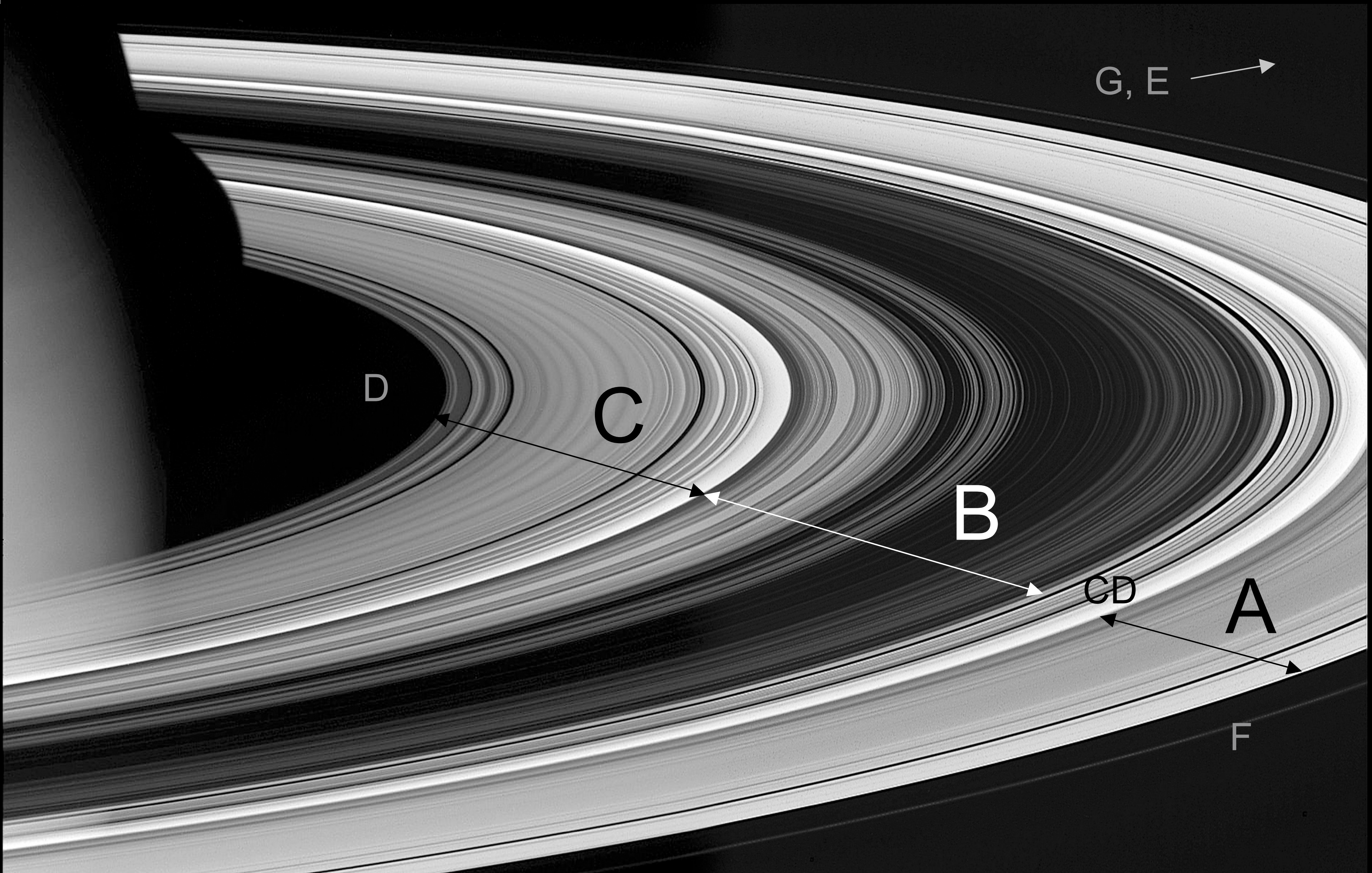
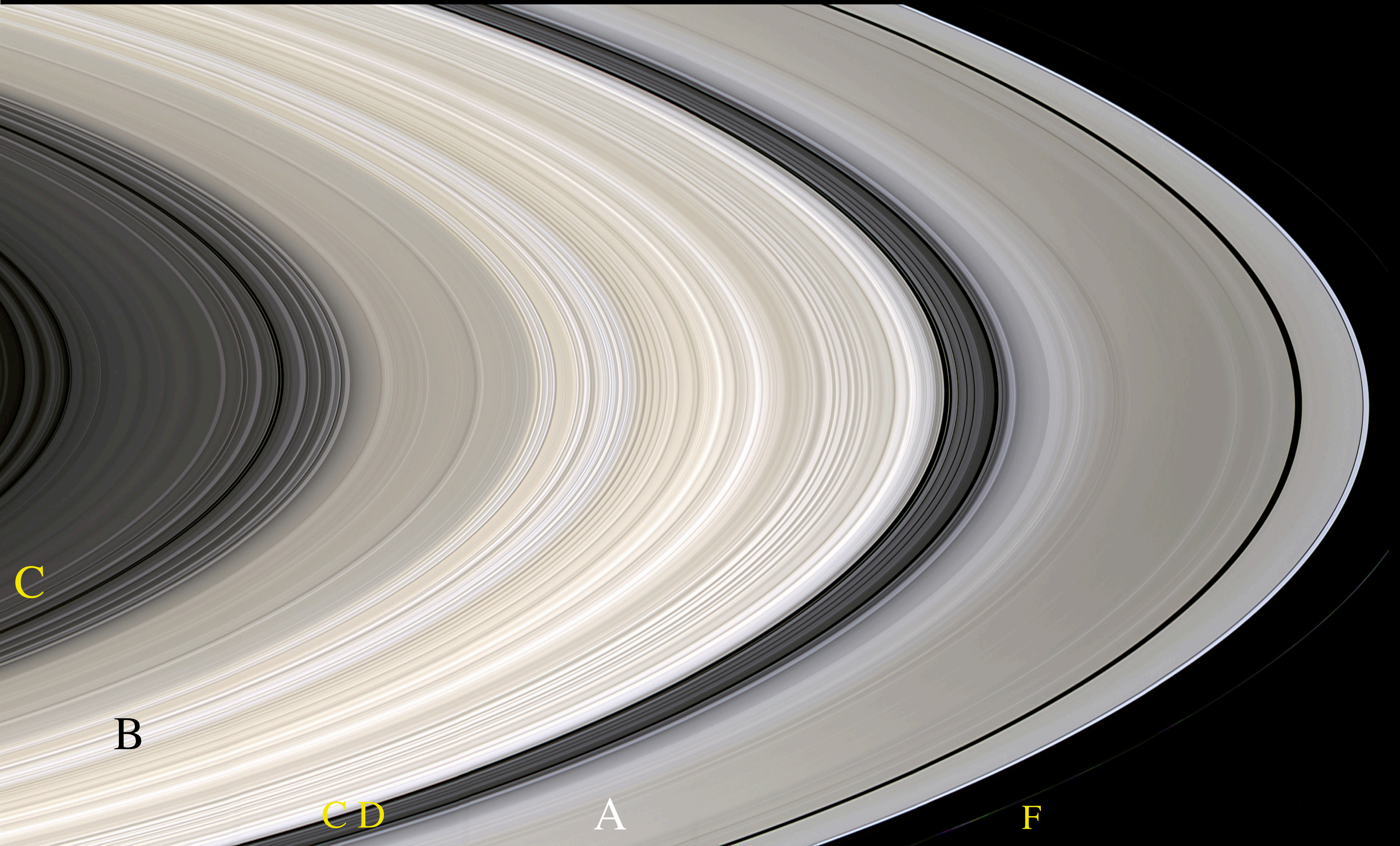
Cassini 7-year CHARM review
Rings and Dust

Jeff Cuzzi

The Dark Side



Away from the Dark Side



Progress this year;
now includes contributions form outside the project

- Some new results on ring temperature near equinox

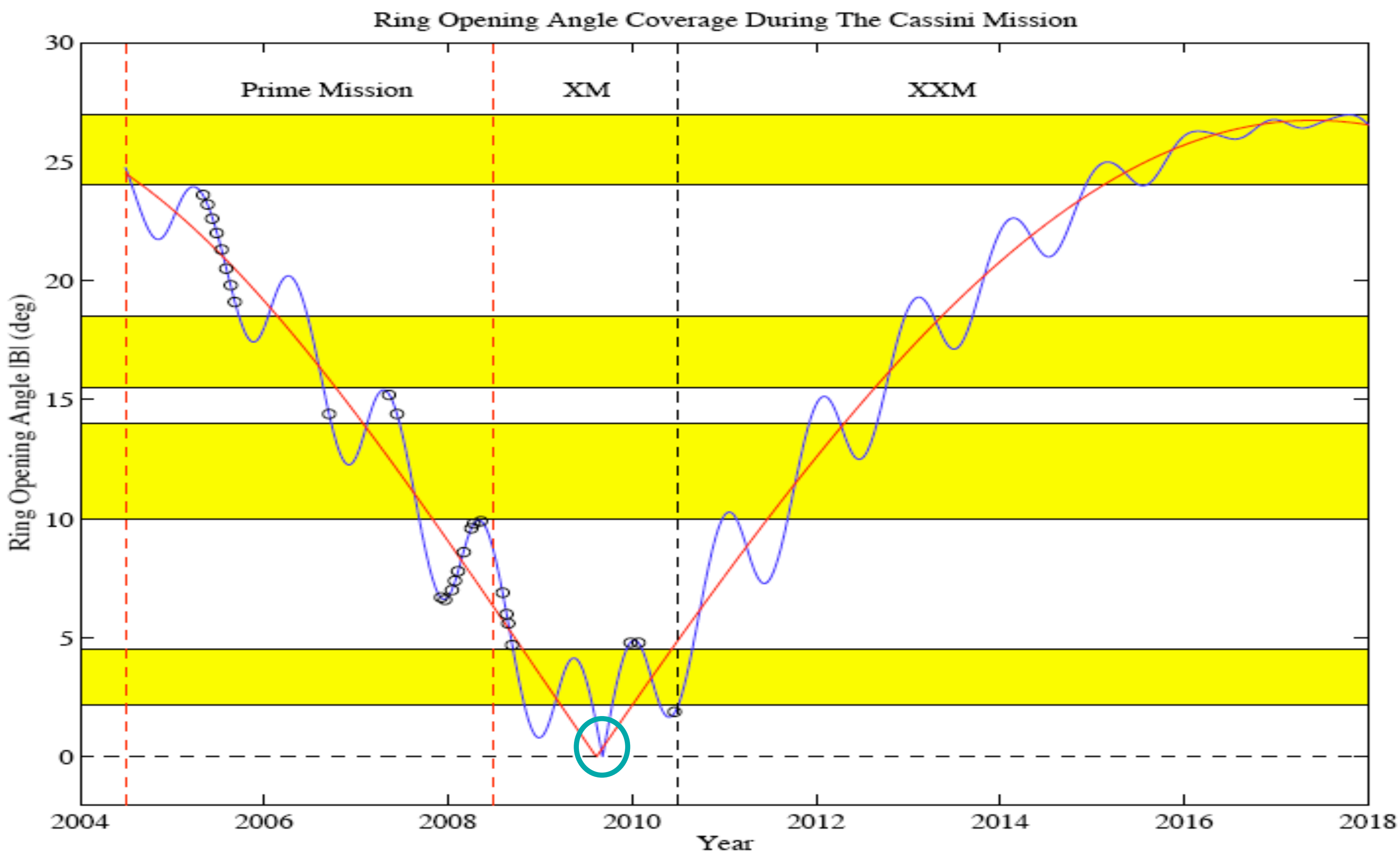
- C ring ripples: ISS and RSS both see vertical ripples
  - may be caused by impact debris sandblasting and tilting ring plane
  - can date several distinct impact events over hundreds of years

- Giant “propeller” objects (several hundred m): their orbits are changing;
  - “migrating” radially or not? New theory of libration

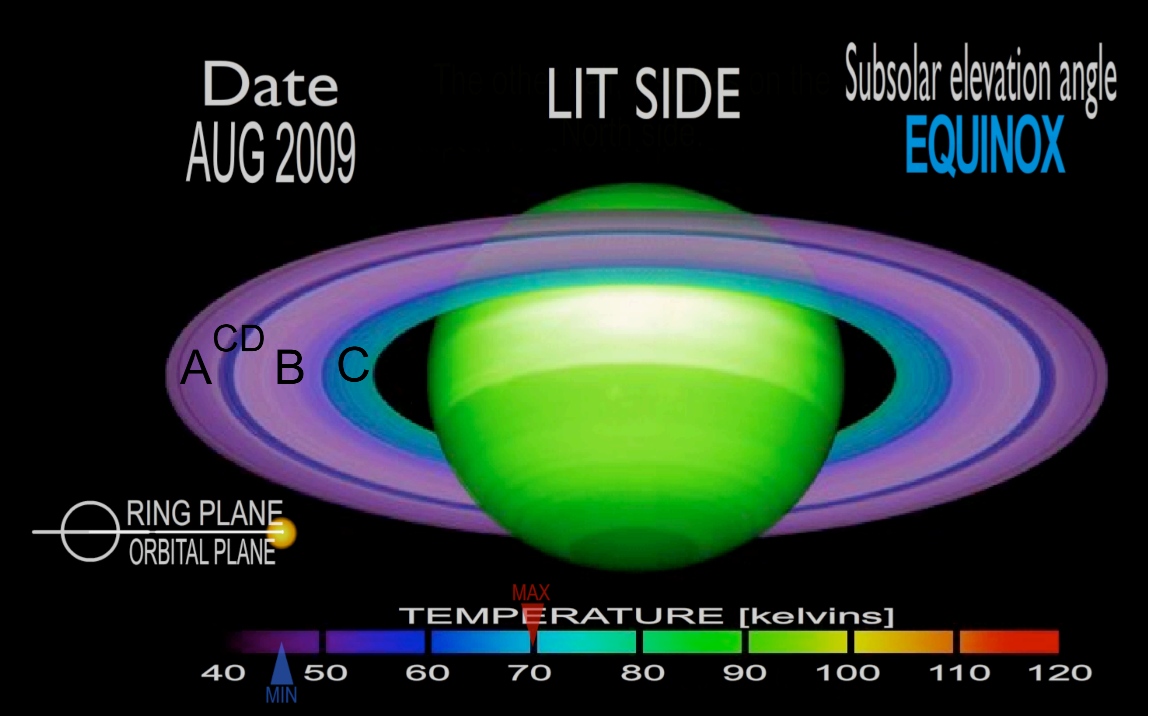
- The F ring
  - ISS - several changes since Voyager: strands, brightening, etc
  - RSS - very narrow core of large particles on same orbit as “dust”;
    - but highly discontinuous; sometimes undetectable
  - ISS: moonlets crashing into F ring core create new strands

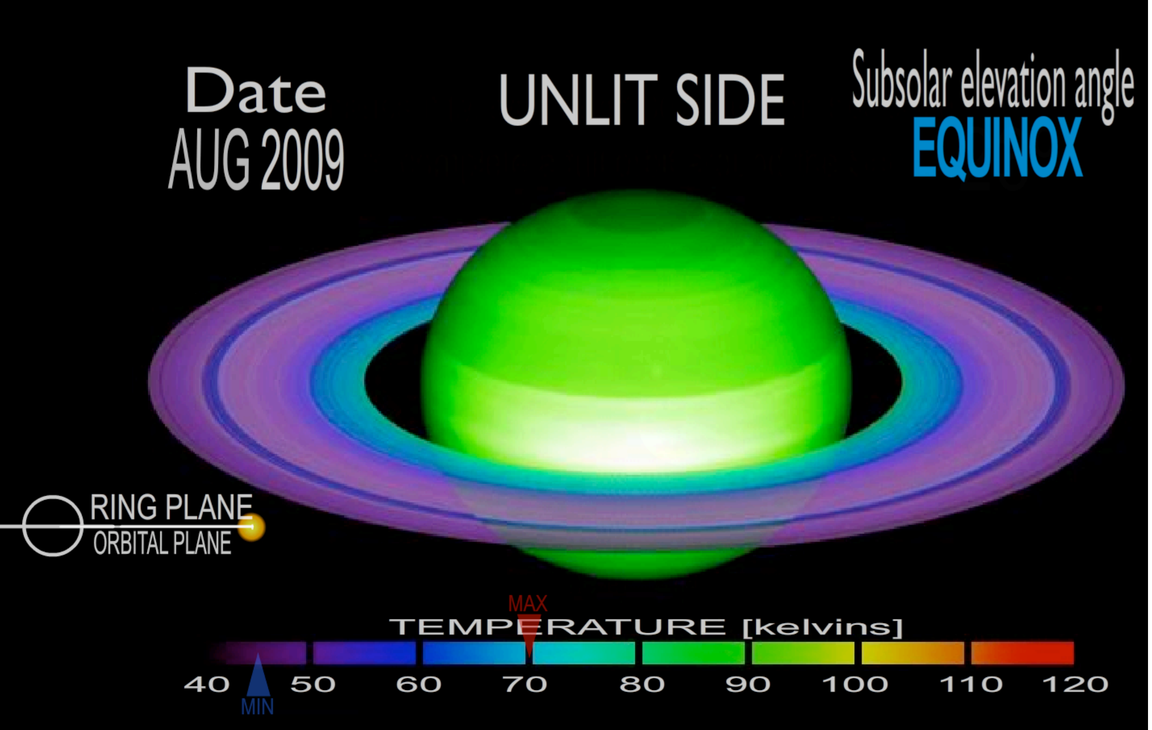
- New thinking on ring composition: organic UV absorbers?

Equinox observations (August 2009)



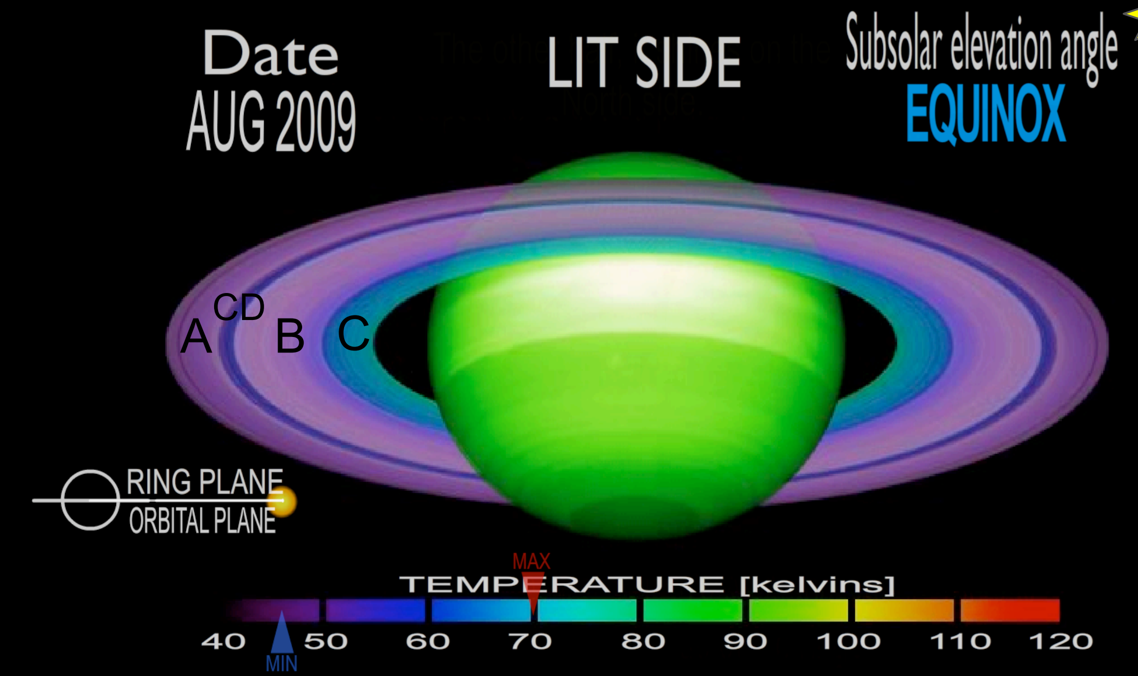
Opening angle affects insolation, ring temperature, RSS transmission, spoke occurrence frequency, diffuse ring structure

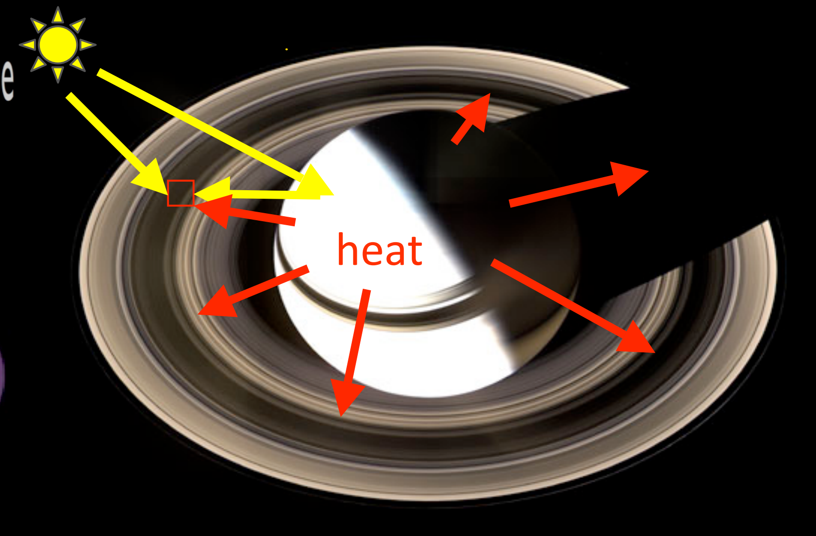


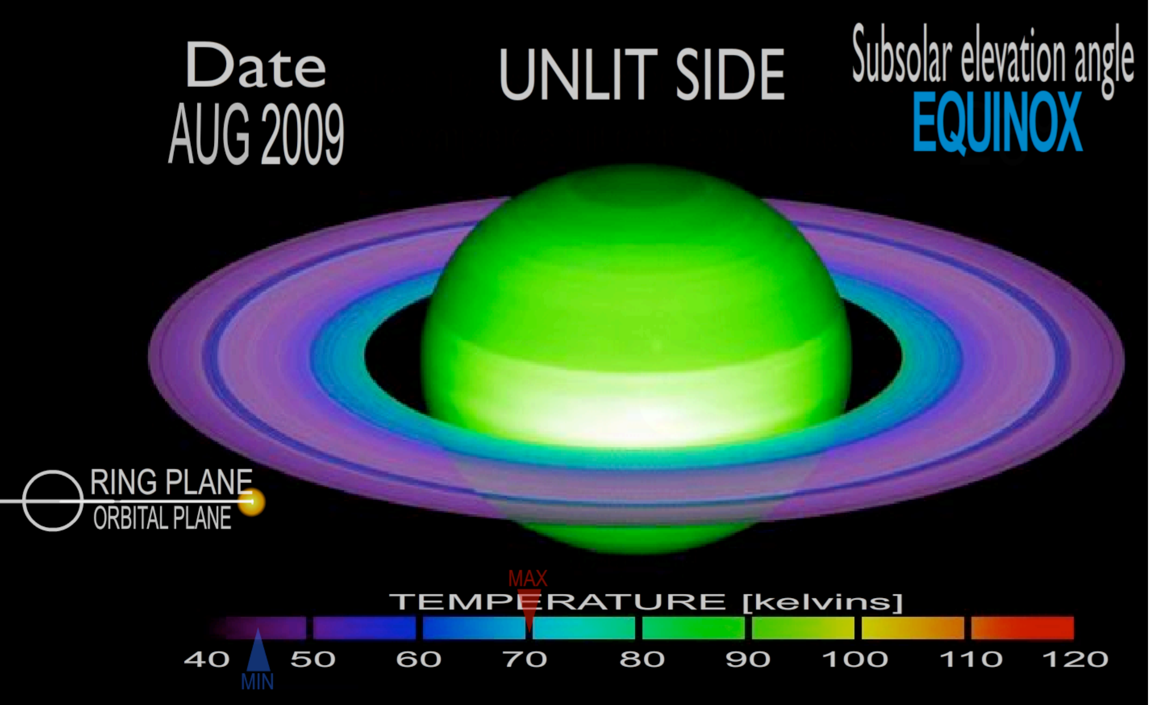


Ring Temperatures at Equinox

- Coldest temperatures ever observed
- Optically thin C ring and Cassini Division warmer than optically thicker A and B rings
- North and south side ring temperatures are essentially identical at similar locations and geometries at equinox







- Optically thin C ring and Cassini Division warmer than optically thicker A and B rings
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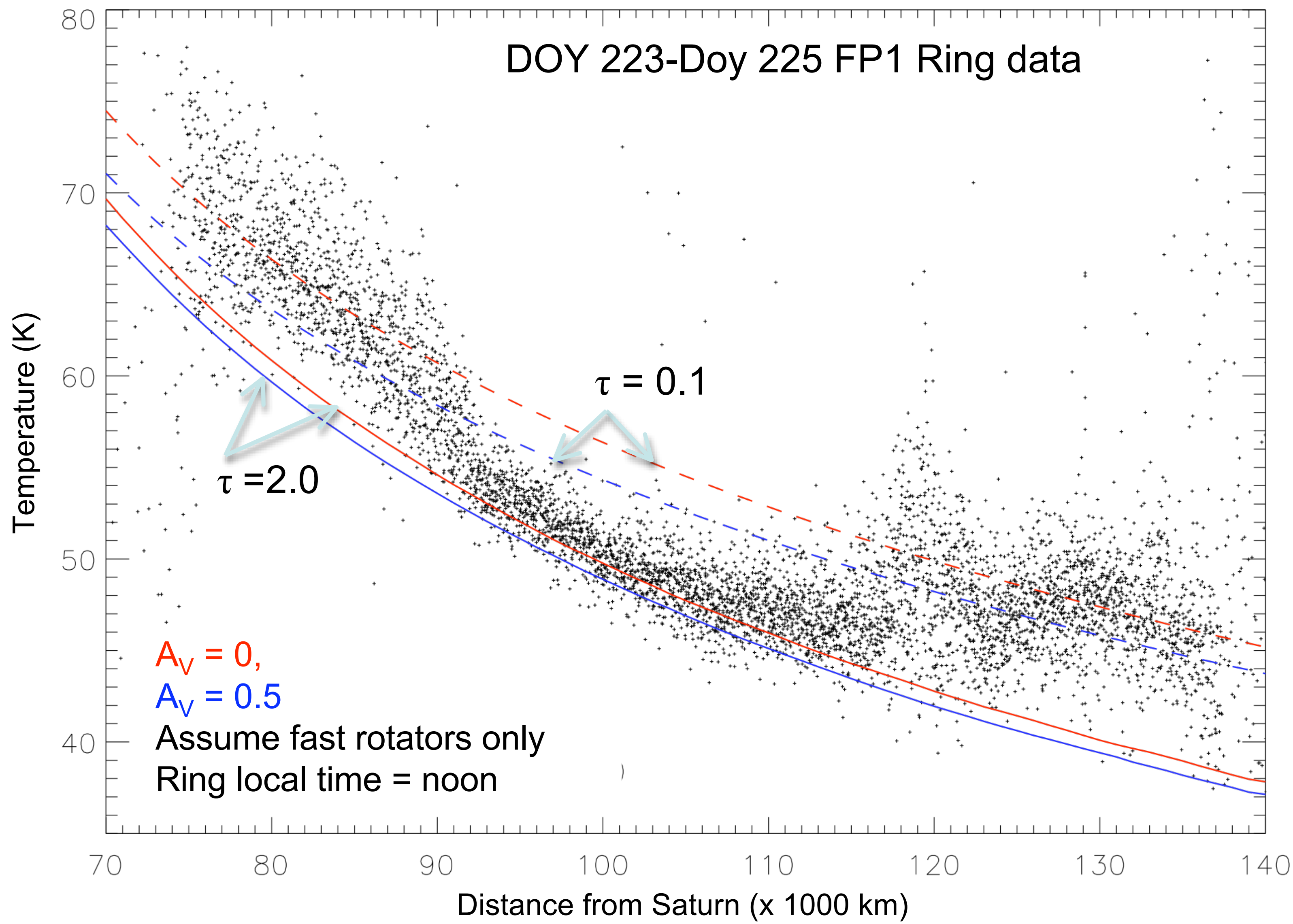
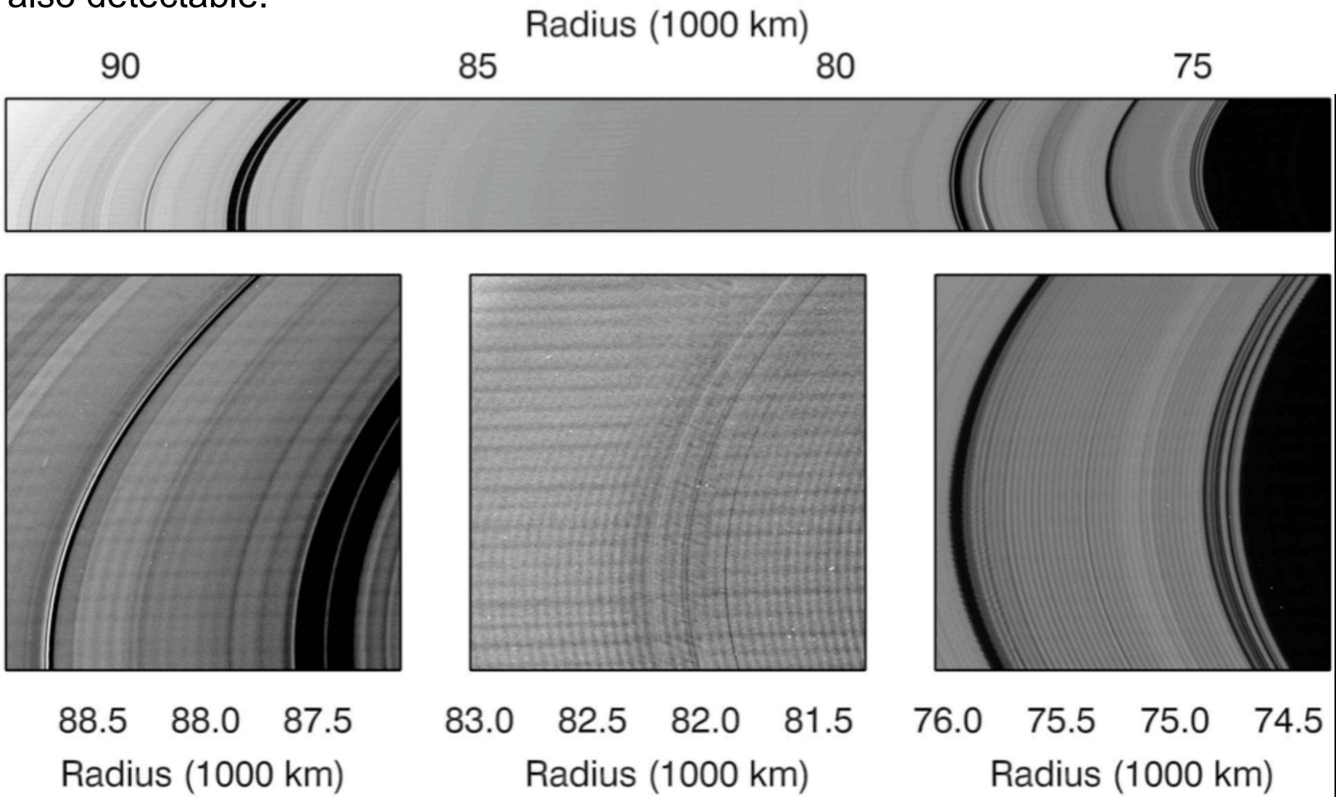
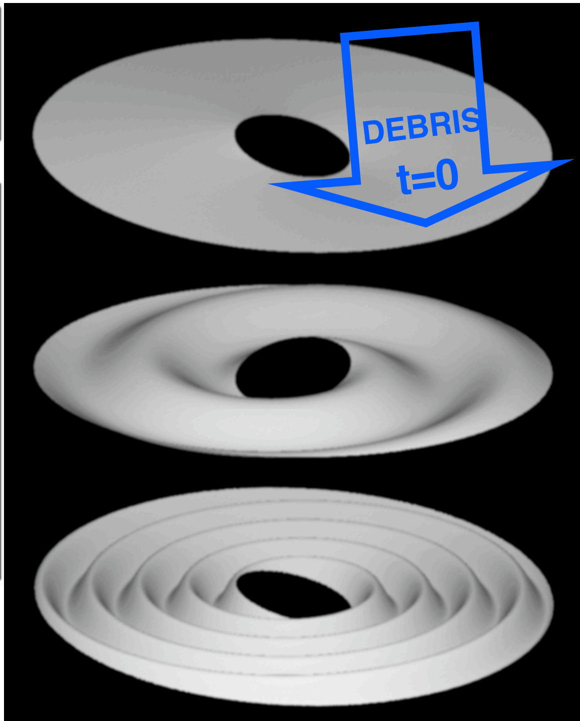
Multilayer Model:
Radial Temperature Dependence on Albedo and Optical Depth



Corrugated rings: fingerprints of impacts

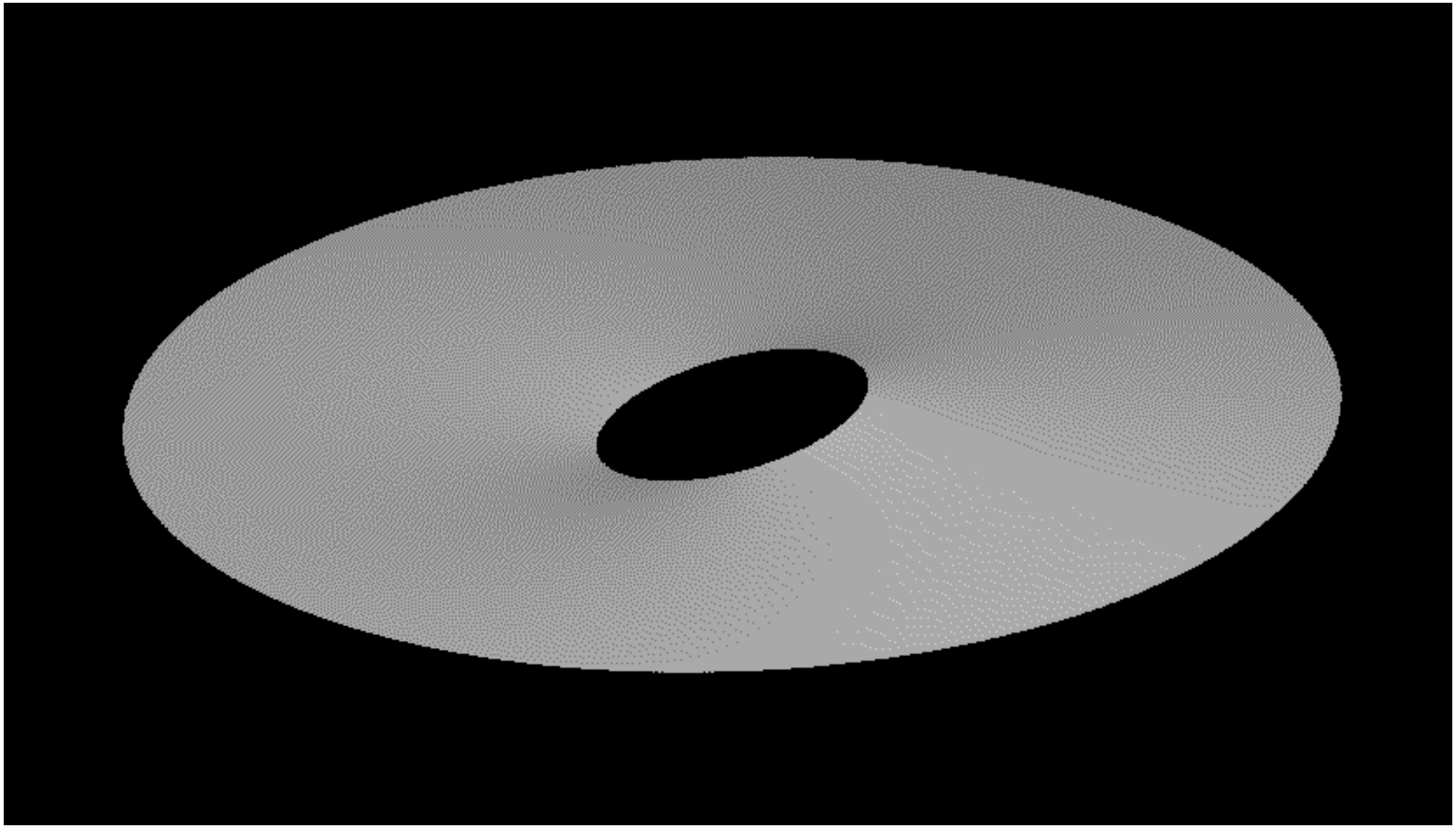
Hedman et al and Showalter et al, (Science, 31 March) describe curious ripples in the D and C rings of Saturn, and Jupiter's ring, respectively. The full extent of the D-C ripple was only revealed in Cassini equinox observations at low angle solar illumination. The left panel shows these ripples, with wavelength decreasing outwards, propagating across the entire 15000km of the C ring. The graphic at right (and the movie in the next slide) illustrates how, if the entire D and C ring was instantaneously tipped, differential precession would cause the tilted plane to wrap up into a wavy sheet with the observed properties. This can be done if the ring was "sandblasted" by a debris cloud across one entire quadrant or sector (blue arrow). The diffuse cloud can arise from a wayward comet, either tidally disrupted by a close encounter or passing through the upper atmosphere of the planet. Changes in the ripple wavelength as a function of time pin down the date of the impacts that caused these initial tilts. In Jupiter's case, the primary cause was debris from Shoemaker-Levy/9 in 1994, and in Saturn's case, the formative impact occurred in 1983. In Jupiter's case, fingerprints of other impacts in 2001 and 2004 are also detectable.





Disk is quickly “tilted” by debris hitting unevenly, then wraps up by differential precession. Wavelength increases outward.

Can age-date the event from wavelength and its radial variation.

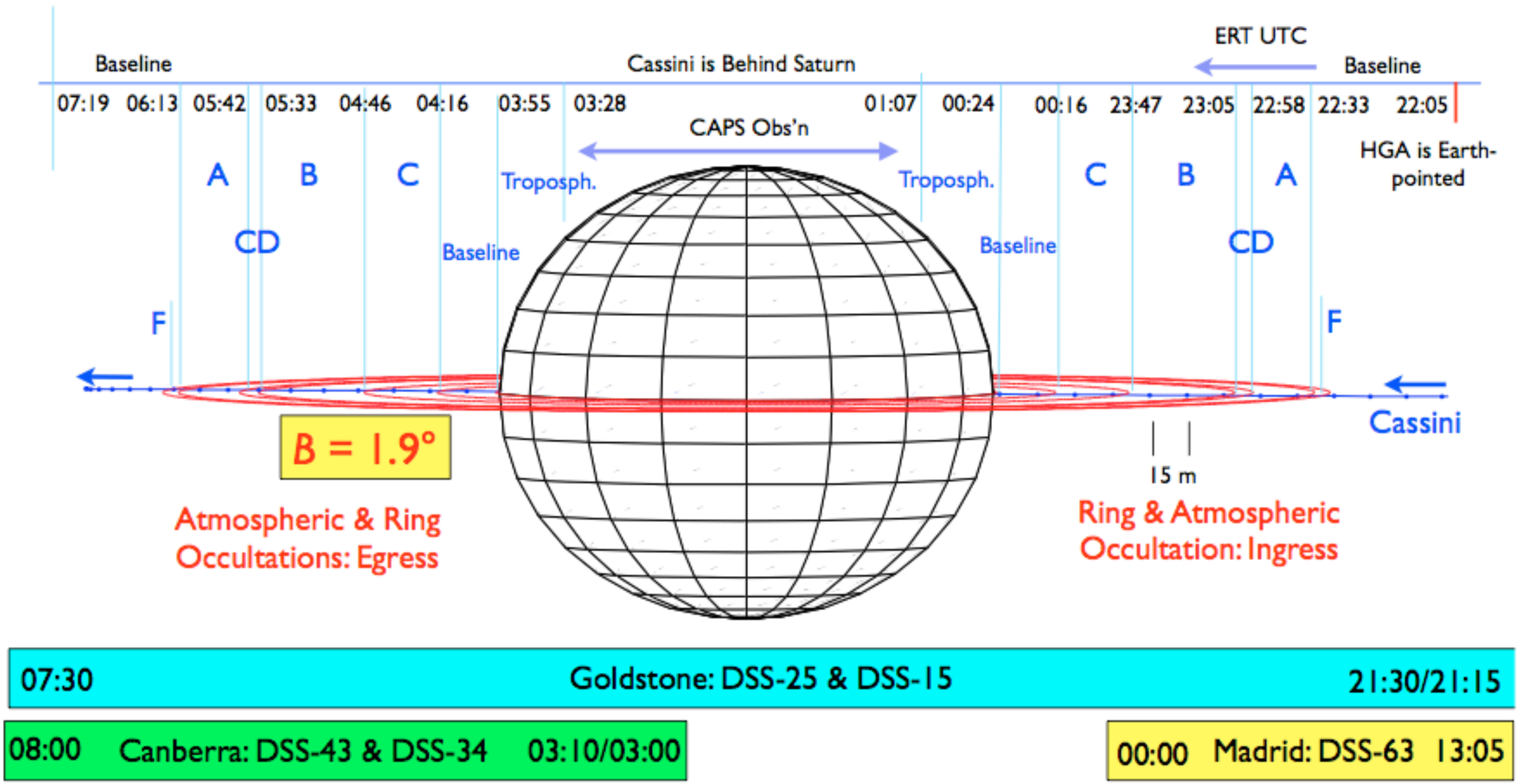


M. Hedman et al Science (2011)

Cassini Rev133: RSS Saturn Ring & Atmospheric Occultations

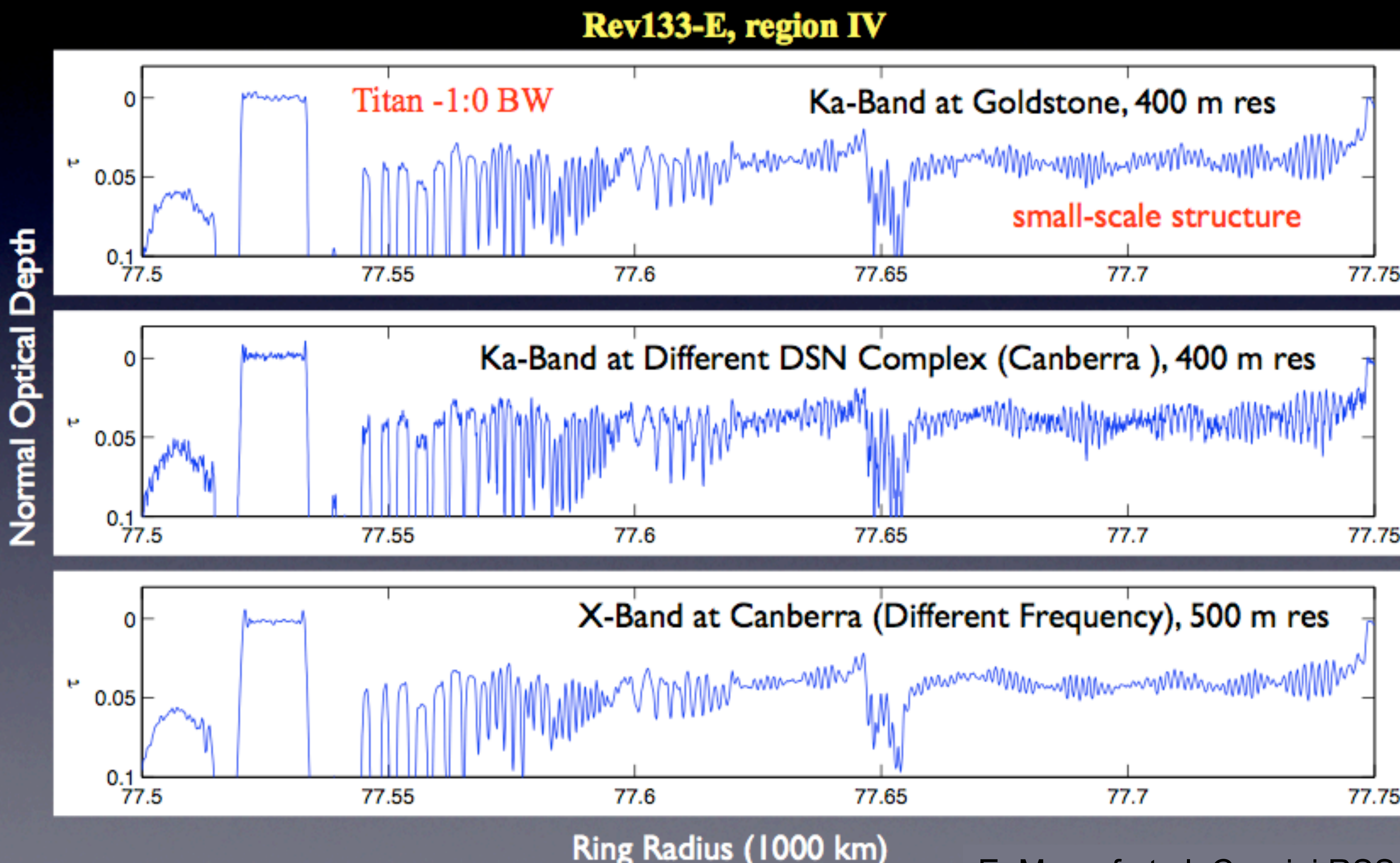
June 18-19, 2010 (DOY 169-170)

View from the Earth

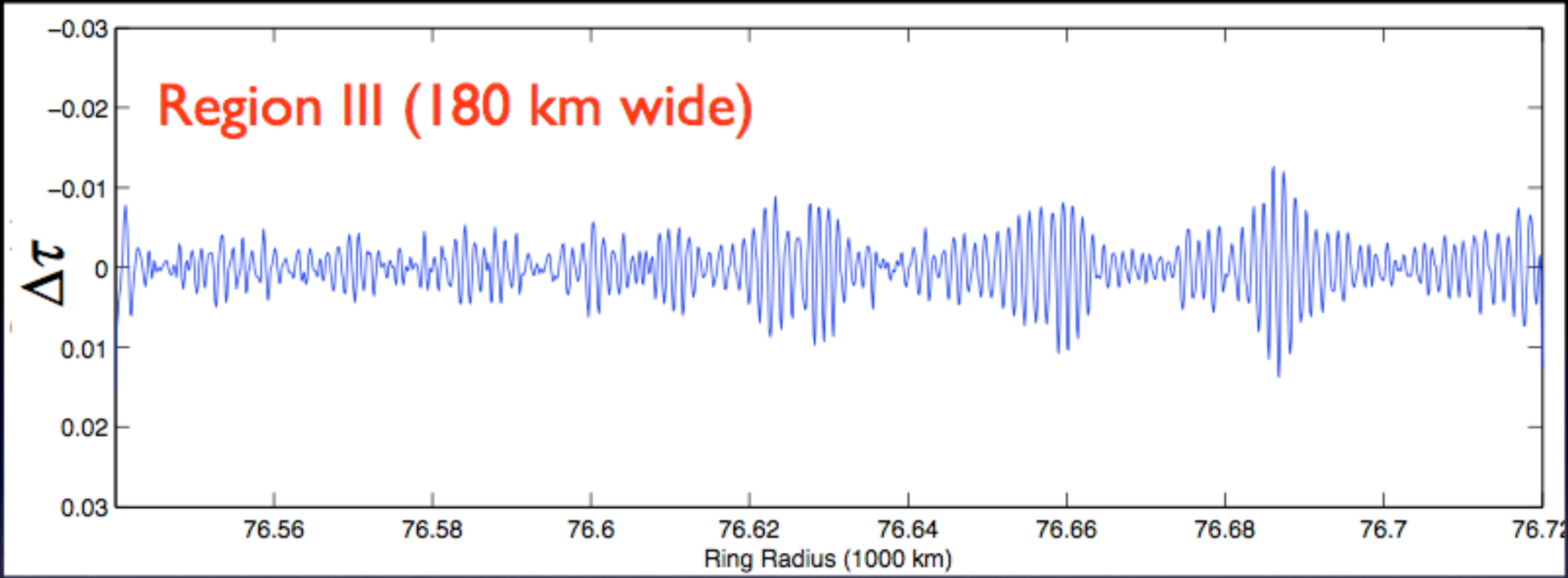


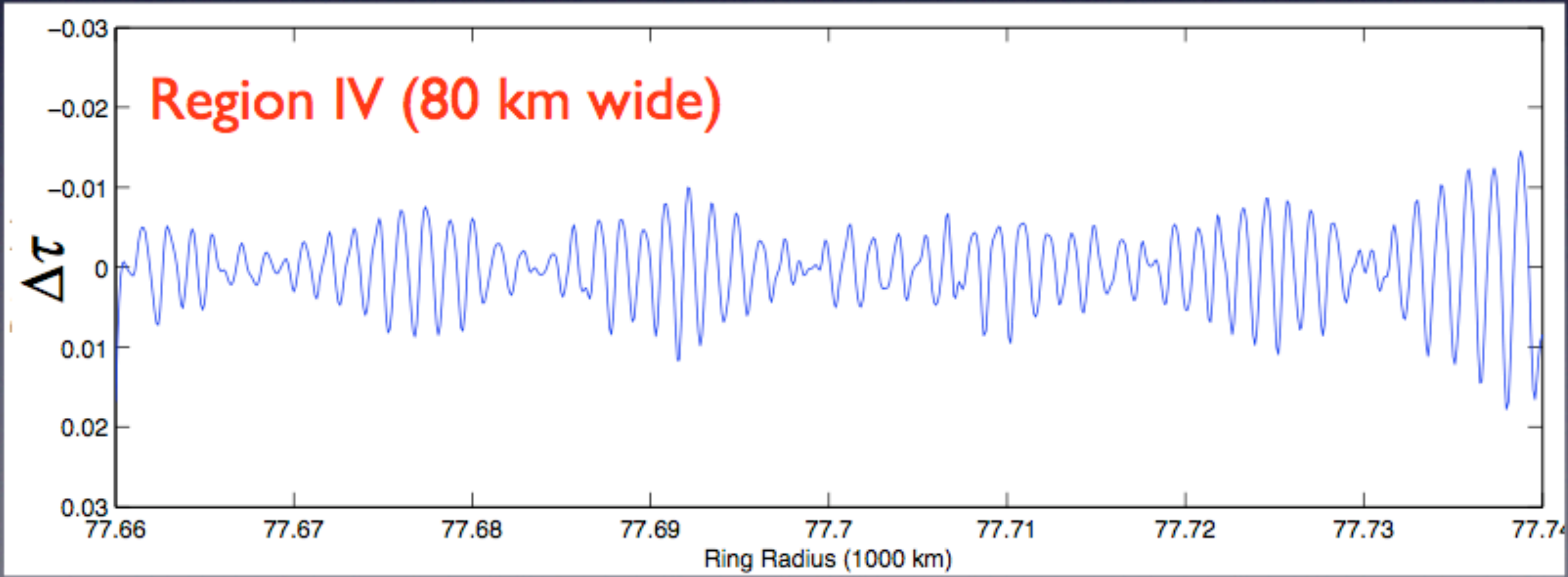
E. Marouf et al. Cassini RSS

- km-scale quasi-periodic structure detectable in the high-resolution RSS optical depth profiles (multiple DSN complexes, 2 frequencies)



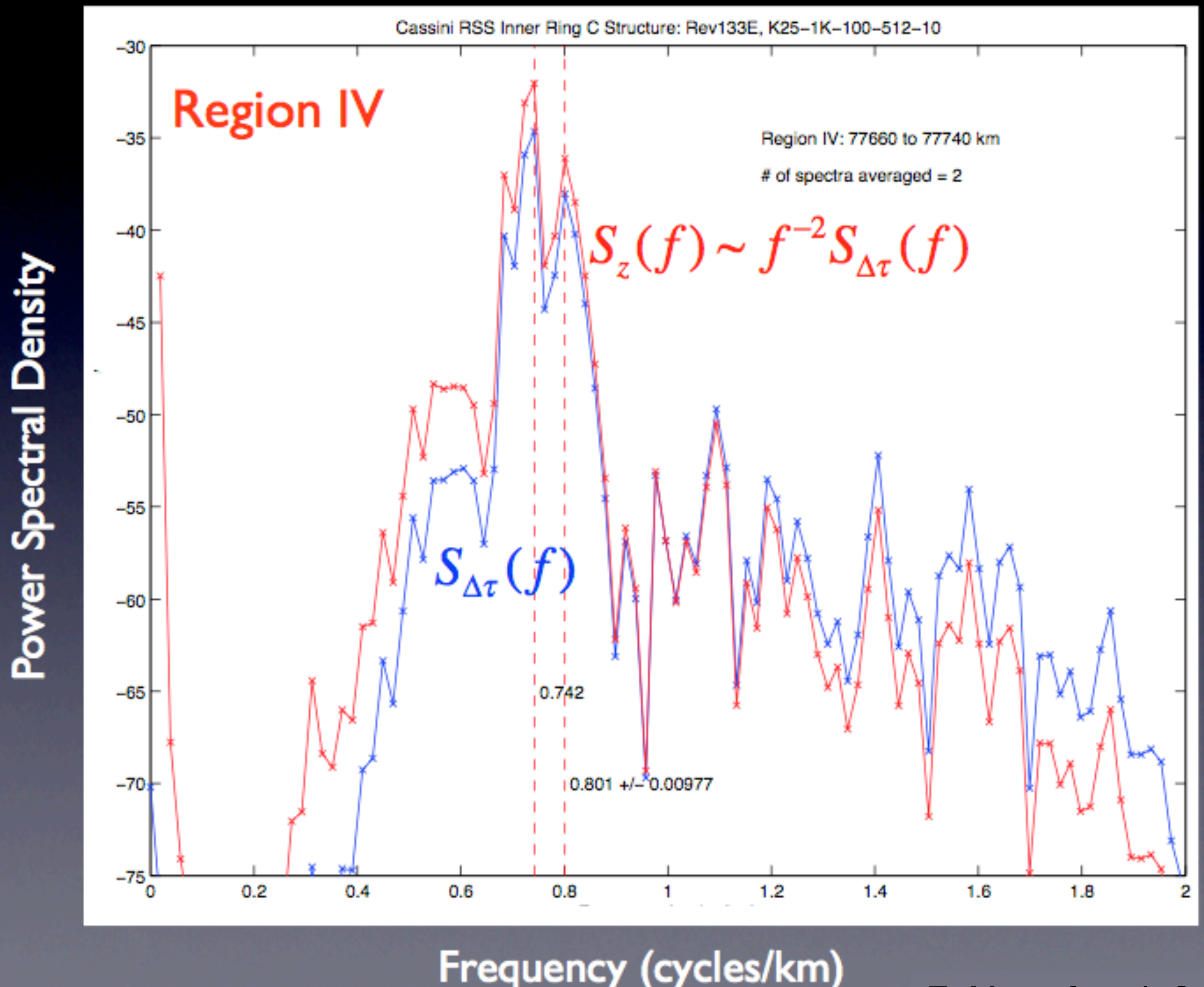
E. Marouf et al. Cassini RSS





E. Marouf et al. Cassini RSS

Structure Amplitude Spectrum



E. Marouf et al. Cassini RSS

The C ring ripples from RSS: Summary

- Detection of dual-tone ~1.3 and 1.2 km wavelength (λ) harmonic structure in inner Ring C; λ-separation ~ 110 m

- λ increases slowly over ~74,480-77,740 km ring radius

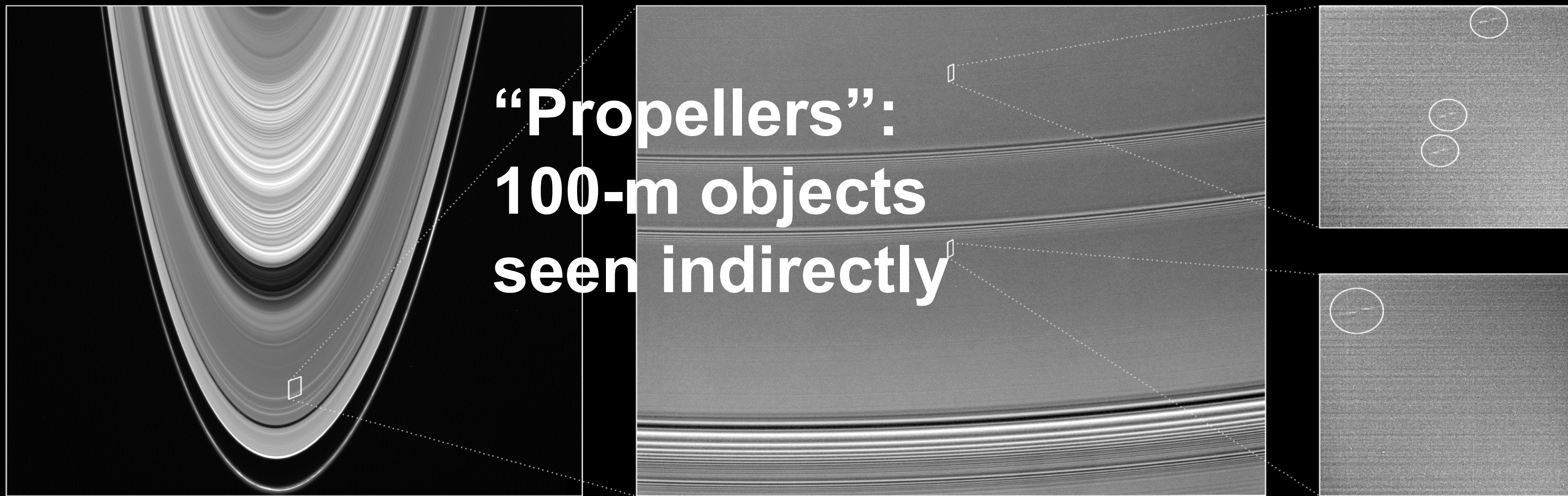
- Likely vertical corrugations similar to those reported by the ISS Team (Hedman *et al.*, 2011) for different structure of λ ~30 km

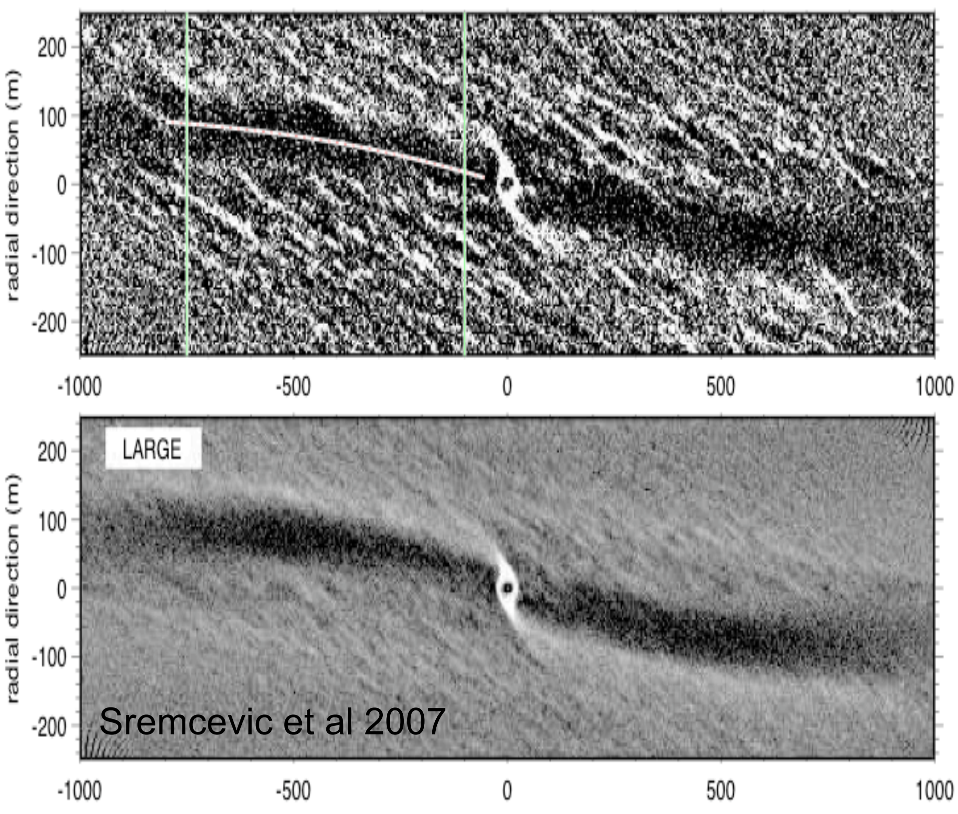
- λ behavior is in general agreement with the corrugation model prediction; important differences persist (impact of ring mass?)

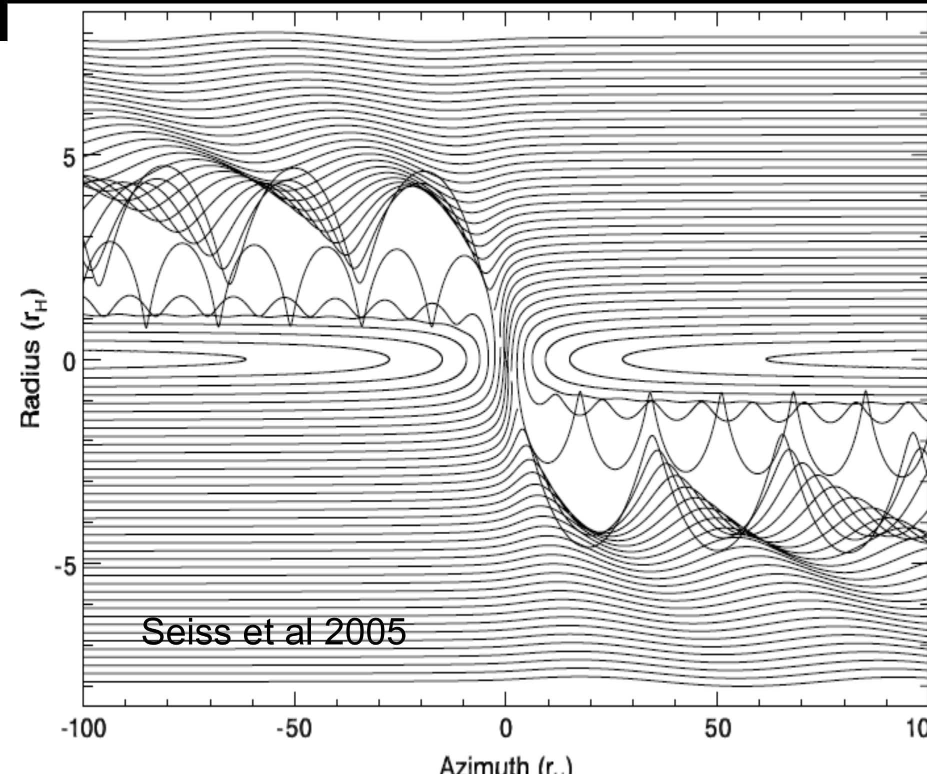
- modeled as narrow-band random process, the observed optical depth fluctuations imply structure of amplitude < ~4-10 m,

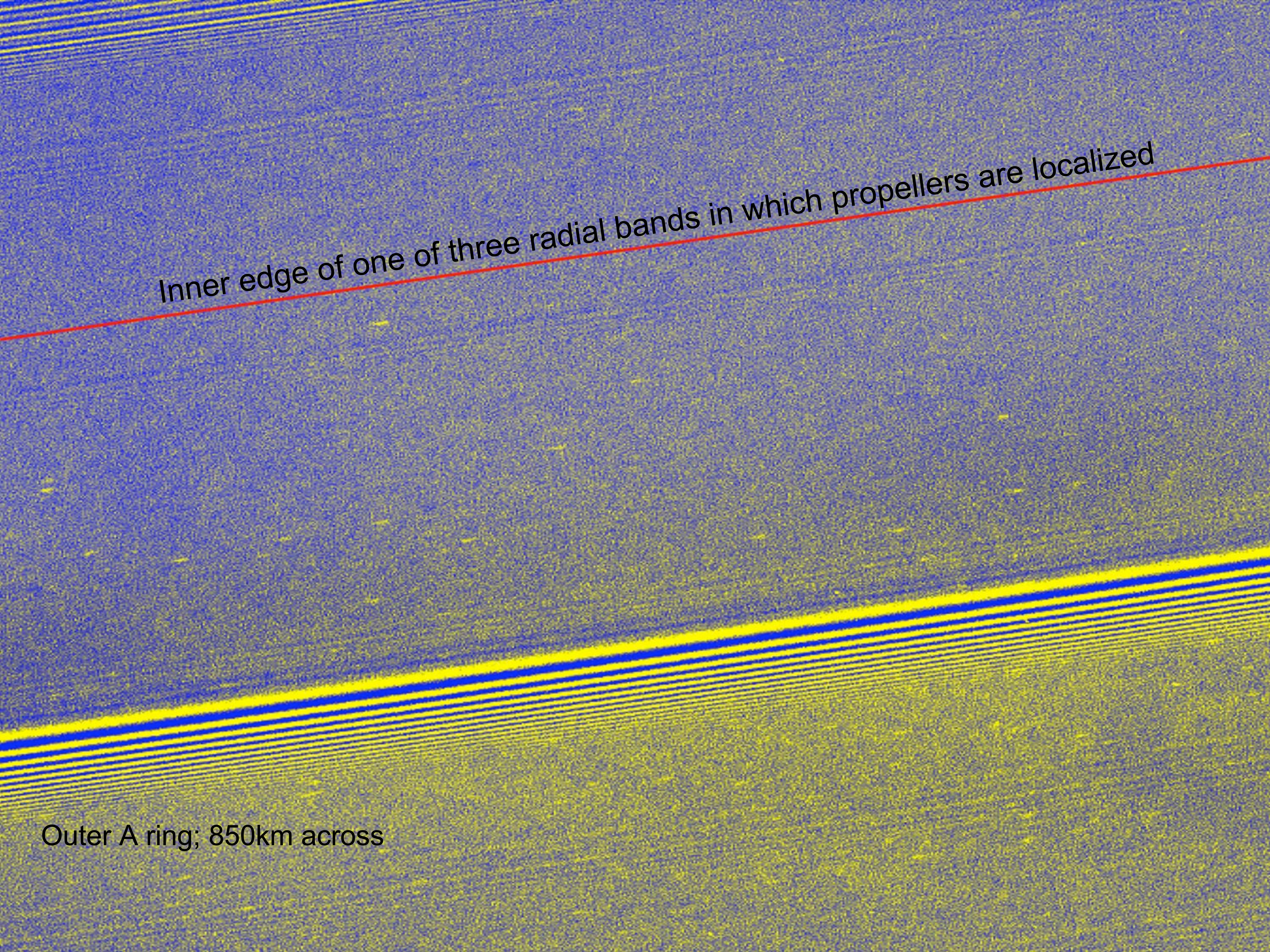
- The RSS/ISS λ-difference implies two distinct ring plane tilting events separated in time by ~600 years (late 1300's); the dual-tone imply 2 sub-events ~50 years apart

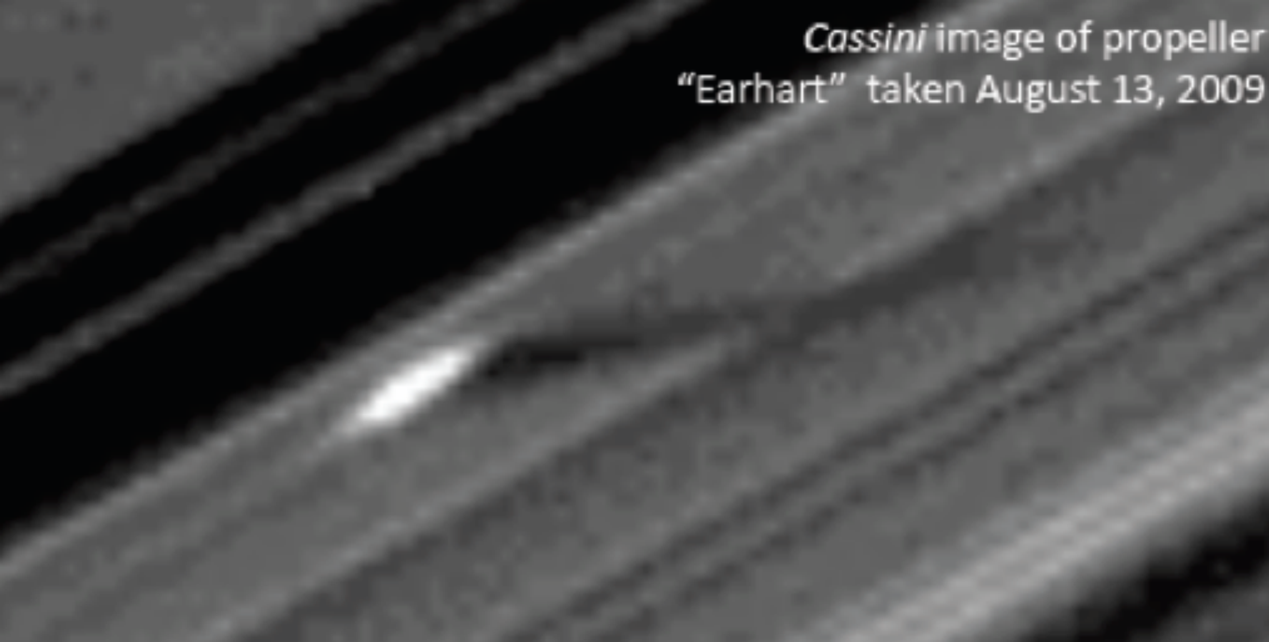
“Propellers”: 100-m objects seen indirectly

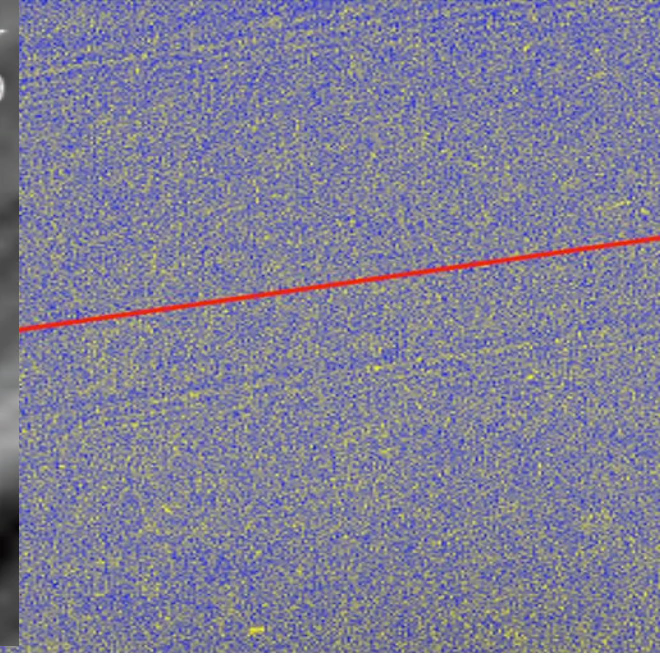


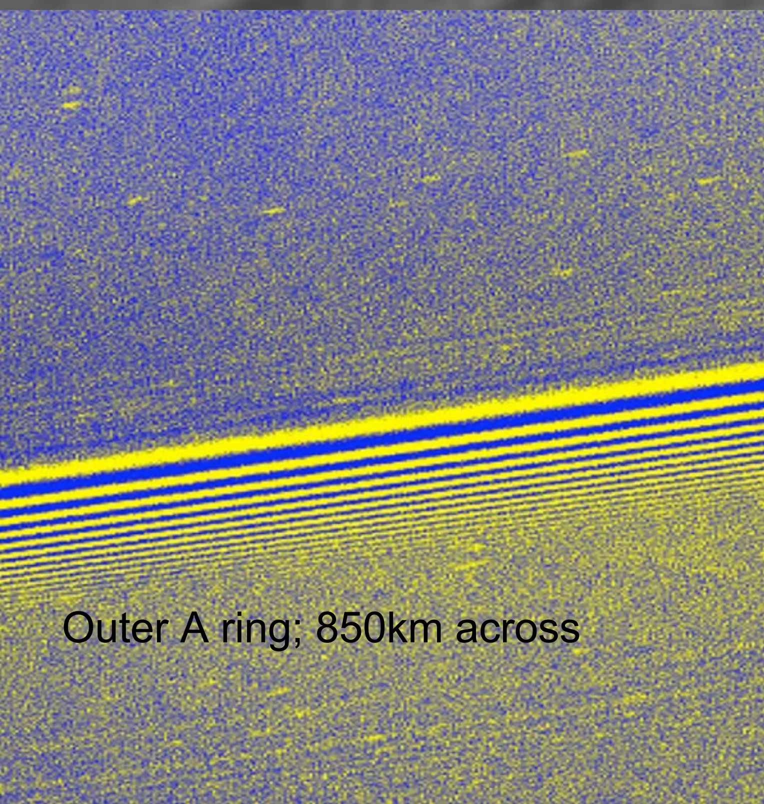





Inner edge of one of three radial bands in which propellers are localized
Outer A ring; 850km across


Cassini image of propeller
"Earhart" taken August 13, 2009

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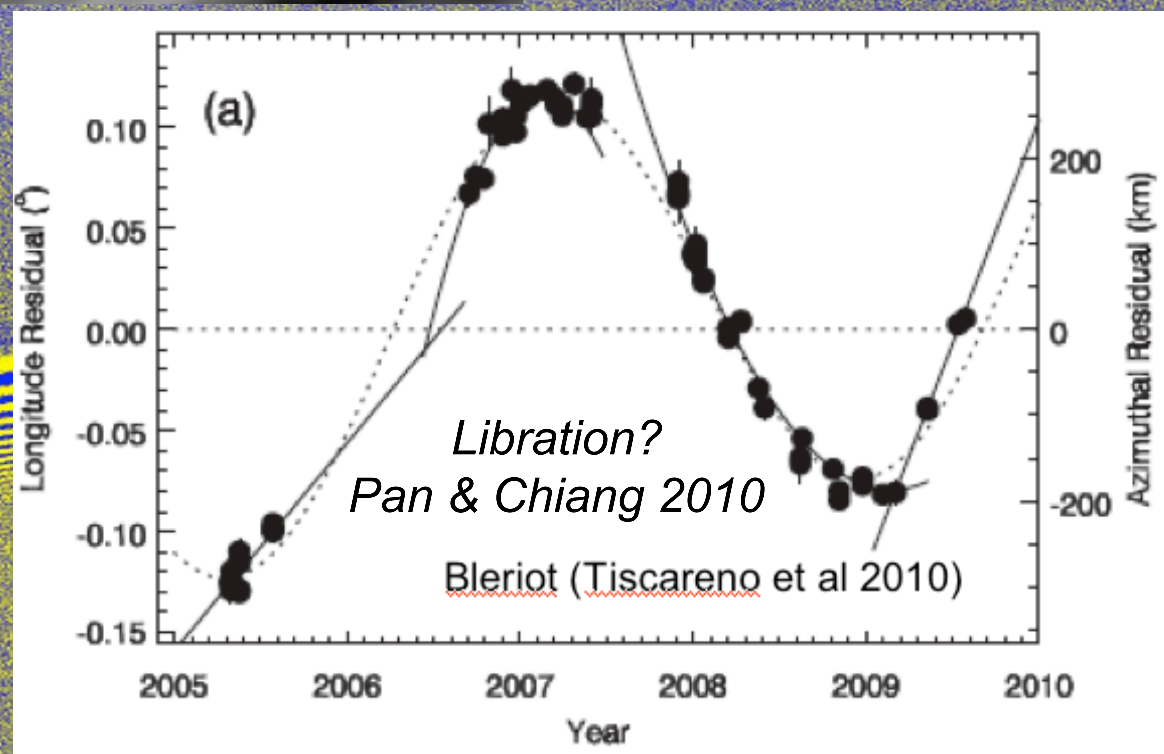
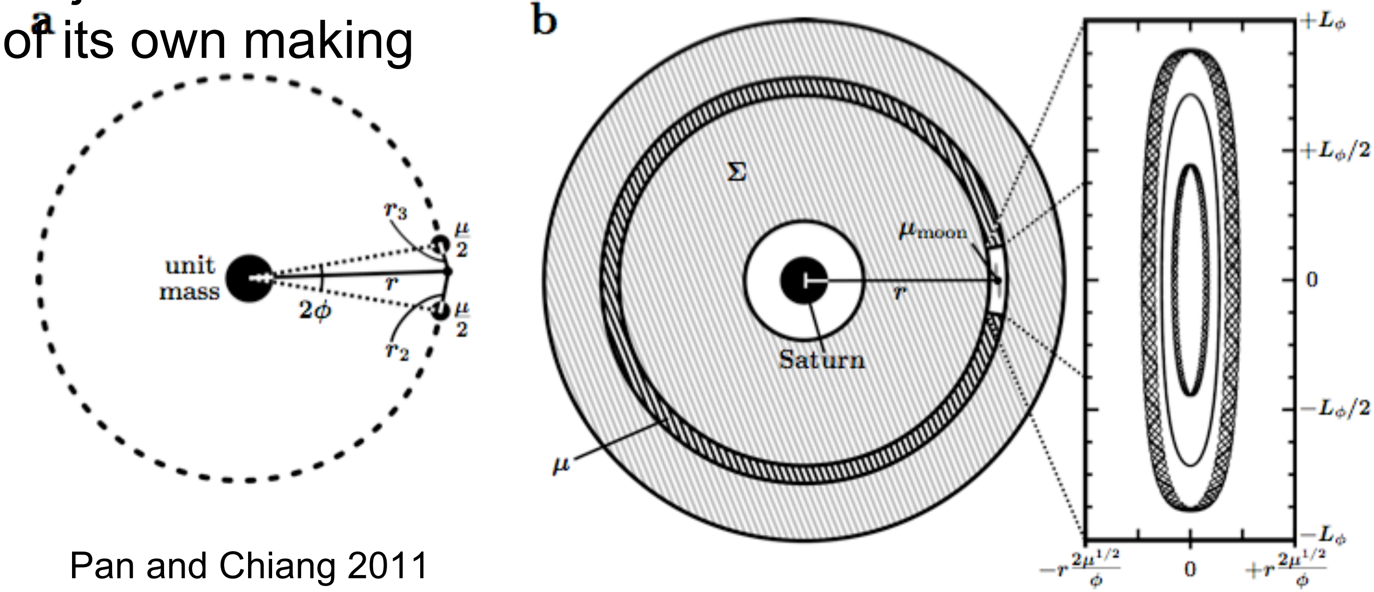
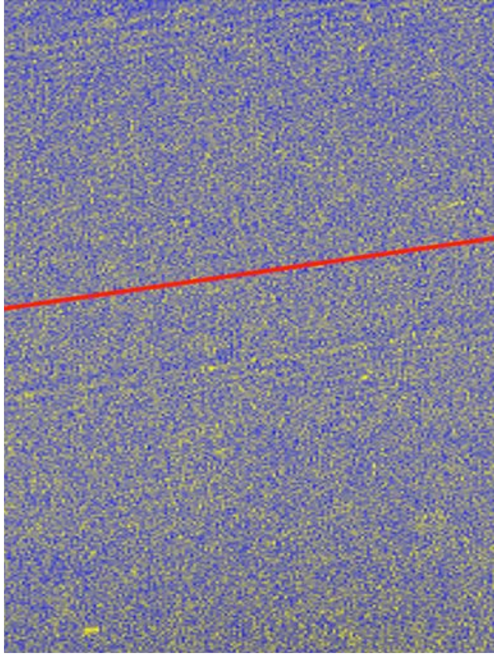
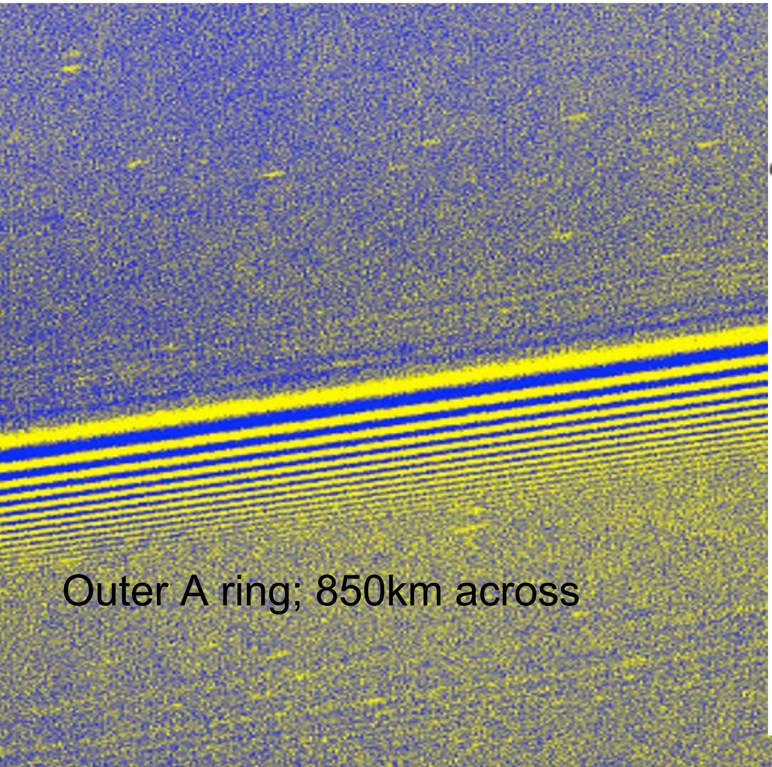

(a)
Libration?
Pan & Chiang 2010
Bleriot (Tiscareno et al 2010)
Longitude Residual (°)
Azimuthal Residual (km)
Year
0.10
0.05
0.00
-0.05
-0.10
-0.15
200
0
-200
2005
2006
2007
2008
2009
2010

Object librates in a “mass hole” of its own making



Pan and Chiang 2011





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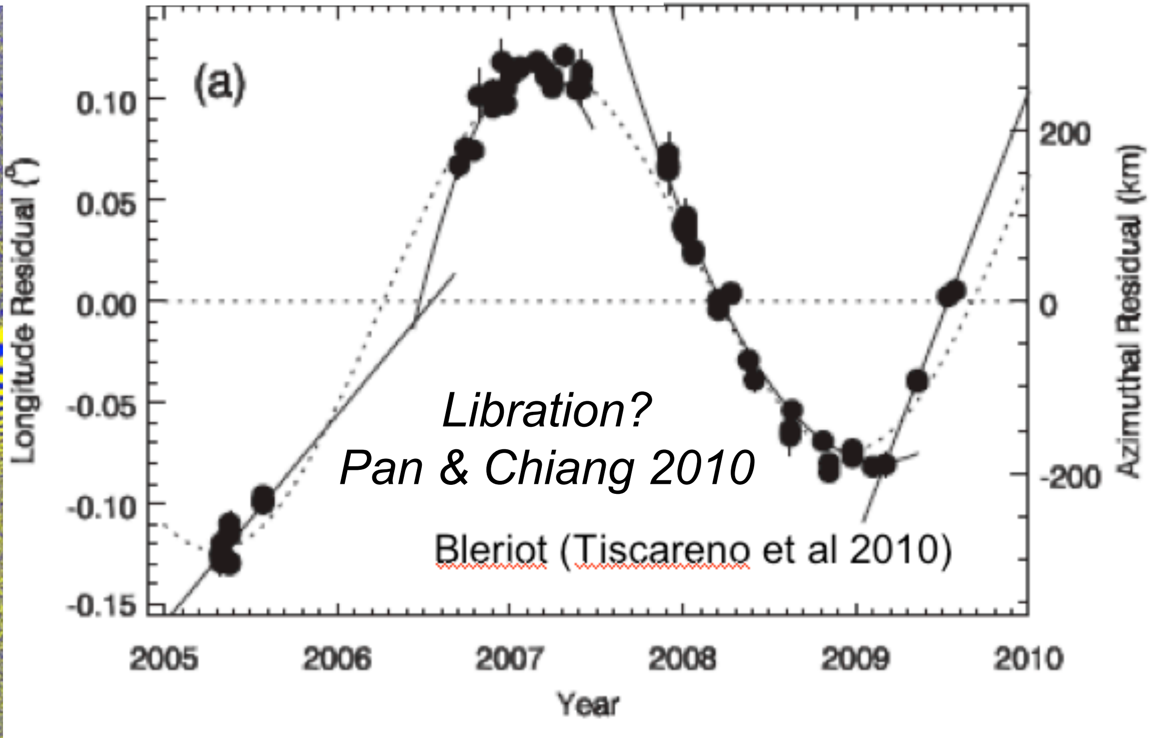

Libration?
Pan & Chiang 2010

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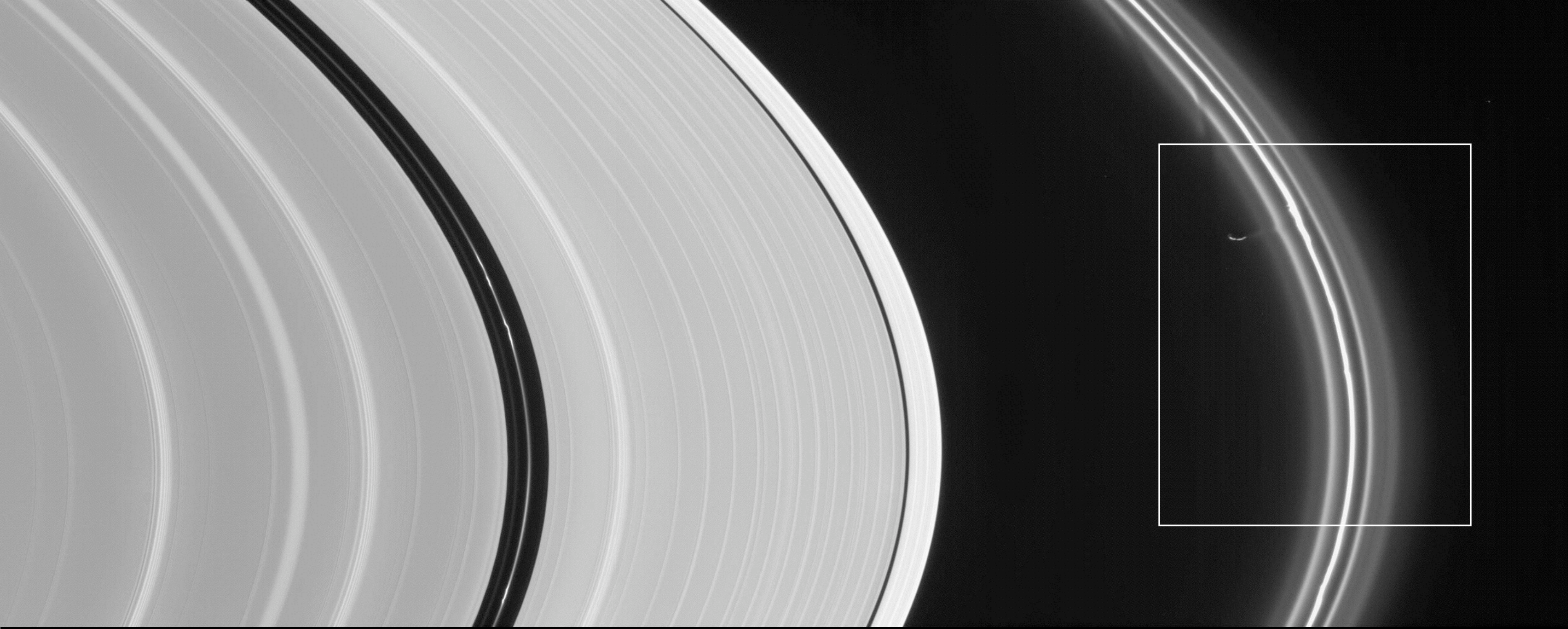


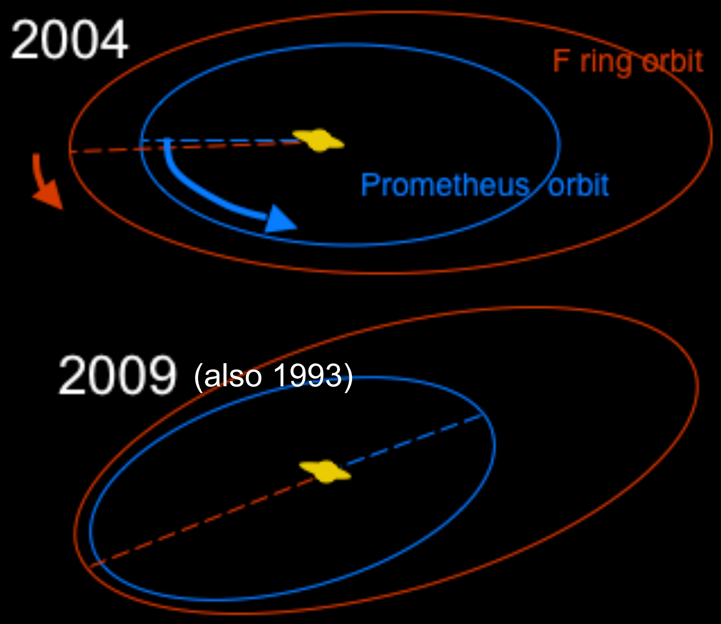
Multiple strands;
Prometheus, Pandora,
and other new objects

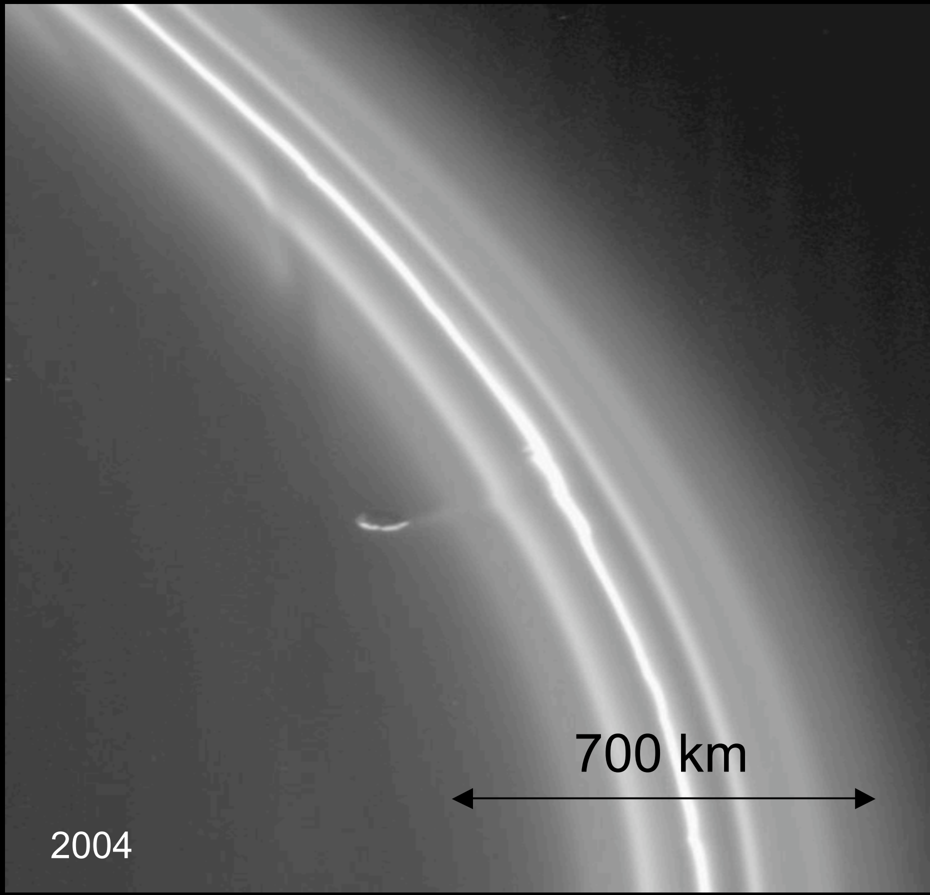
Outer A ring

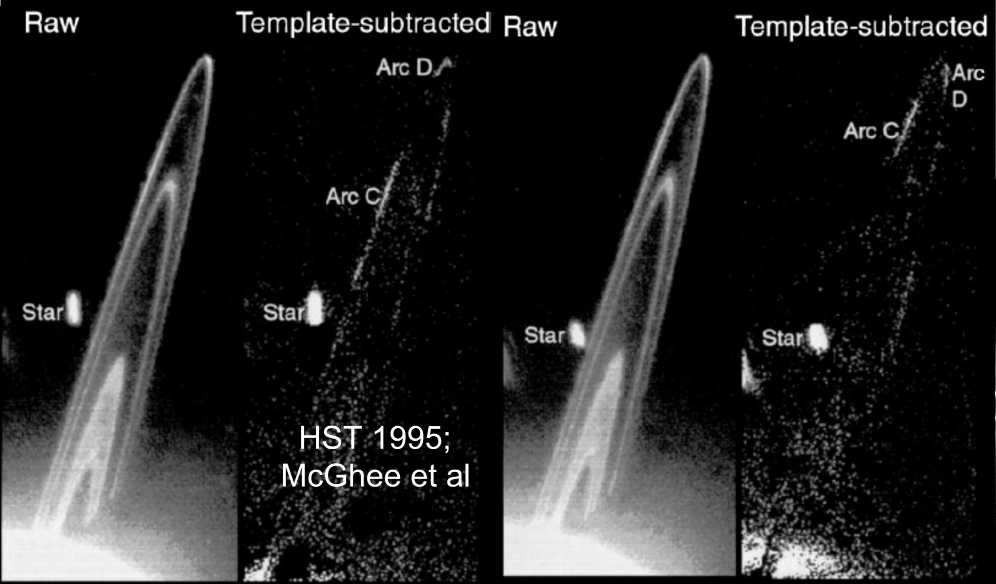
F ring

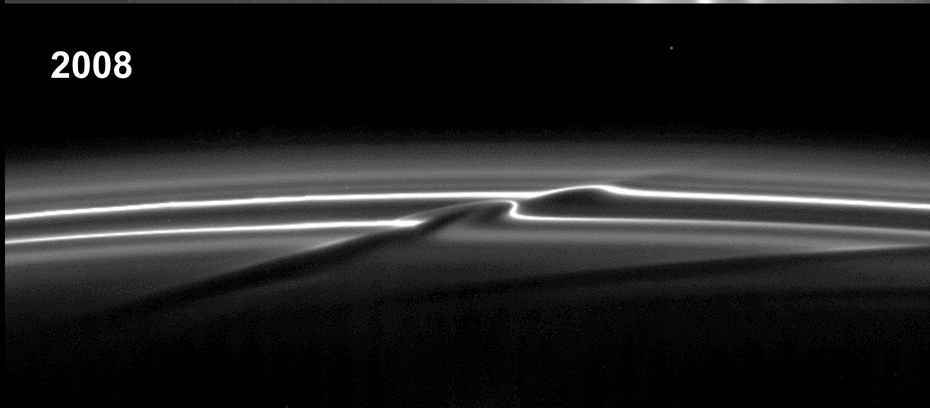
10,000km or 6000 miles

Prometheus: “Nemesis” of the F ring? Need a few more years to tell..

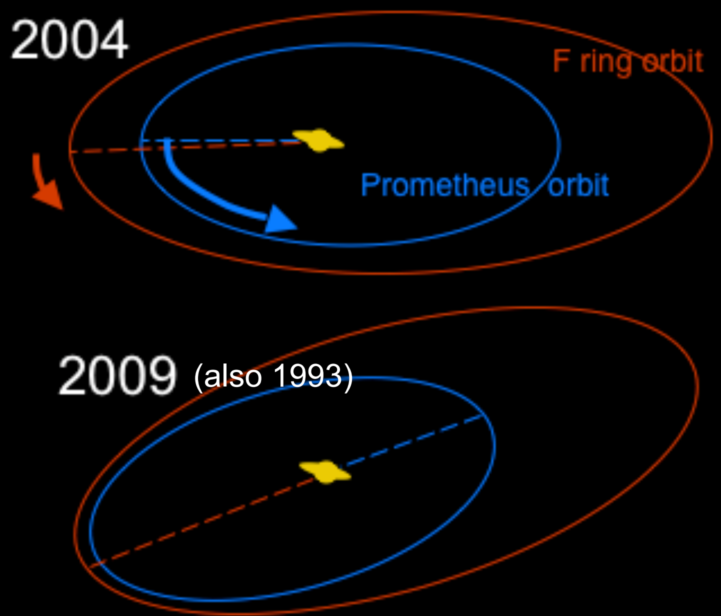


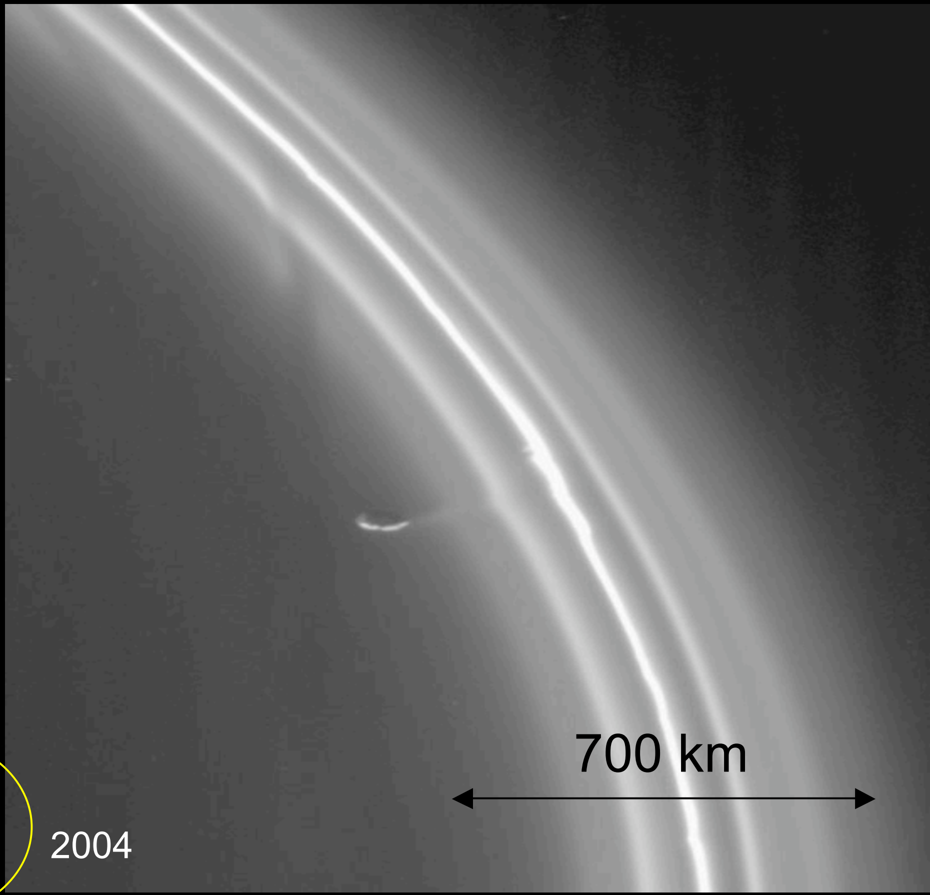


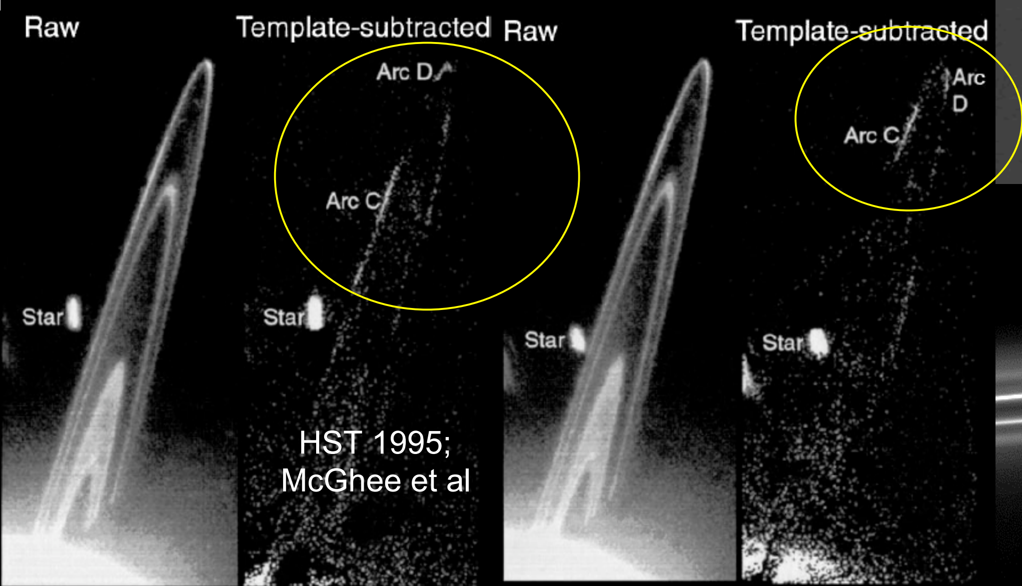


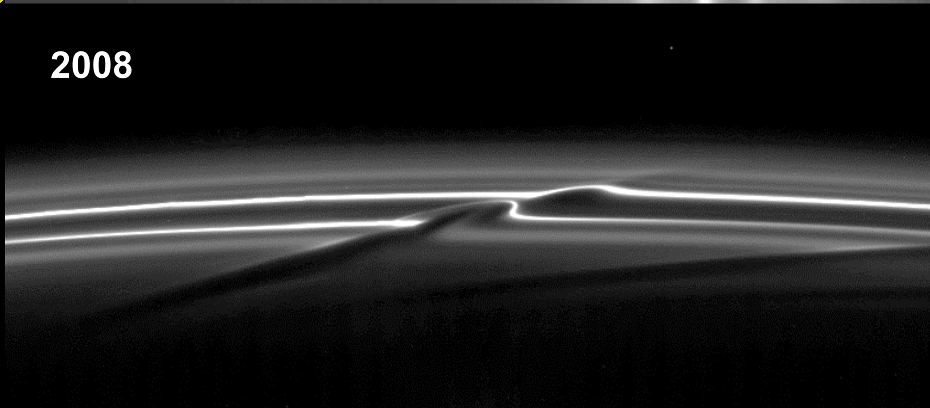


Prometheus: "Nemesis" of the F ring? Need a few more years to tell..

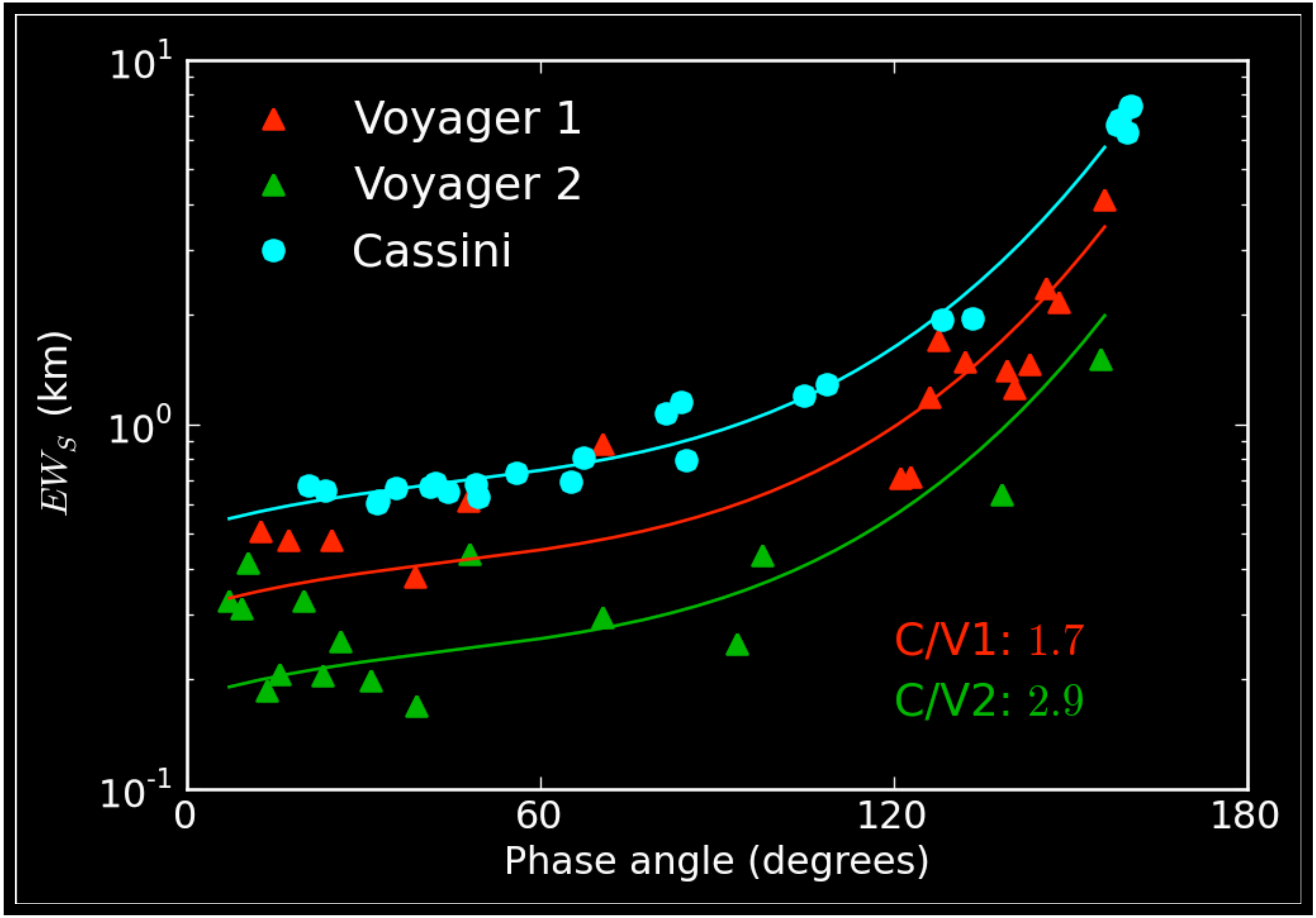






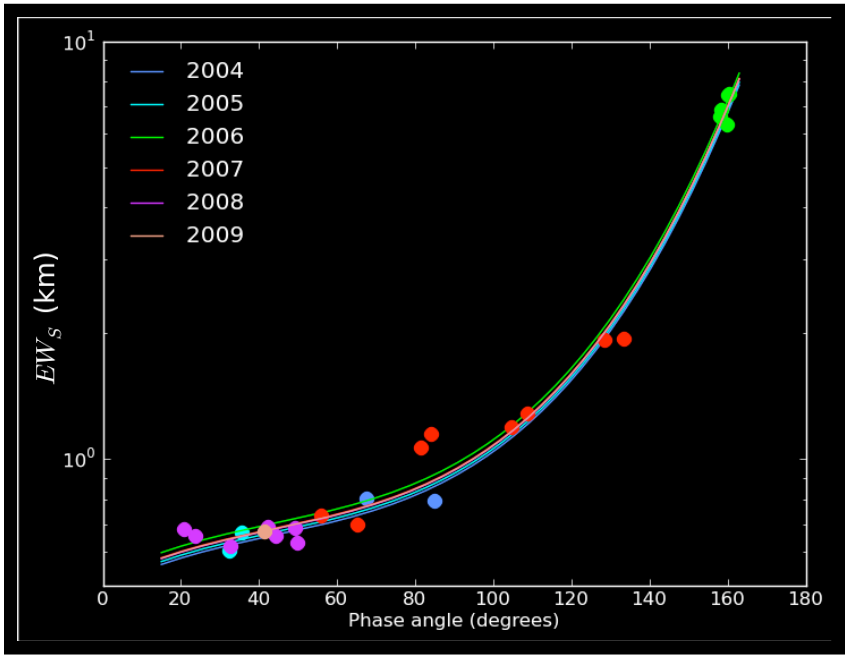


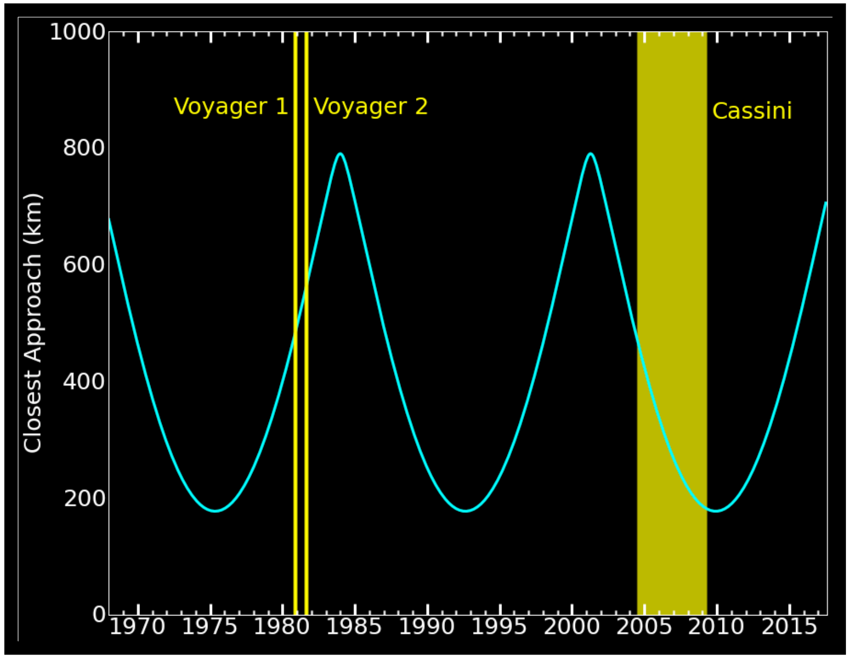
The *Brightening* of the F Ring between Voyager and Cassini



R. French and M.Showalter (2011)

Don't Blame Prometheus (?)





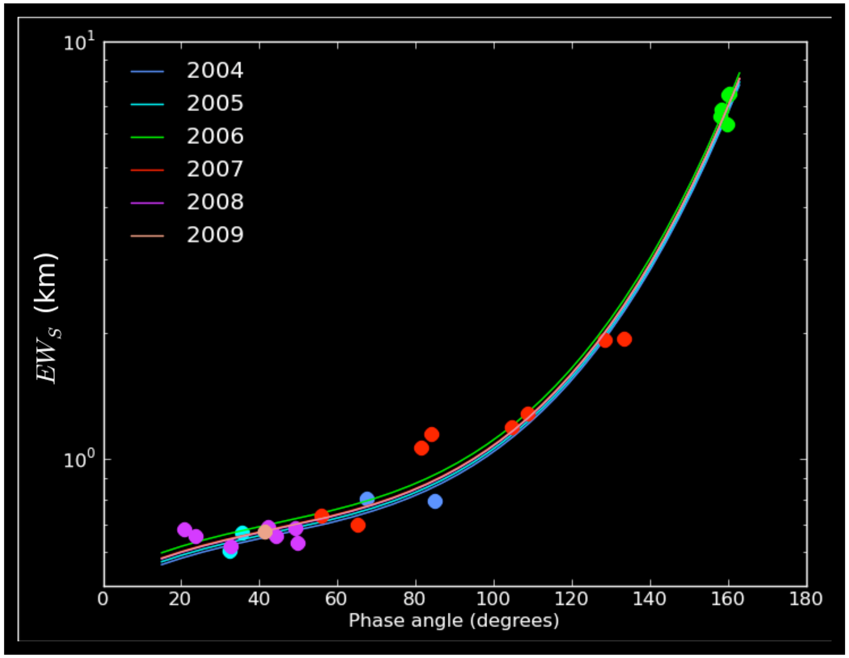
There was no evidence of brightness variation from 2004-2009

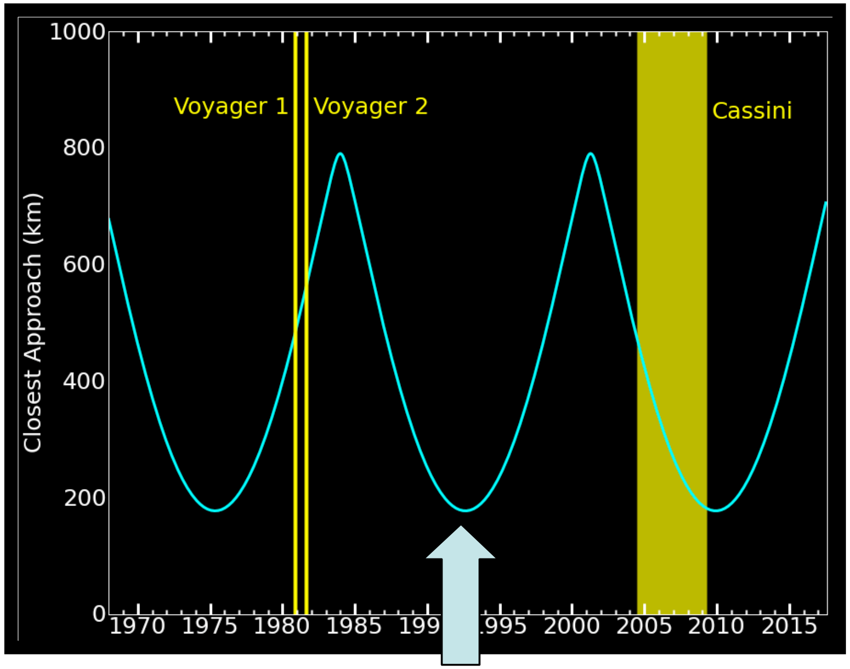
(well, ignoring that big explosion)

…while the distance between Prometheus and the F ring changed a lot *during* Cassini …

R. French and M.Showalter (2011)

Don’t Blame Prometheus (?)





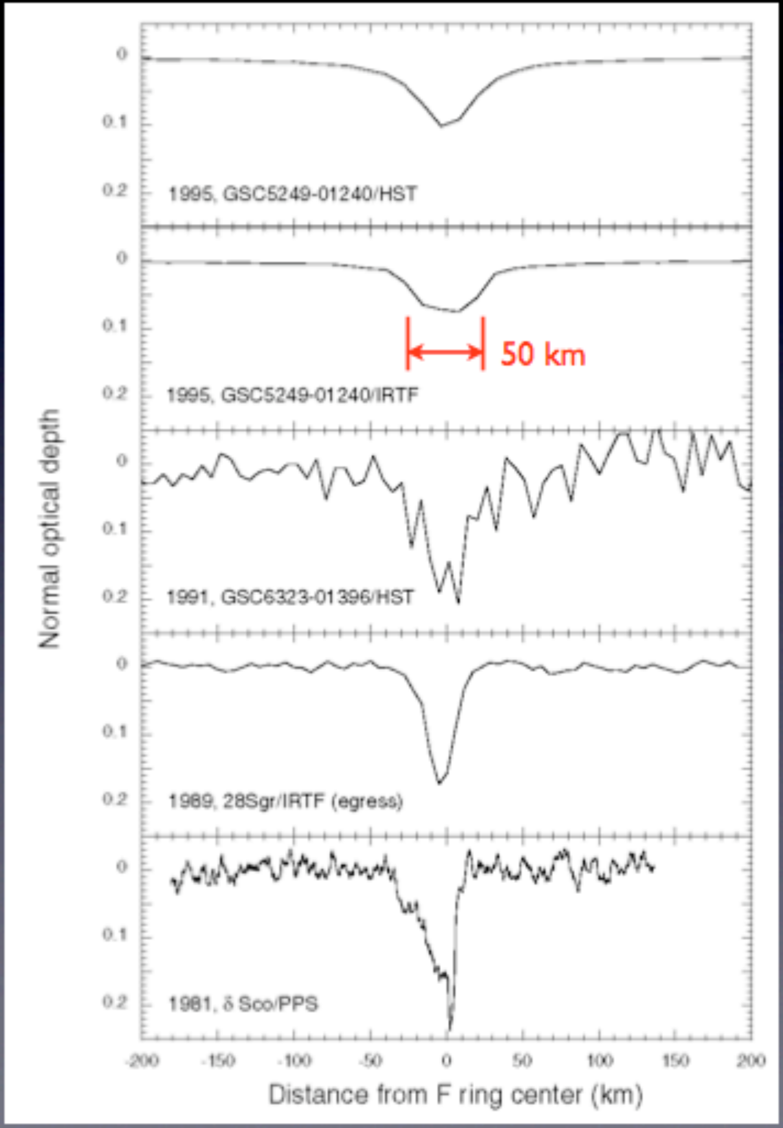
There was no evidence of brightness variation from 2004-2009

(well, ignoring that big explosion)

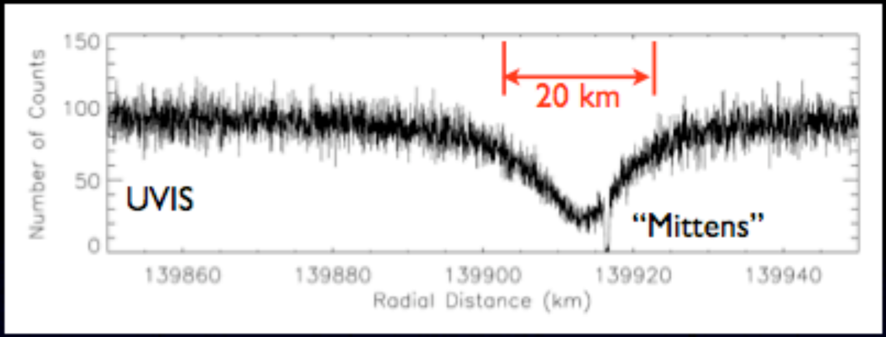
But what might have happened here? We do know that at least one massive clump (“C”) appeared in the 1996-1996 ring plane crossing campaigns (McGhee et al)

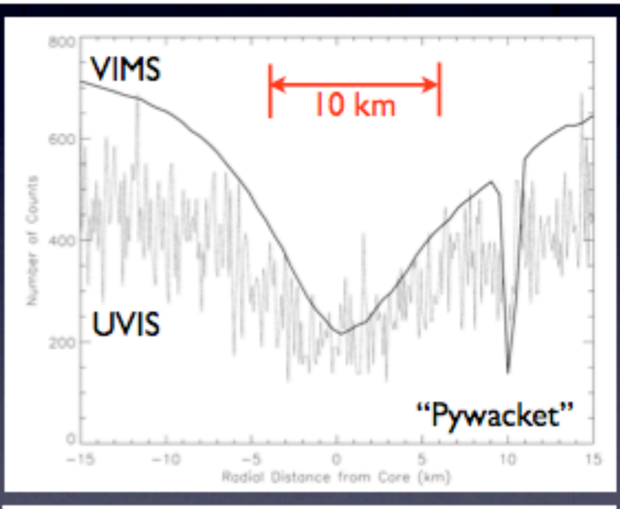
RSS Core is different from stellar occ's "core"

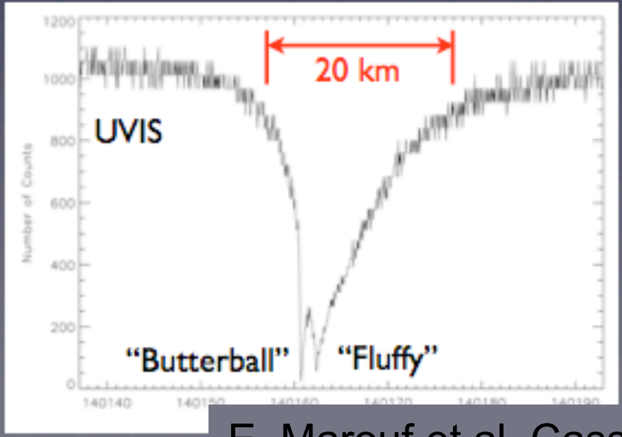
HST Stellar Occultations: Bosh *et al.* 2002



Cassini UVIS/VIMS Stellar Occultations: Esposito *et al.* 2008



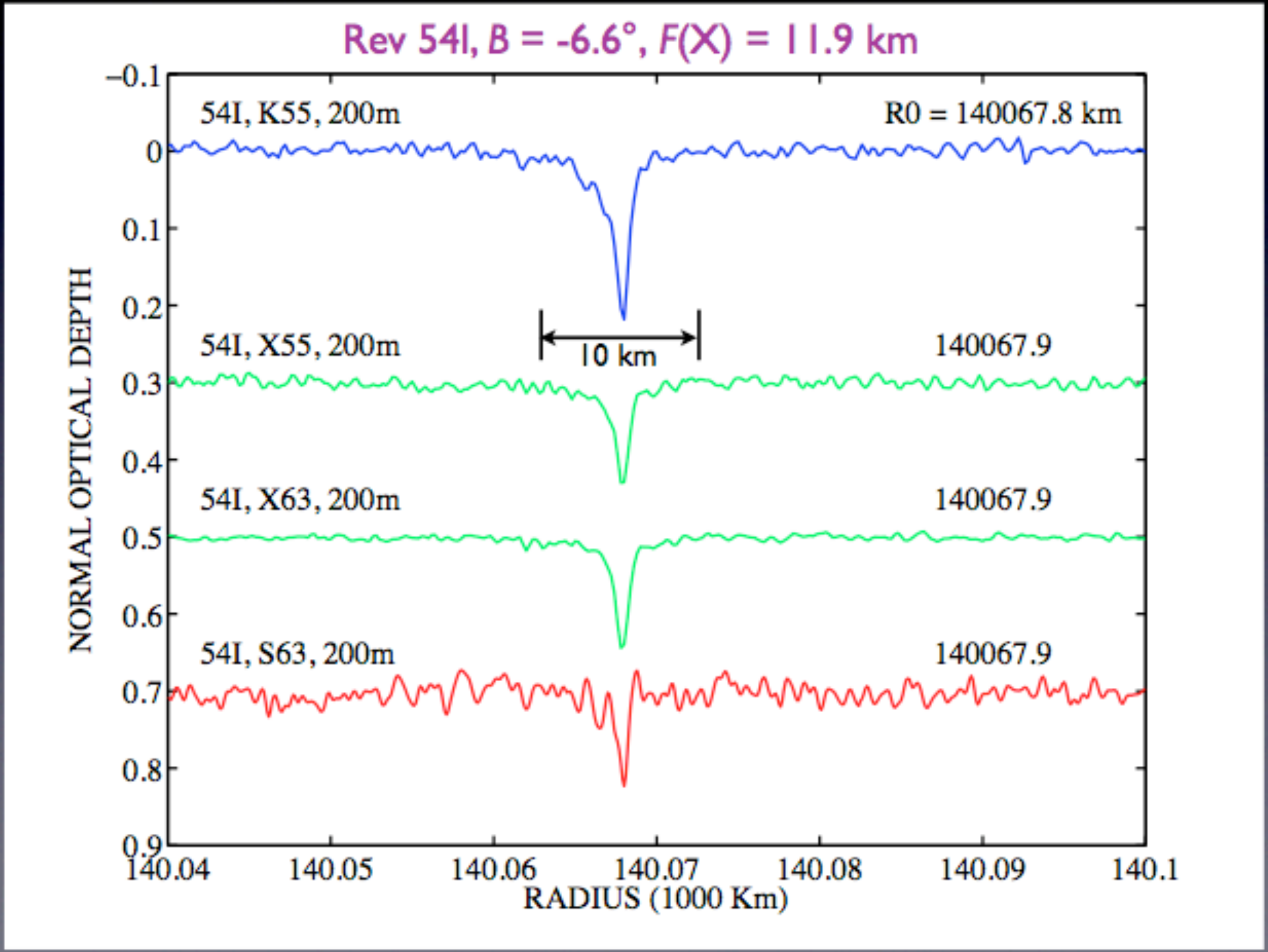




E. Marouf et al. Cassini RSS

F-Ring is detectable in only 15 out of 49 crossings (29 Occ's)

- almost always a single strand ~ 1 km wide (2 exceptions)
- strand must extend azimuthally > Fresnel scale (10's km's)



200 m res

Ka-Band (34m)

0.94 cm-λ

X-Band (34m)

3.6 cm-λ

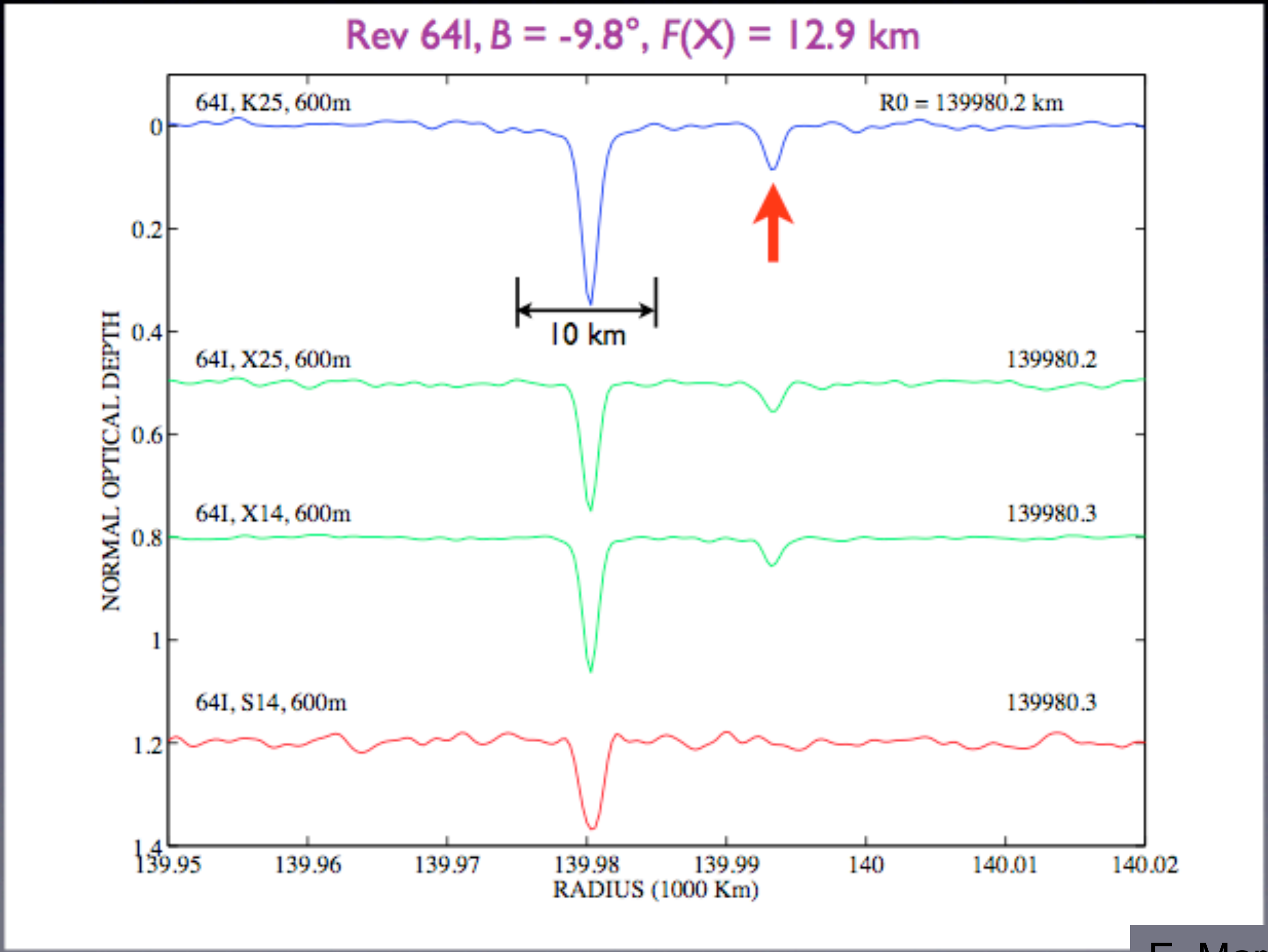
X-Band (70m)

S-Band (70m)

13 cm-λ

E. Marouf et al. Cassini RSS

- normal optical depth < ~ few to several tenths; wavelength dependent
- sizes > ~1 mm to 10's of cm's
- tracer of most ring mass?; "core" of the F-Ring?
- April 27, 2008, crossing shows a tenuous second strand (1 of 2 exceptions)



600 m res

Ka-Band (34m)

0.94 cm-λ

X-Band (34m)

3.6 cm-λ

X-Band (70m)

S-Band (70m)

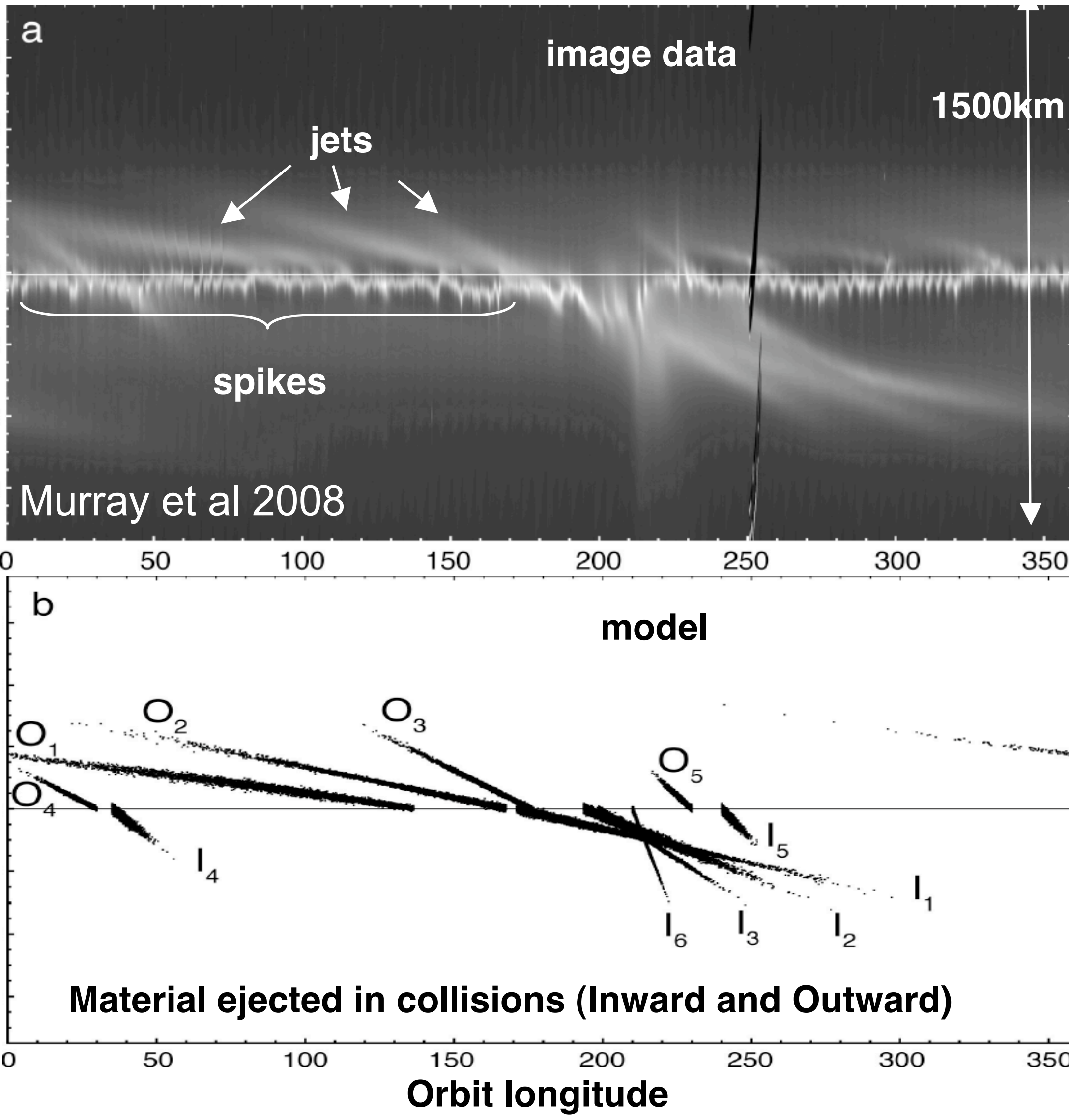
13 cm-λ

E. Marouf et al. Cassini RSS

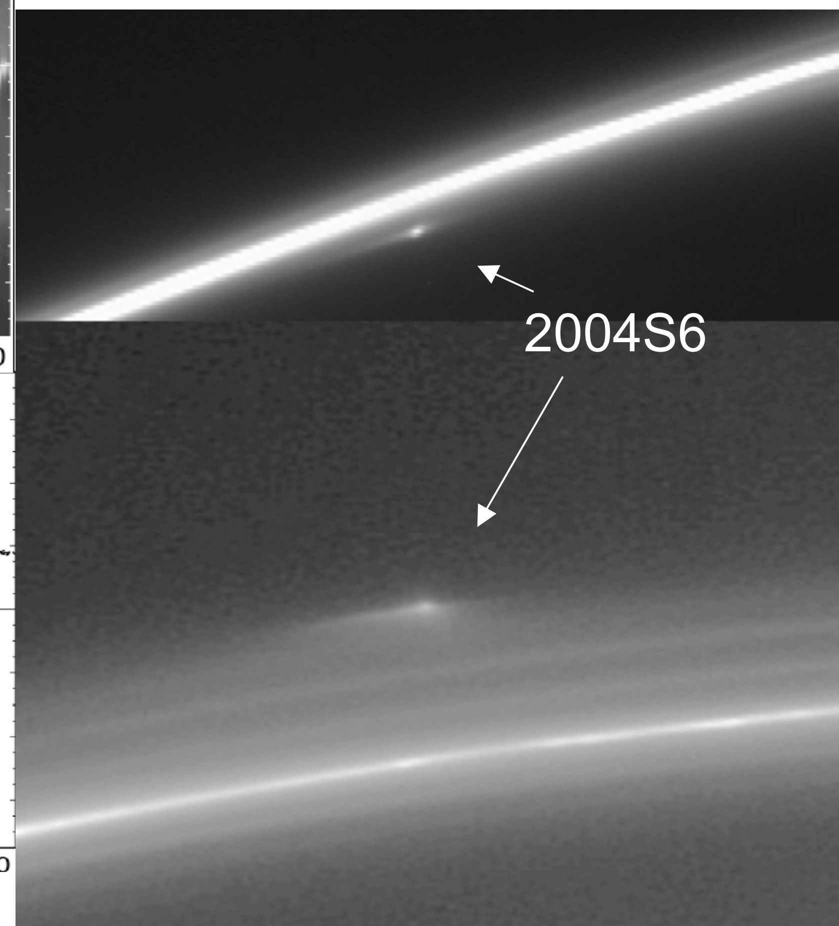
F region contains numerous embedded km-size moonlets, which get excited by Prometheus and Pandora, and then disturb the ring strands,

AND

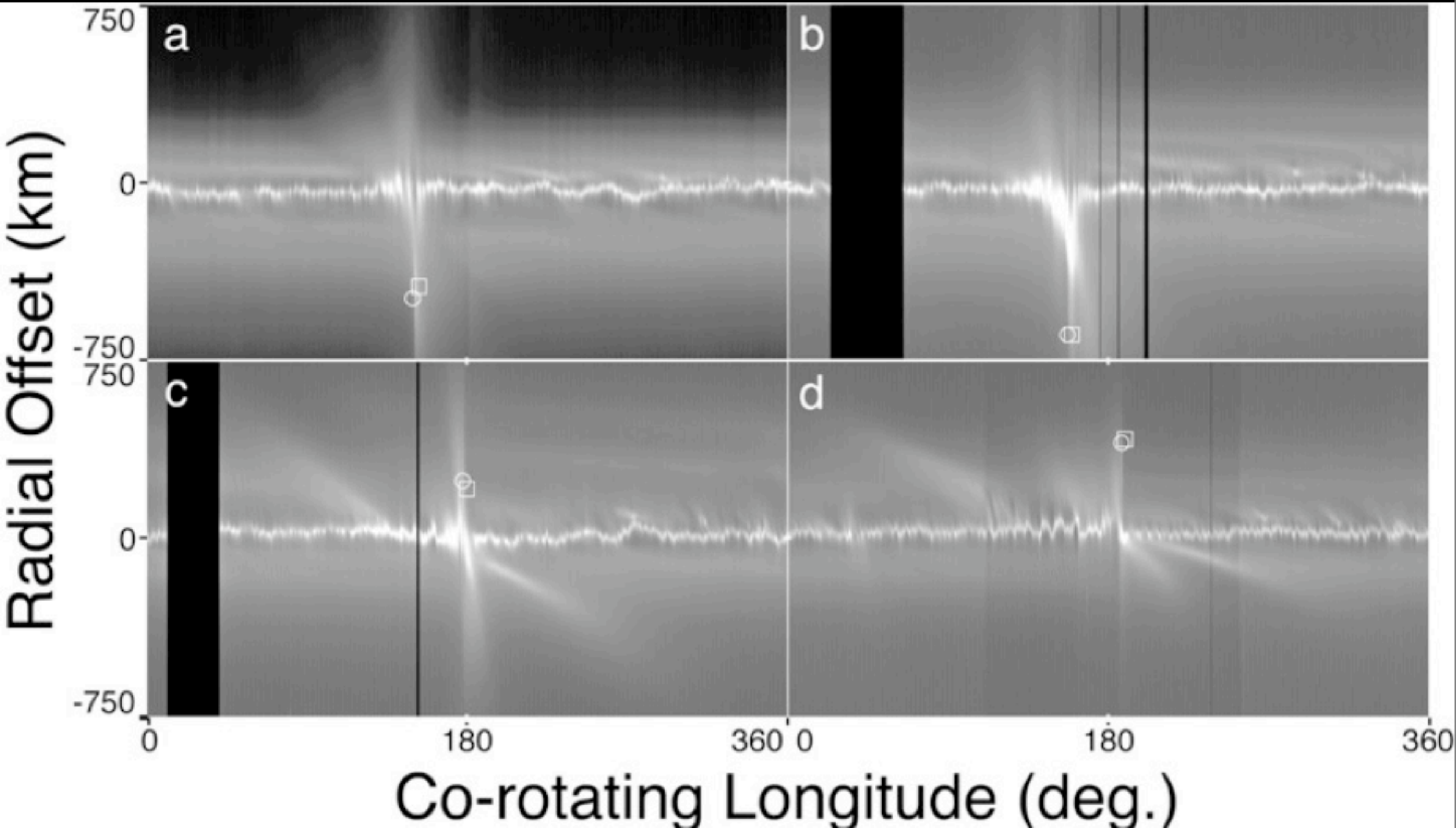
Fewer objects on dramatically crossing orbits, few of which have been detected



2004S6 has an eccentric orbit that crosses the F ring, leading to collisions

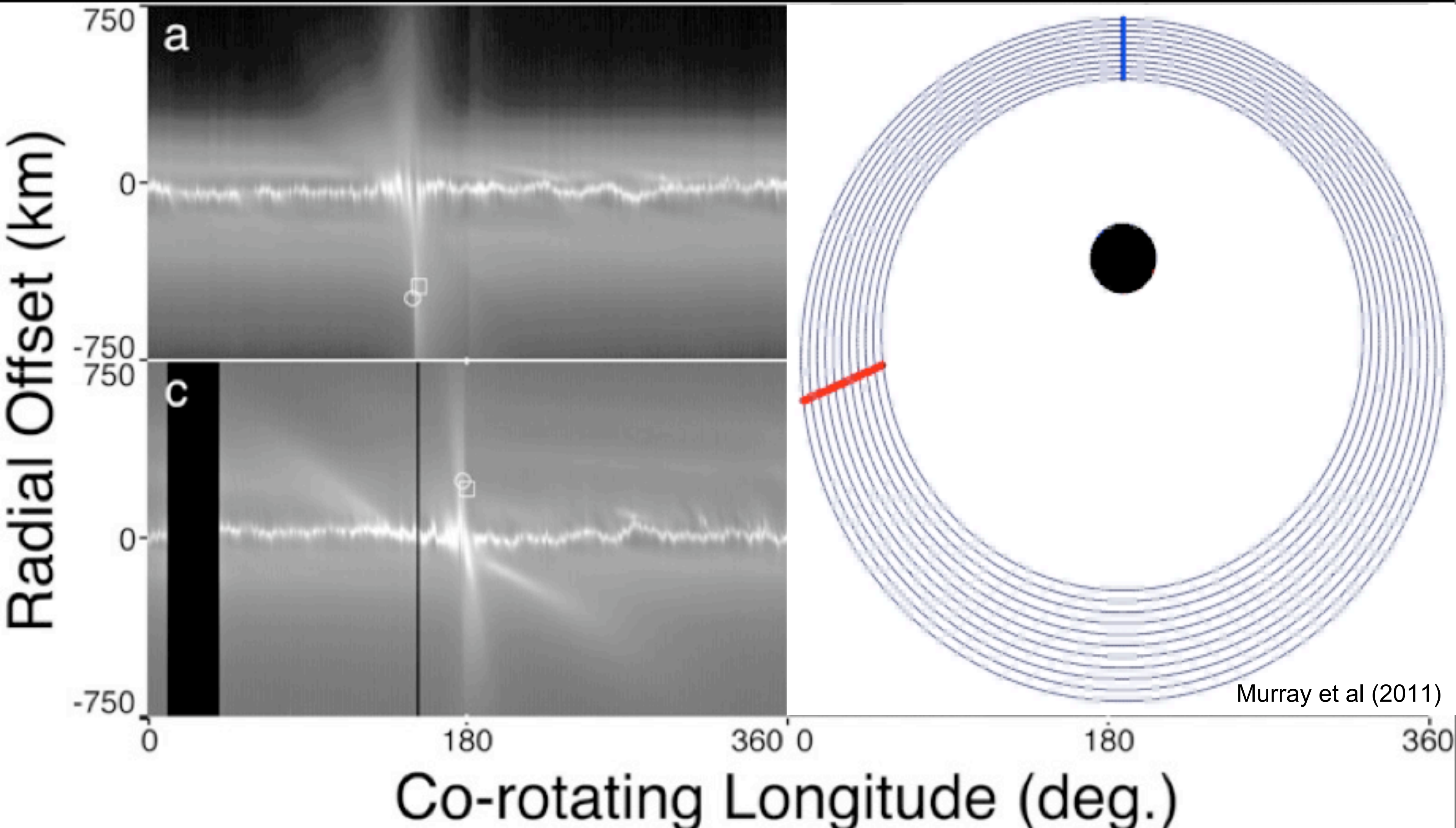


Association of Jets with S/2004 S 6

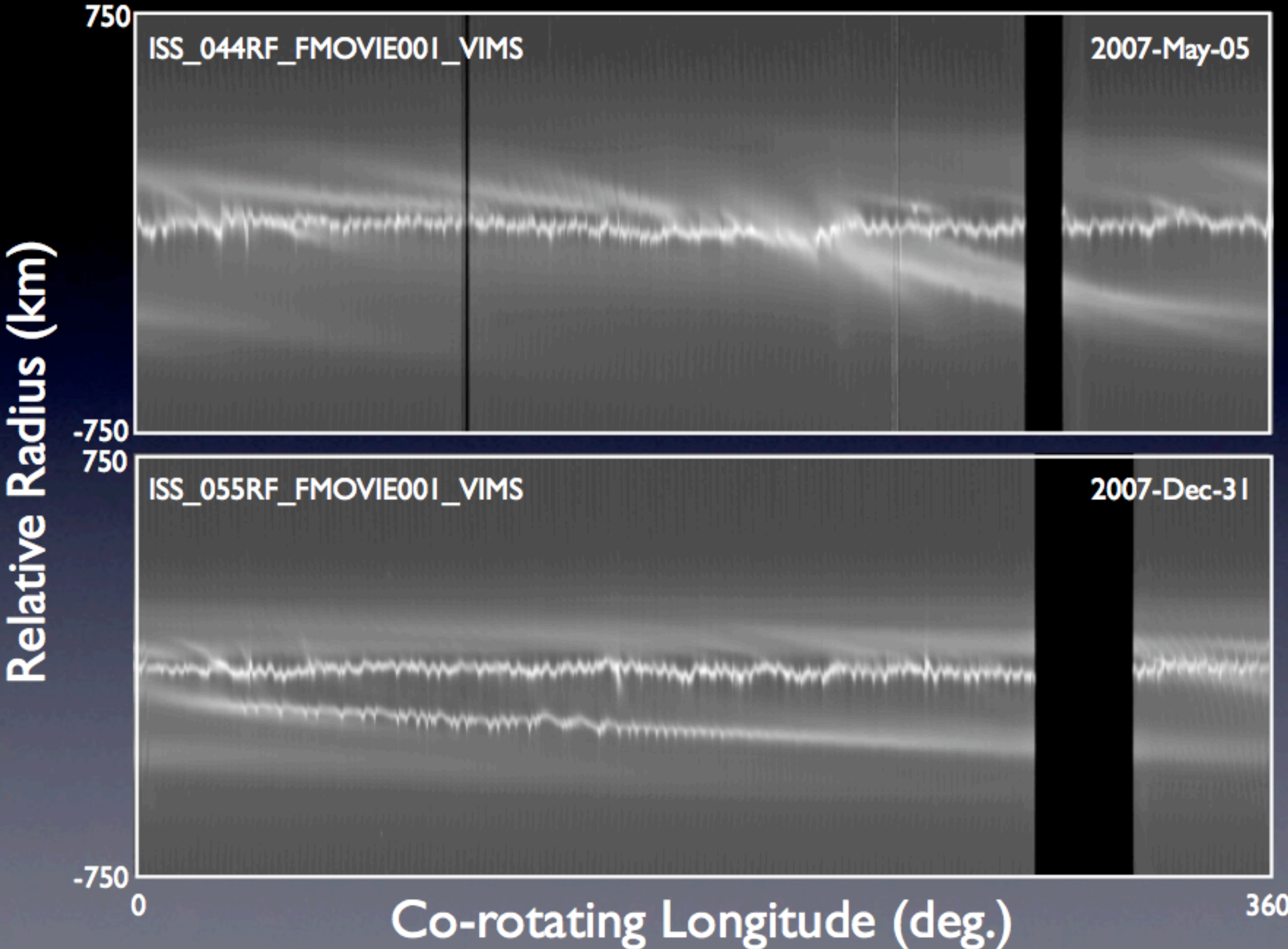


Murray et al. (2008)

Association of Jets with S/2004 S 6



Murray et al. (2008)



Murray et al (2011)

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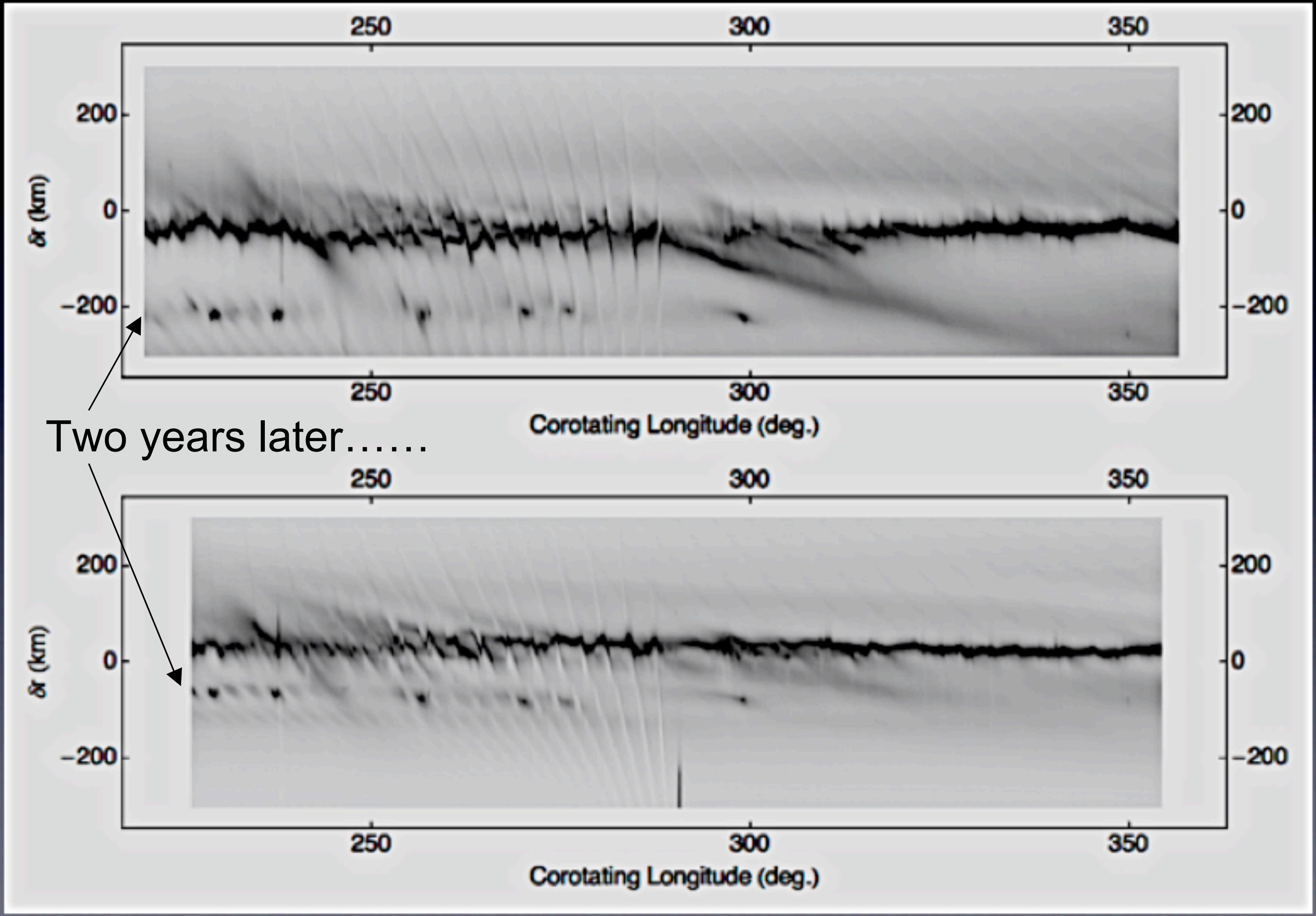
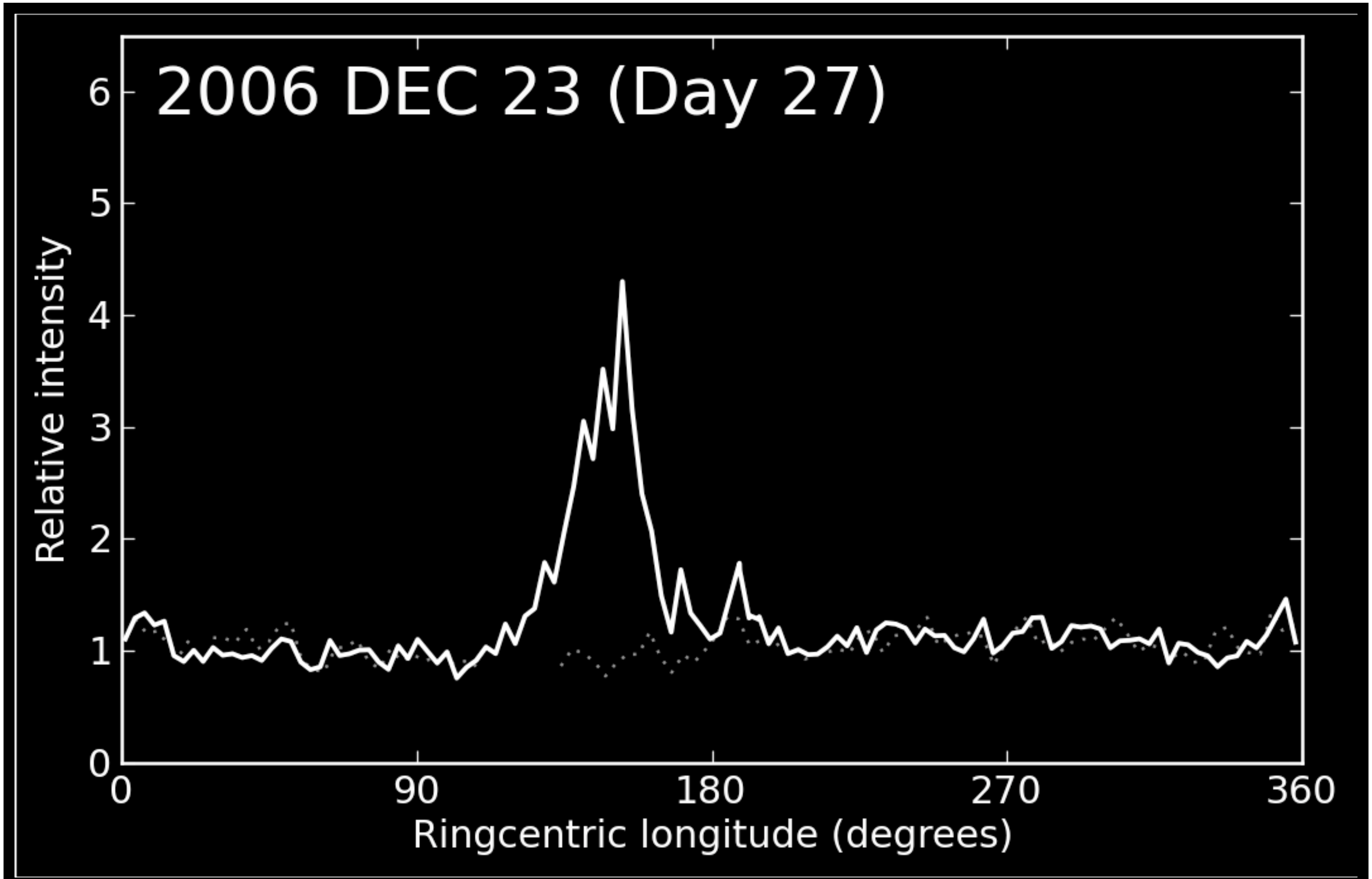


Comparison of material at opposite ansae

Evolution of a New Clump in the F ring



R. French & M. Showalter (2011)

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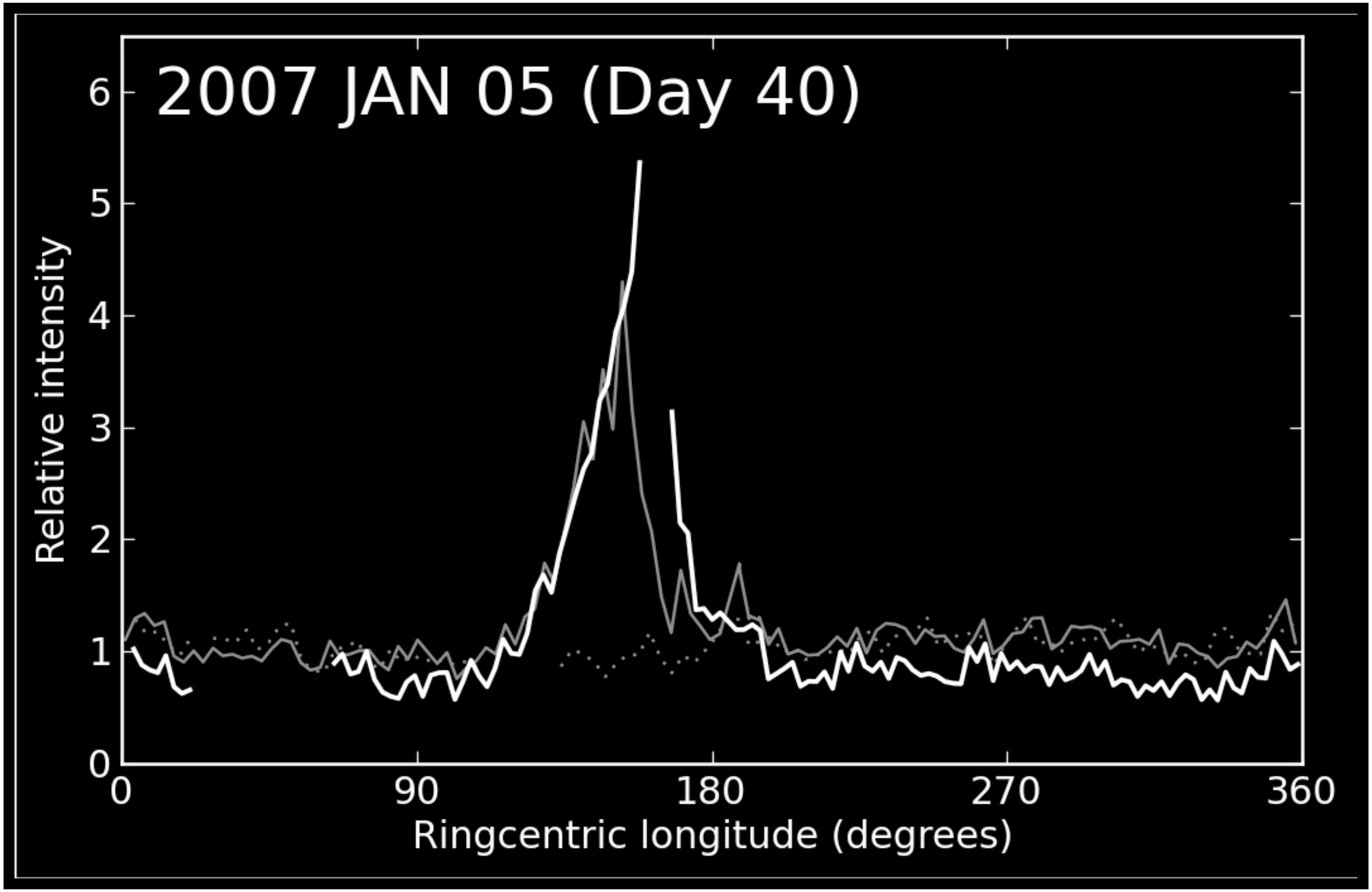

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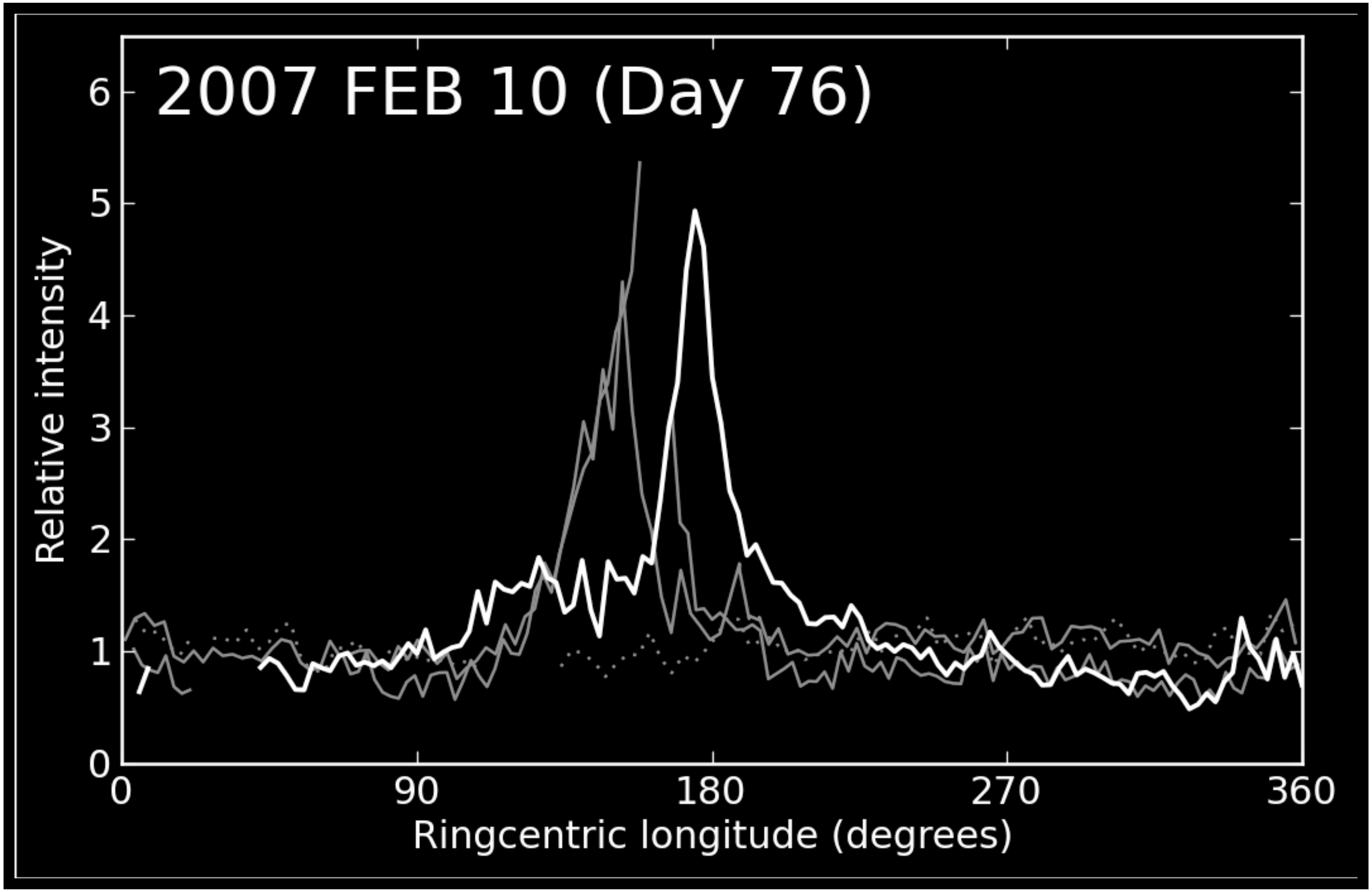
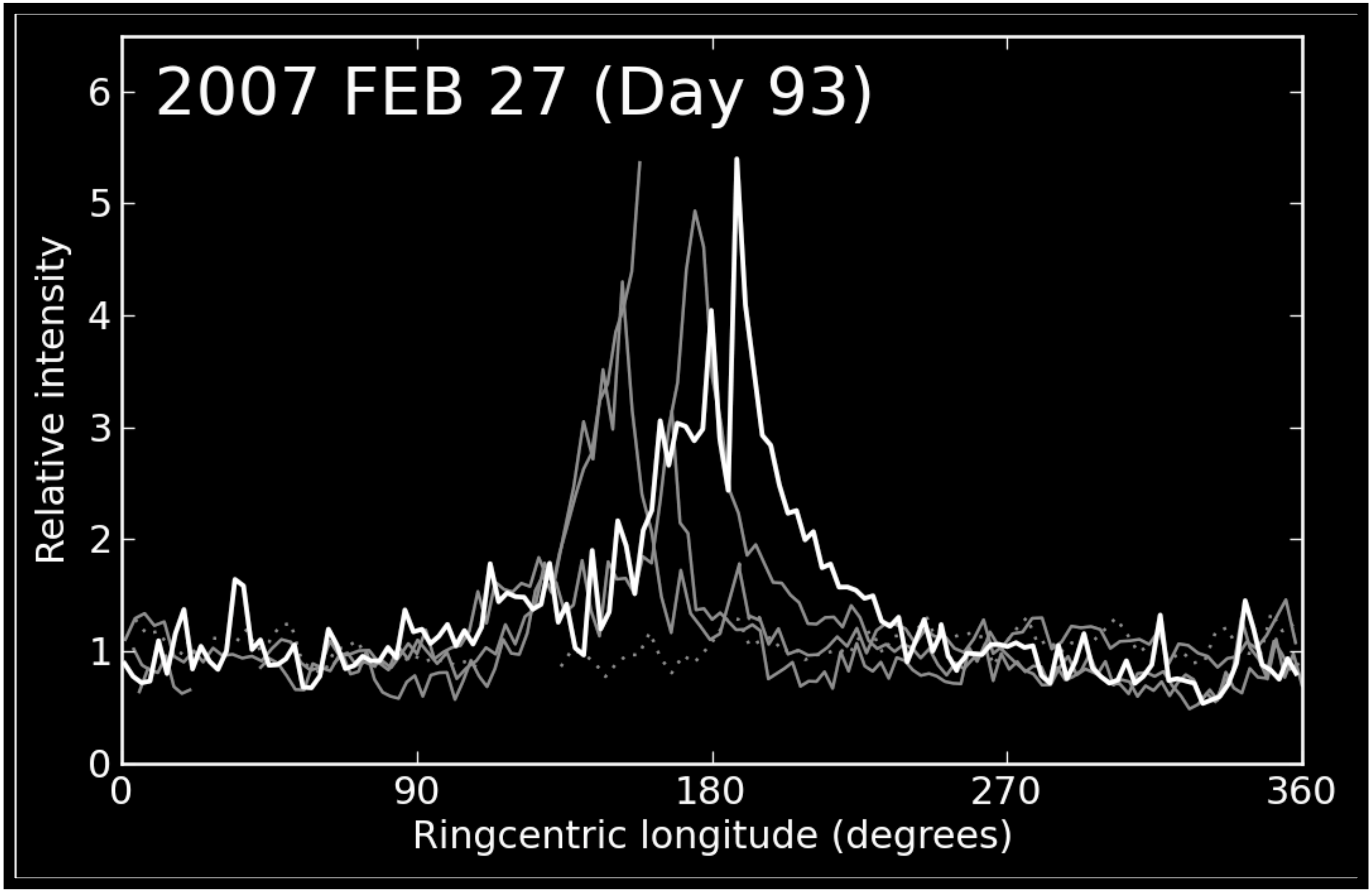


R. French & M. Showalter (2011)

Evolution of a New Clump in the F ring



R. French & M. Showalter (2011)

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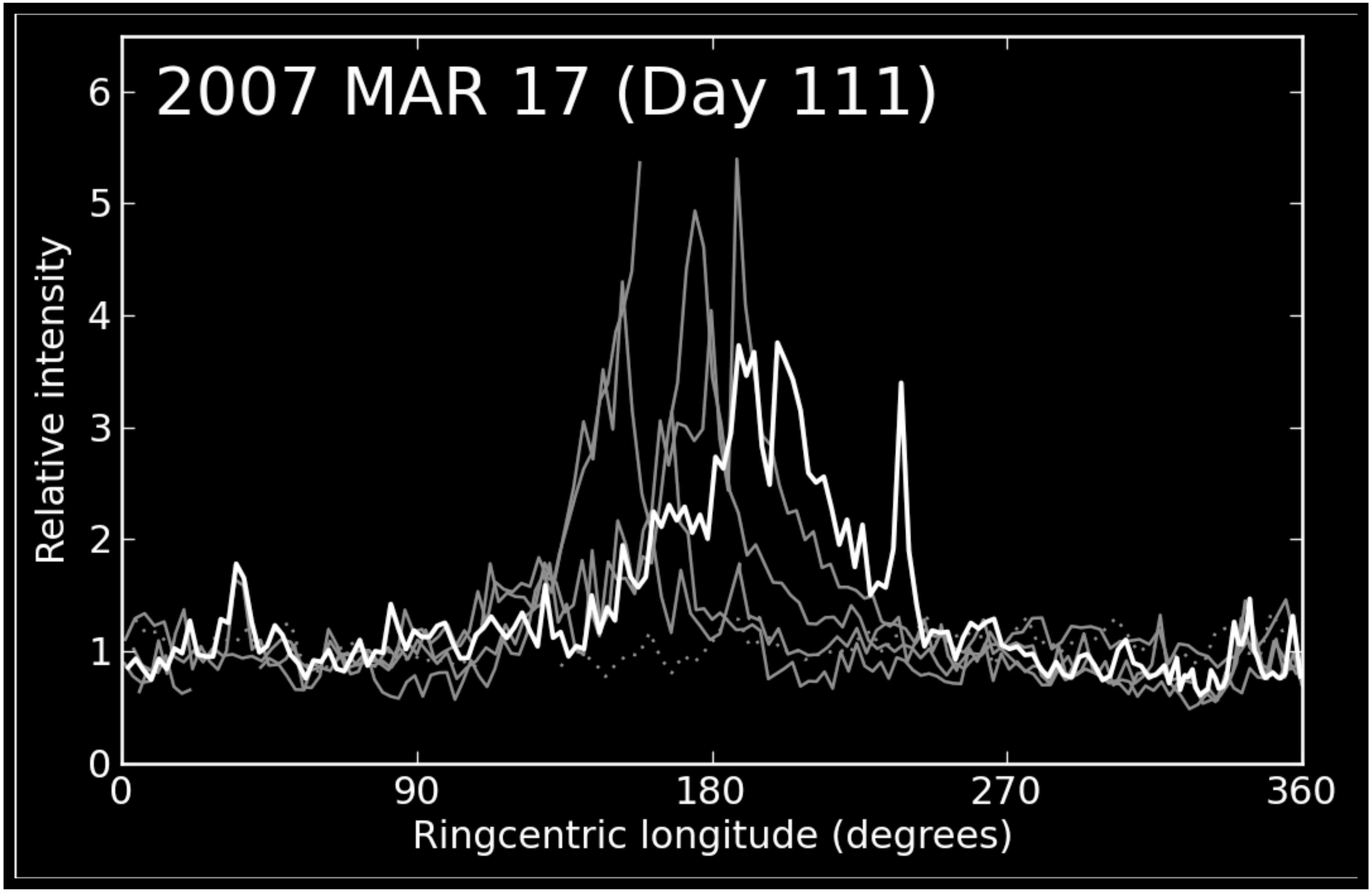

R. French & M. Showalter (2011)

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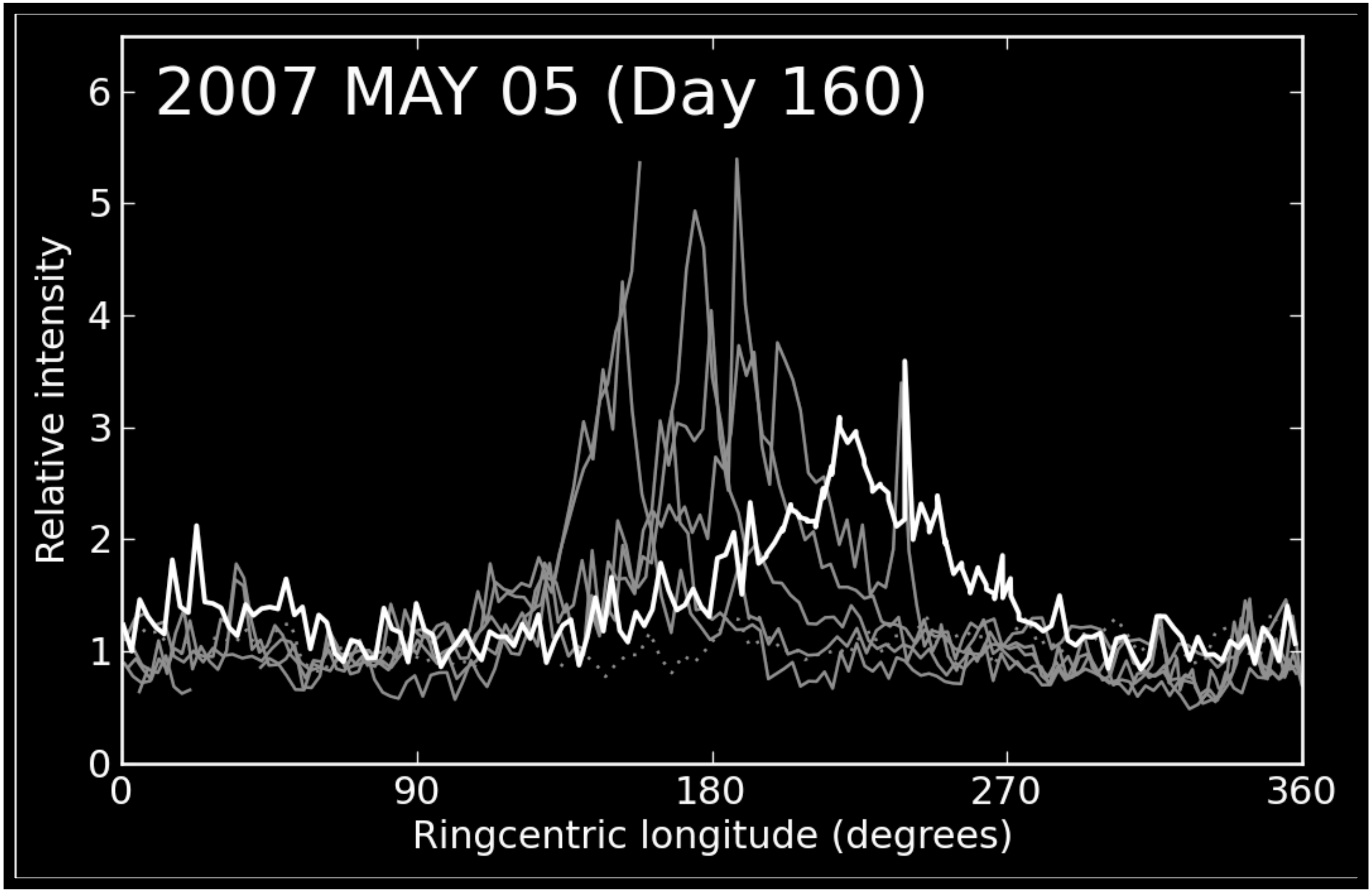
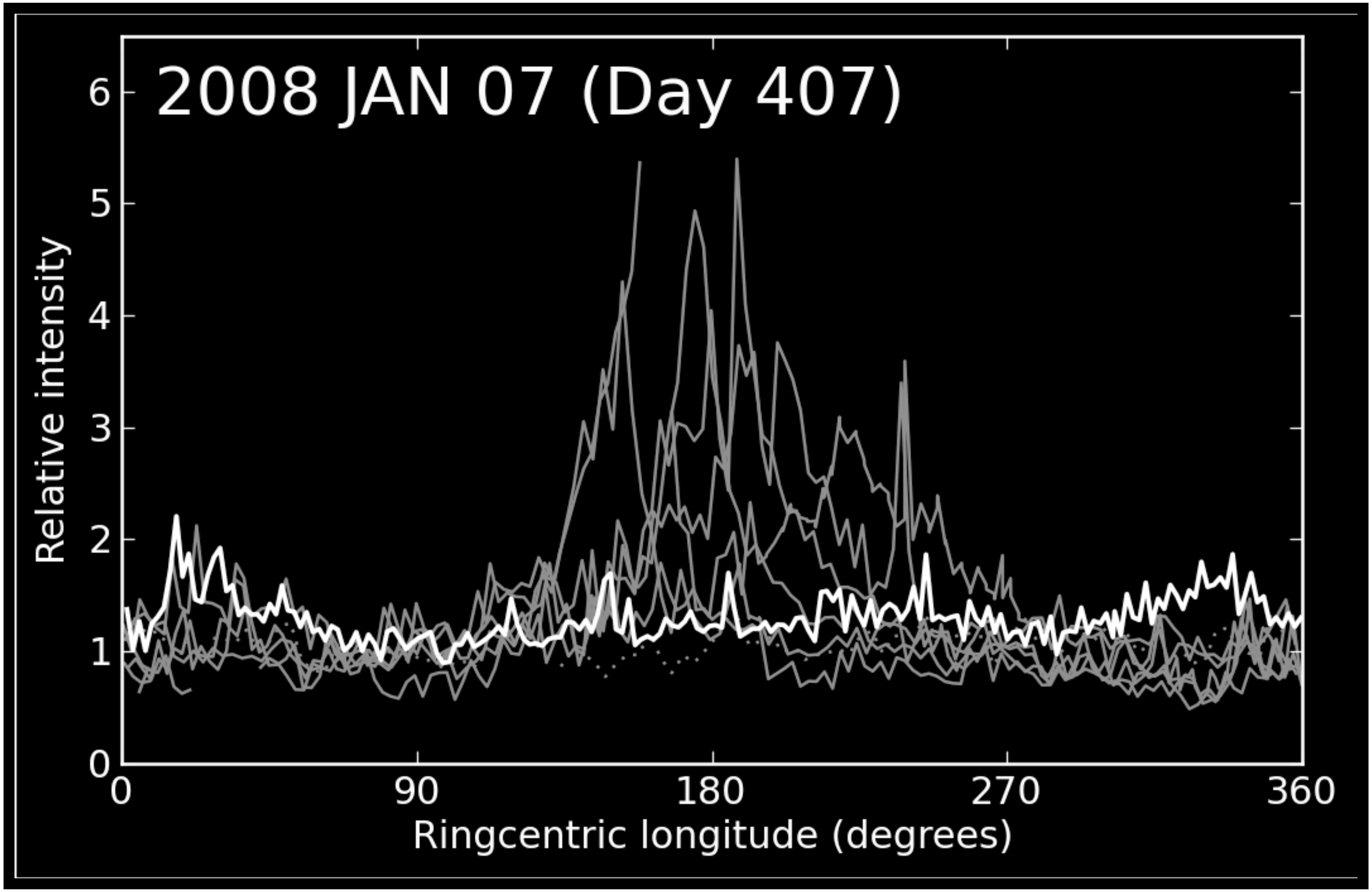


R. French & M. Showalter (2011)

Evolution of a New Clump in the F ring



R. French & M. Showalter (2011)

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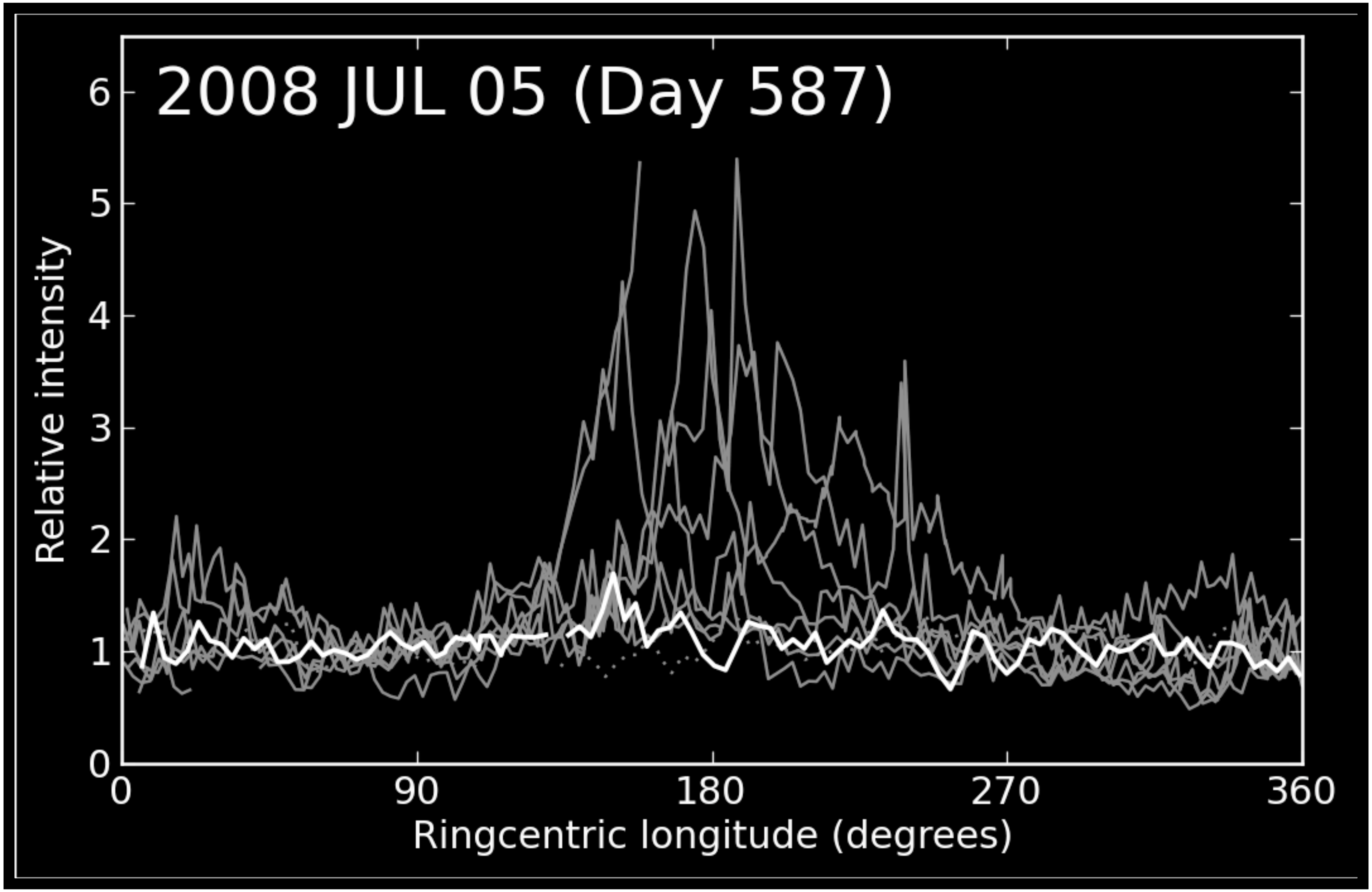
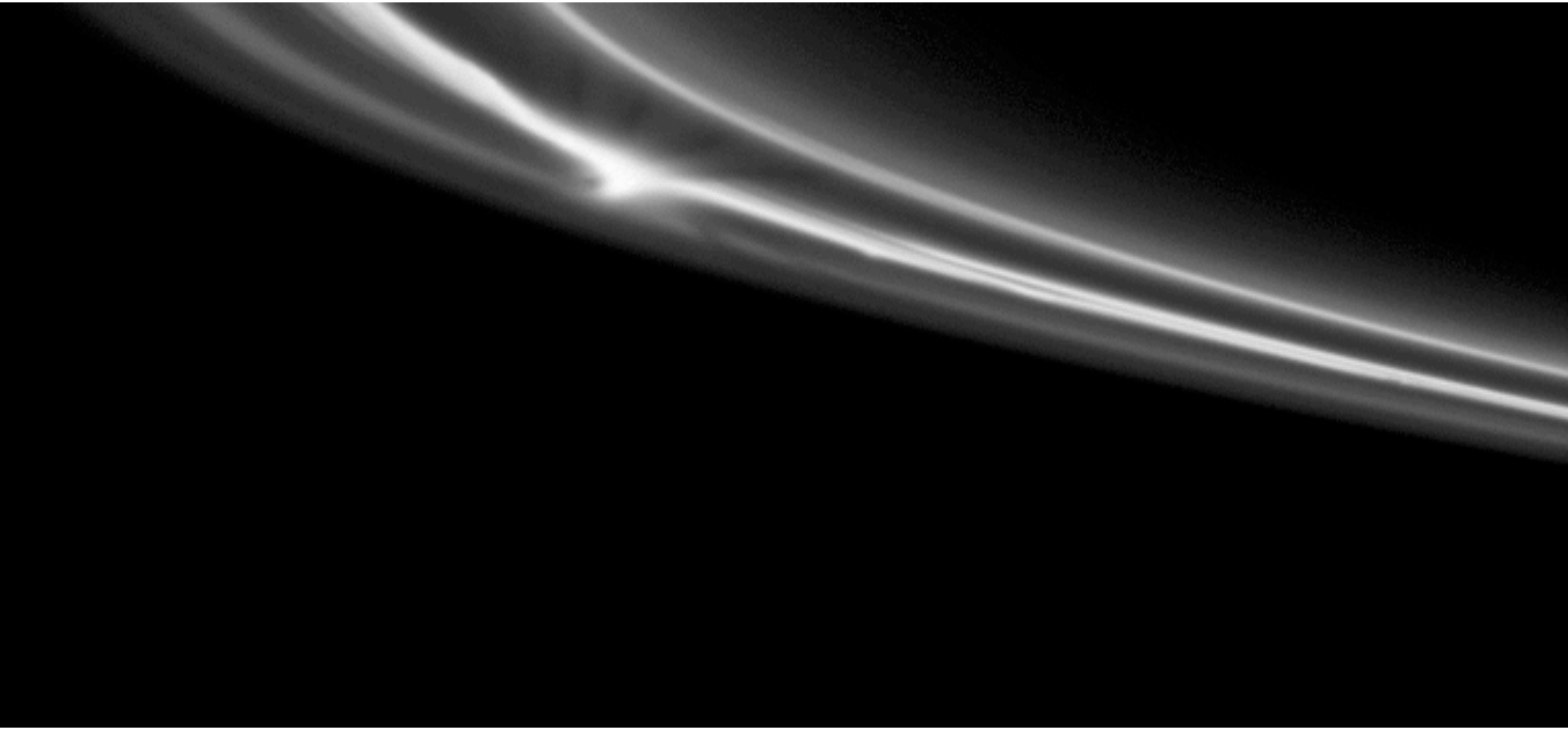
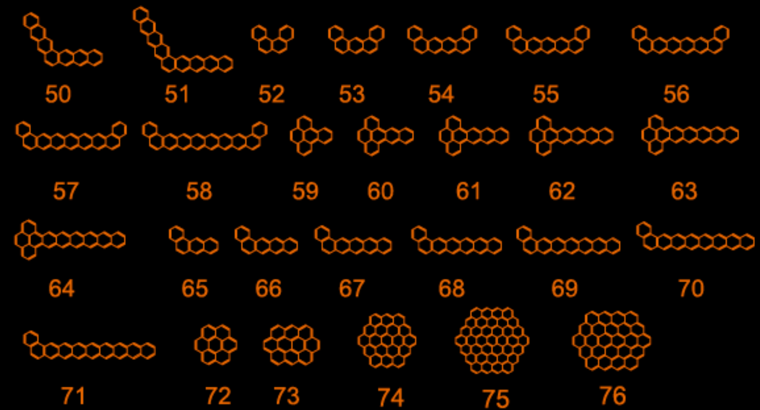


R. French & M. Showalter (2011)

Bursty F ring activity continues

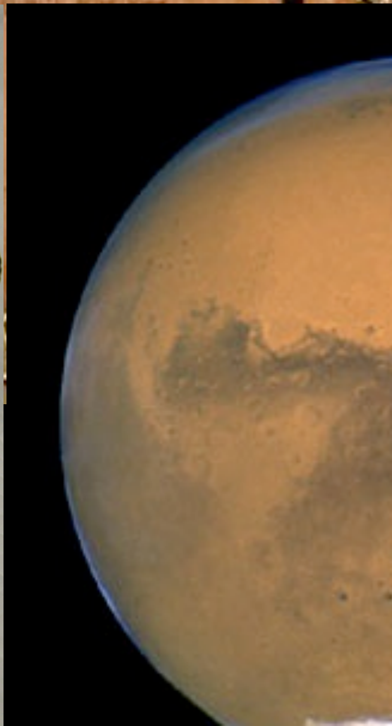


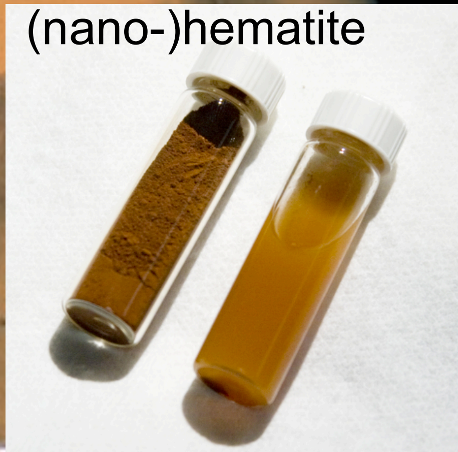
Even though the closest approach of Prometheus to the F ring strands was in December 2009, the resulting stirring of embedded moonlets might take a while to make its presence felt because collision probabilities are low. This very large burst was seen October 2010, and was released May 2011. It must have formed very soon before the image, because it has not spread appreciably in angle. Note the “fan” of diagonal dark lanes centered on the burst, which indicates the presence of a massive embedded object on a more eccentric orbit (Beurle et al 2010). Also note how disturbed the nearby F ring core - normally so narrow - appears.



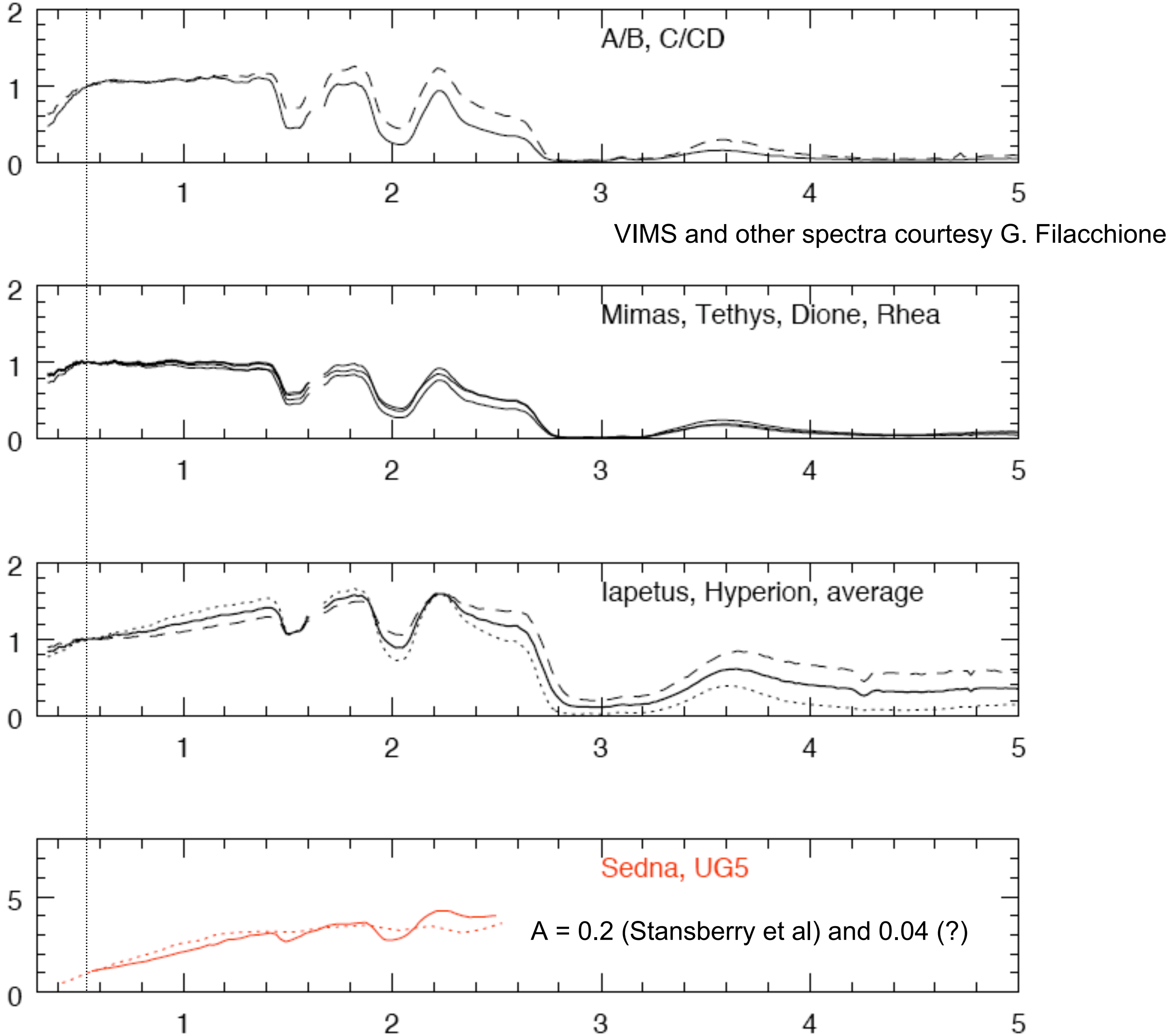
Why are the rings reddish?
“organic” or inorganic origin?
Lack of spectral features
Suggests nano-inclusions

Cuzzi et al 2010; Saturn from Cassini-Huygens

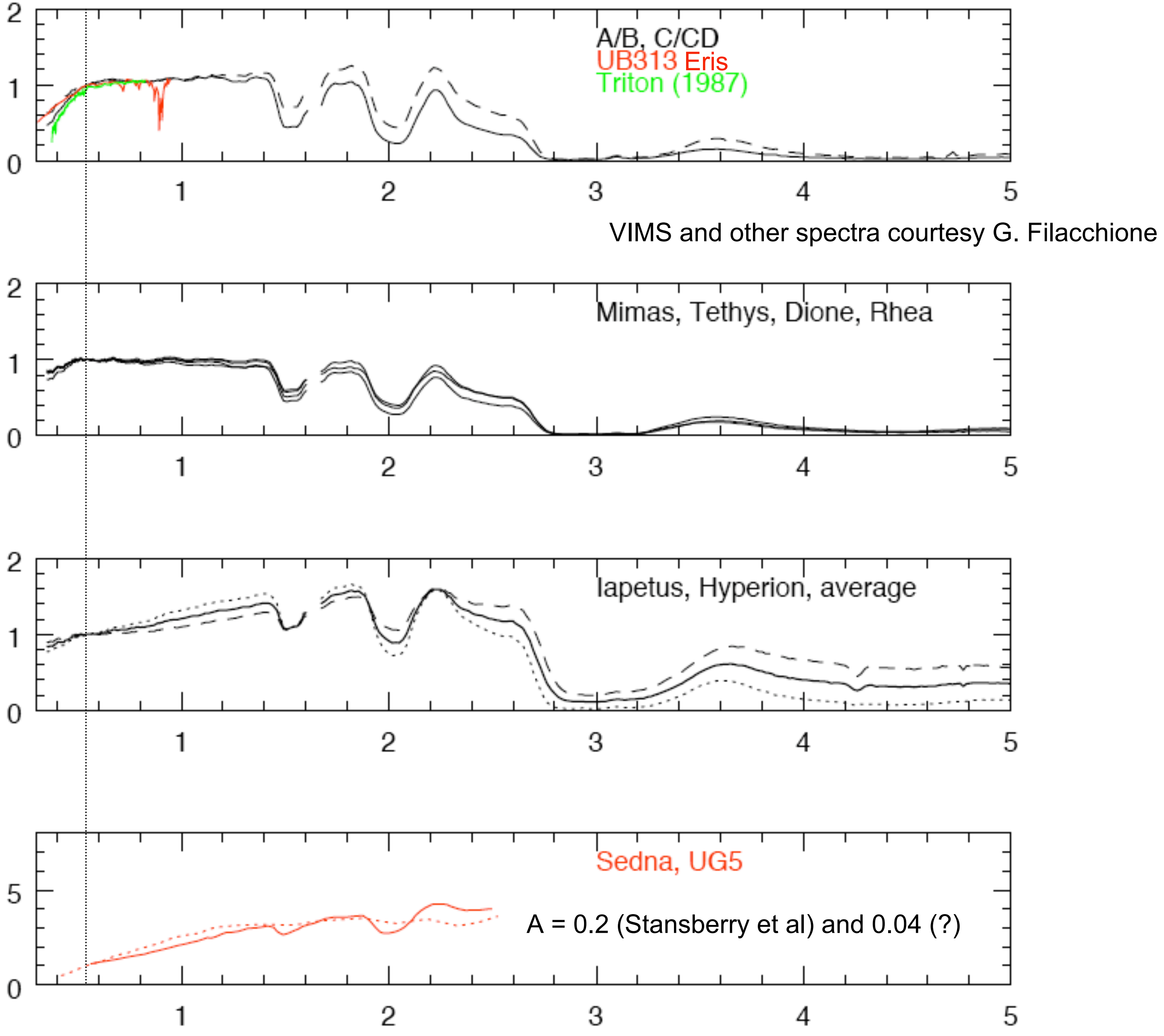




Comparison of rings with other icy obects

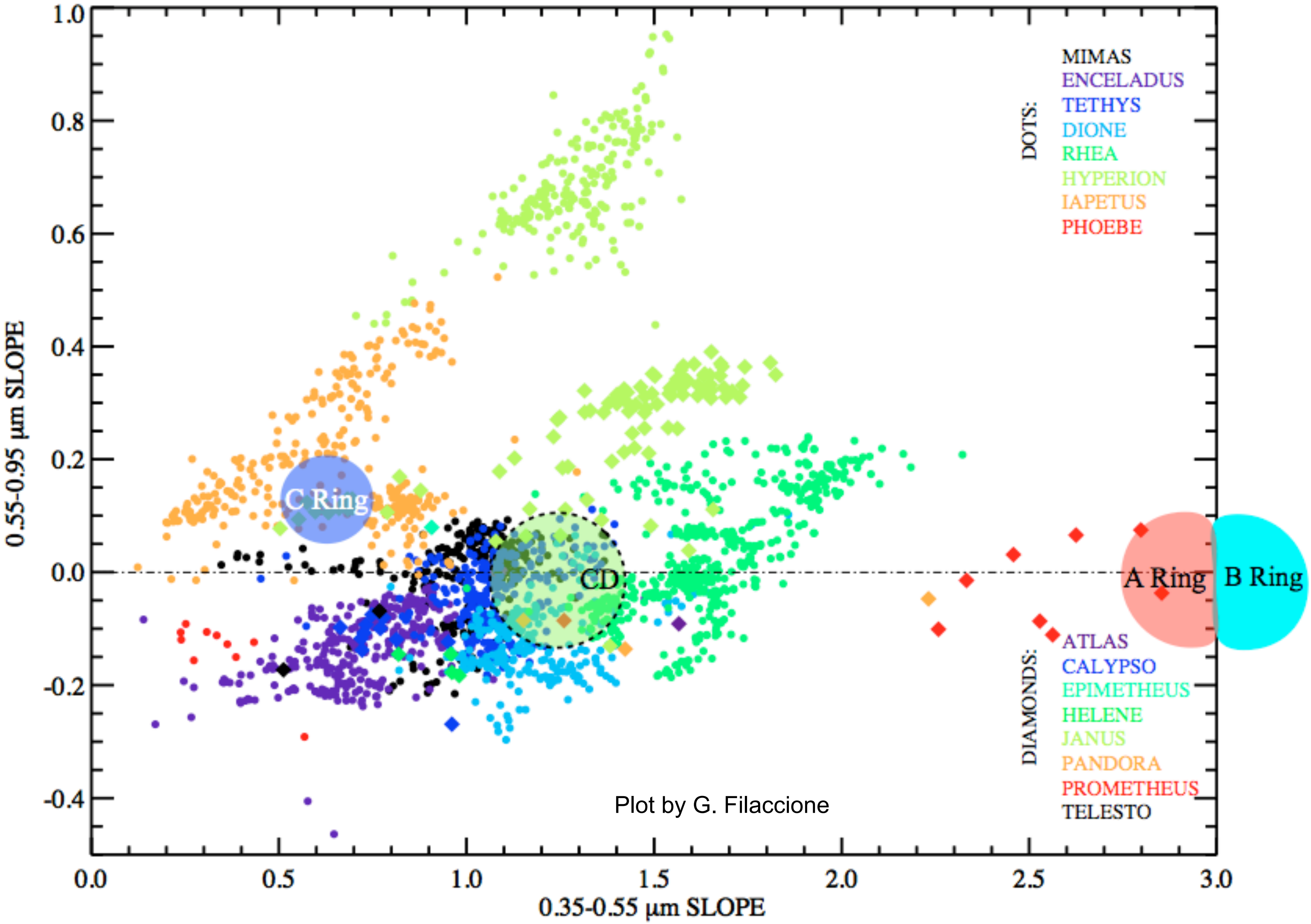


Comparison of rings with other icy obects

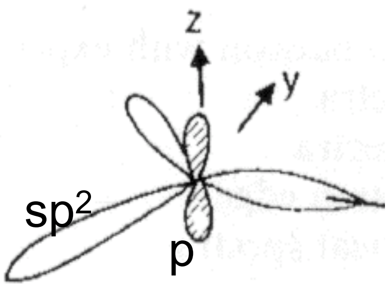


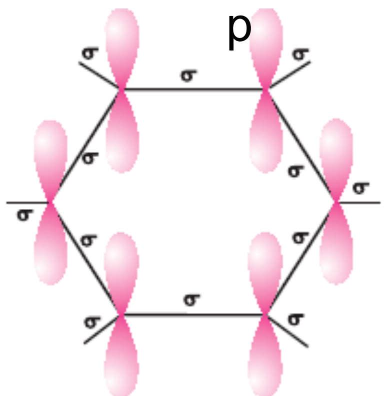
VIS Slopes

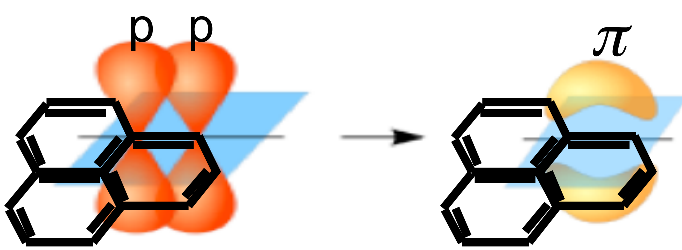
Comparison of rings with other icy objects

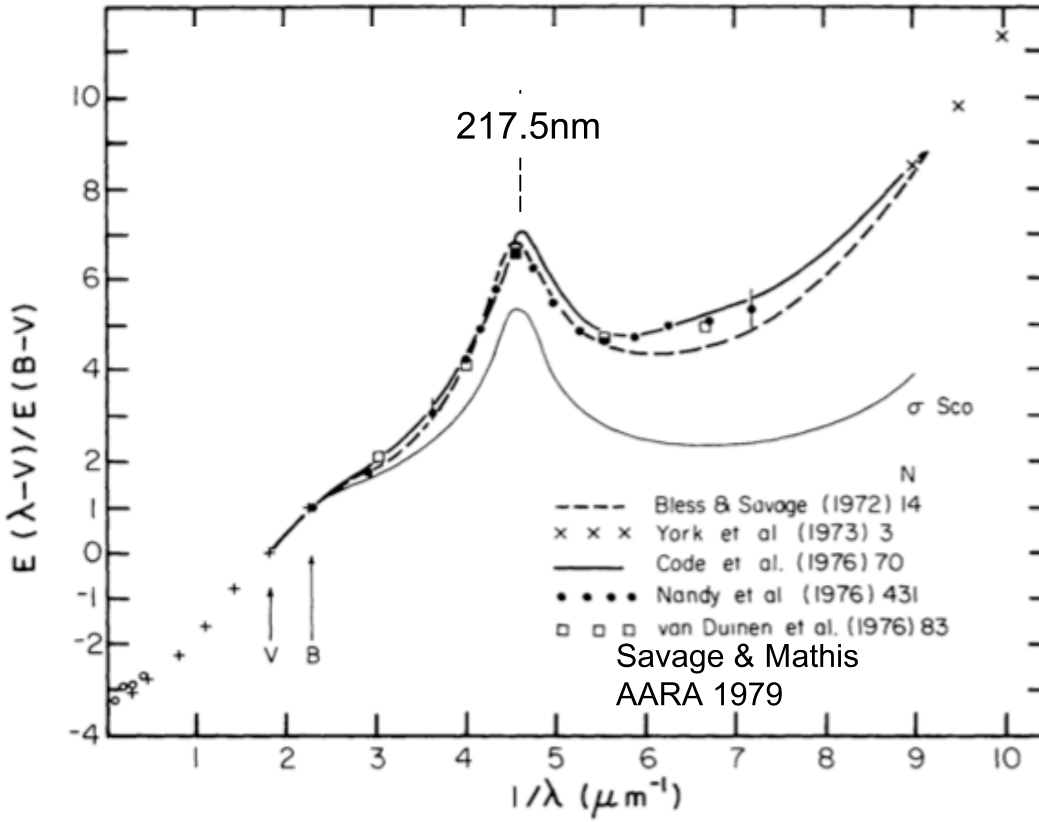


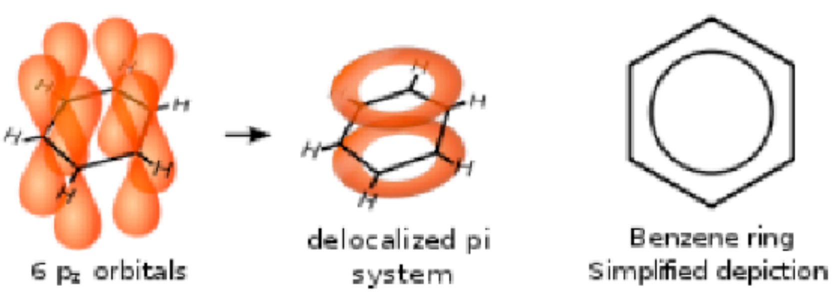
Carbon - ring structure causes UV absorption

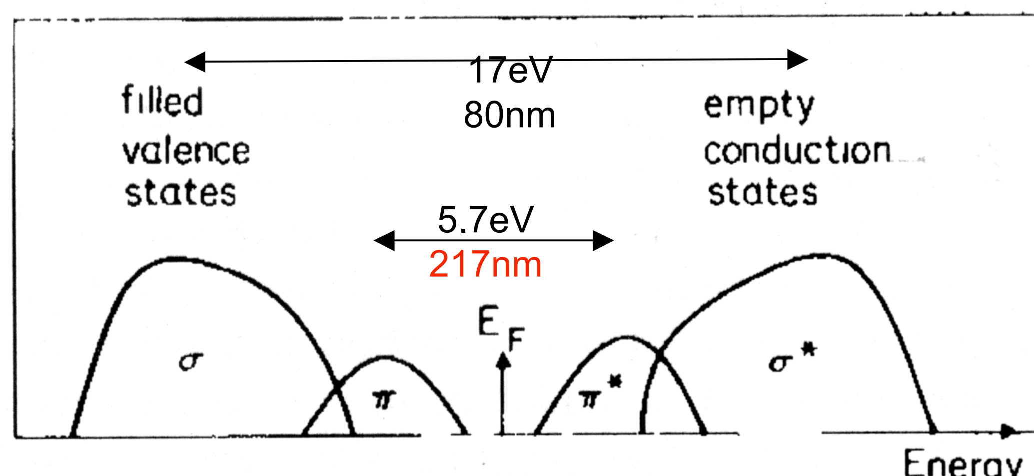


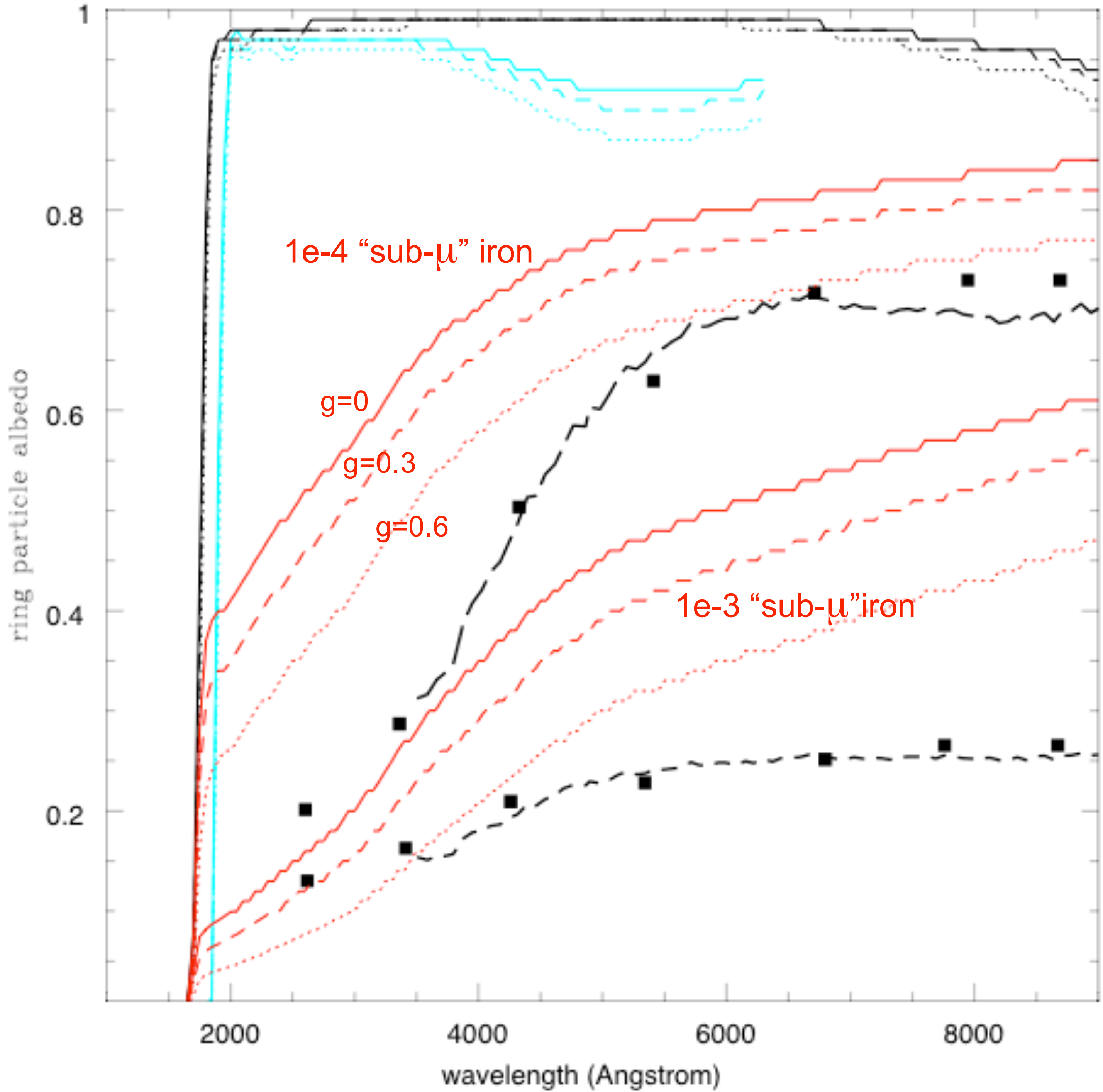




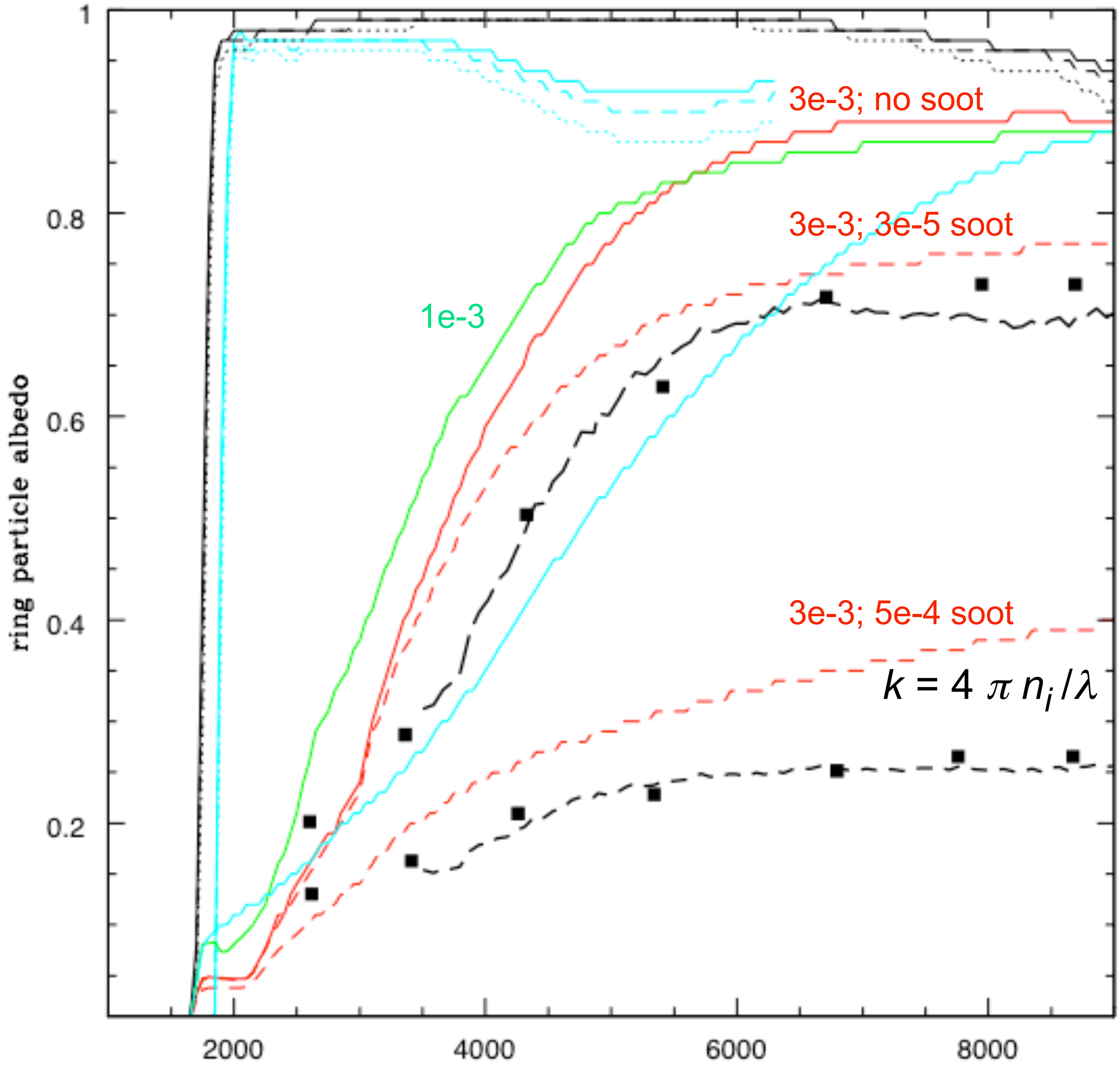








1e-4 “sub-μ” iron
g=0
g=0.3
g=0.6
1e-3 “sub-μ”iron
ring particle albedo
wavelength (Angstrom)
1
0.8
0.6
0.4
0.2
2000
4000
6000
8000



3e-3; no soot
3e-3; 3e-5 soot
1e-3
3e-3; 5e-4 soot
$k = 4 \pi n_i / \lambda$
ring particle albedo
wavelength (Angstrom)
1
0.8
0.6
0.4
0.2
2000
4000
6000
8000

Backup