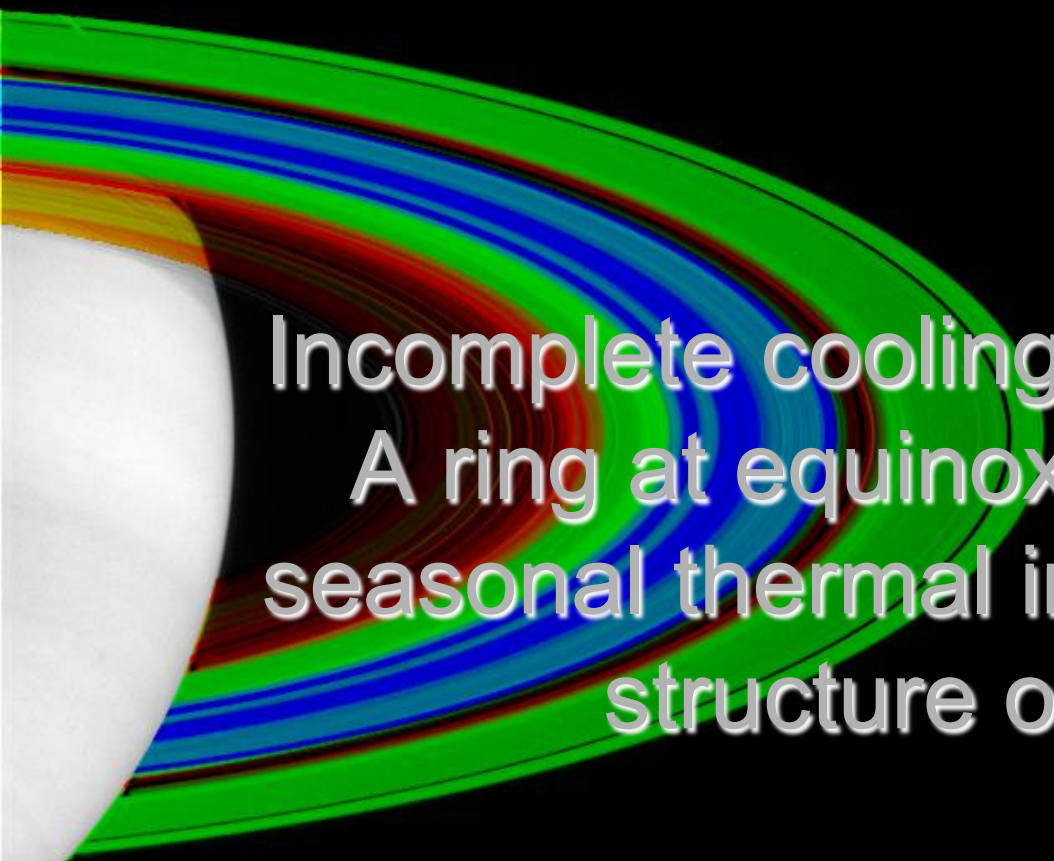

Incomplete cooling down of Saturn's A ring at equinox: Implication for seasonal thermal inertia and internal structure of particles

Ryuji Morishima, Linda Spilker, Shawn Brooks (JPL), Estelle Deau, Stu Pilorz (SETI)

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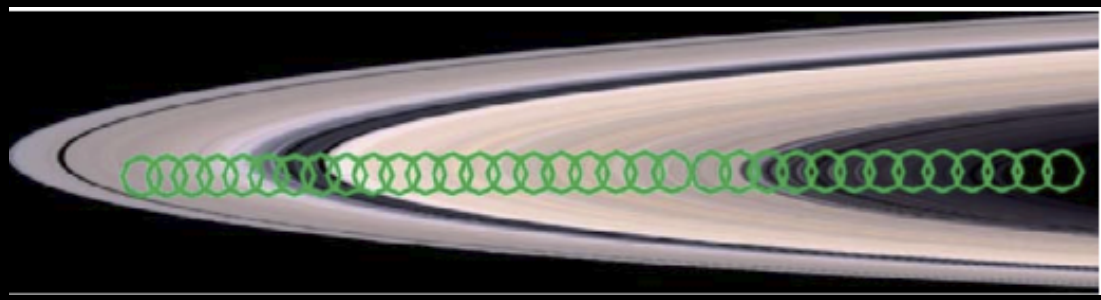
Introduction

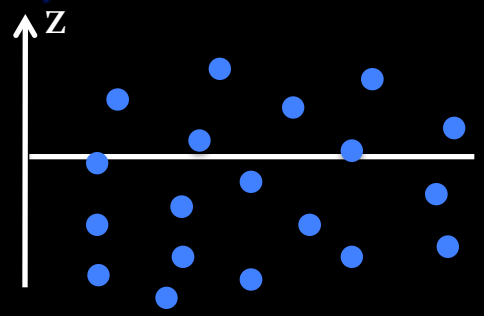
- Cassini Composite Infrared Spectrometer (CIRS) have measured millions of temperatures of Saturn's rings.
- Ring temperatures vary seasonally with ring opening angle; lowest at solar equinox in Aug 2009.
- Equinox temperature of A ring is much higher than model predictions with Saturn flux only (Spilker et al. 2013).
- If A ring is not completely cooled down at equinox, this can allow us to constrain particle properties (size and seasonal thermal inertia).

A CIRS radial scan
(Spilker et al. 2006)

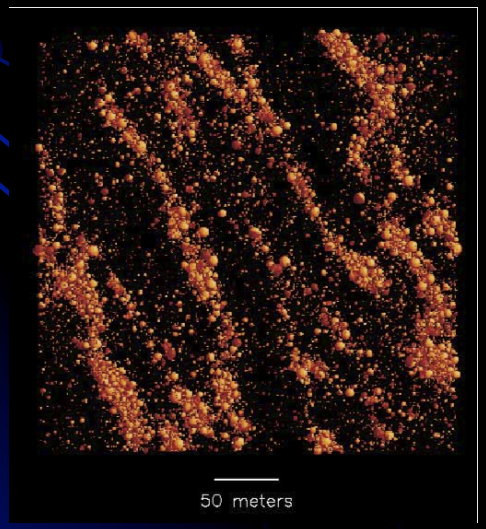


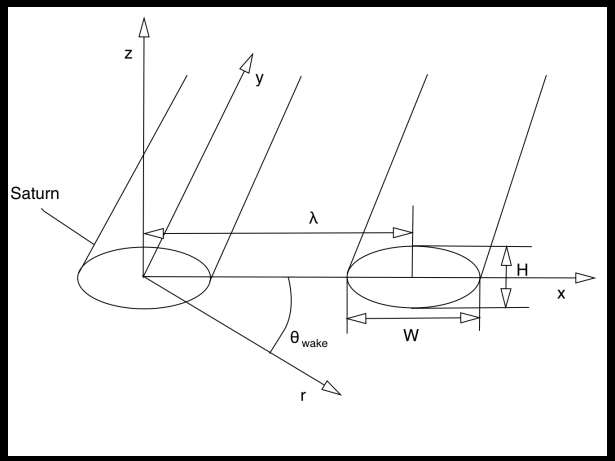
Thermal modeling of equinox temperature

- Multilayer model (H >> r) (Morishima et al. 2009):
  - Classical radiative transfer in VIS and TIR
  - Plane-parallel approximation
  - Bimodal spin distribution (fast and slow)

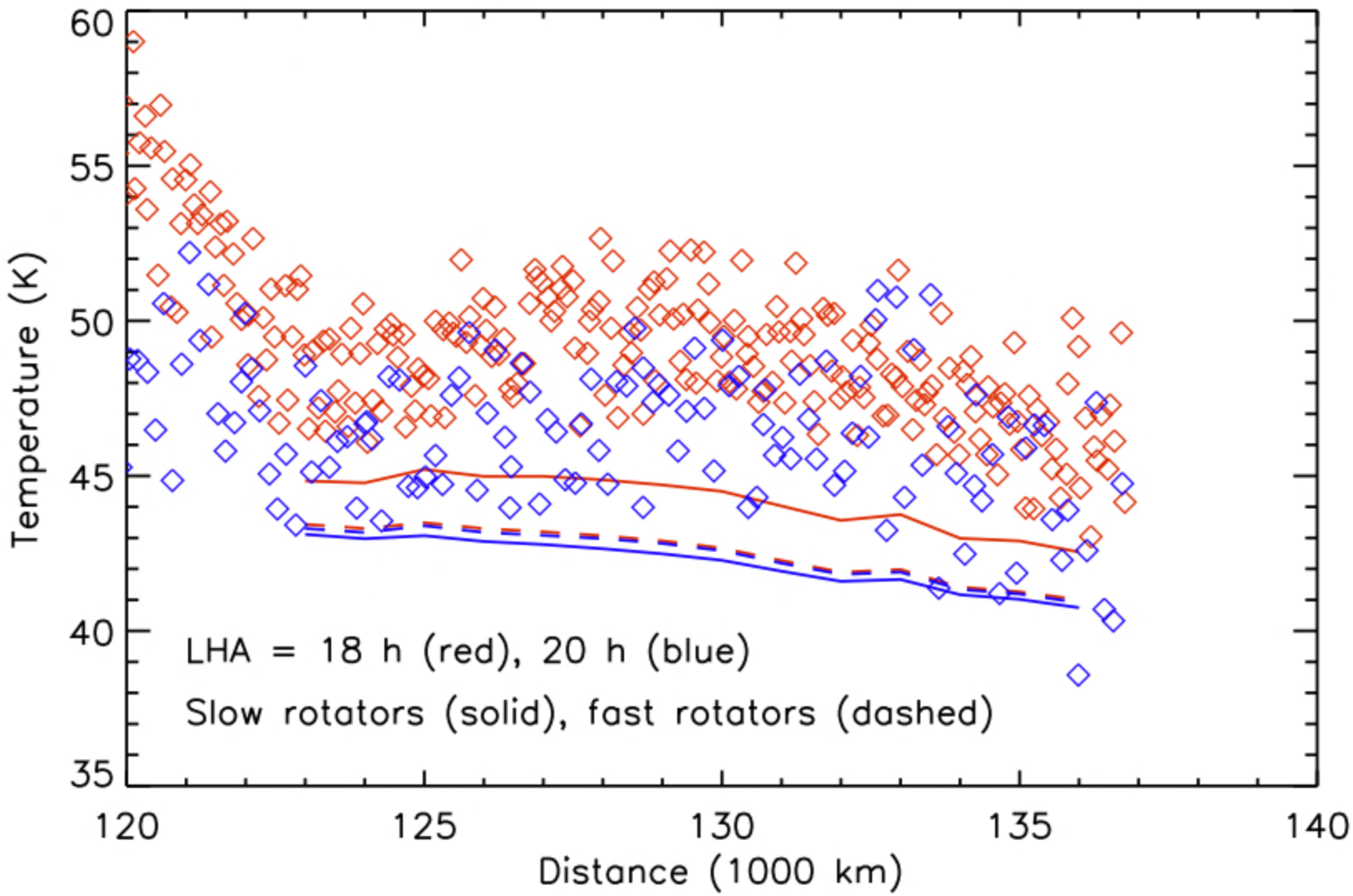


- Monolayer wake model (H = r) (Morishima et al. 2014)
  - Wakes are mimicked by elliptical cylinders
  - 3D structure -> 1D radiosity

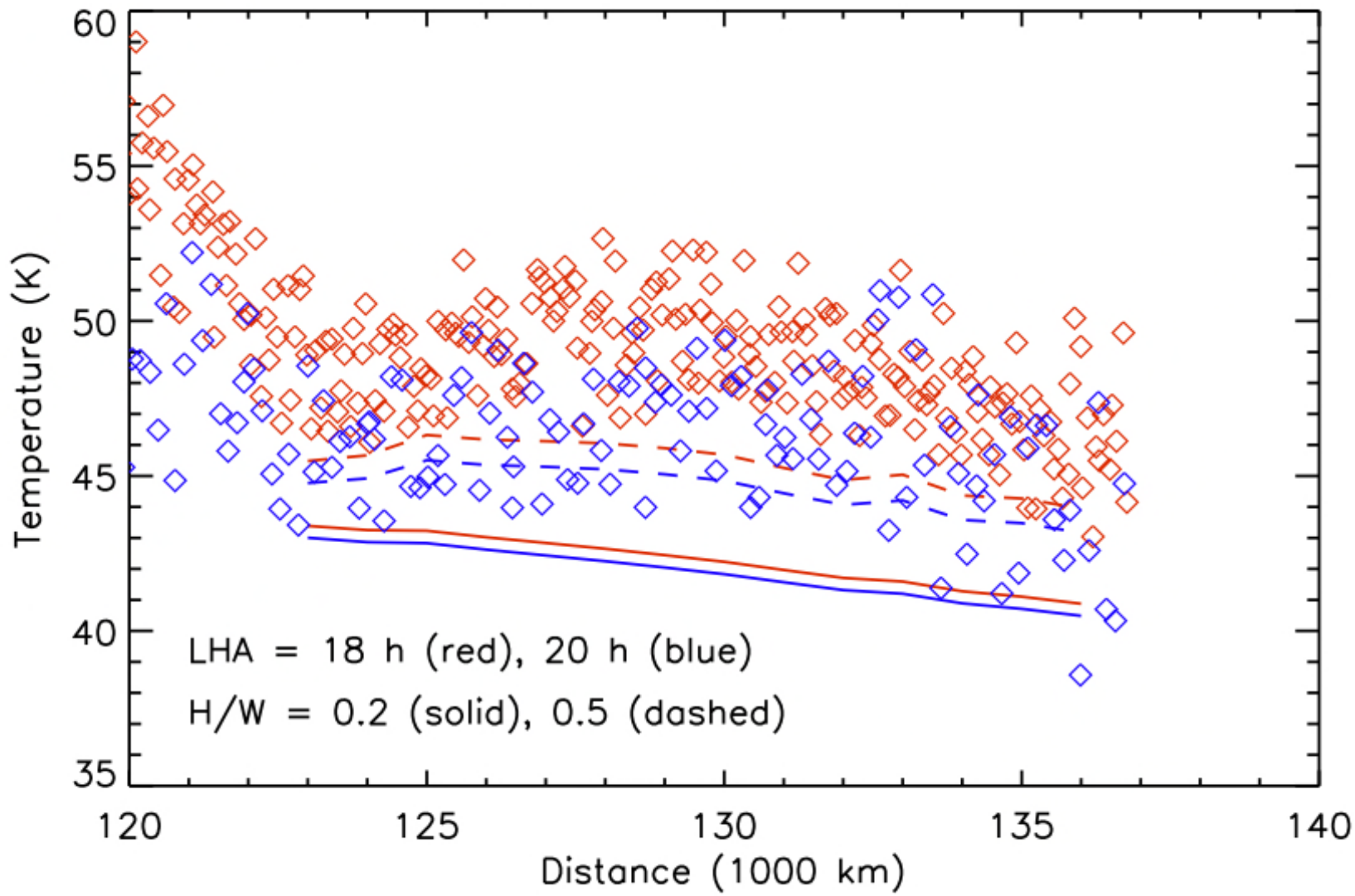




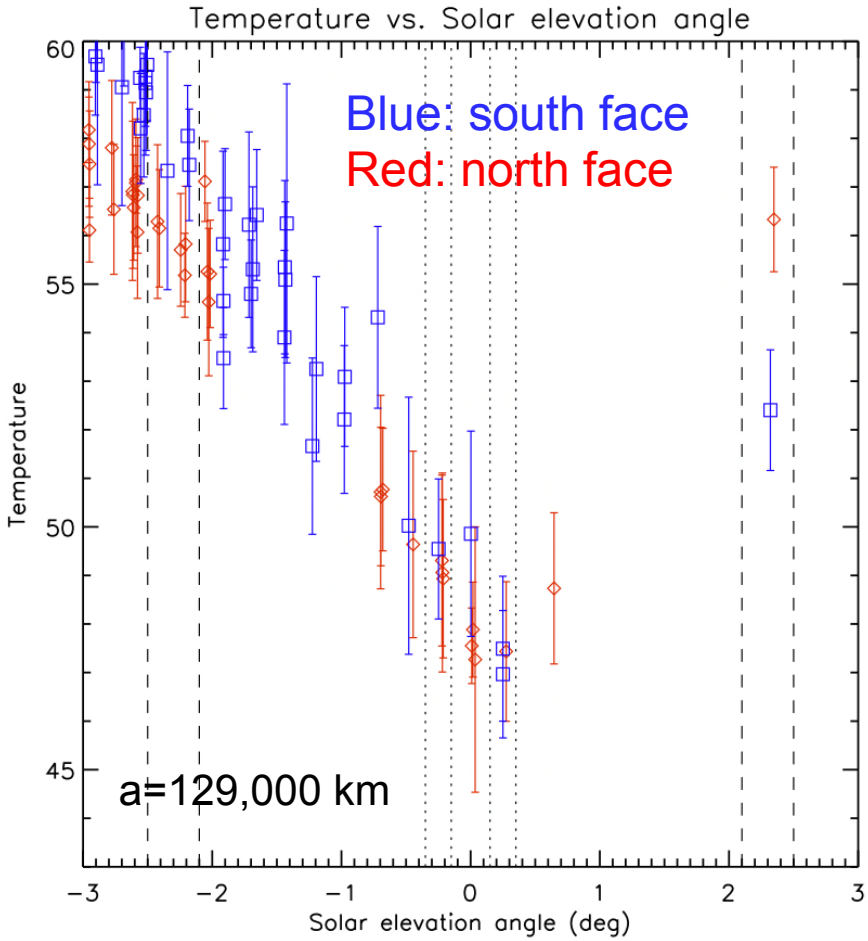
Multilayer model

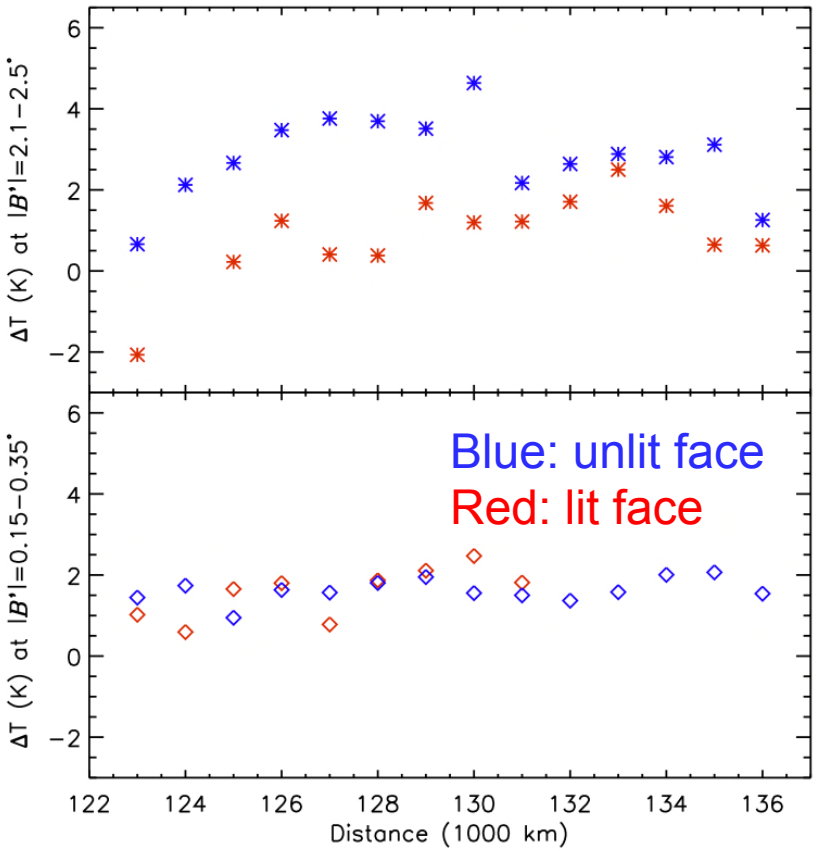


Monolayer wake model



Temperature asymmetry around equinox





Incomplete cooling of A ring summary

- Equinox temperature is higher than model prediction regardless of ring structure assumed.
- Models cannot reproduce radial temperature profiles: temperature anomaly is prominent for the middle A ring.
- Ring temperature before equinox is higher than that after equinox.

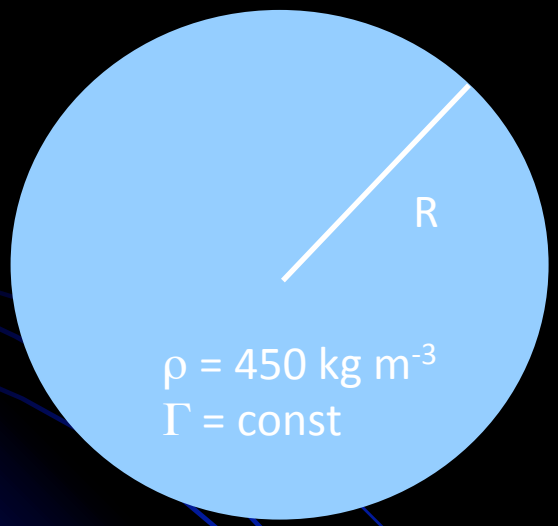
- We conclude that the A ring was not completely cooled down at equinox.

Modeling seasonal temperature variation

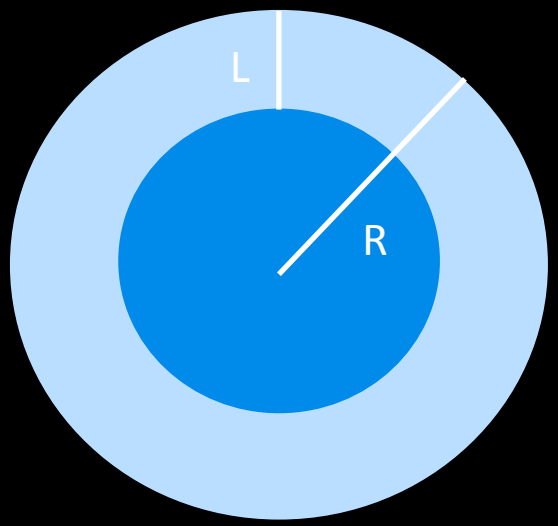
- Examine seasonal temperature variations of the south and north faces
- Exclude low solar phase data and shadow data to ignore geometry dependence and diurnal variation
- Model fit using a simple seasonal model (Froidevaux 1981) including time dependence
- Adopt equilibrium equinox temperature due to Saturn flux only from the multilayer model

Internal structure model

Deep internal structure of ring particle can be constrained
Skin depth: $(K/(\rho C\Omega))^{1/2}$ ~ 1m (seasonal) ~ 1mm (diurnal)



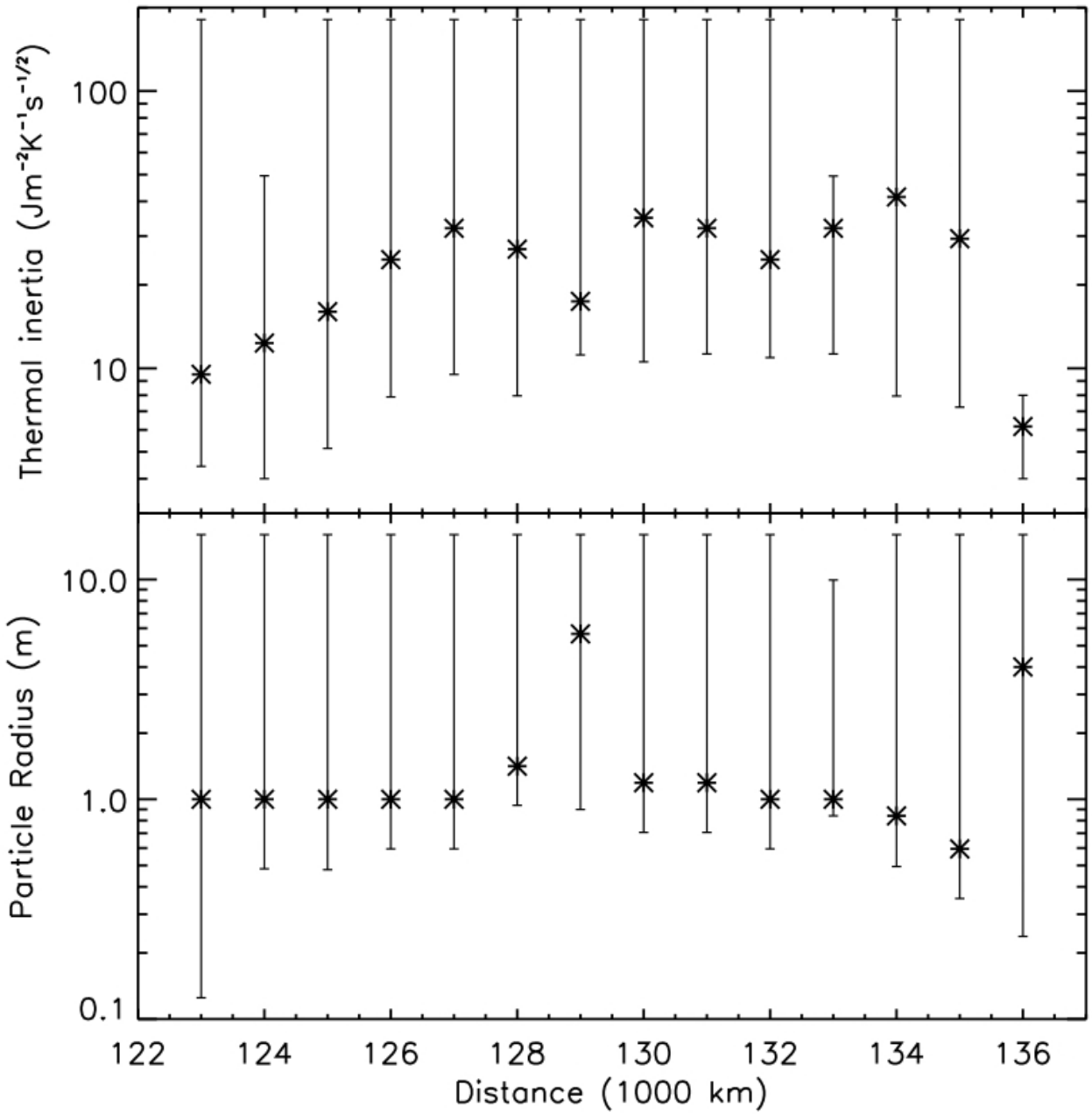
Model 1
Parameter: R and Γ



Model 2
Parameter: R and L

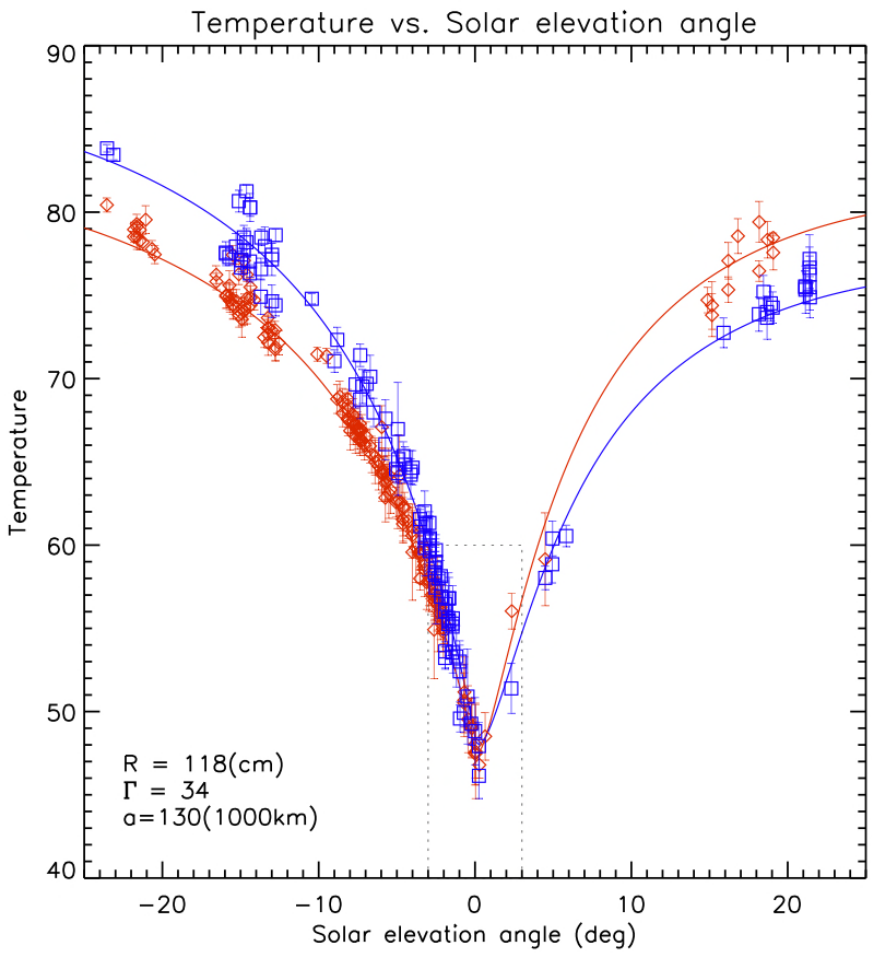
Core
ρ = 900 kg m^{-3}
Γ = 2600 $Jm^{-2}K^{-1}s^{-1/2}$

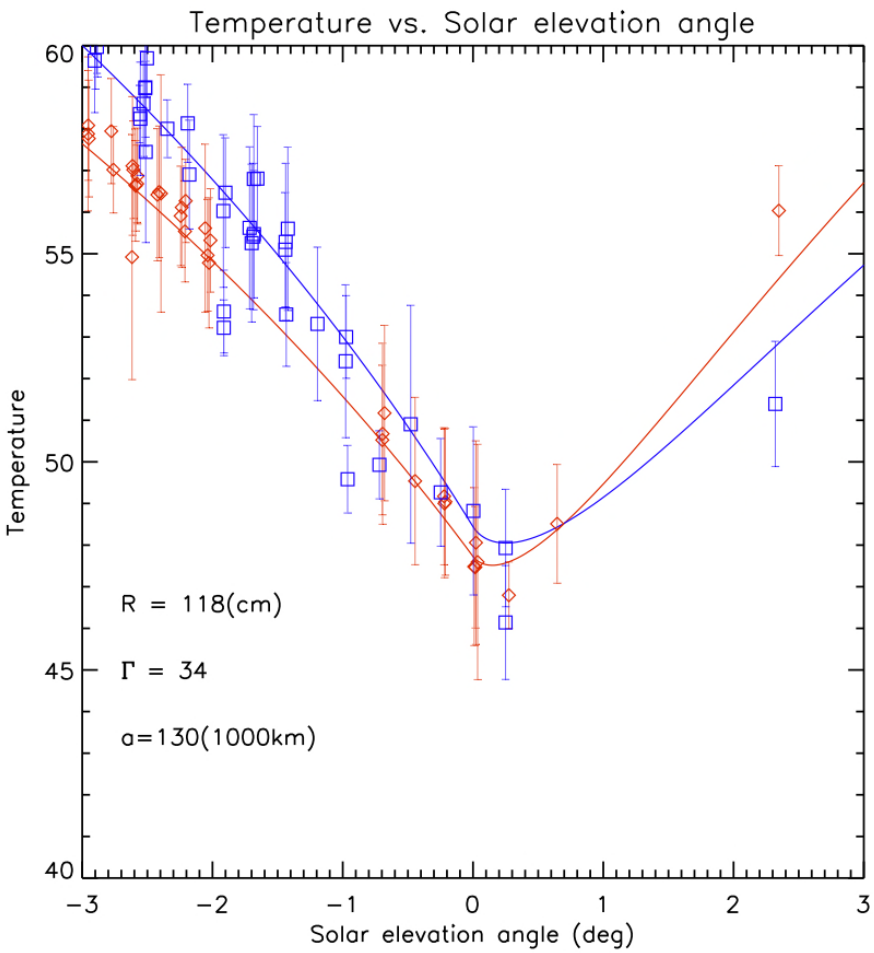
Regolith mantle
ρ = 100 kg m^{-3}
Γ = 10 $Jm^{-2}K^{-1}s^{-1/2}$
(Morishima et al. 2011, 2014)



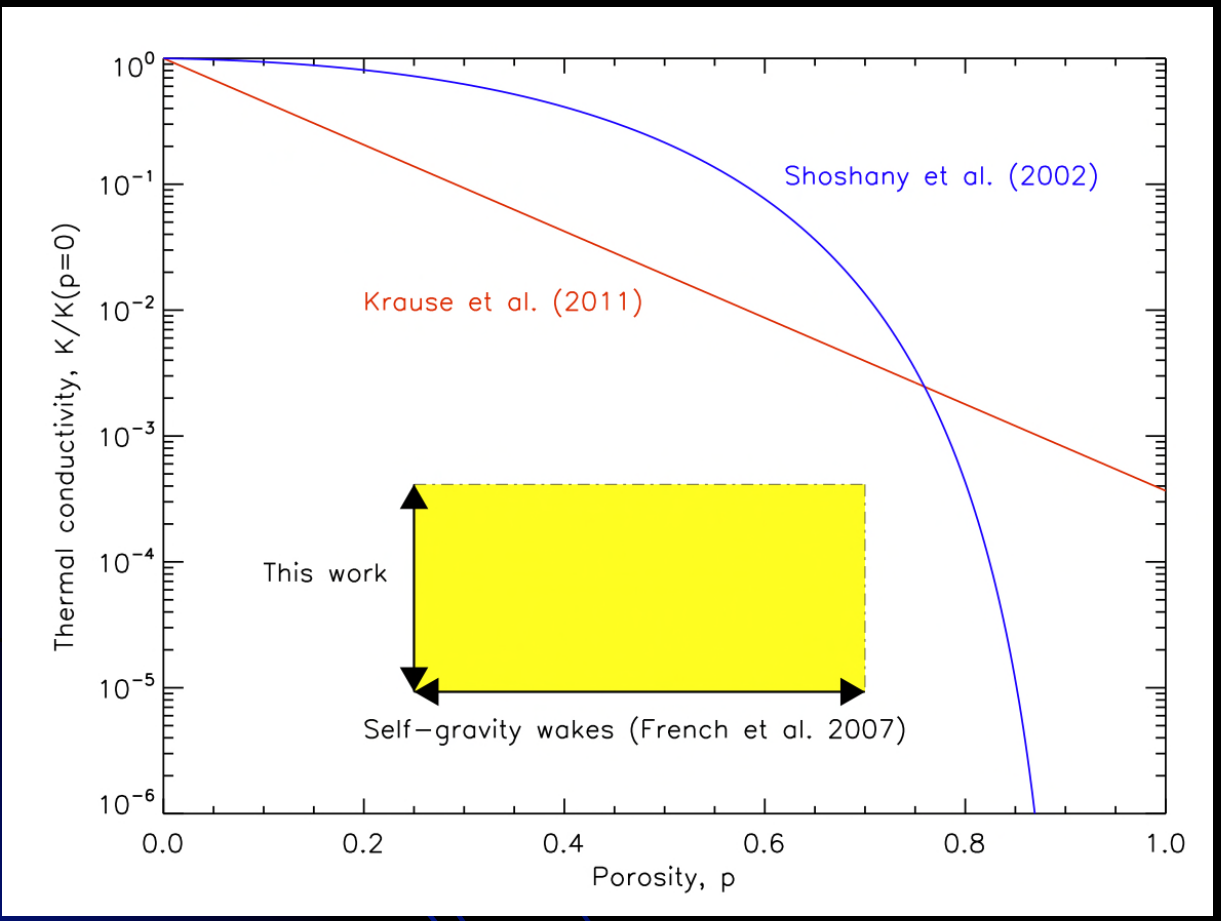
Model1 results (uniform)

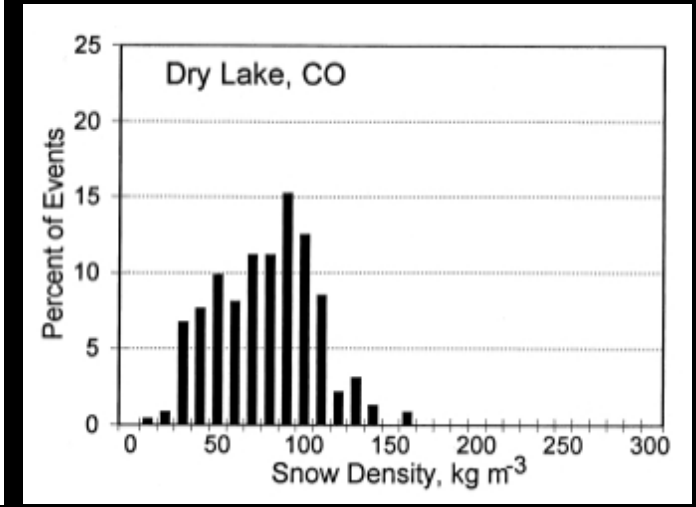
An example of model fits





Expected regolith density

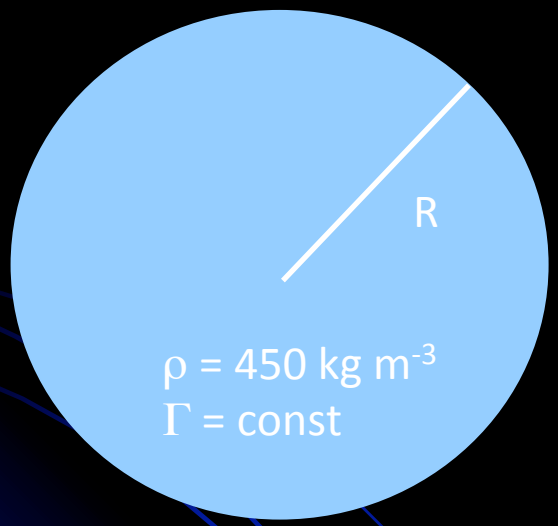




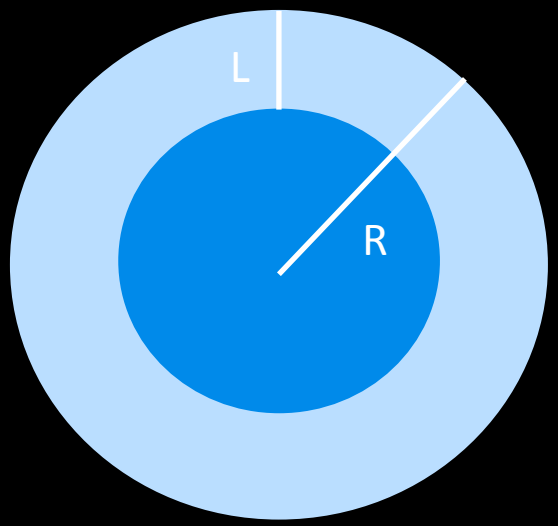
Ring regolith is as fluffy as fresh snow on Earth

Internal structure model

Deep internal structure of ring particle can be constrained
Seasonal skin depth ~ particle size ~ 1 m
(vs. diurnal skin depth ~ 1 mm)



Model 1
Parameter: R and Γ



Model 2
Parameter: R and L

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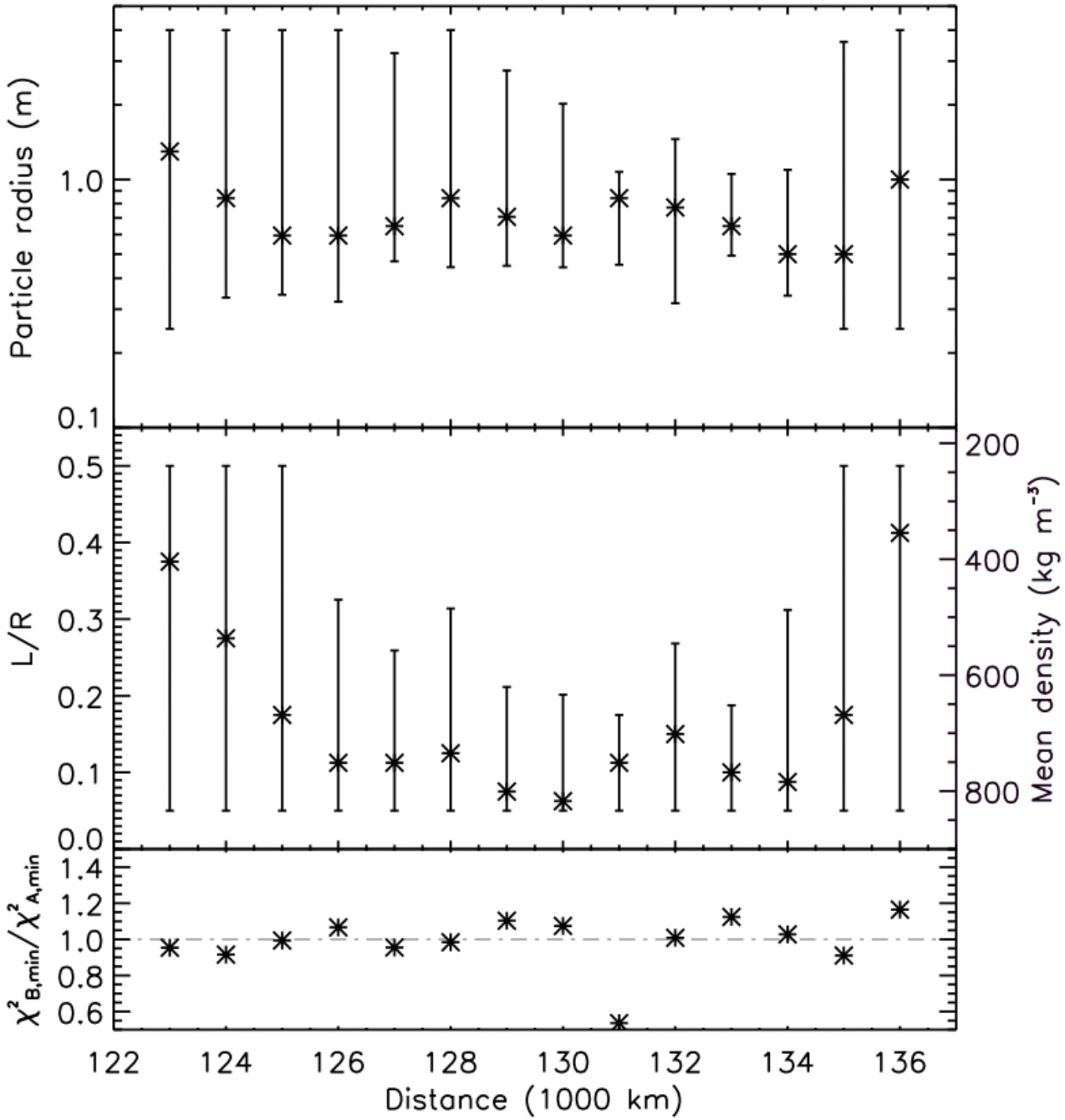
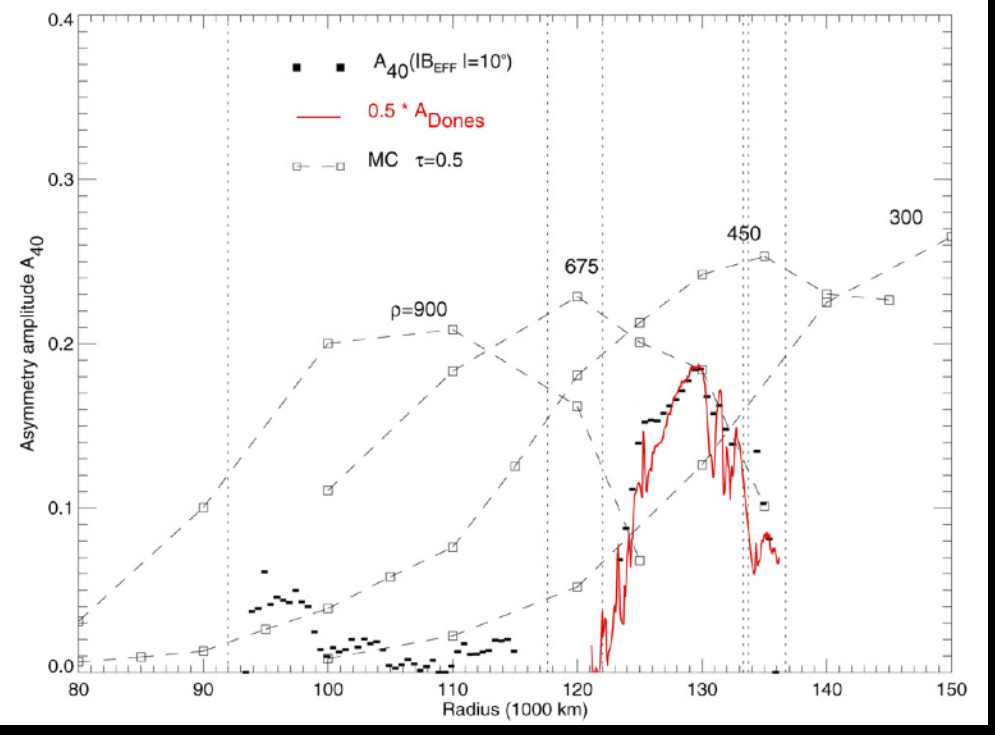
Regolith mantle
ρ = 100 kg m^{-3}
Γ = 10 Jm^{-2}K^{-1}s$^{-1/2}$
(Morishima et al. 2011, 2014)

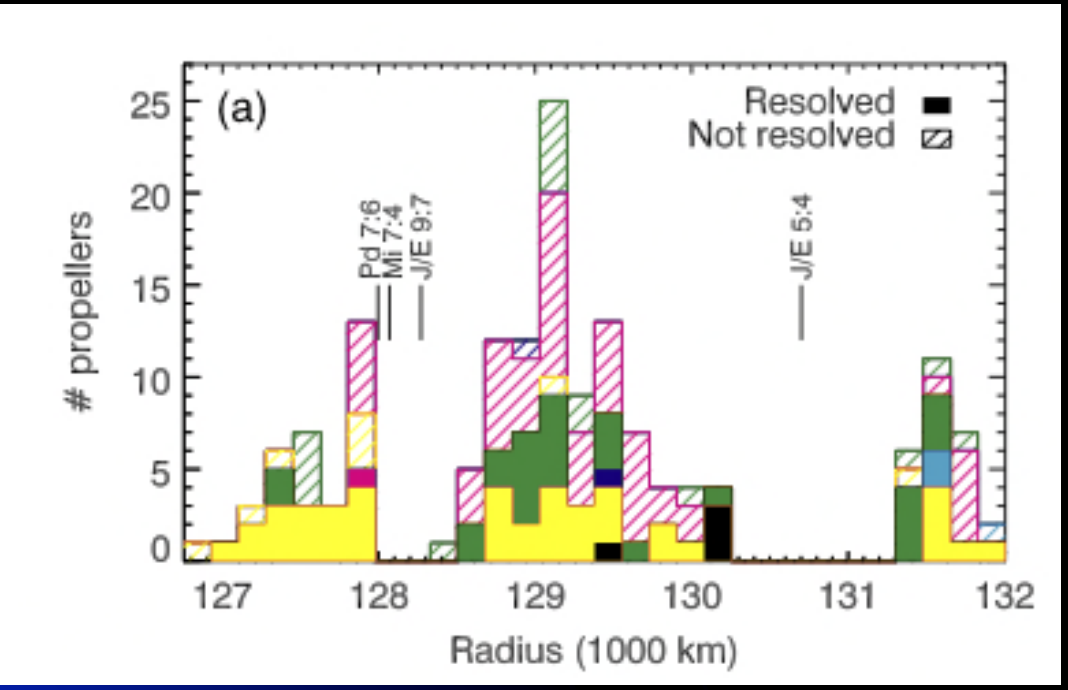


Model2 results (core)



Radial density variation is consistent with that suggested from azimuthal brightness asymmetry.

(French et al. 2007)



The middle A ring is populated with propeller-forming moonlets.

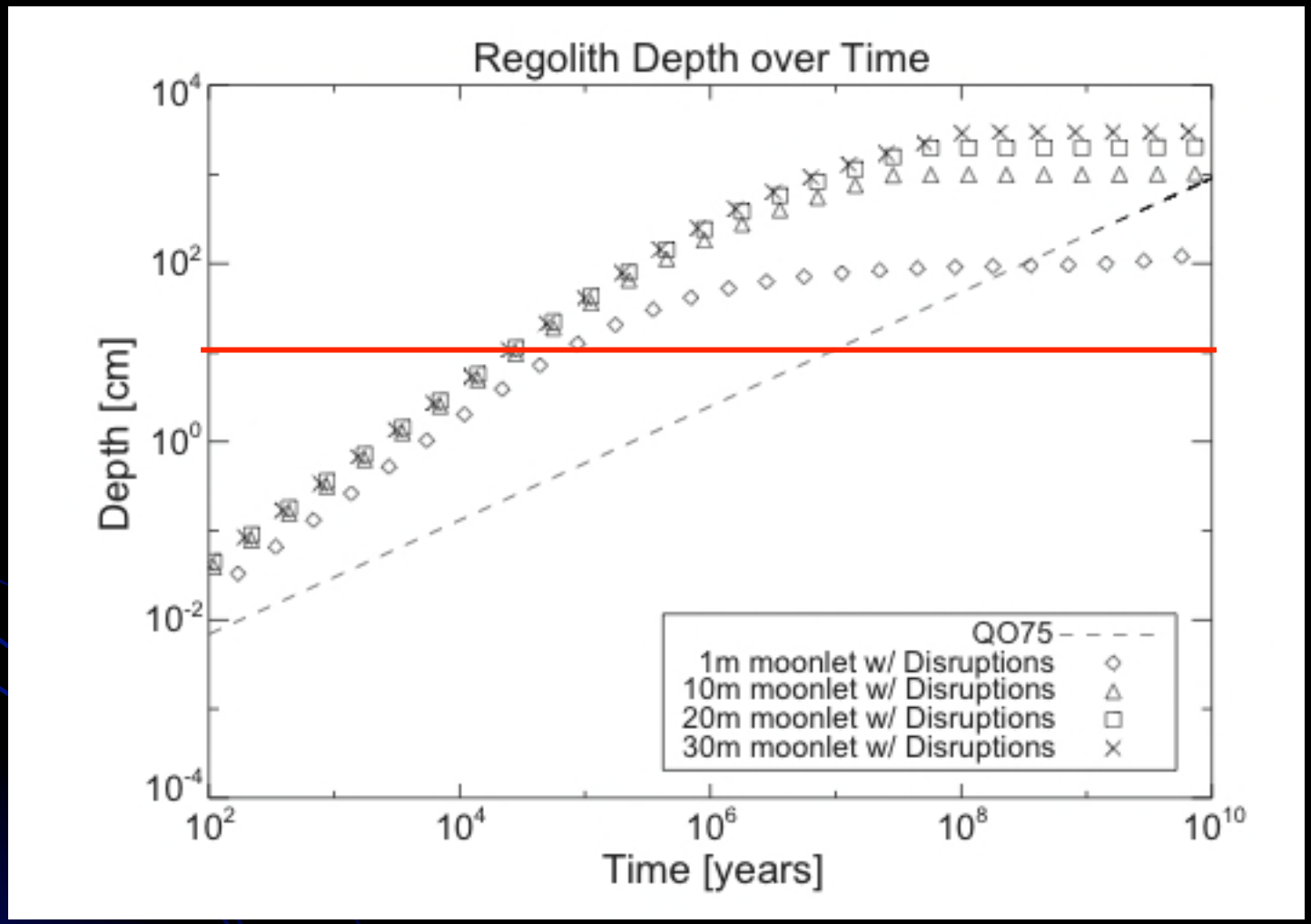
(Tiscareno et al. 2008)

Summary

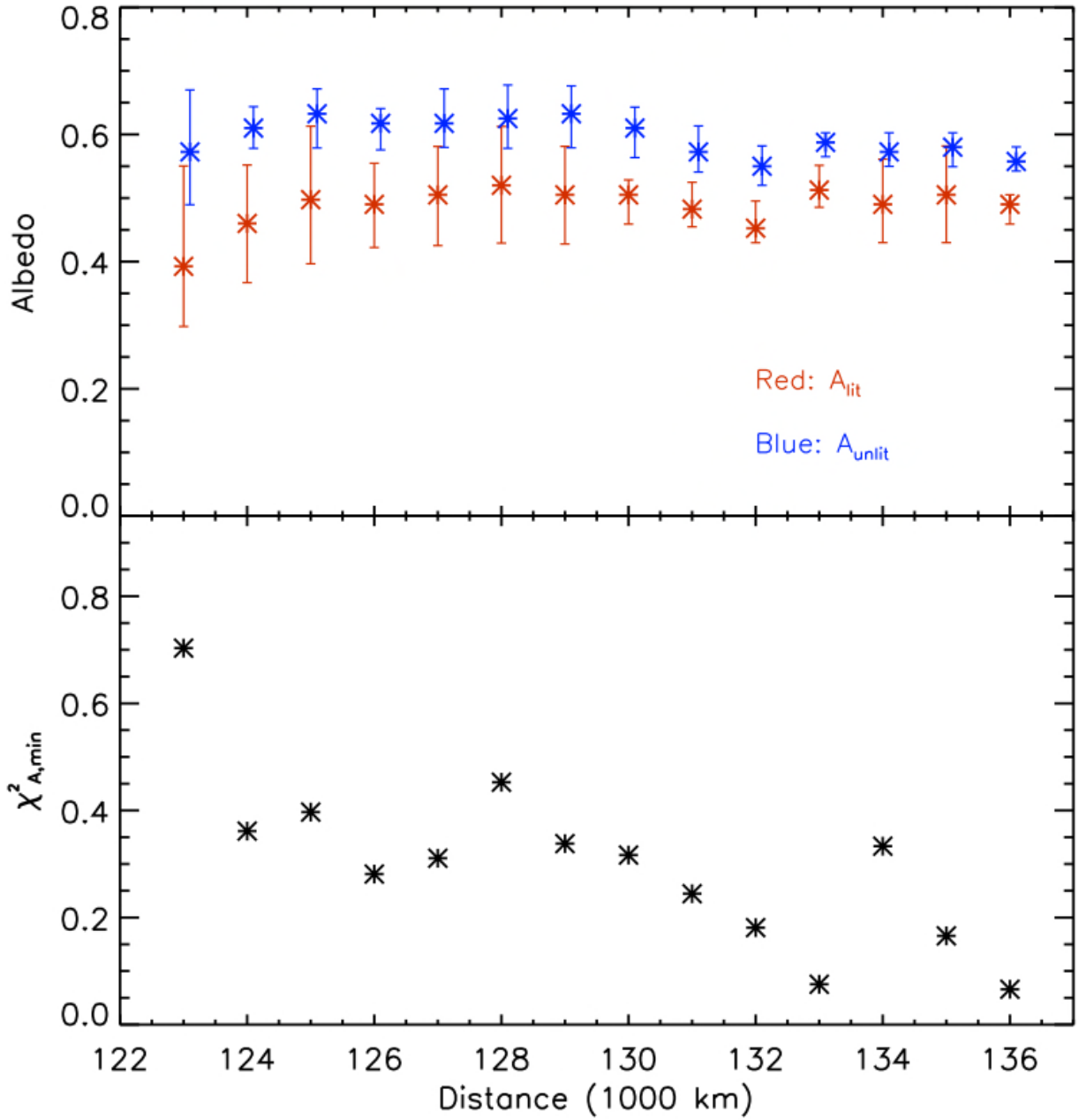
- Effective particle size is ~ 1 m or slightly less
- Seasonal thermal inertia is 10-30 in MKS units; high at middle A ring
- Core size is ~ 0.9 particle radius at middle A ring and less in inner and outermost A ring.

- Density increase from inner to middle A ring may be caused by outward transport of dense particles with moonlets; tidal break up when they migrate inward.
- Low thermal inertia of outermost A ring may be due to enhanced collisional dust production or accumulation of E ring particles.

Young A ring?



Elliott and Esposito (2011)


Albedo
Red: A_{lit}
Blue: A_{unlit}
$\chi^2_{A,min}$
Distance (1000 km)
0.0
0.2
0.4
0.6
0.8
122
124
126
128
130
132
134
136