Constraining the micro and macro-structures of Saturn's C ring by modeling Cassini optical and thermal opposition effect

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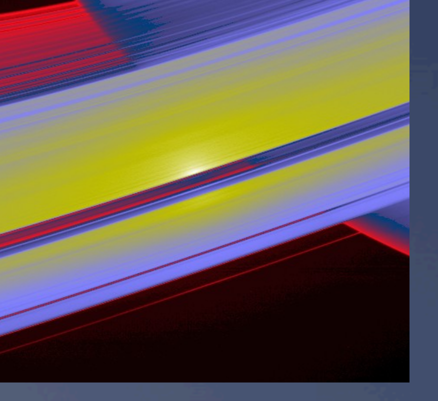
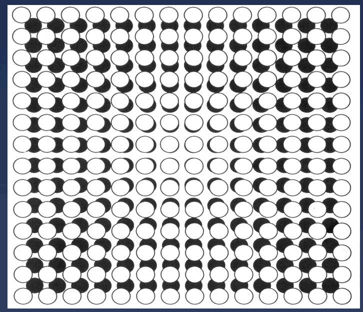


Introduction

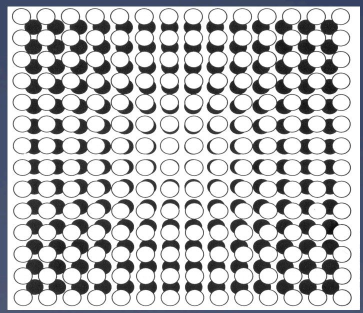
Why study the ring opposition effect?

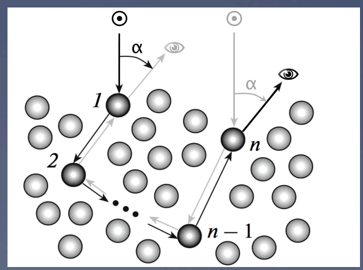
With the opposition effect, we can constrain:

- the ring layer (macro-structure)
  - ring (interparticle) shadow hiding
  - ring roughness



- the regolith layer (micro-structure)
  - regolith roughness
  - regolith shadow hiding
  - coherent backscattering





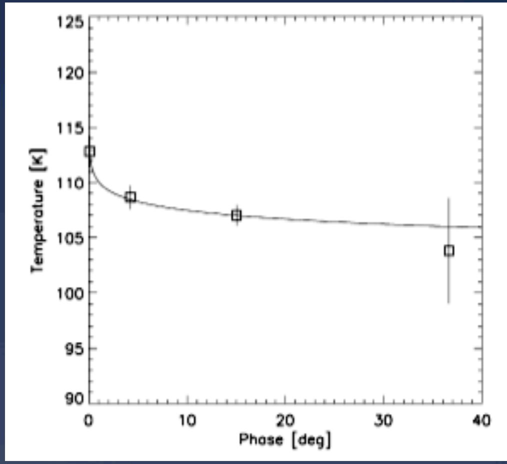
HOWEVER
Coherent backscattering is a matter of debate among theorists.

(Shkuratov & Zubko 2008 Icarus
Petrova et al. 2008 Icarus
Tishkovets & Mischenko 2010 JQSRT
Hapke & Nelson 2010 JQSRT)

Using thermal data to narrow down CB

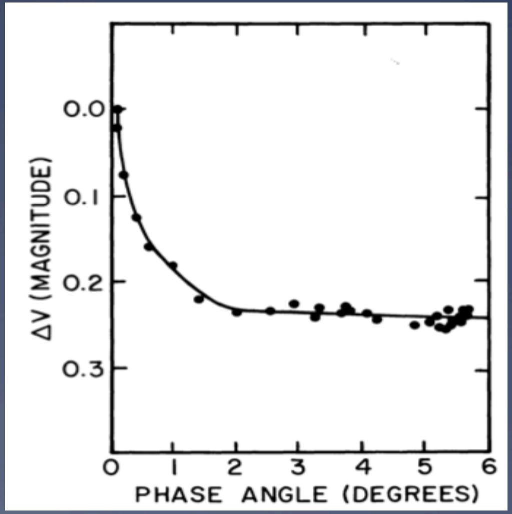
Thermal Opposition Effect

* observed by Altobelli (2007) in far-infrared
* is independent of the coherent backscattering

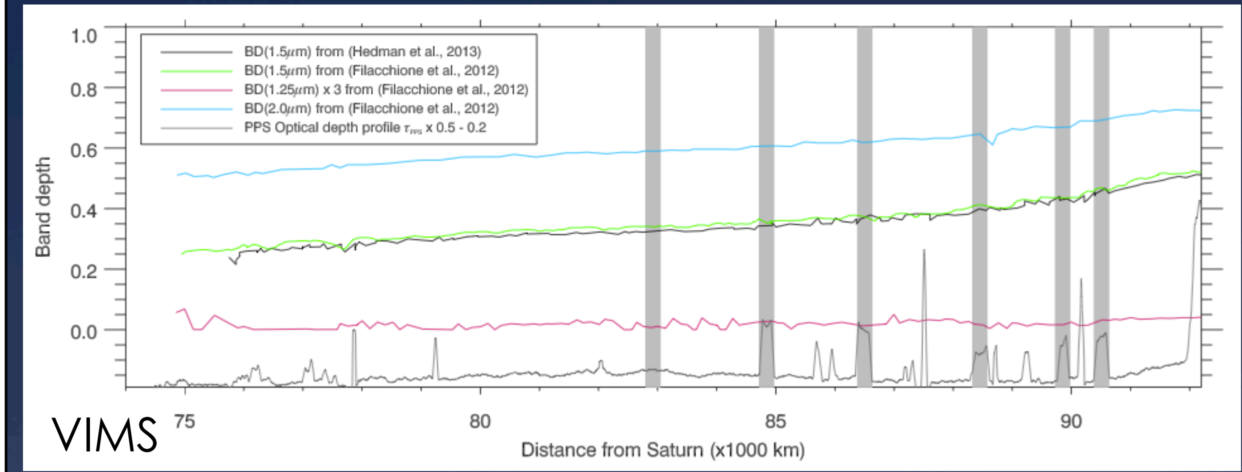


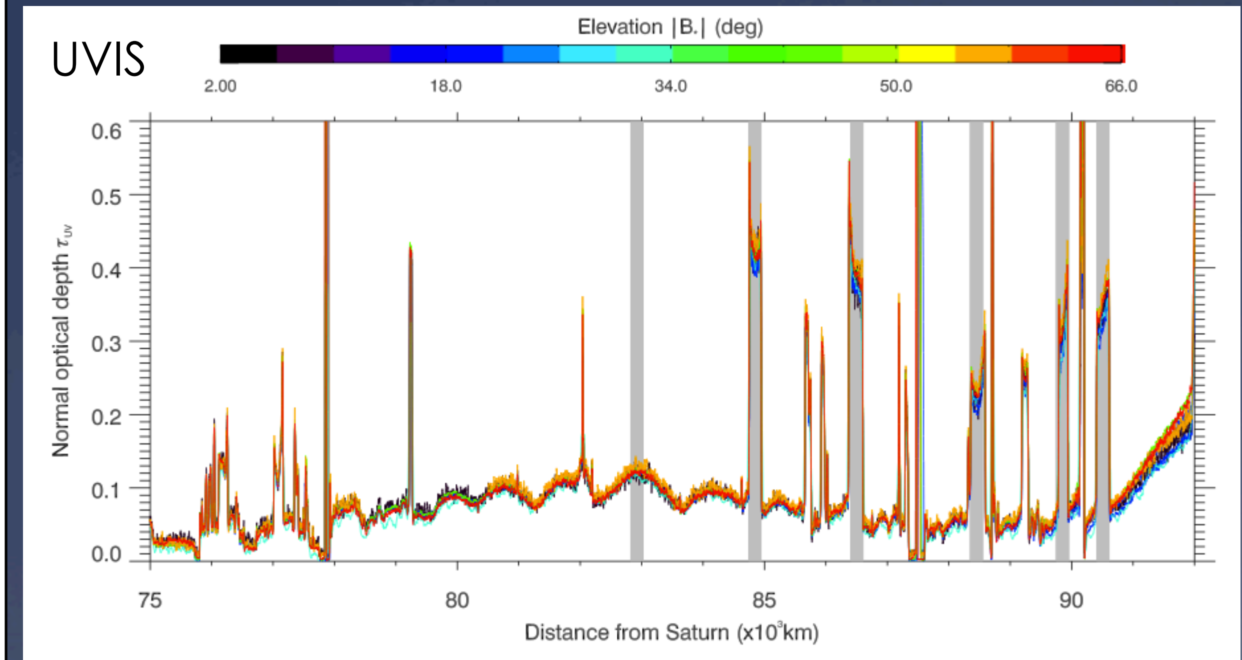
Visible Opposition Effect

* observed by Muller (1883)
* can be explained by coupling of regolith Shadow Hiding, interparticle Shadowing, and Coherent Backscattering (Salo and French, 2010)



Why the C ring?



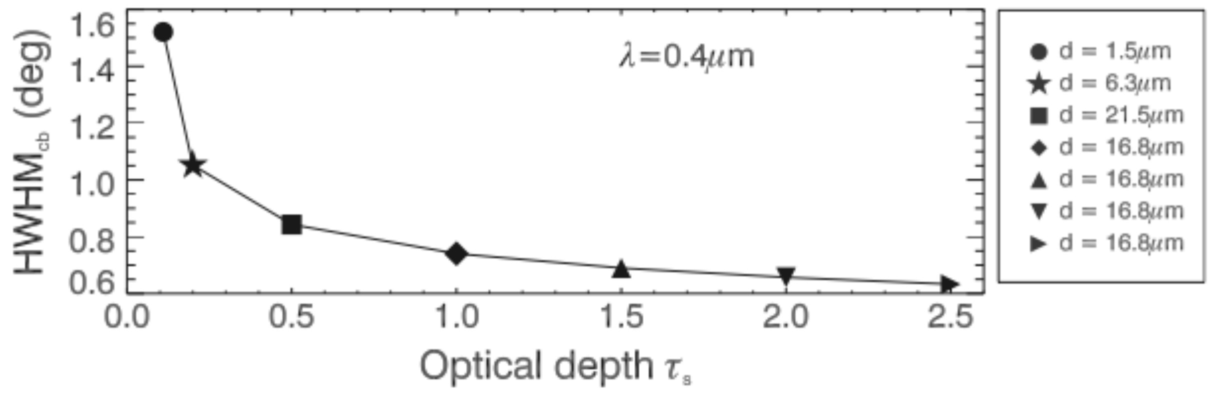


The C ring has very distinct radial variations of microscopic signatures and macroscopic signatures

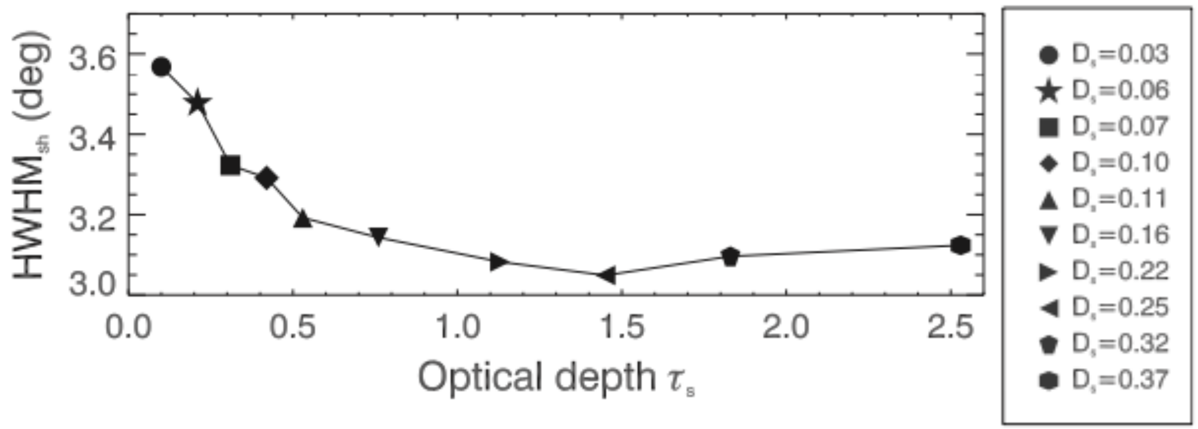
Problem Statement

Convolved signatures of CB and SH

Coherent backscattering (Poulet et al., 2002/Shkuratov et al., 1999)



Interparticle shadowing (Lumme & Bowell,1981)



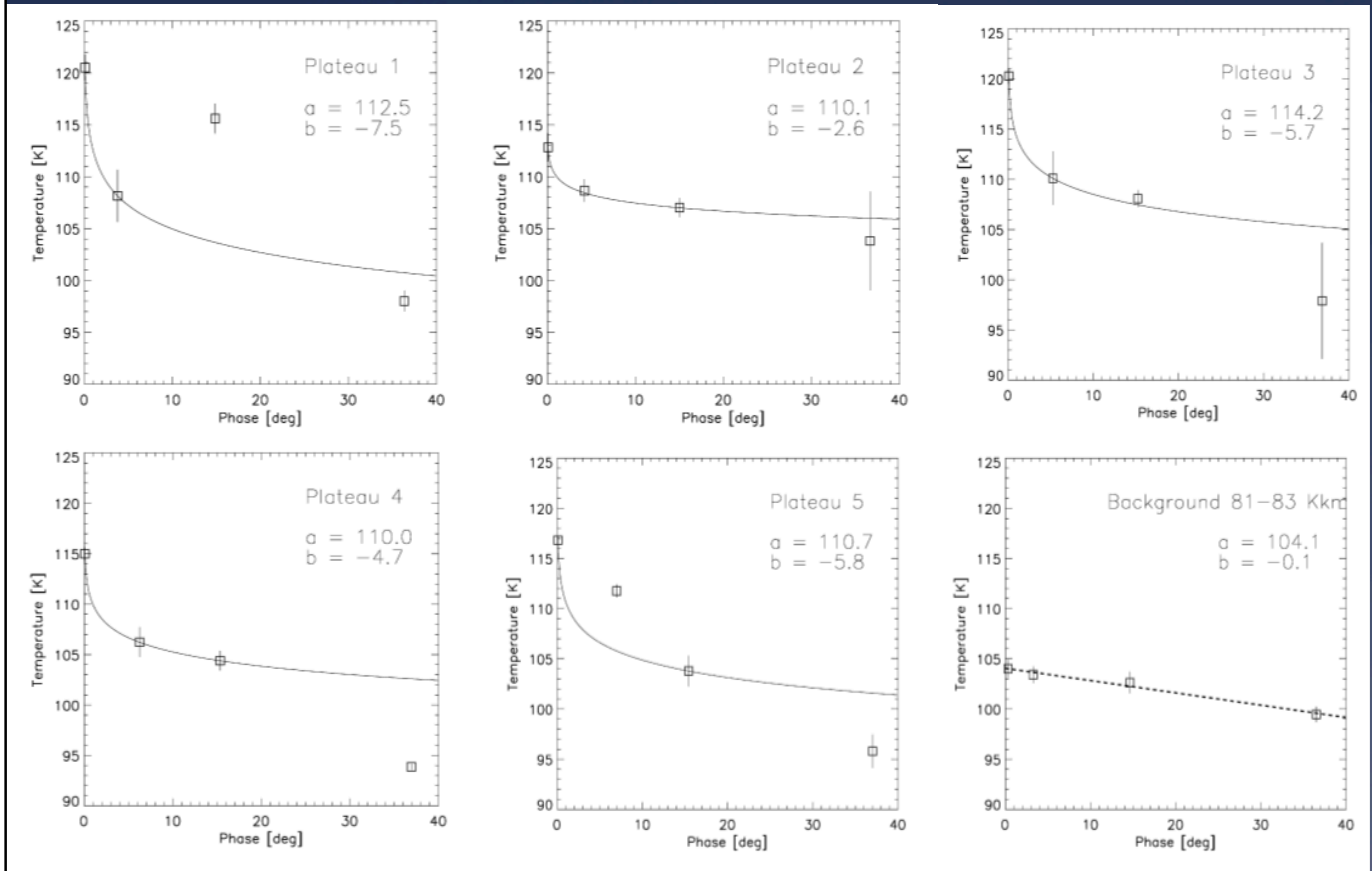
Déau 2014 **Icarus** *In Press*

d : grain size
(from Filacchione et al., 2012)
D : filling factor
(from Salo & Karjalainen, 2003)
τ : optical depth
(proxy from Déau et al., 2013)

Signature of coherent backscatter is **similar** to the one of the interparticle shadowing.

Previous thermal results

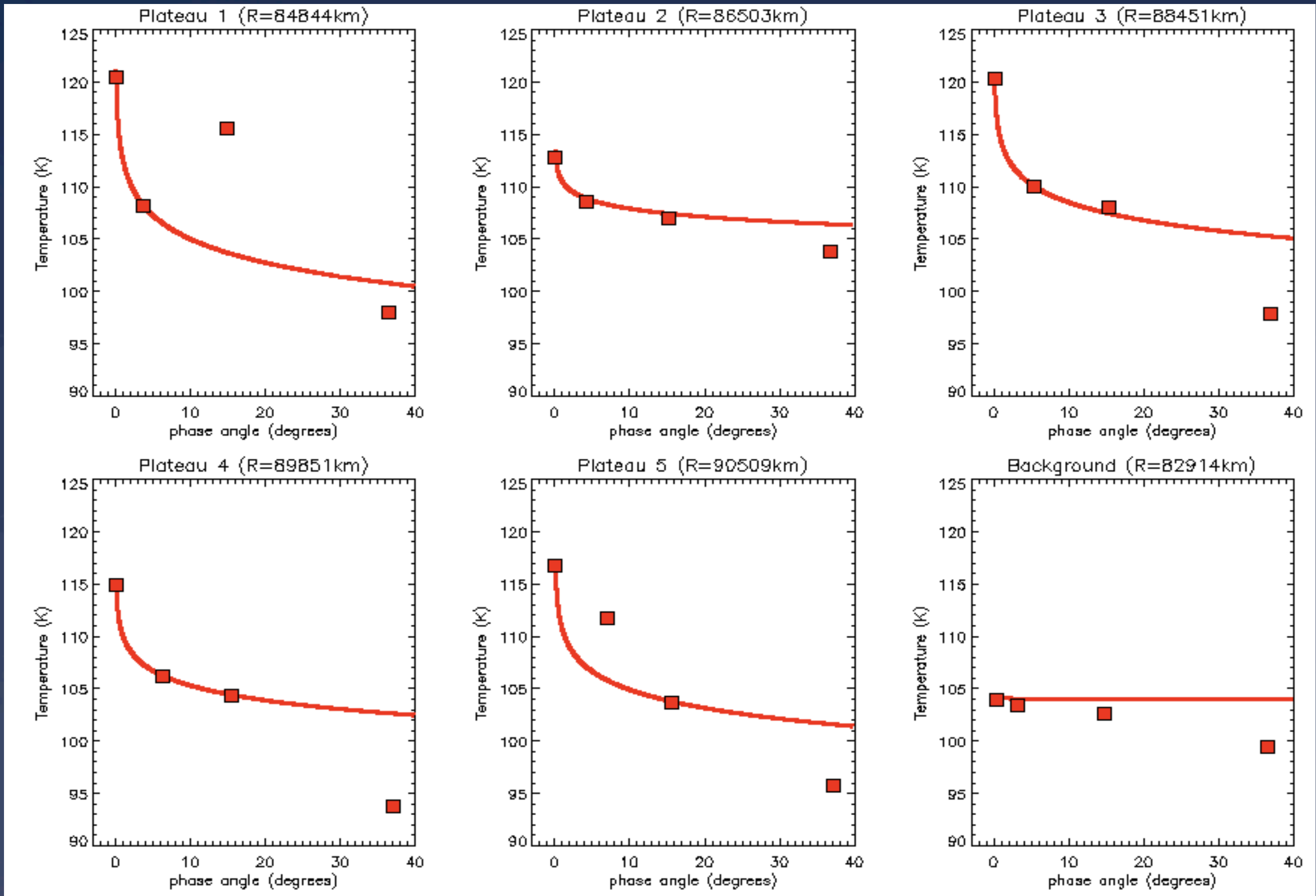
Using CIRS (Composite Infrared Spectrometer) Focal Plane 3 (mid-IR)



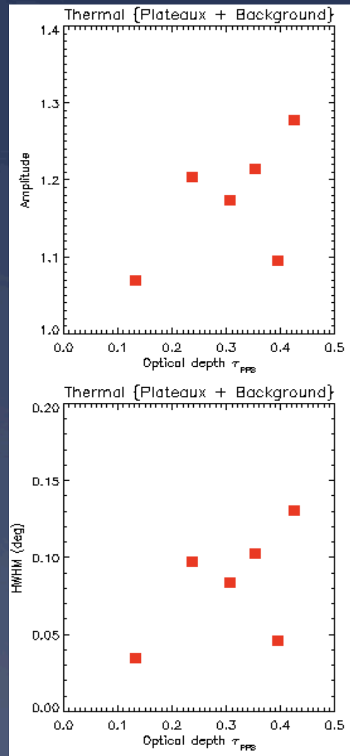
- "narrow thermal surge"
- logarithmic trend $T = a_0 * \text{Log}\, \alpha + a_1$
- could be a linear trend?

(Altobelli et al., 2007 Icarus)

C ring : CIRS puzzle # 1

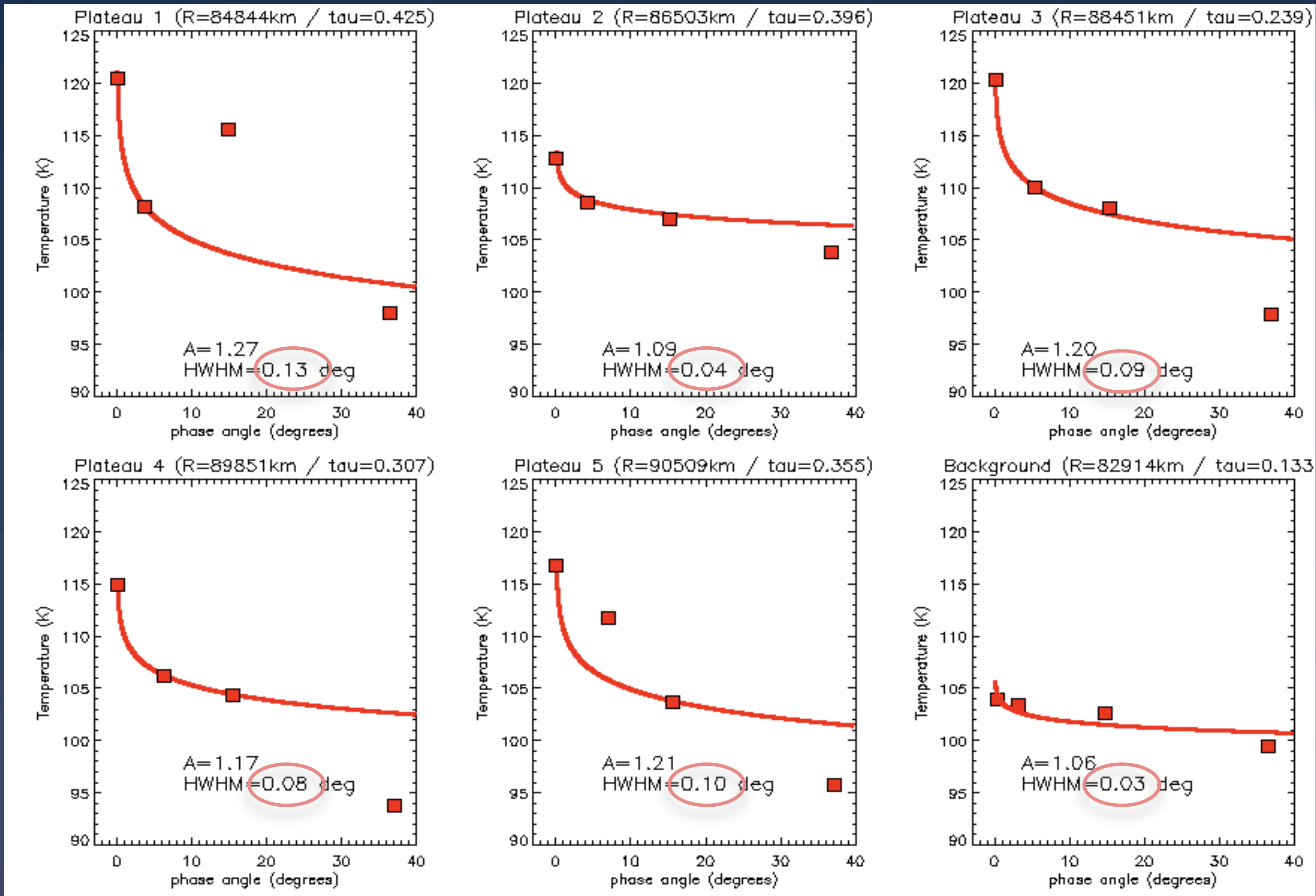


Trend of the thermal surge morphology with τ is not clear



(Déau et al., 2012, DPS)

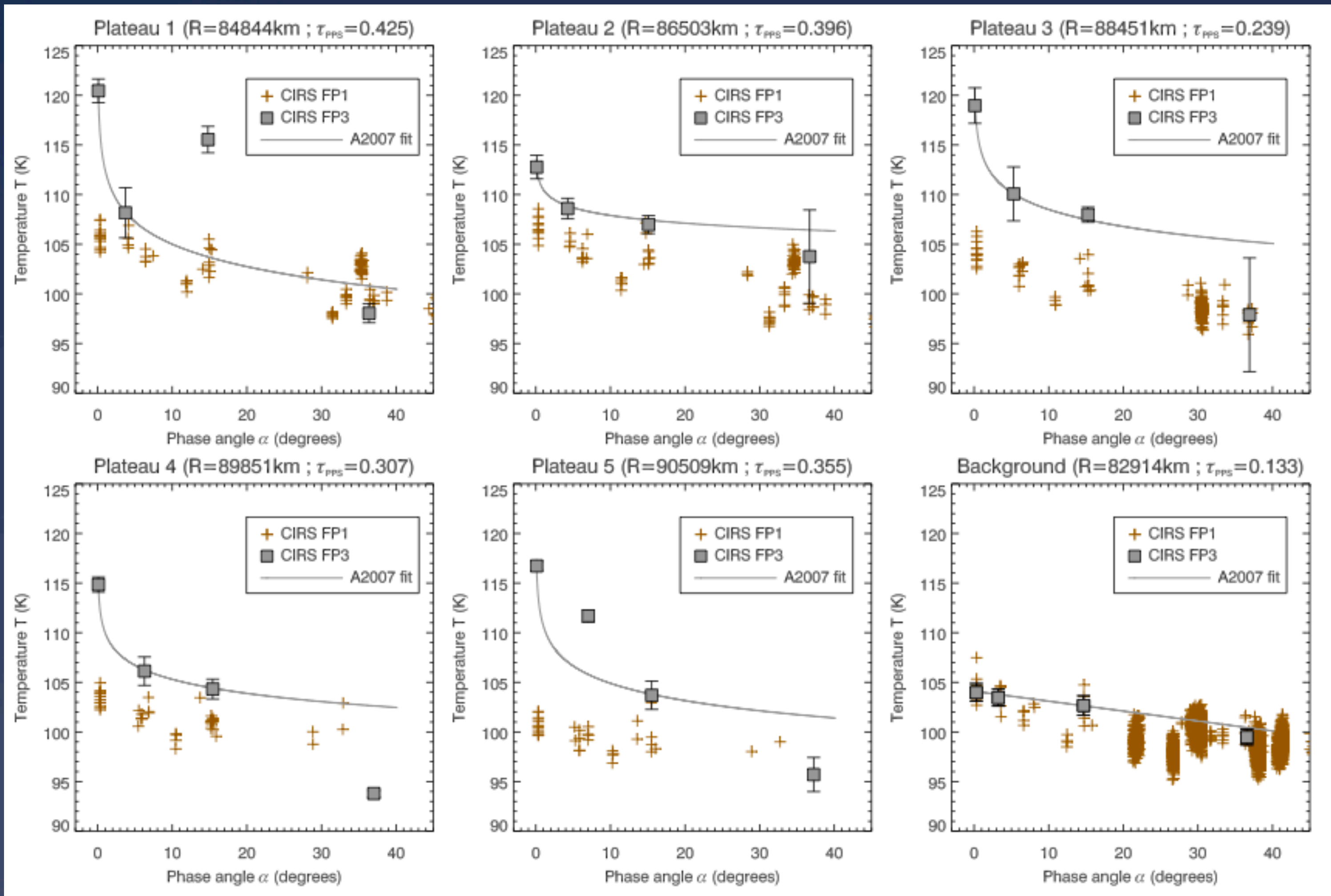
C ring : CIRS puzzle # 2



Thermal surge is surprisingly very narrow

(Déau et al., 2012, DPS)

C ring : CIRS puzzle # 3



Fp3 and Fp1 effective temperatures are not compatible

↕

"broad thermal surge" ?

(Déau et al., 2012, DPS)

Goal of this work

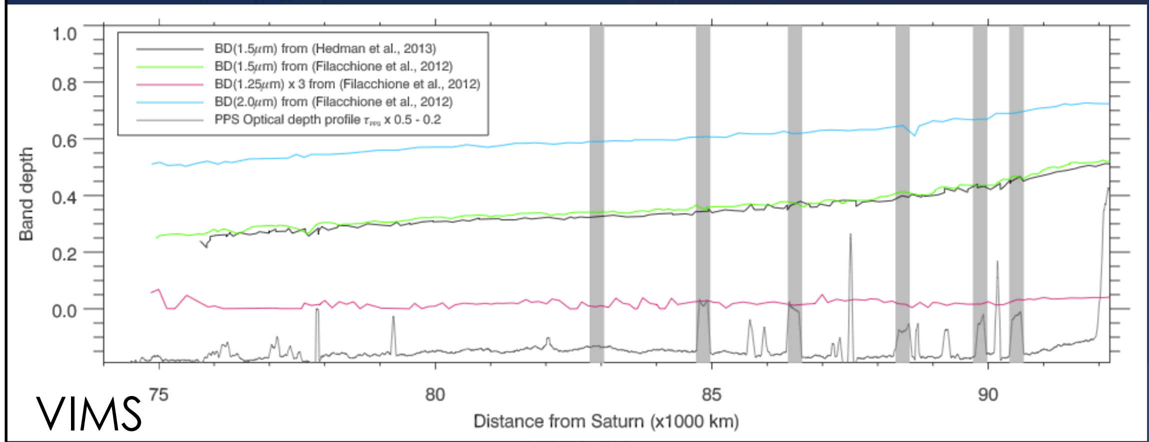
- Unveil the nature of the optical and thermal opposition effects
- Define domain of shadow hiding

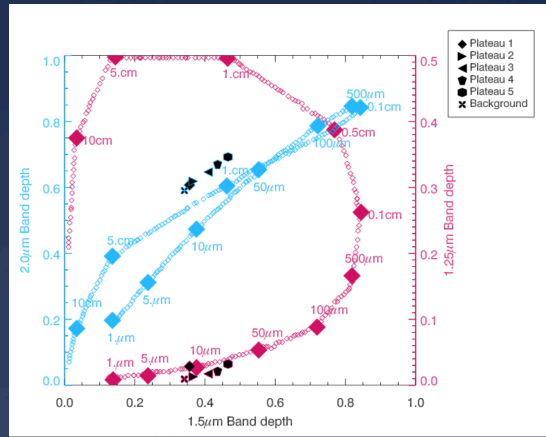
☑

- Constrain the rings micro and macro-structures

Methods & models

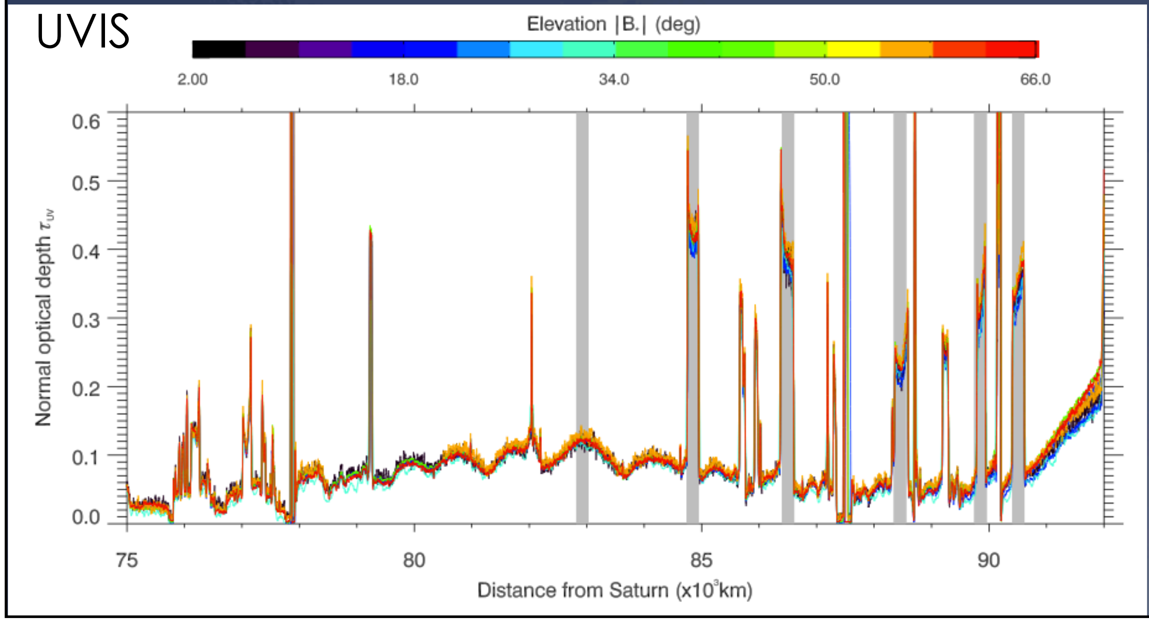
Micro and macro signatures data

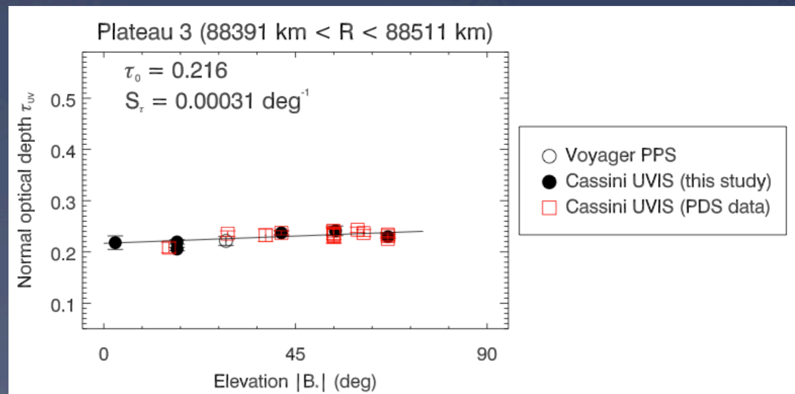




Band depth → grain size (microscopic signature meta-data)

Optical depth → τ-slope (macroscopic signature meta-data)





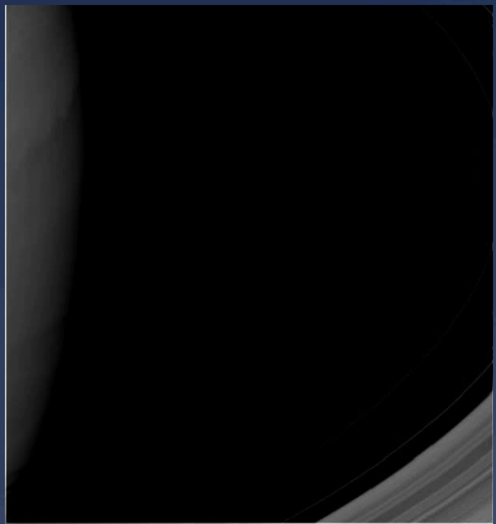
Background's τ-slope is ≈ zero

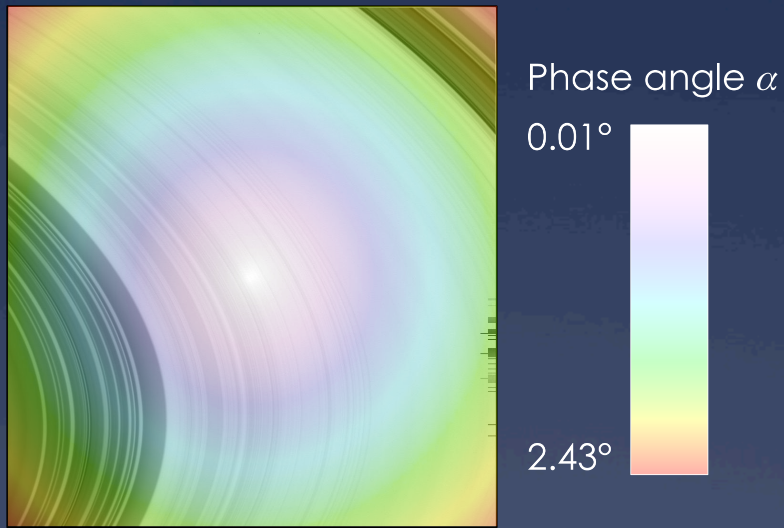
(Déau et al., In prep.)

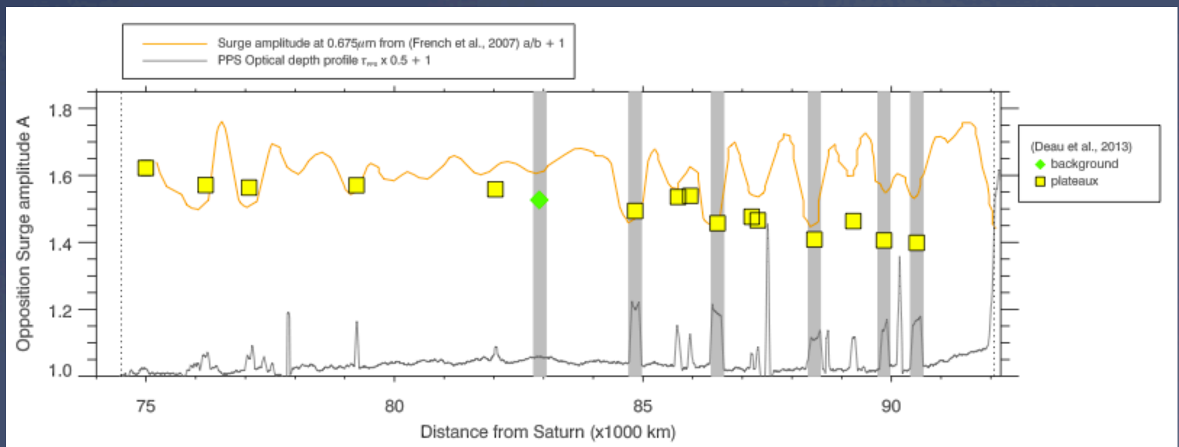
ISS data

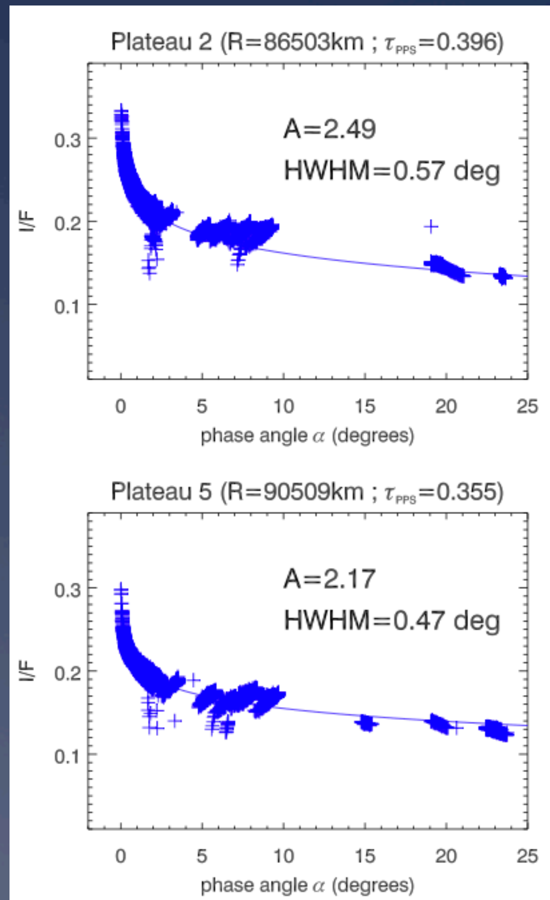
ISS_010RI_0PHASE001_VIMS

(Déau et al., 2013 Icarus)

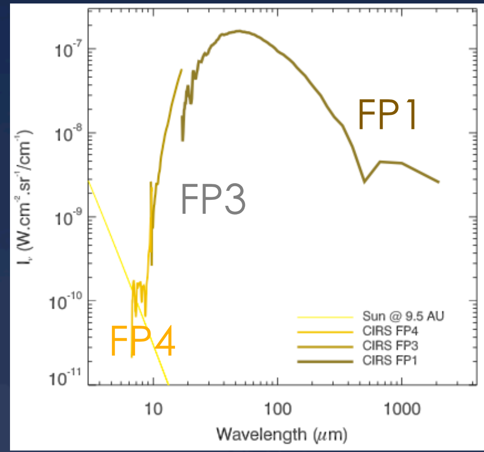




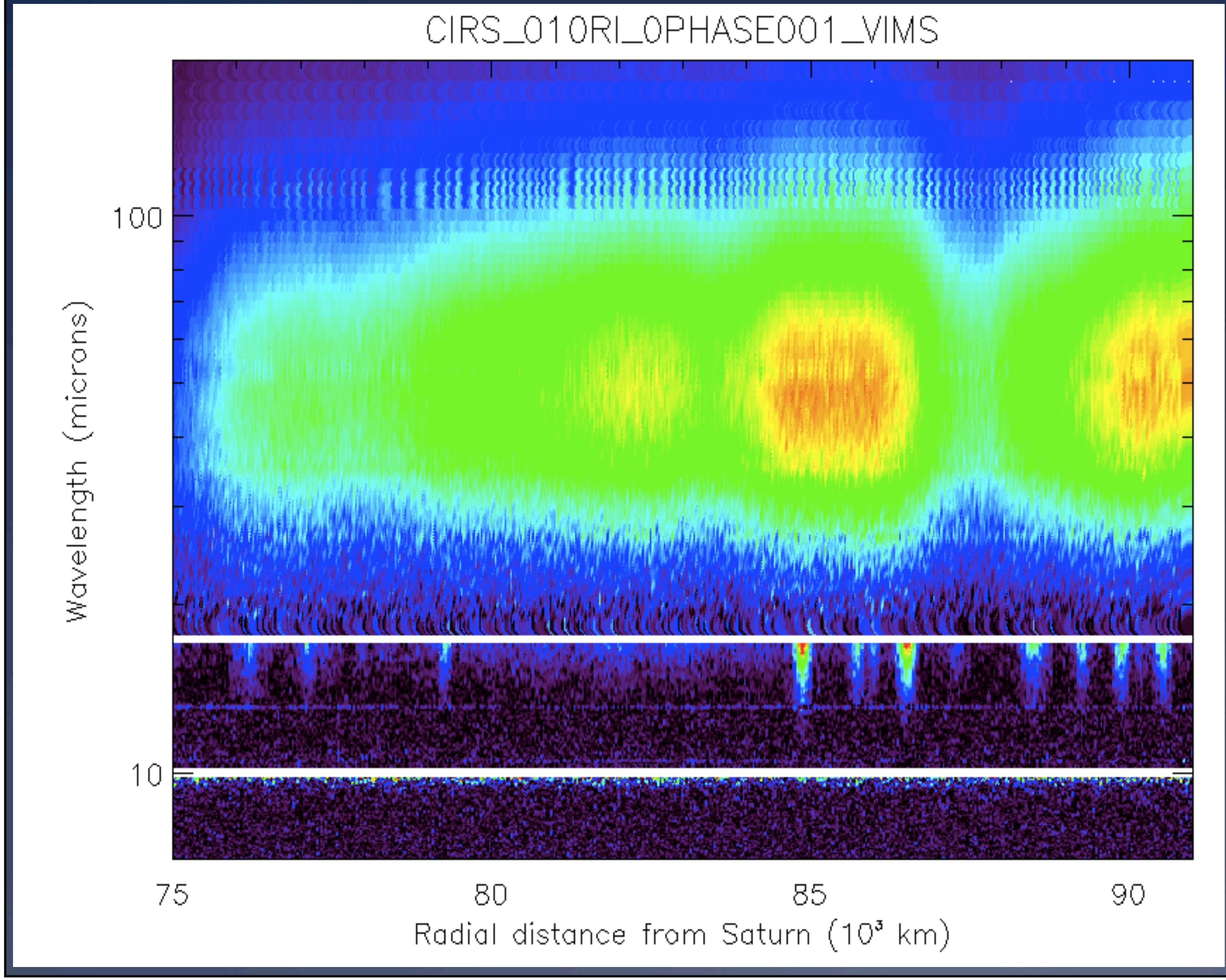




CIRS data



An IR spectrogram



Fp1 (far IR)

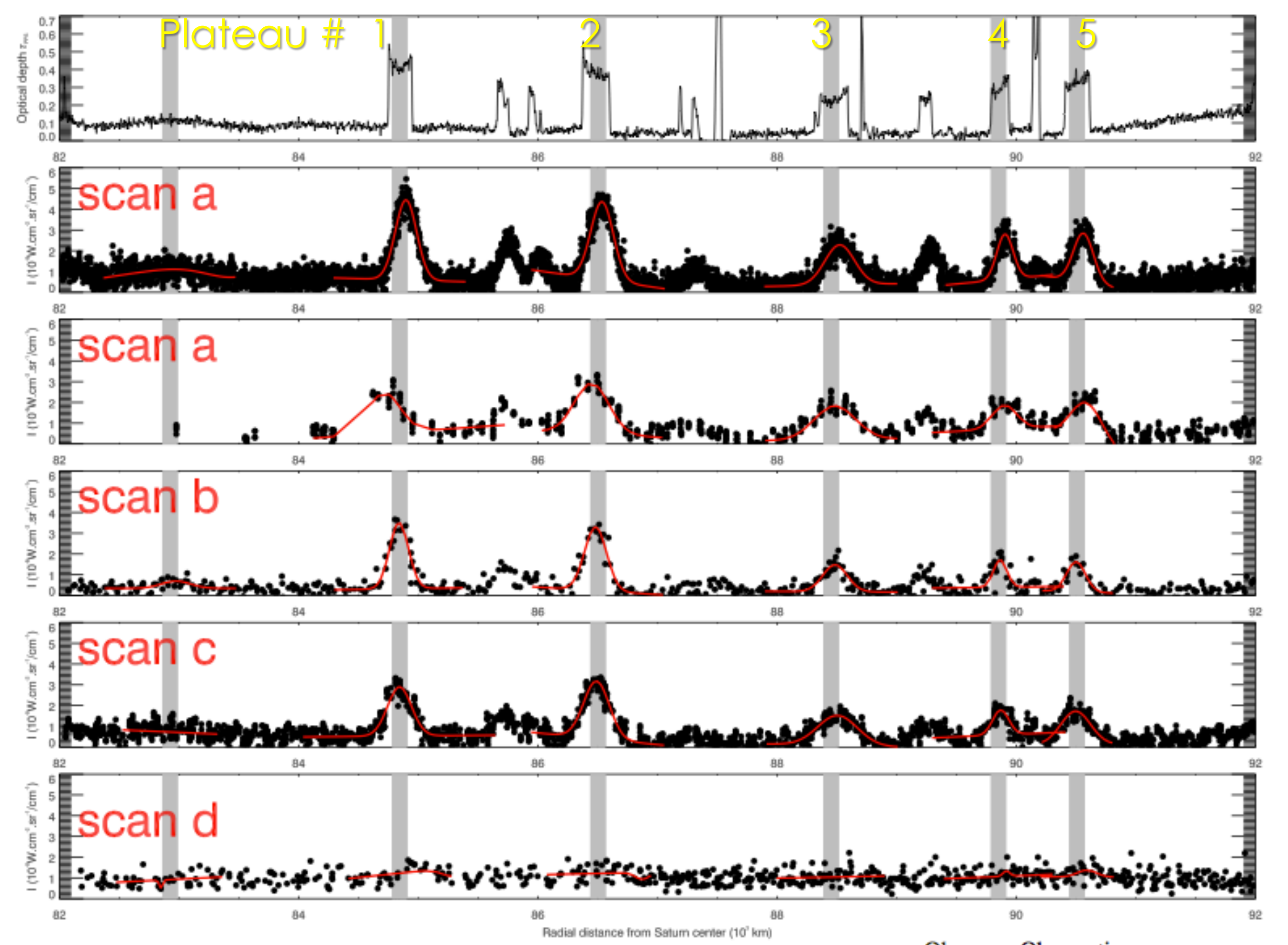
Work with Fp3
in spectral radiance
($15.5\mu m \le \lambda \le 16\mu m$)
not with fit temperature

Fp3 (med IR)

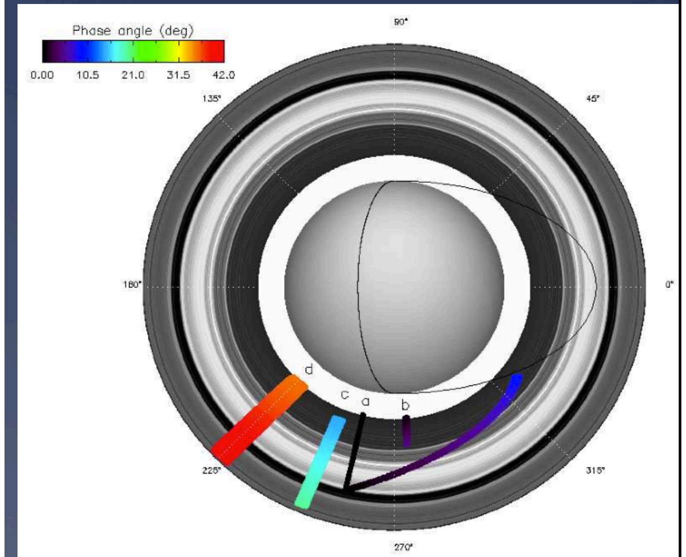
Fp4 (near IR)

Puzzle #3 explained

CIRS data



Add the second portion of scan a (α = 3°) changes the space parameter of the morphological parameters (puzzle #2 solved)



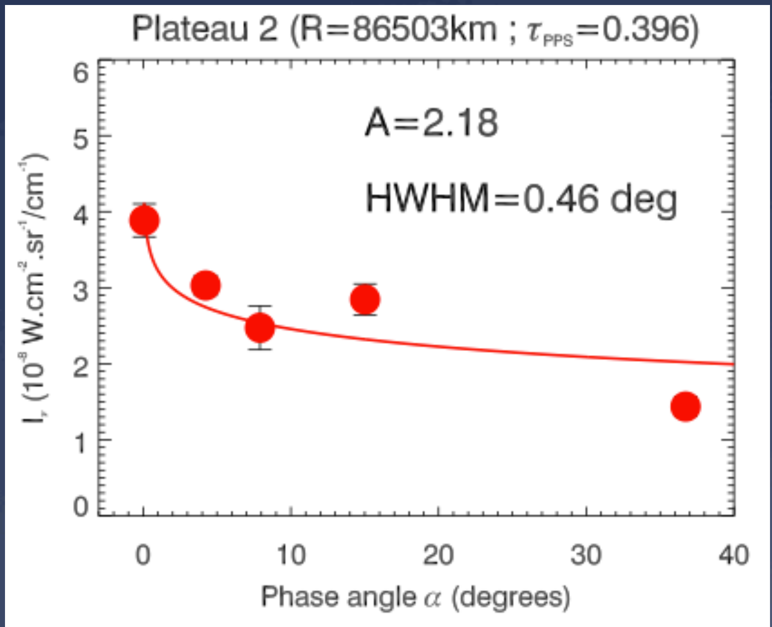
Novel method: Gaussian fit to retrieve accurate signal with small error-bars

Obs.	Observation name	Start Date
scan a	CIRS_010RI_0PHASE001_VIMS	2005-177T03:15:45
scan b	CIRS_008RI_SUBML20LP001_PRIME	2005-140T11:28:15
scan c	CIRS_007RI_TEMPL20LP001_PRIME	2005-122T04:01:05
scan d	CIRS_009RI_SUBML20LP001_PRIME	2005-157T03:00:35

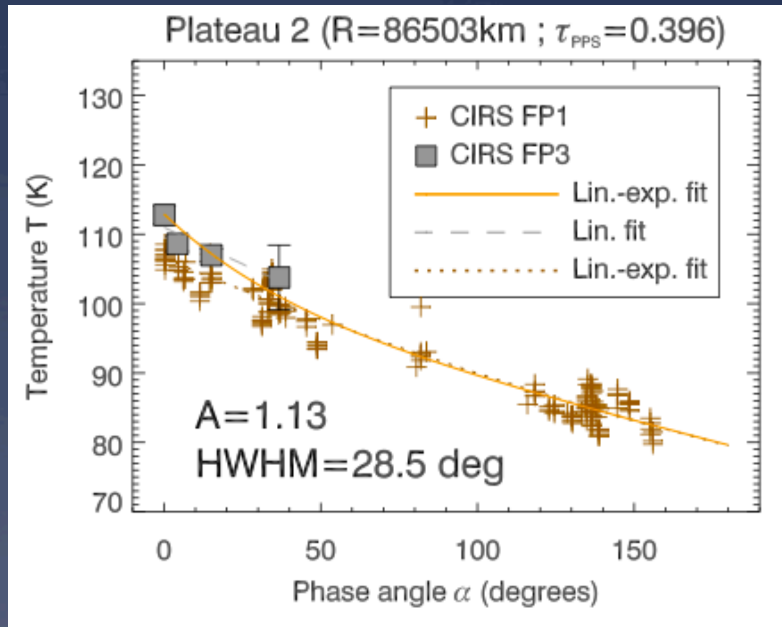
CIRS data

2 strategies

Narrow surge with FP3 in radiance



Broad surge with FP3+FP1 in T_{eff}



Models & Methodology

(Déau et al., In prep.)

	Model	Eq.	Prediction	Fit	Narrow surge	Broad surge	I/F	I_ν	T
morphological	Logarithmic model	Eq.(14)	☐	☑	☑	☐	☑	☐	☐
morphological	Logarithmic model	Eq.(19)	☐	☑	☑	☐	☐	☑	☐
morphological	Logarithmic model	Eq.(20)	☐	☑	☑	☐	☐	☐	☑
morphological	Linear-by-parts model	Eq.(17)	☐	☑	☑	☐	☑	☐	☐
morphological	Linear model	Eq.(23)	☐	☑	☐	☑	☐	☐	☑
morphological	Linear-logarithmic model	Eq.(21)	☐	☑	☑	☐	☐	☑	☐
morphological	Linear-logarithmic model	Eq.(21)	☐	☑	☑	☐	☐	☐	☑
morphological	Linear-exponential model	Eq.(25)	☐	☑	☐	☑	☐	☐	☑
physical	Coherent backscattering model	Eq.(32)	☑	☐	☑	☐	☑	☐	☐
physical	Shadowing model	Eq.(35)	☑	☐	☐	☑	☑	☑	☑
physical	Shielding model	Eq.(36)	☑	☐	☐	☑	☐	☐	☐
physical	Thermo-physical model	Eq.(37)	☑	☐	☐	☐	☐	☐	☑
physical	Toy-model	Eq.(43)	☐	☑	☐	☑	☑	☐	☐
physical	Toy-model	Eq.(45)	☐	☑	☑	☑	☐	☑	☐

The perfectly complete model doesn't exist yet.

Our method is:

(1) Compare morphological parameters that fit the data to microscopic and macroscopic signatures

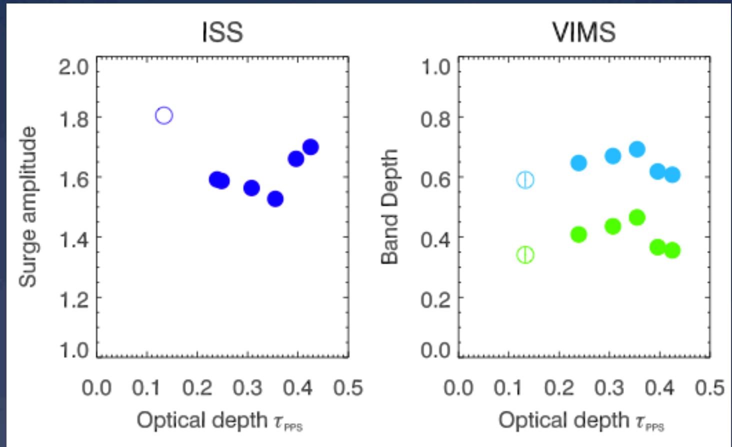
(2) Compare morphological parameters that fit the data to the ones predicted by radiative transfer models

(3) Derive physical parameters from fit and compare them with the ring properties from independent studies

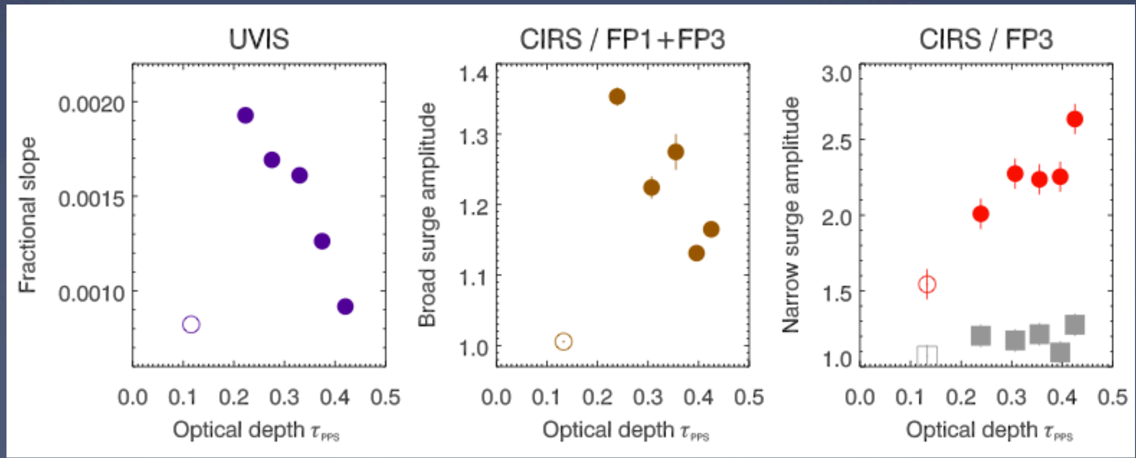
Results

(1) Comparison of surge morphology with micro and macro-signatures

<u>* Microscopic signature</u>
Water ice band depth



<u>* Macroscopic signature</u>
Slope of optical depth with elevation

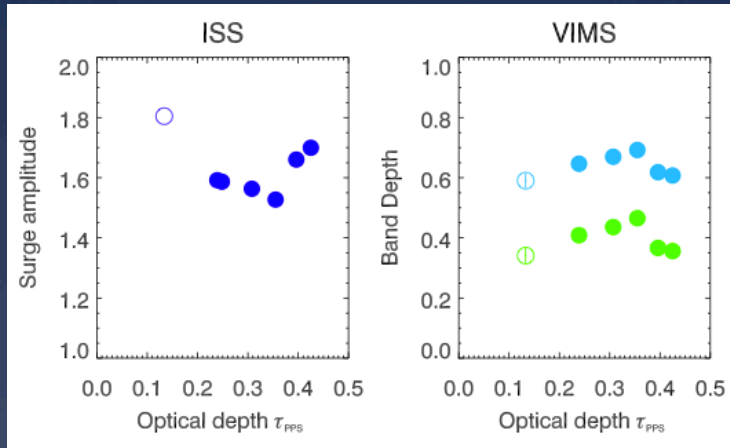


puzzle #1 solved

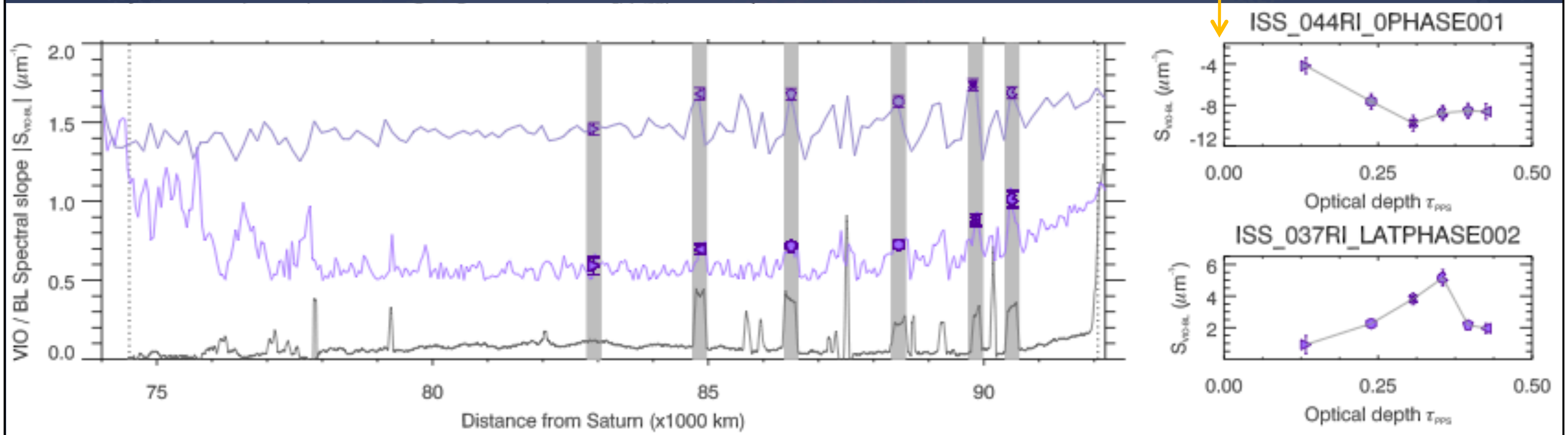
(1) Comparison of surge morphology with micro and macro-signatures

*** Composition**

VIO/BL-slope



This slope should probe a contaminant called the "UV-absorber", see (Hedman et al., 2013)



(2) Comparison with predicted trends

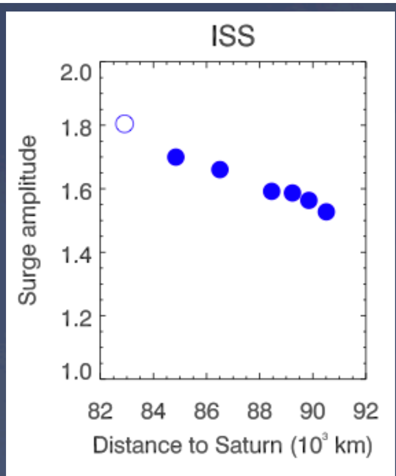
Coherent backscattering model

$$A_{cb} \sim 1 + \frac{\exp(-d/L)}{2}$$

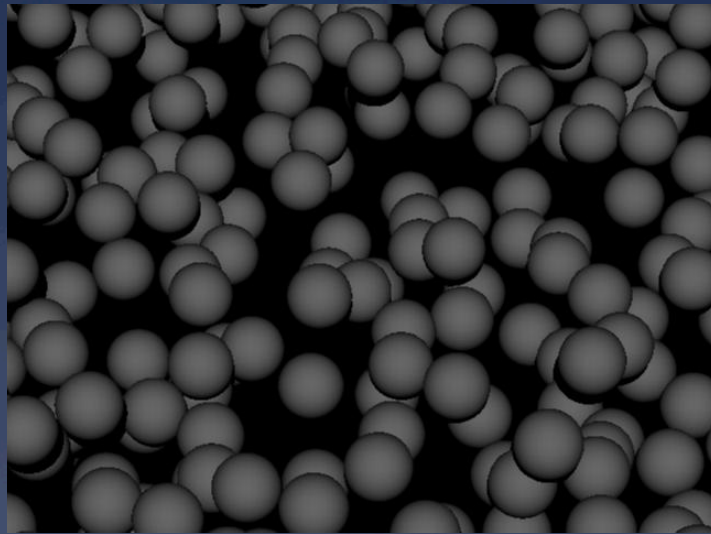
Region	τ_{PPS}	d (μm)	L (μm)	A_{cb}
Plateau 1	0.425	4.59	75.35	1.47
Plateau 2	0.396	4.70	74.23	1.47
Plateau 3	0.239	9.47	65.77	1.43
Plateau 4	0.307	12.05	70.10	1.42
Plateau 5	0.355	15.35	72.48	1.40
Background	0.133	4.33	52.25	1.46

A_{cb} ↘

A ↘



Interparticle shadowing (ray-tracing)

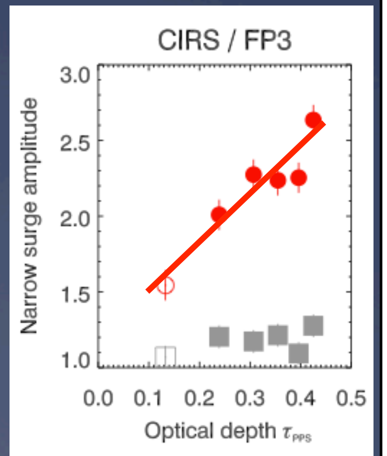


mono-size distribution
B=21°, B'=21°

A_{sh} ↗

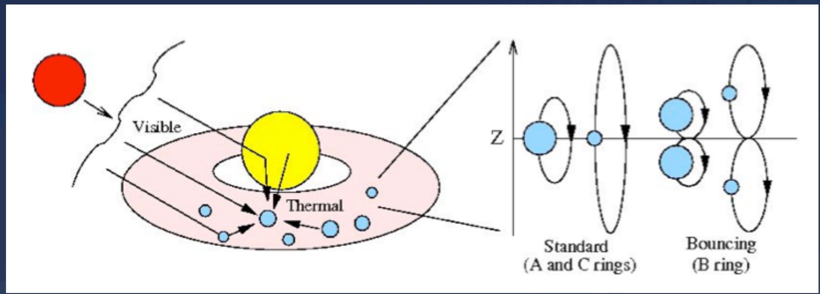
A ↗

Region	τ_s	A_{sh}
Plateau 1	0.425	1.85
Plateau 2	0.396	1.76
Plateau 5	0.355	1.81
Plateau 4	0.307	1.76
Plateau 3	0.239	1.69
Background	0.133	1.53



(2) Comparison with predicted trends

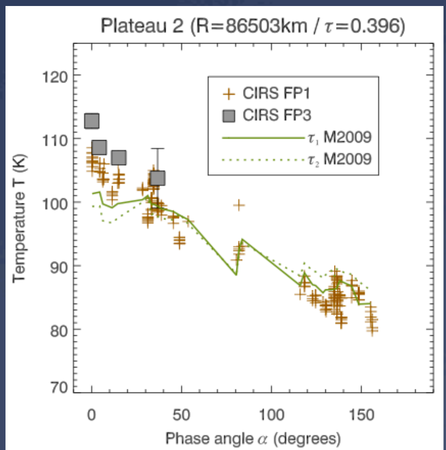
Multilayer thermal transport model

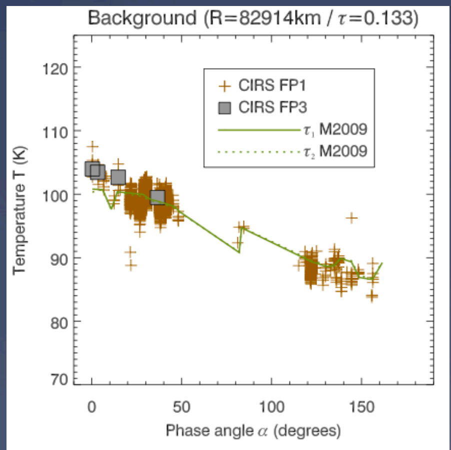


(Morishima et al., 2010)

τ_1 : raw optical depth

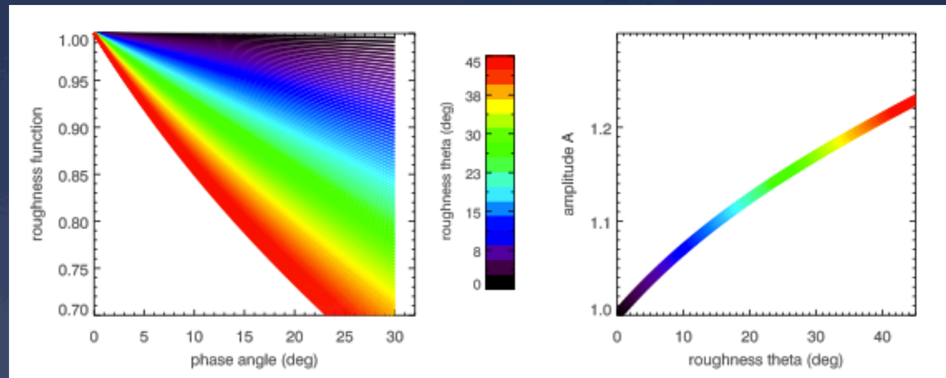
τ_2: convolved optical depth to FP1 footprint



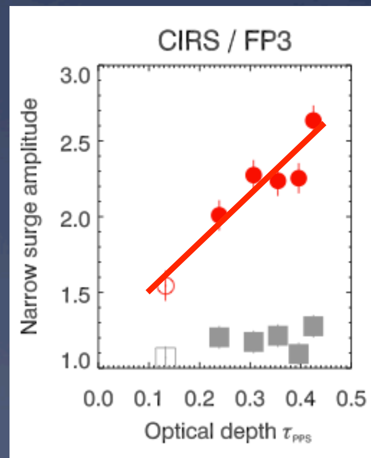


Shadowing domain $\alpha < 40°$

Roughness model



Could be consistent if roughness correlated with τ



Conclusions

Conclusions

(1) Compare morphological parameters that fit the data to microscopic and macroscopic signatures

* optical surge --> microscopic signature
* broad thermal surge --> macroscopic signature

(2) Compare morphological parameters that fit the data to the ones predicted by radiative transfer (RT) models

* There is a thermal surge caused by shadowing (α domain < 40°)
* Coherent backscattering explains well amplitude surge trend of plateaus and background

(3) Derive physical parameters from RT model fit and compare them with the ring properties from independent studies

* Roughness
* Filling factor

} Work in progress

Supplementary material

Future work

(Déau et al., in prep.)

Constraining the micro and macro-structures of Saturn's rings by modeling Cassini optical and thermal opposition effect: 1. The C ring

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