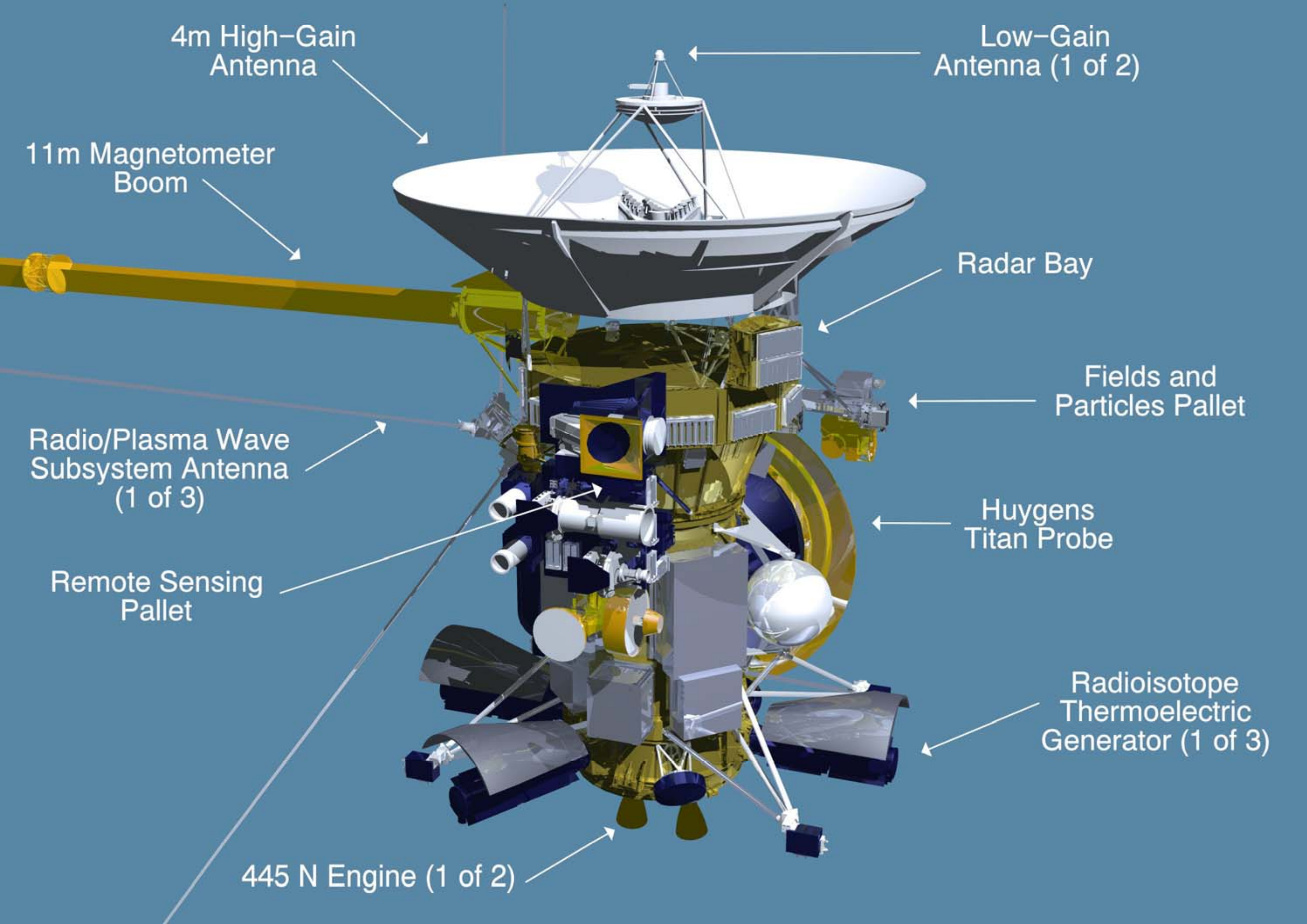
History of Saturn’s Rings

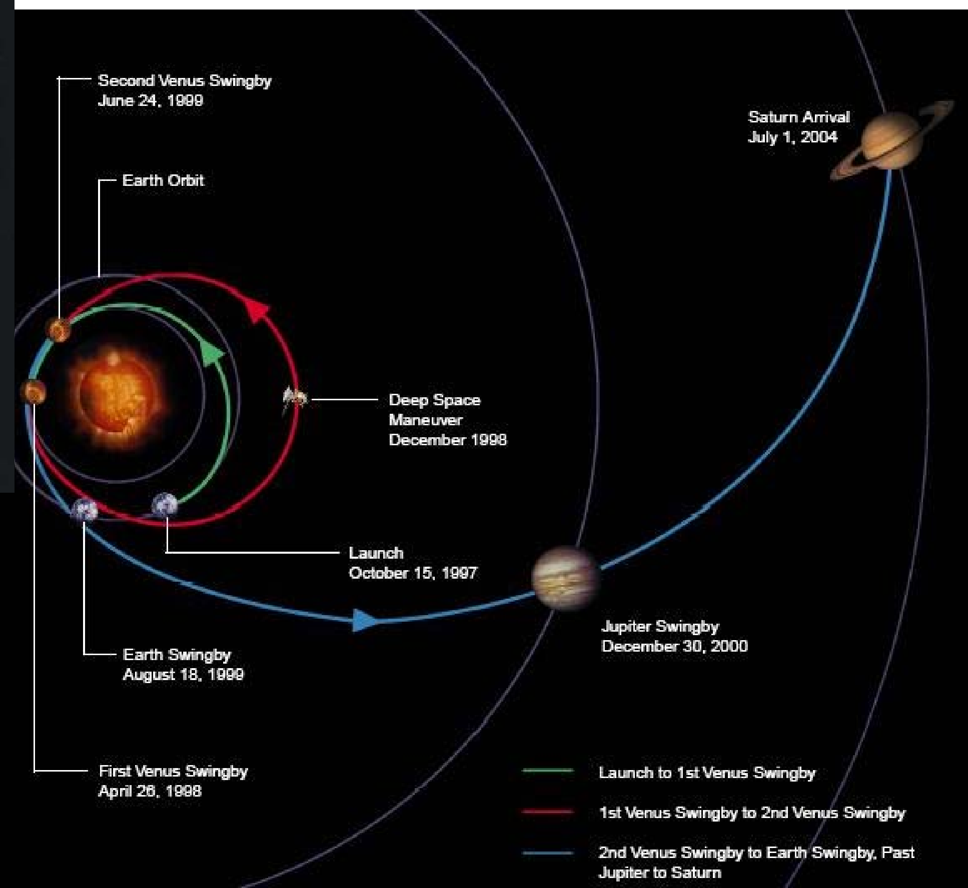
Larry W. Esposito
LASP, University of Colorado
CHARM 27 May 2008

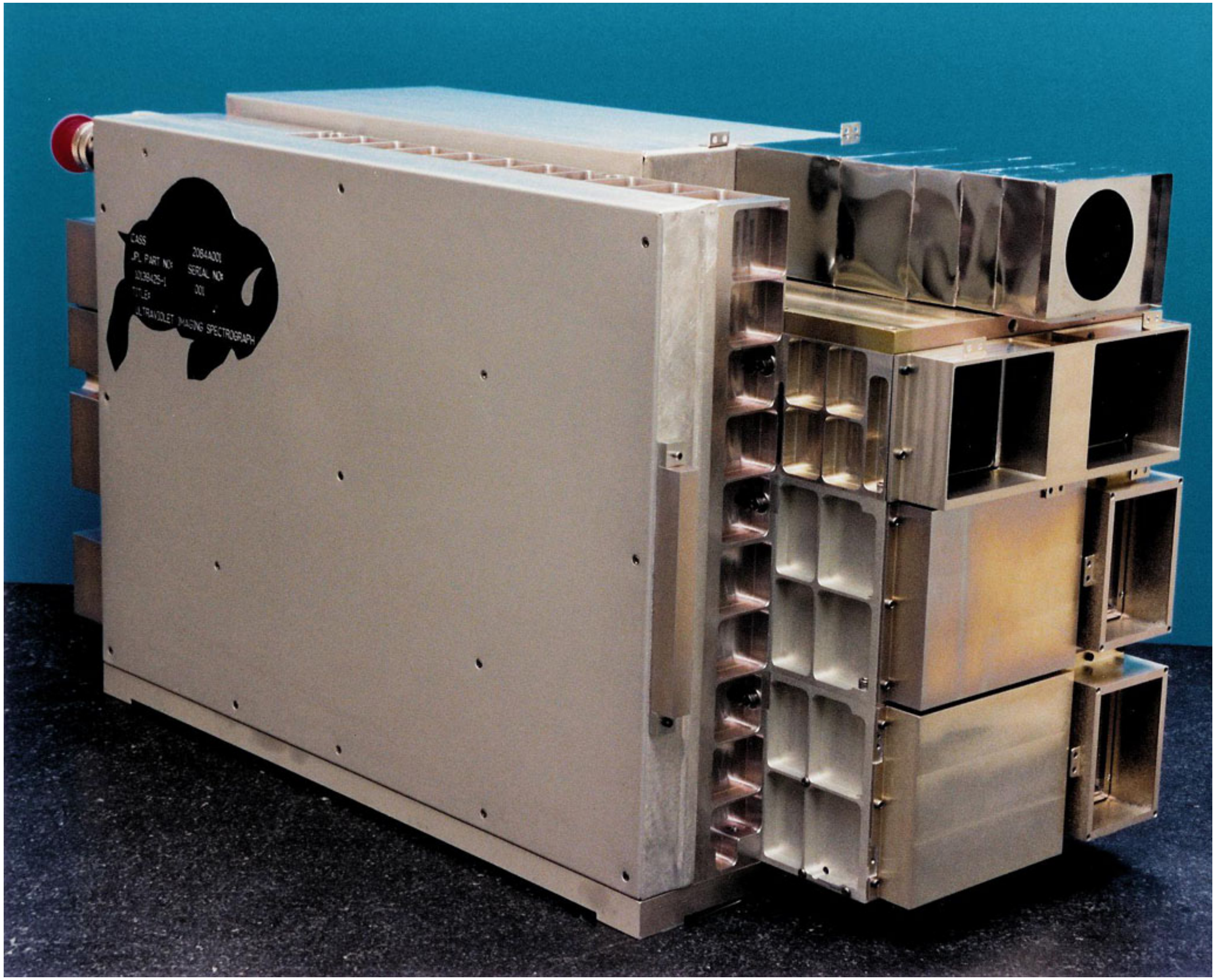
CASSINI SPACECRAFT



Launched on October 15, 1997 from KSC

7 Year cruise on Venus-Venus-Earth-Jupiter Gravity Assist trajectory

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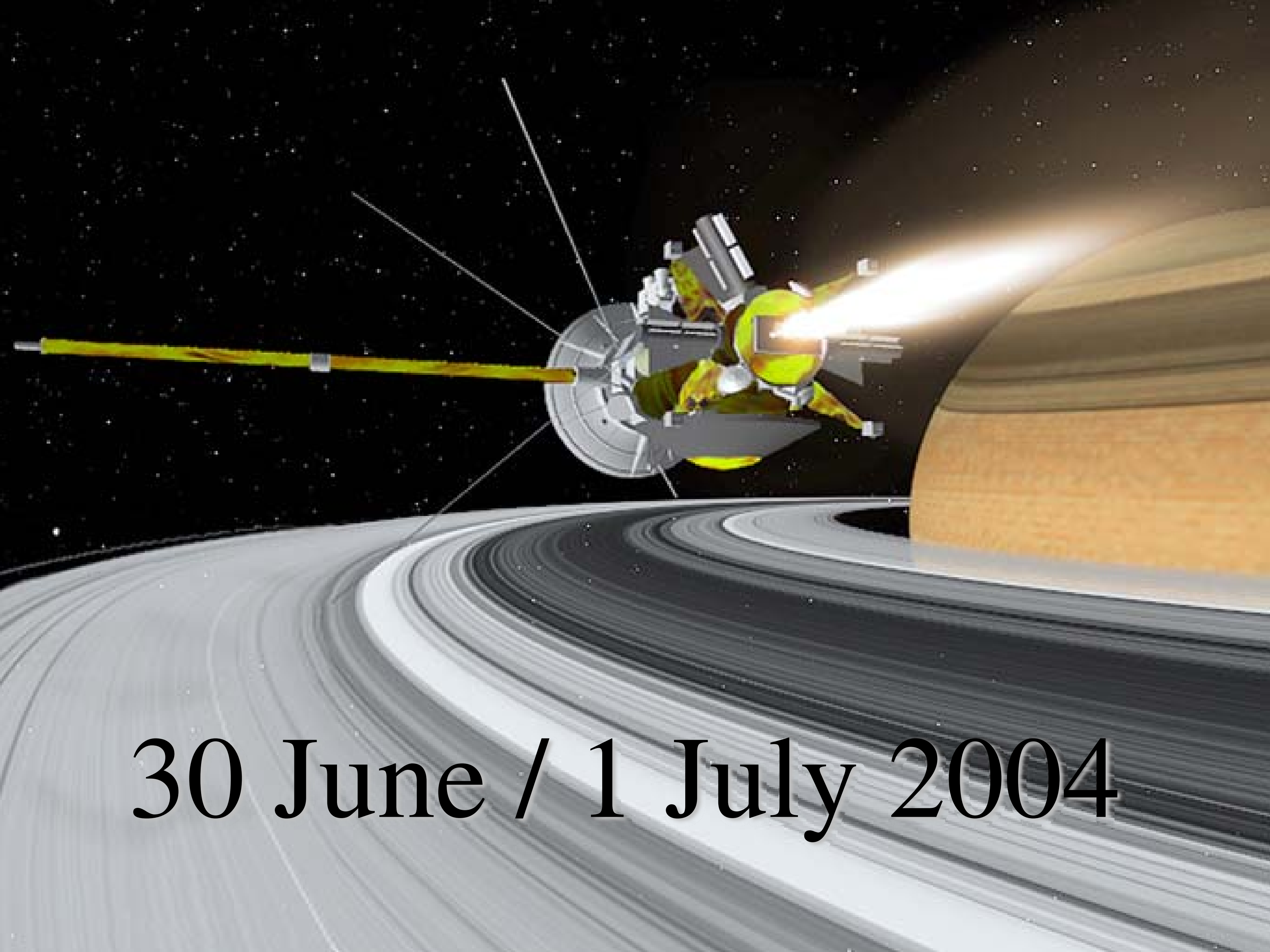
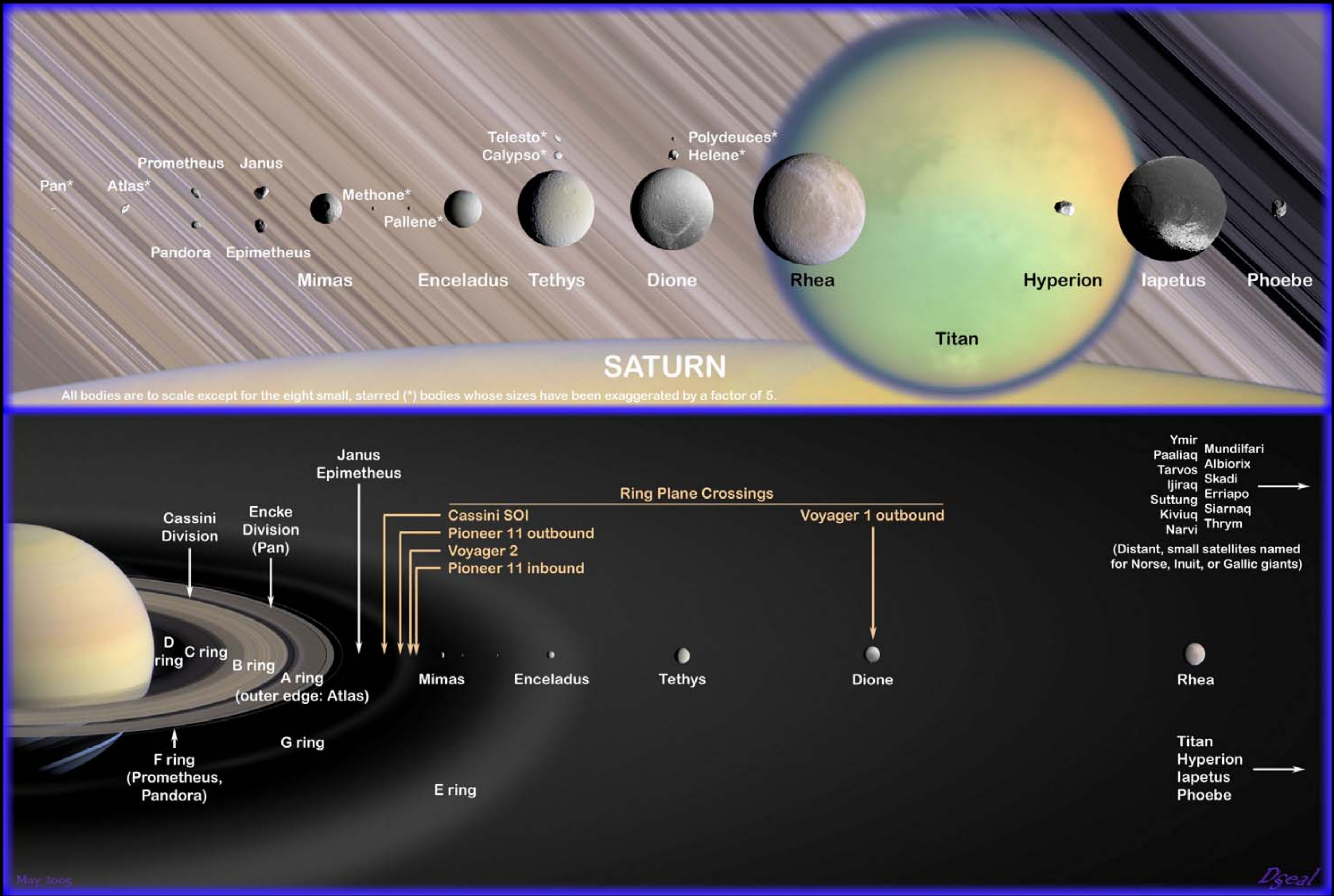
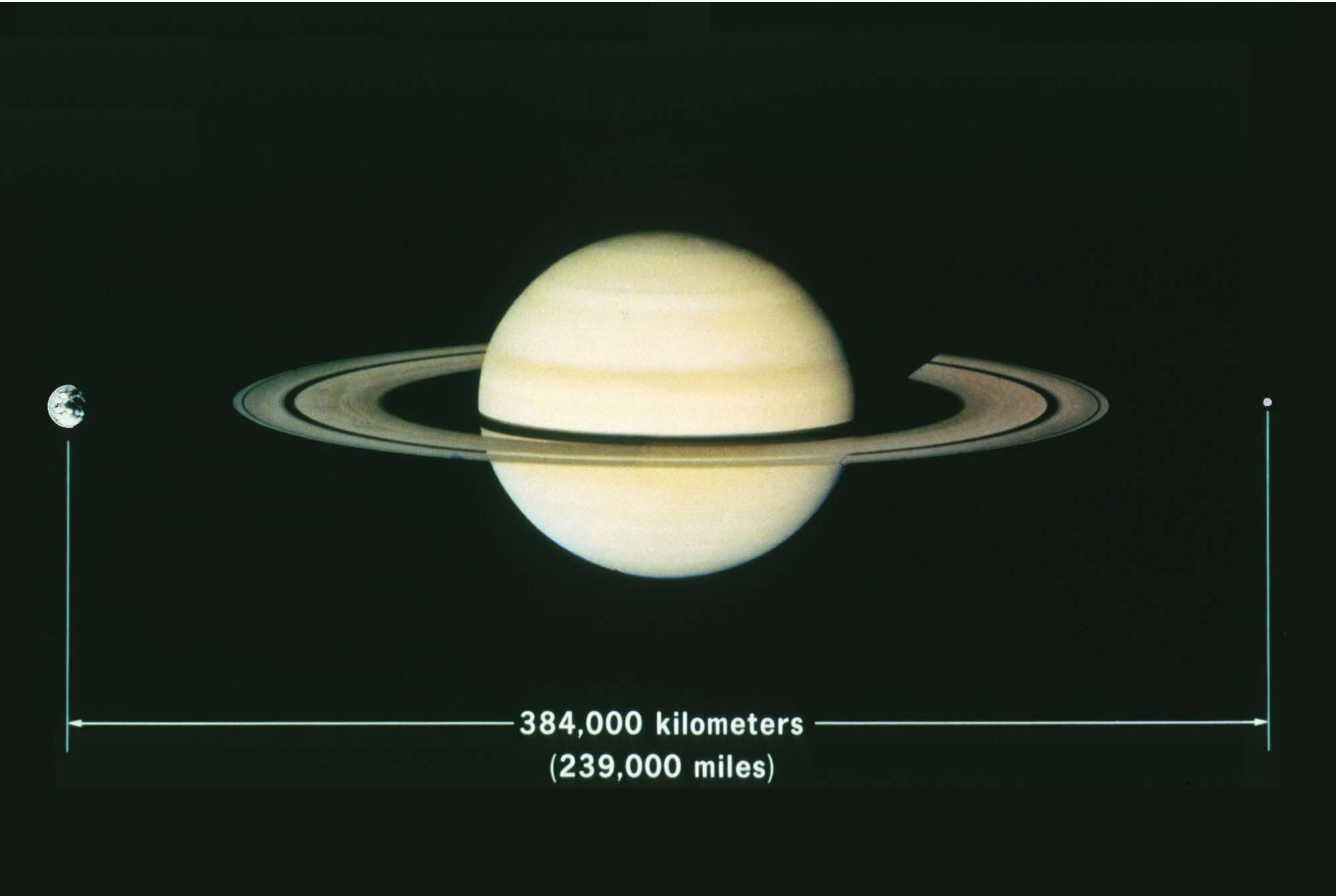
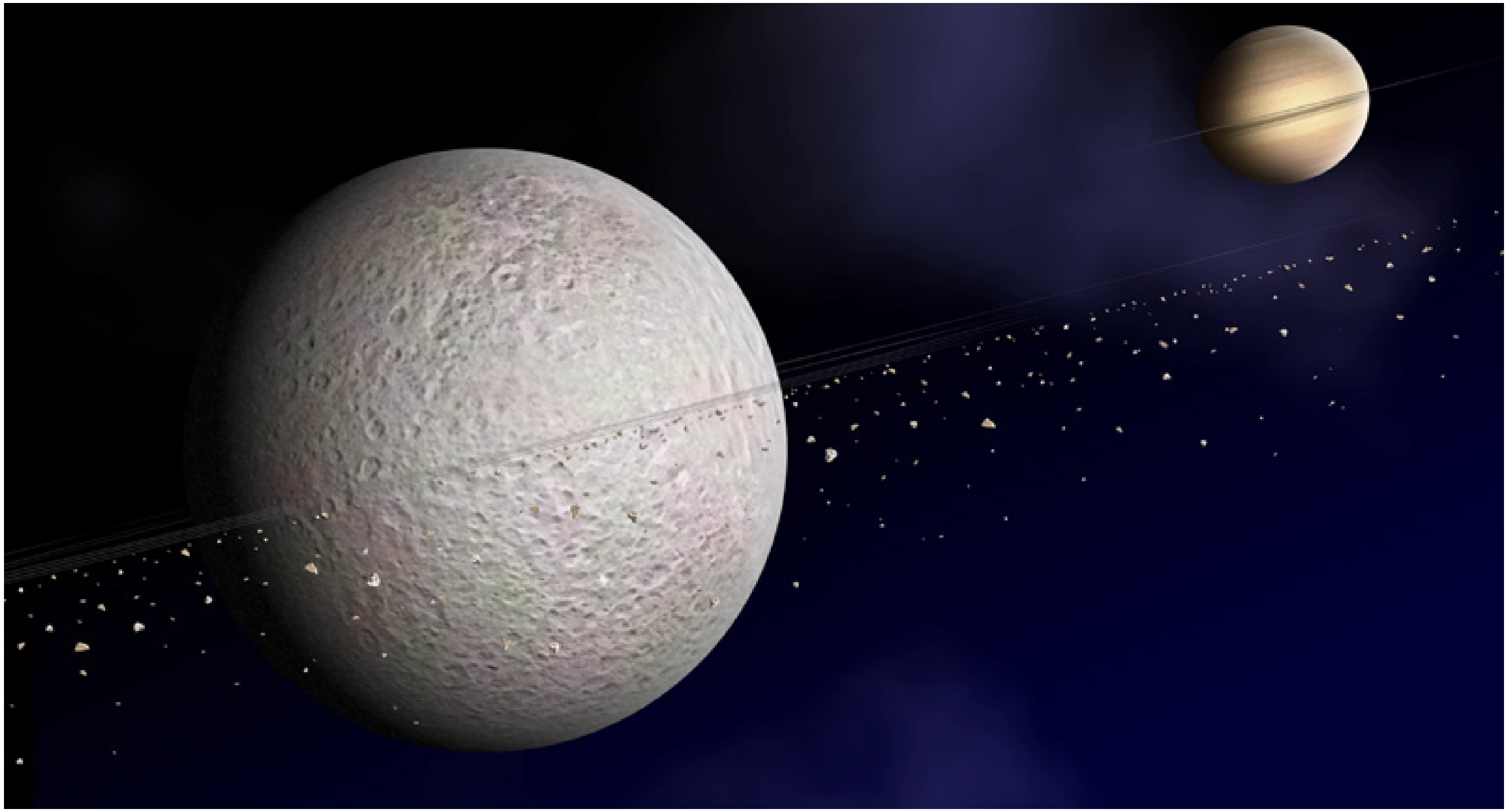
ULTRAVIOLET IMAGING SPECTROGRAPH

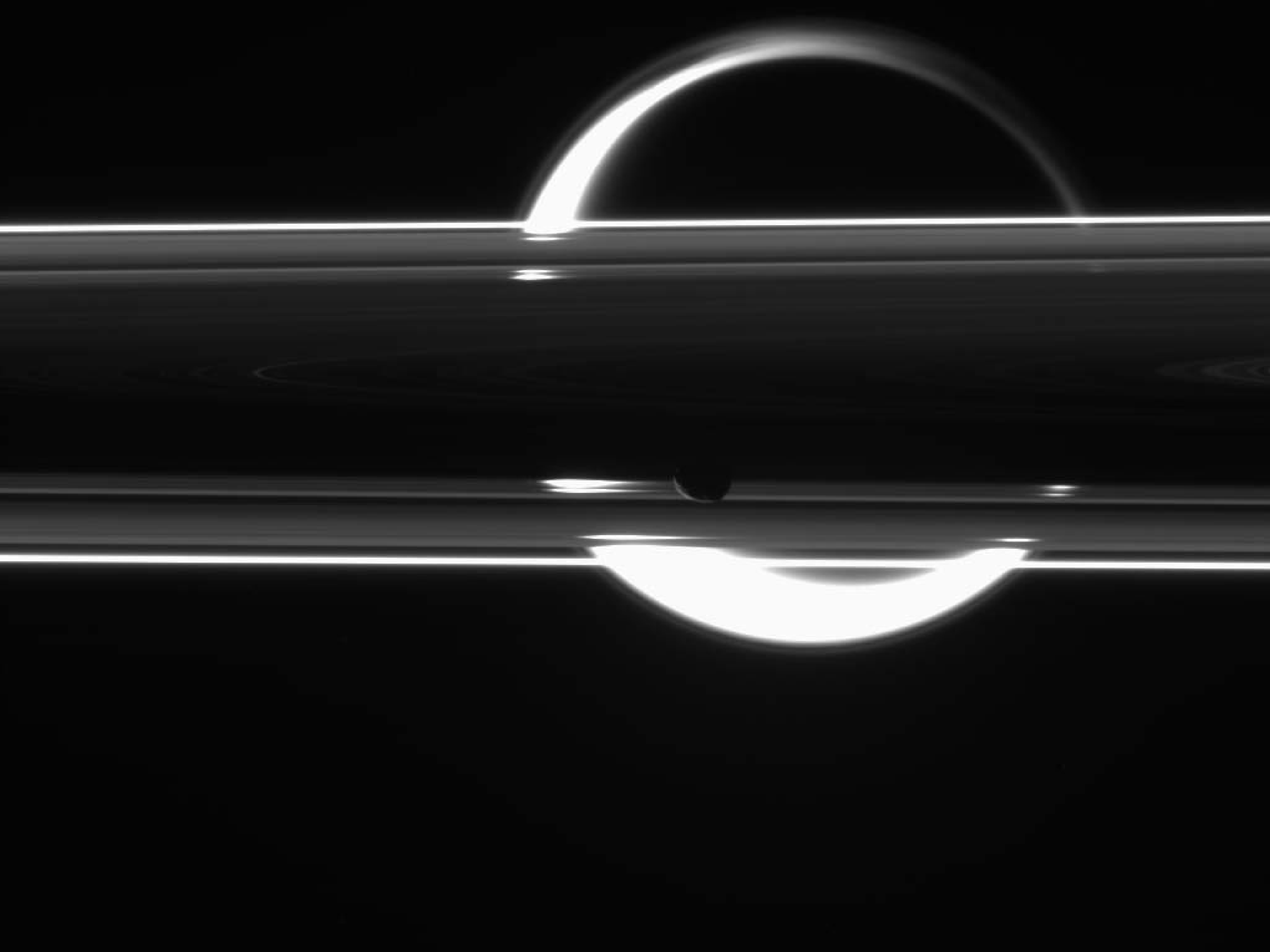

30 June / 1 July 2004

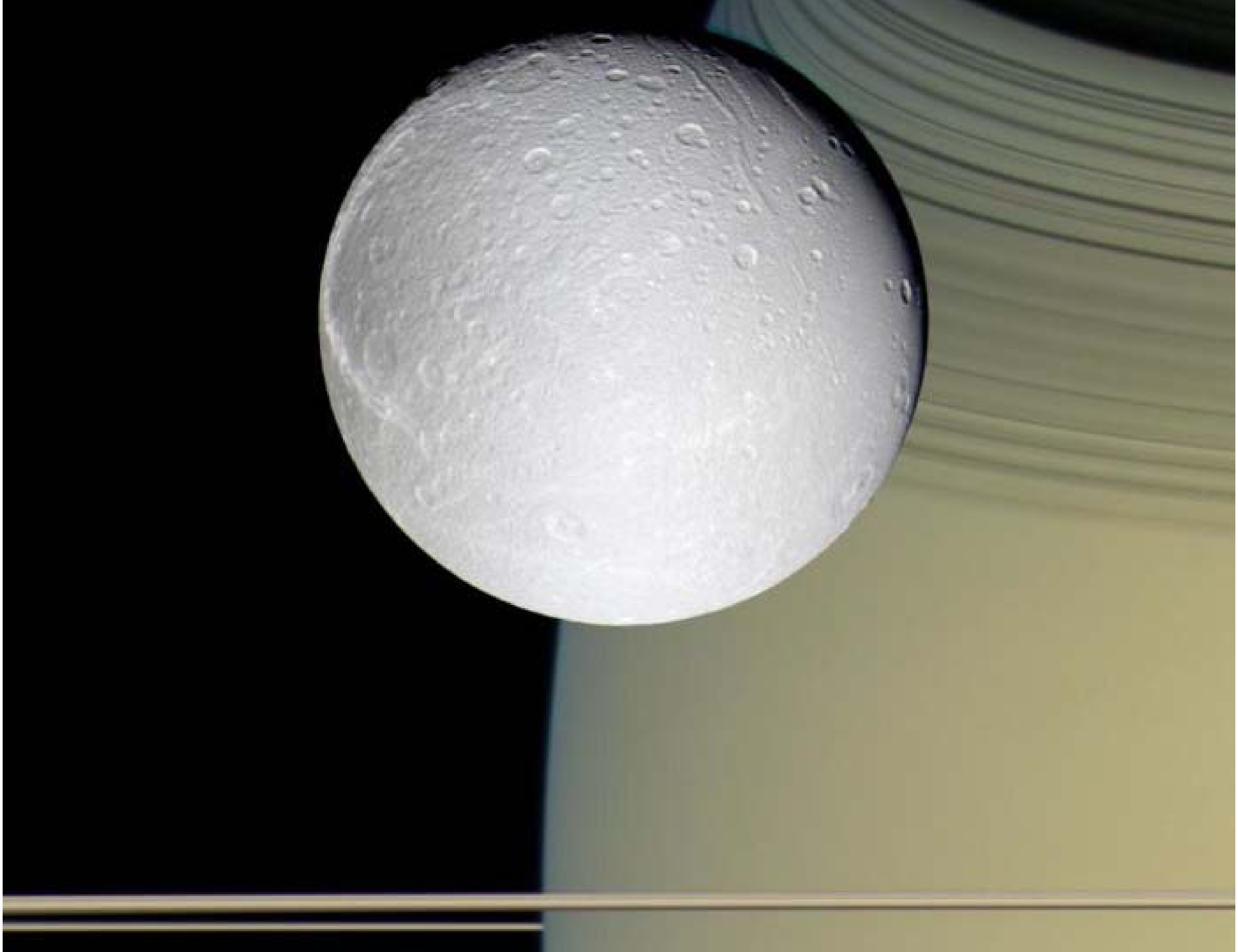
THE SATURNIAN SYSTEM

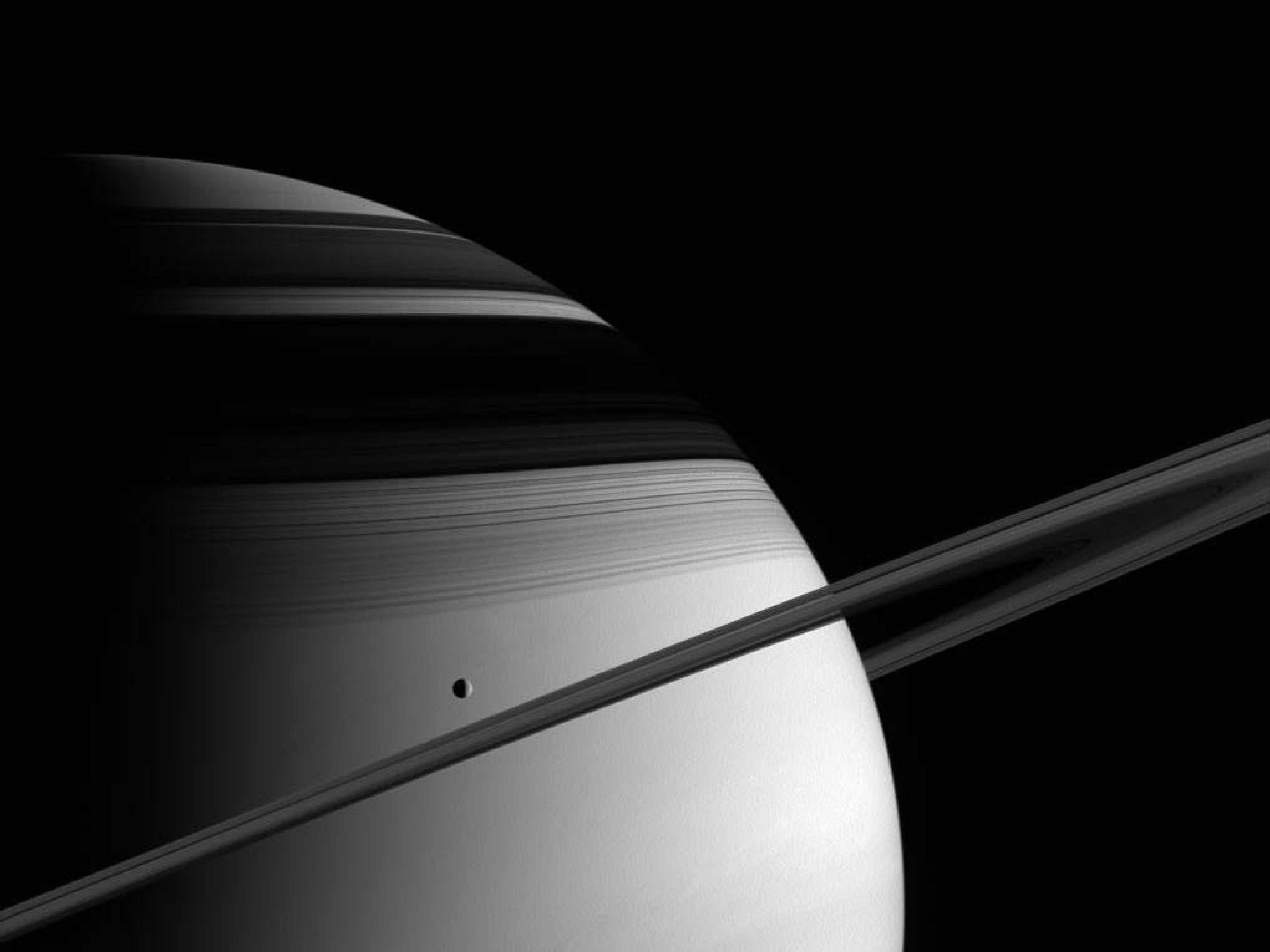


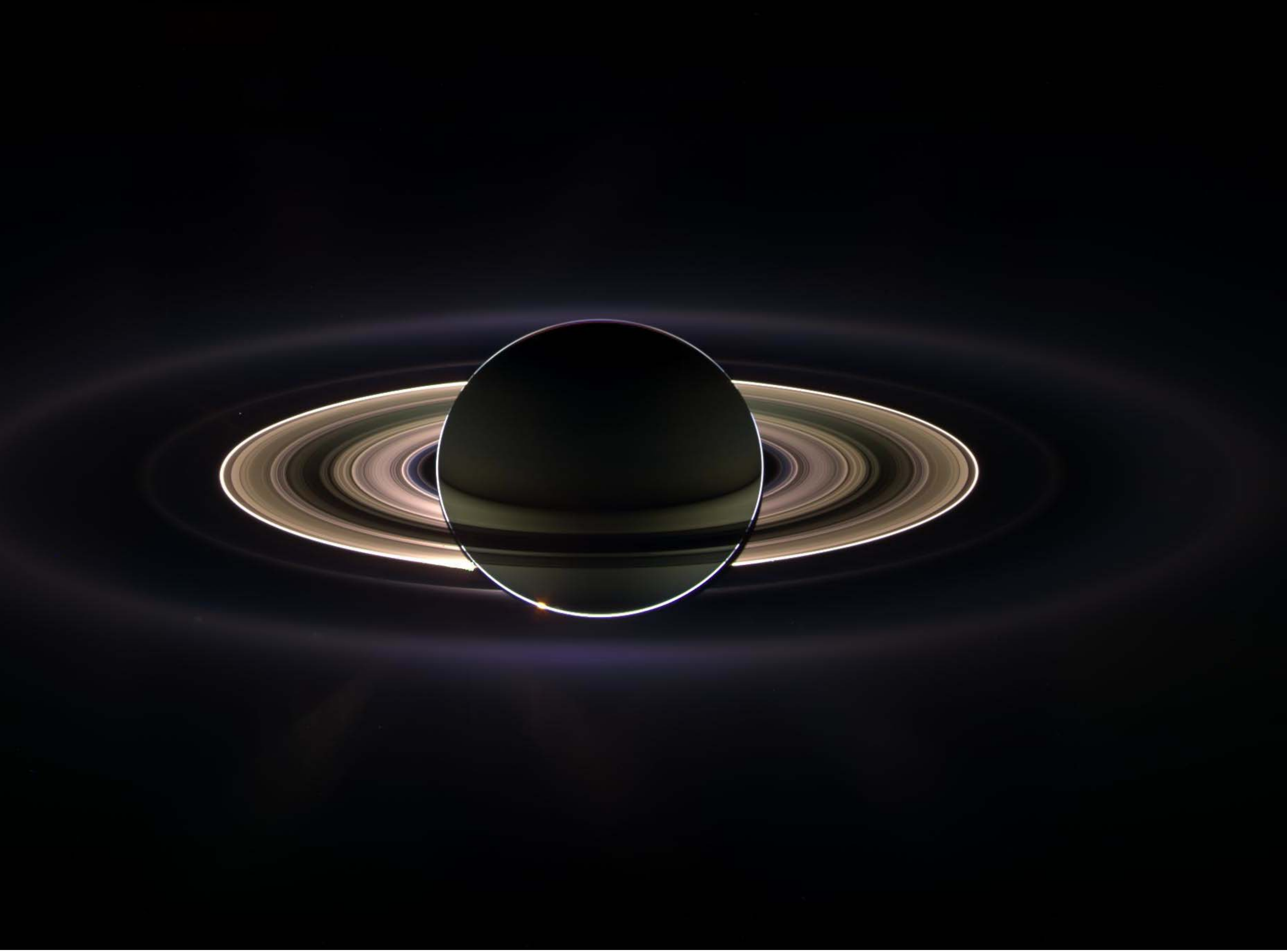

384,000 kilometers
(239,000 miles)

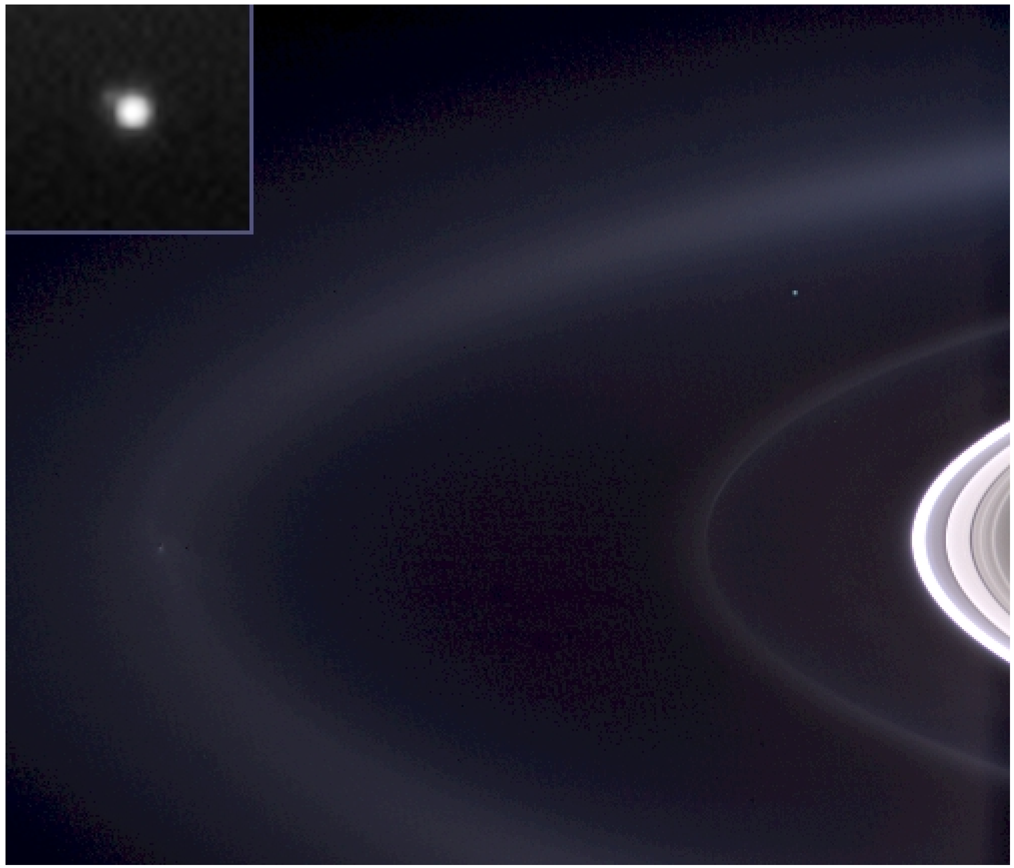




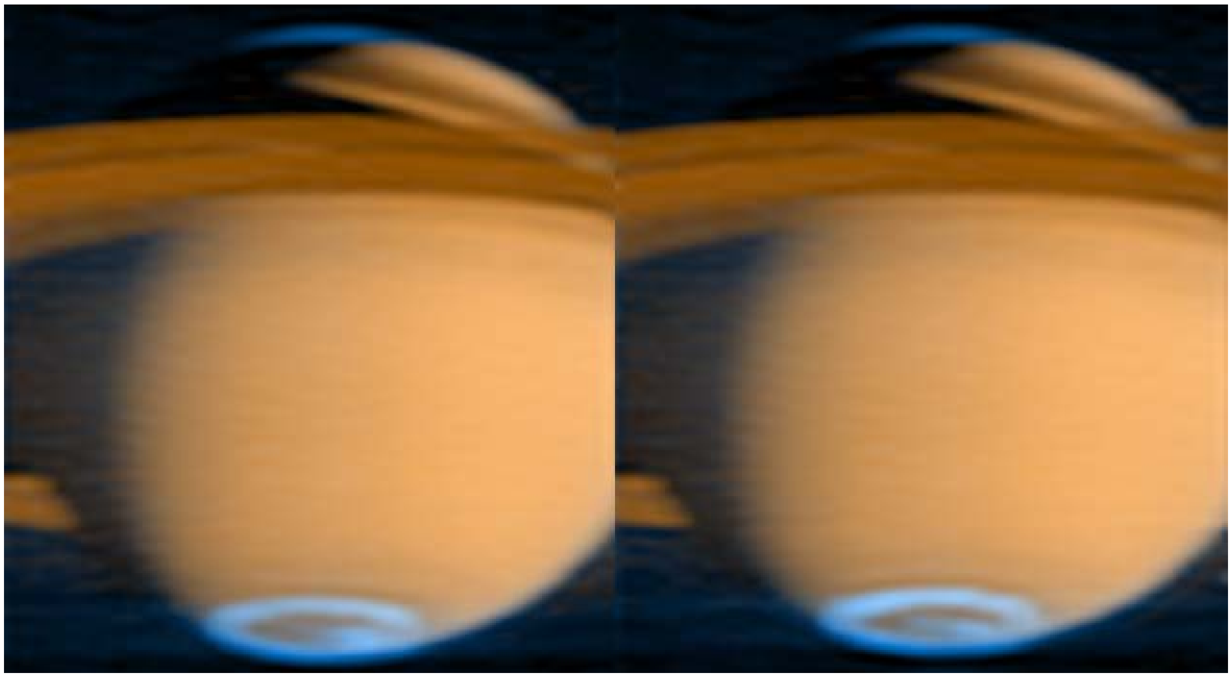


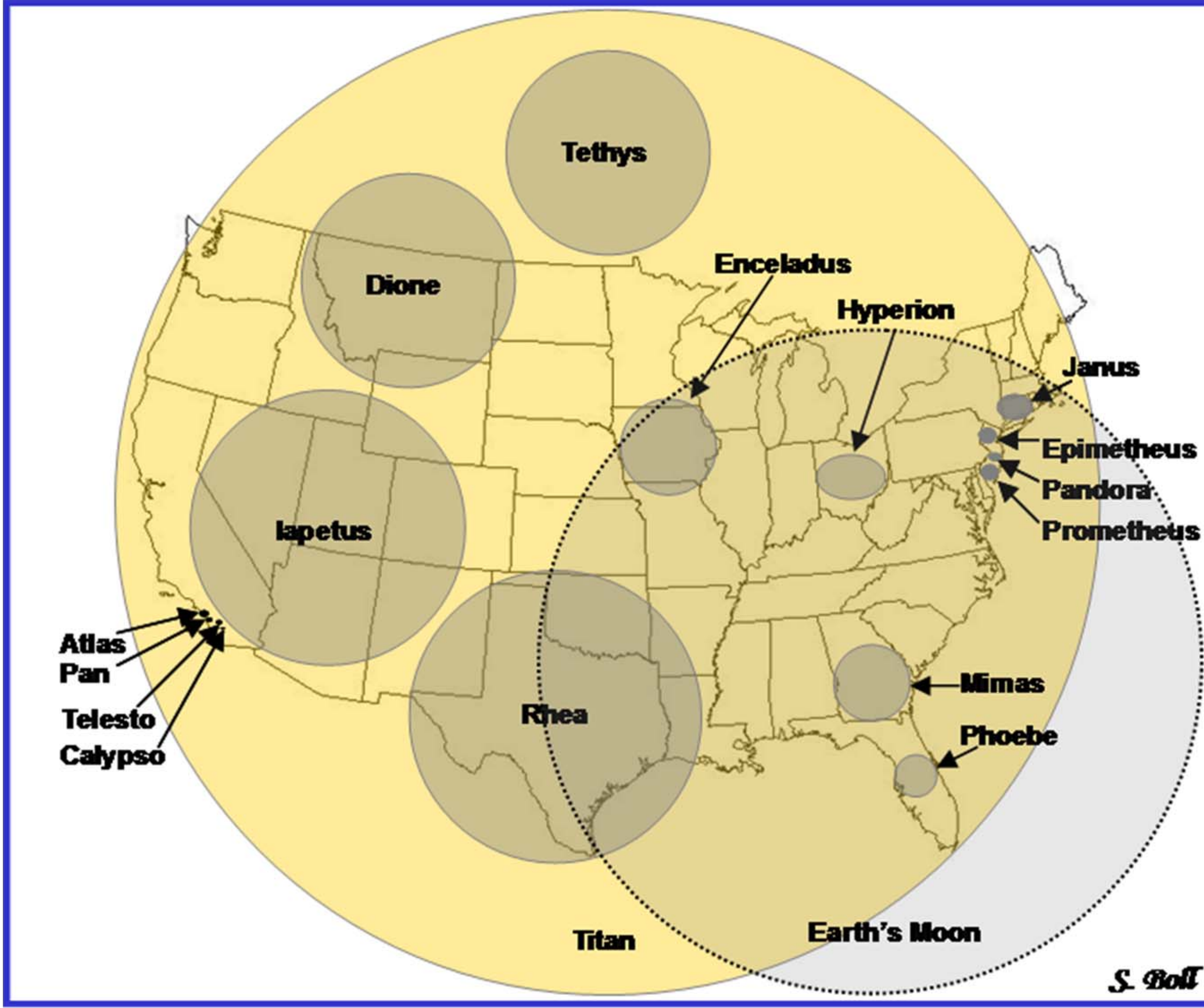




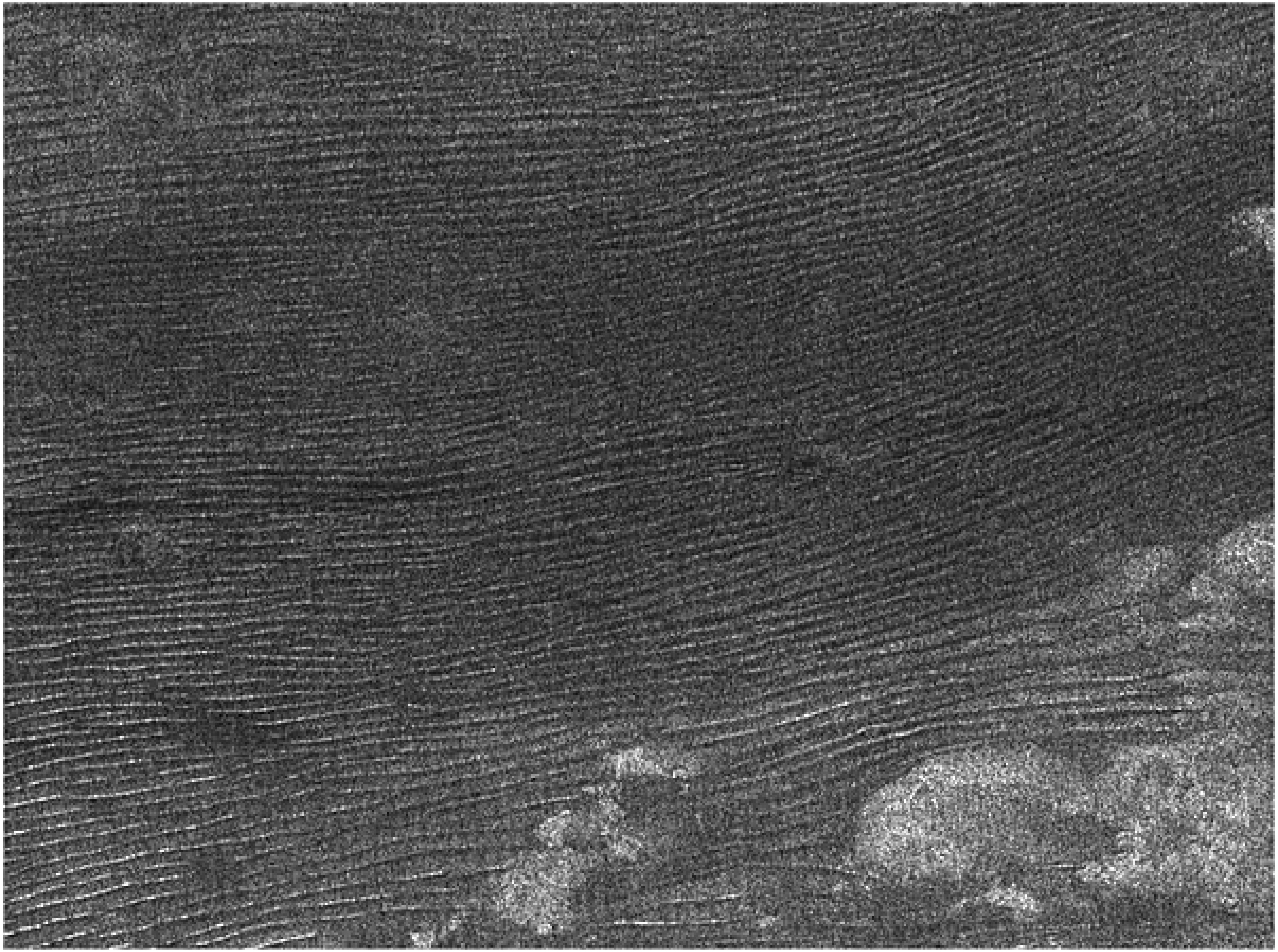


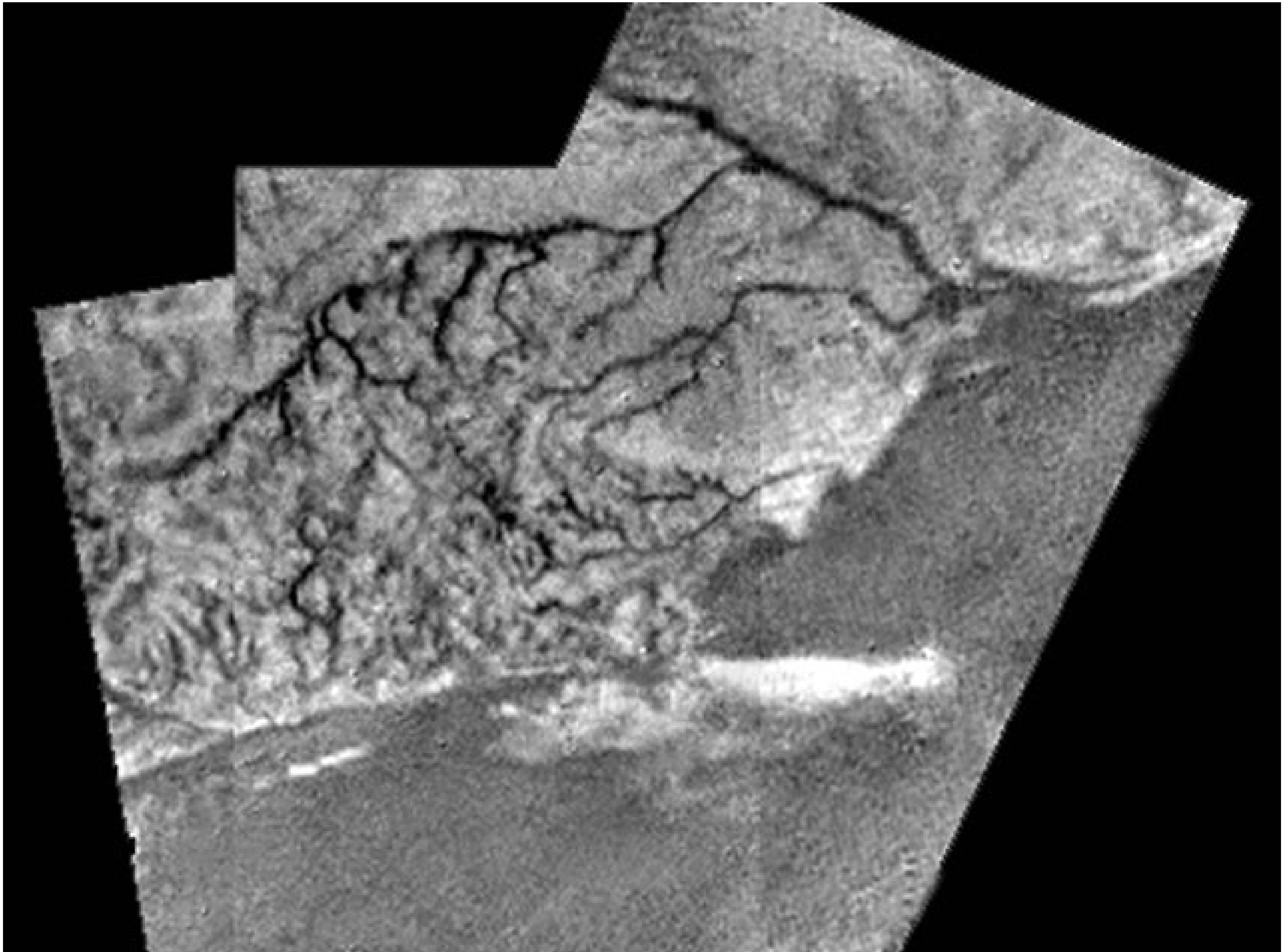
Saturn's "Northern Lights"

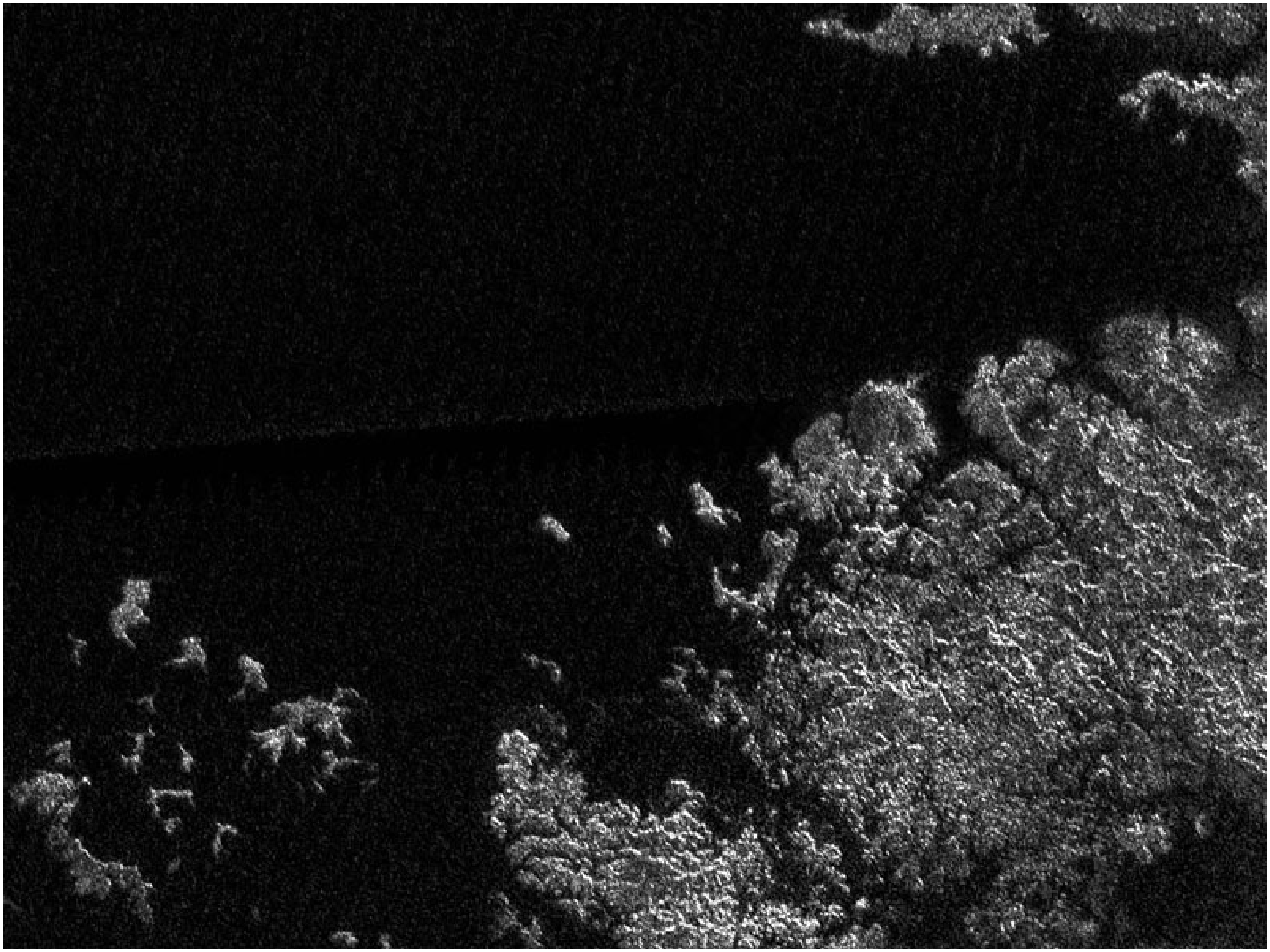


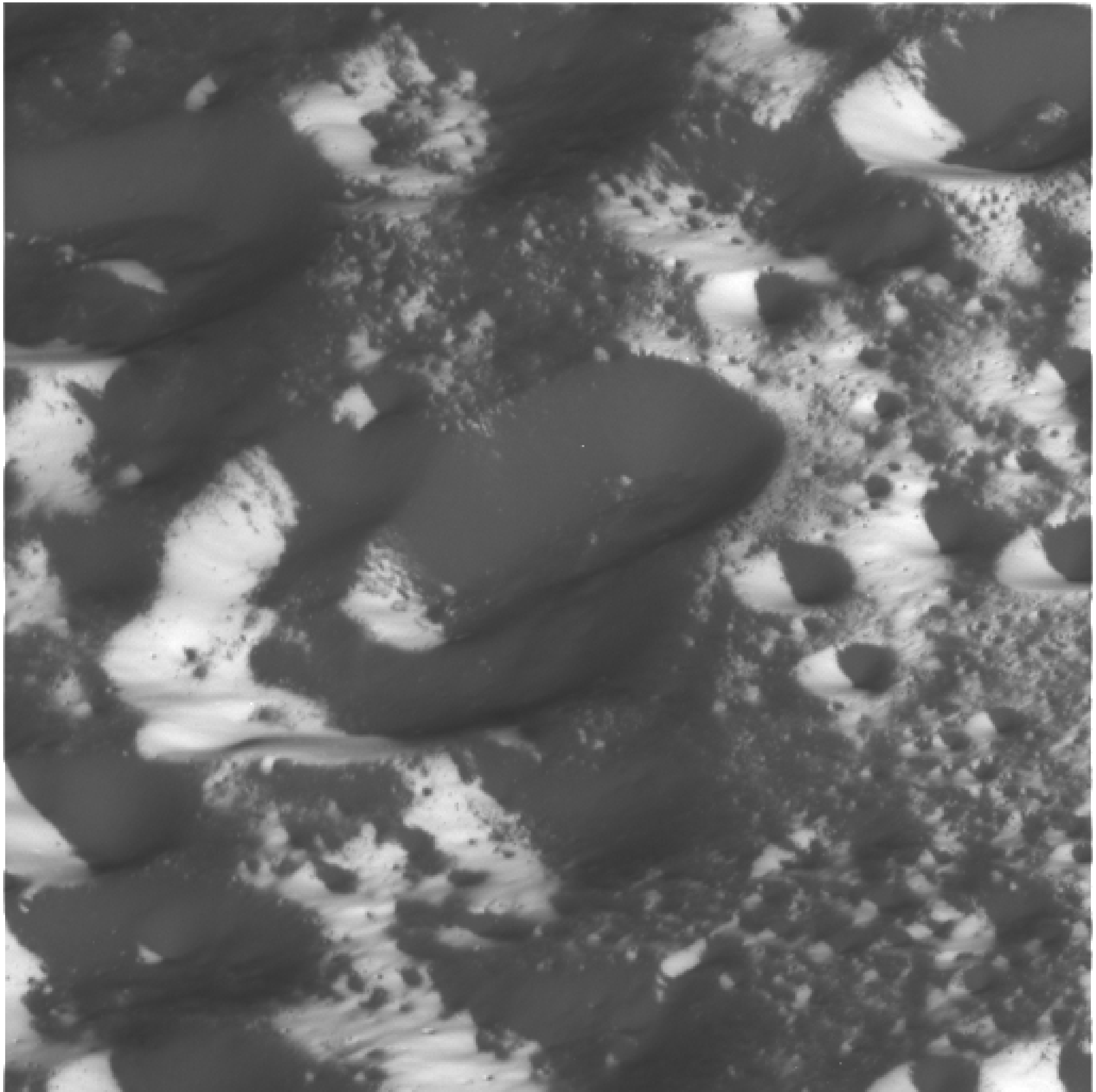


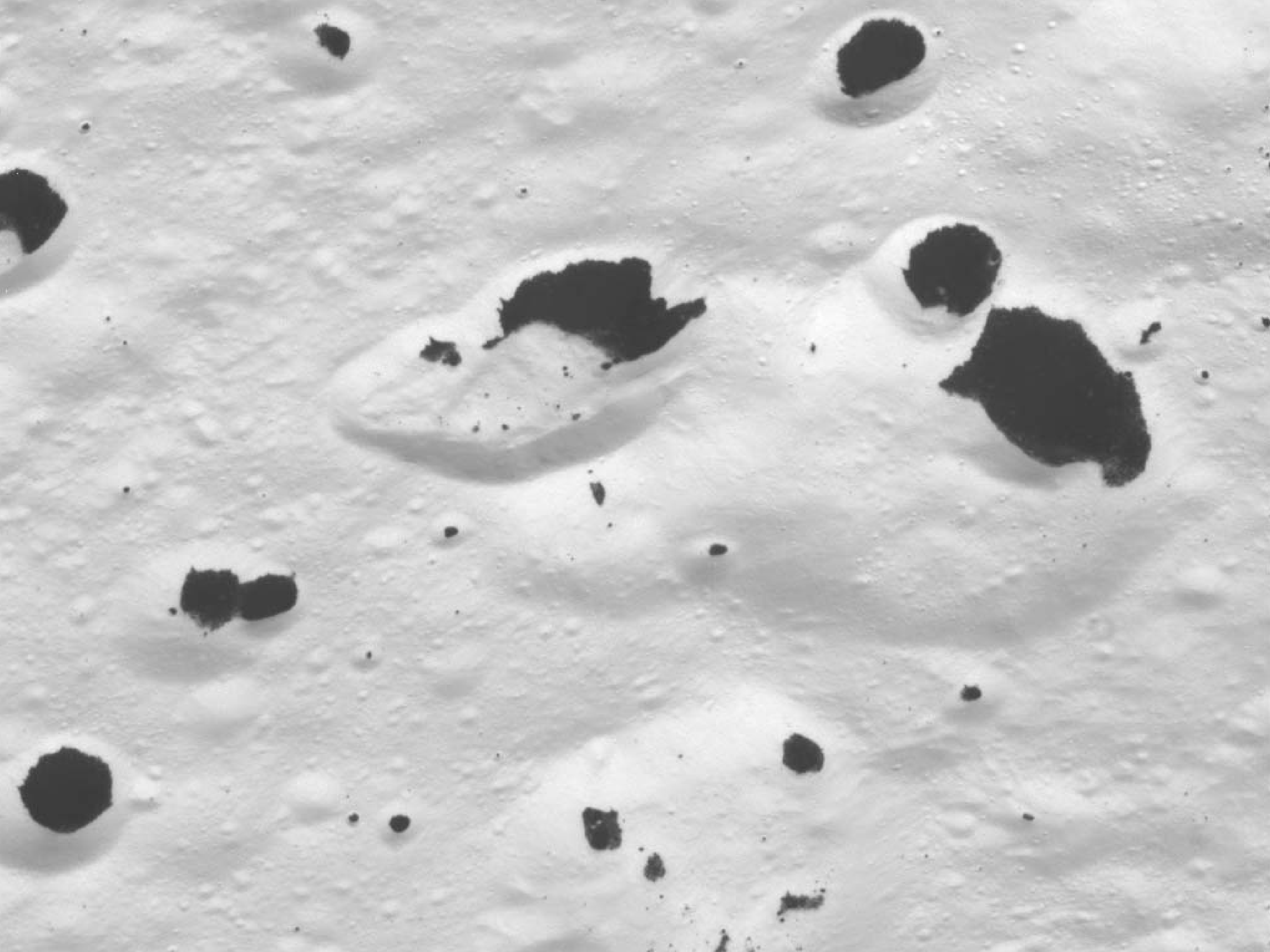
Tethys
Dione
Enceladus
Hyperion
Janus
Epimetheus
Pandora
Prometheus
Iapetus
Atlas
Pan
Telesto
Calypso
Rhea
Mimas
Phoebe
Titan
Earth's Moon
S. Bolt

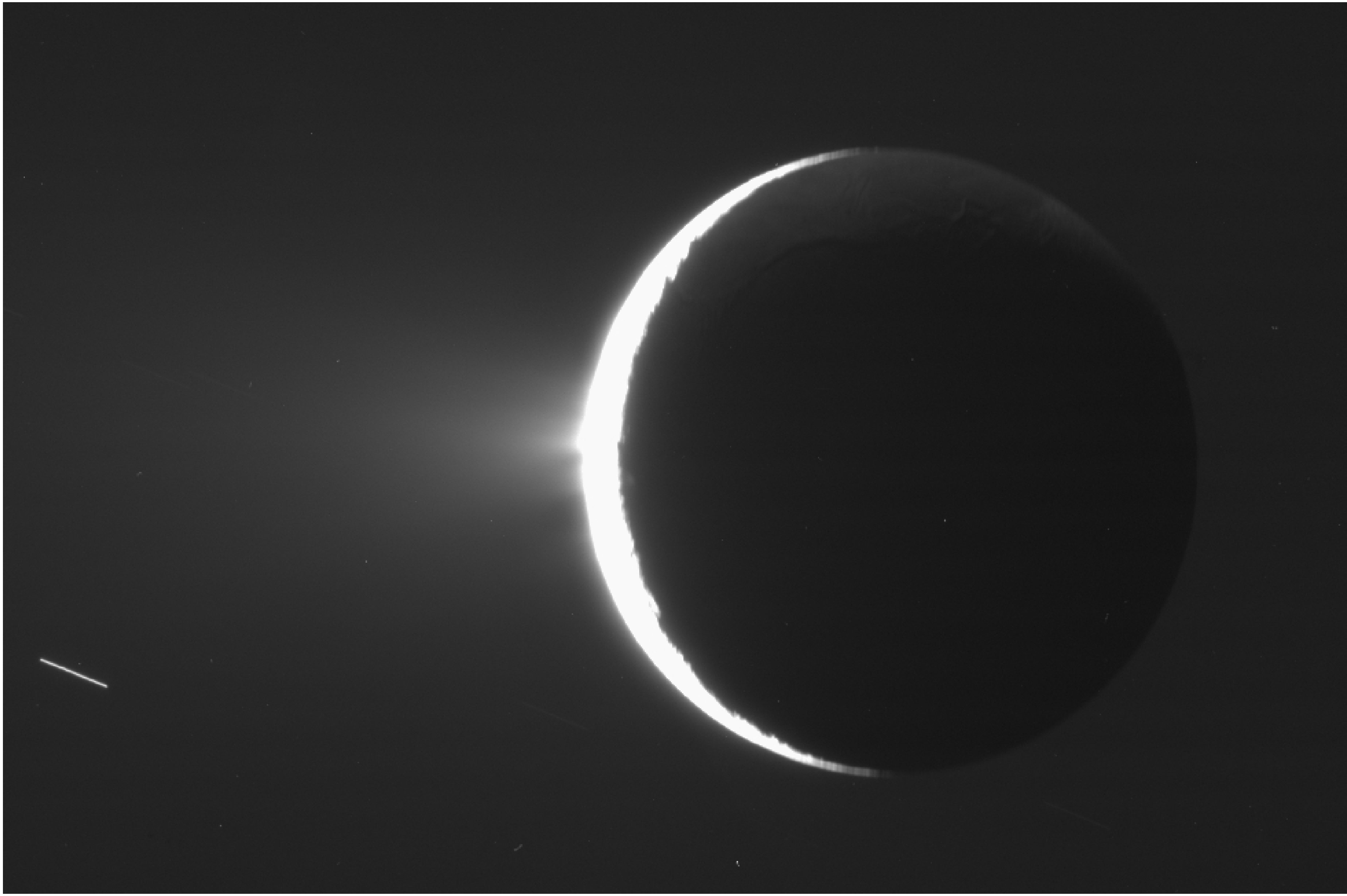


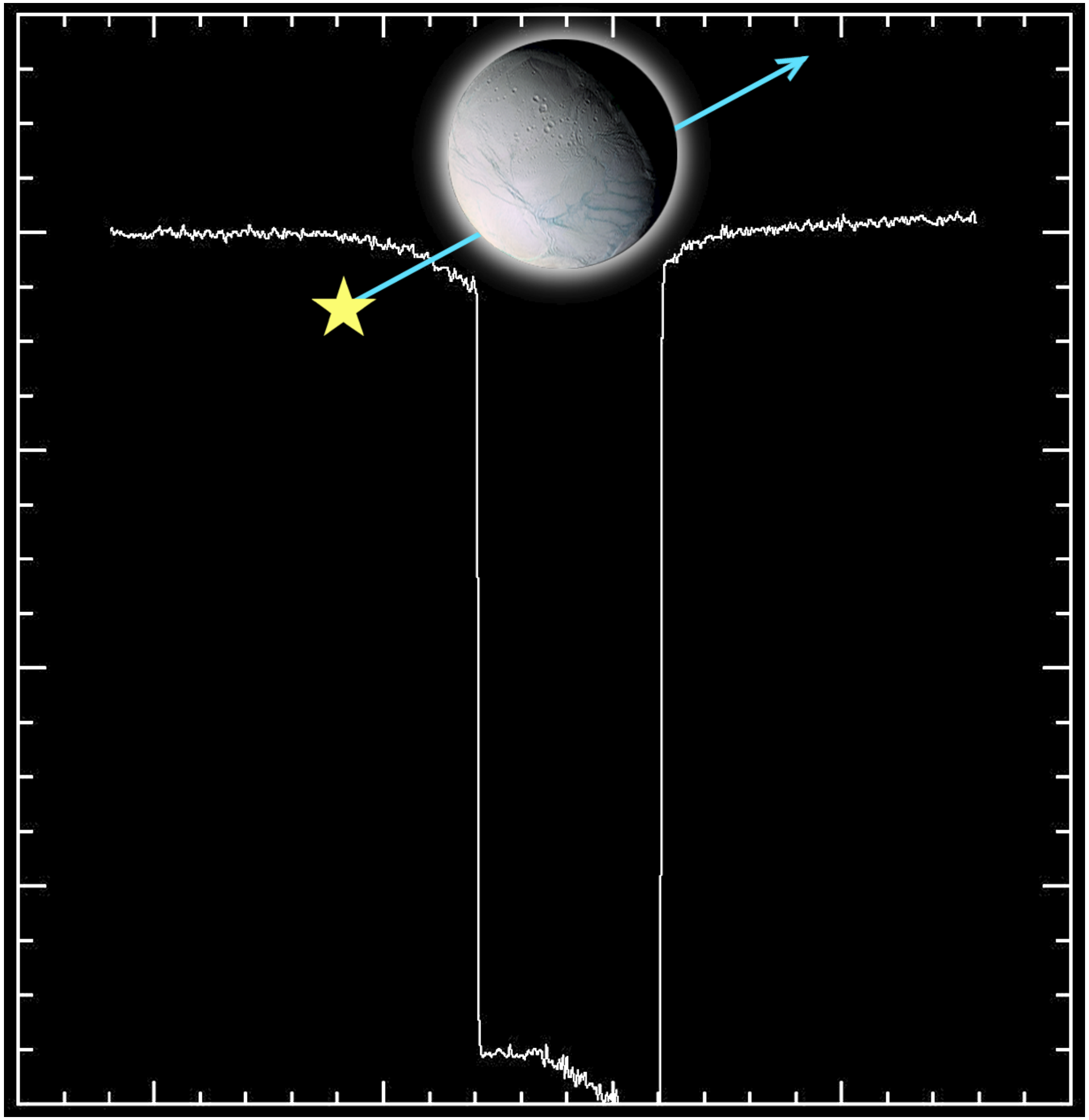






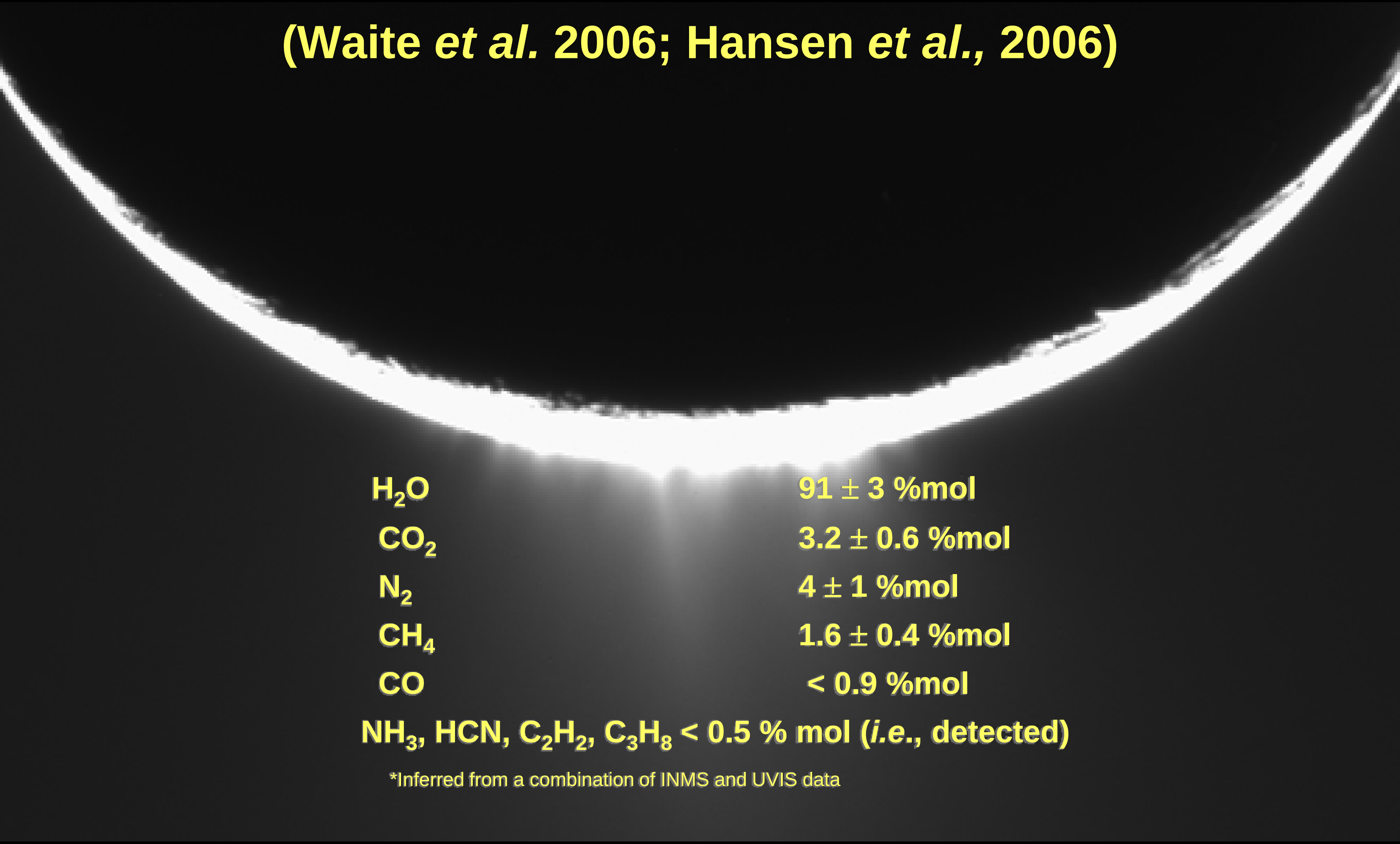






GEYSER COMPOSITION

(Waite *et al.* 2006; Hansen *et al.*, 2006)



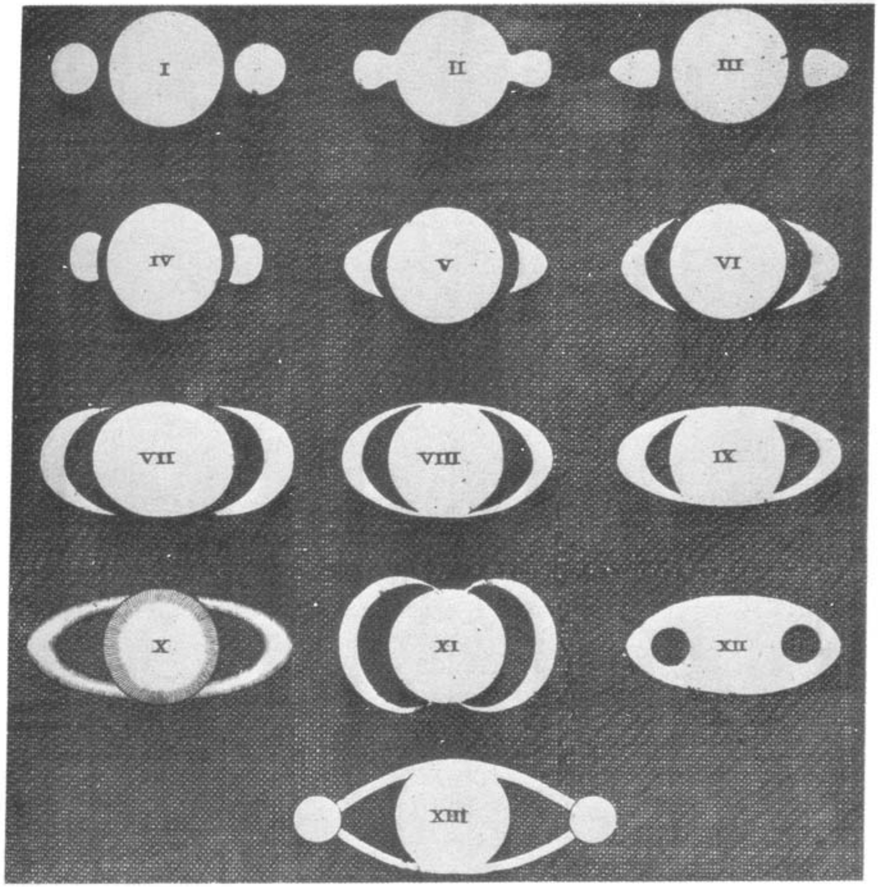
H_2O	91 ± 3 %mol
CO_2	3.2 ± 0.6 %mol
N_2	4 ± 1 %mol
CH_4	1.6 ± 0.4 %mol
CO	< 0.9 %mol

NH_3, HCN, C_2H_2, C_3H_8 < 0.5 % mol (*i.e.*, detected)

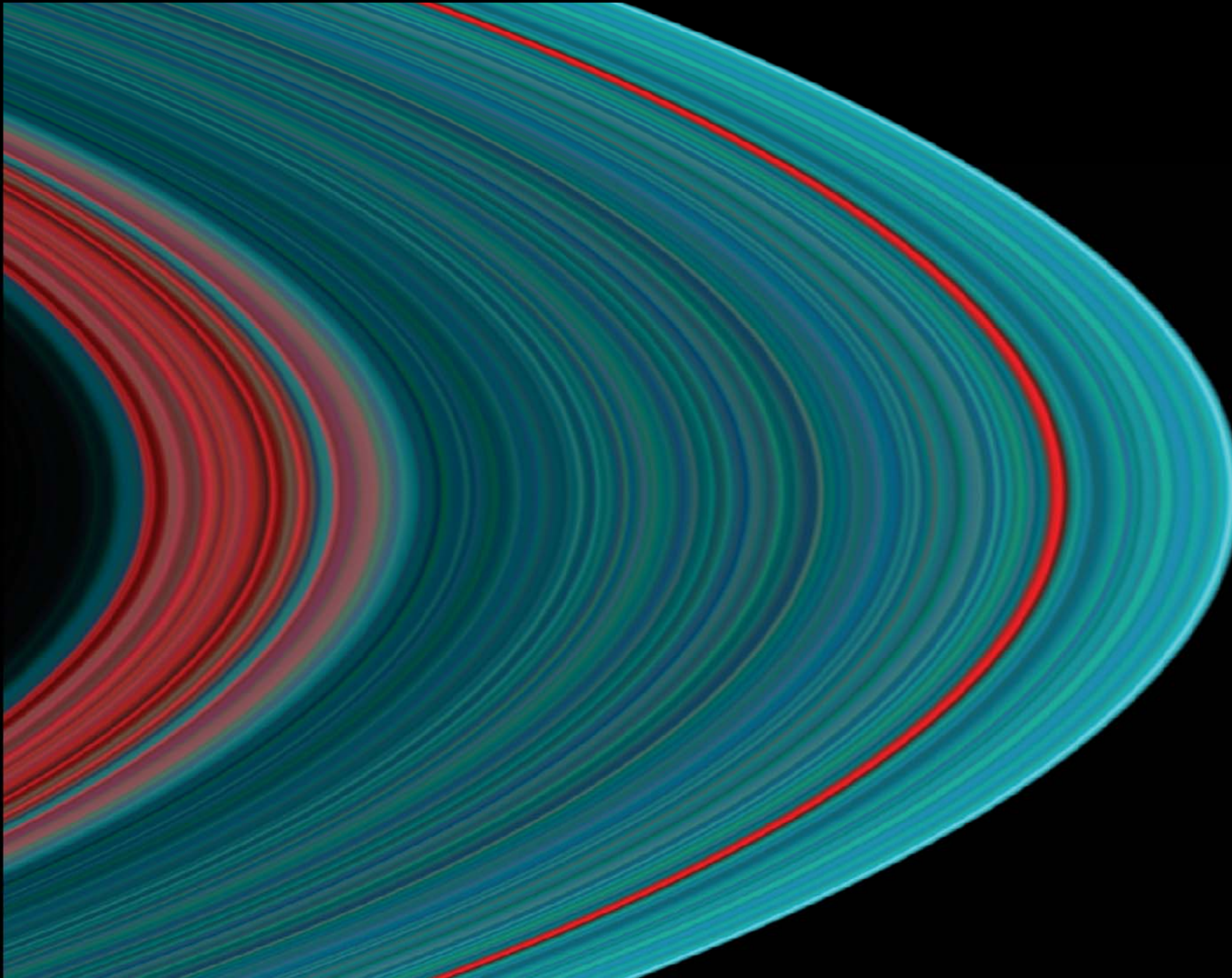
*Inferred from a combination of INMS and UVIS data

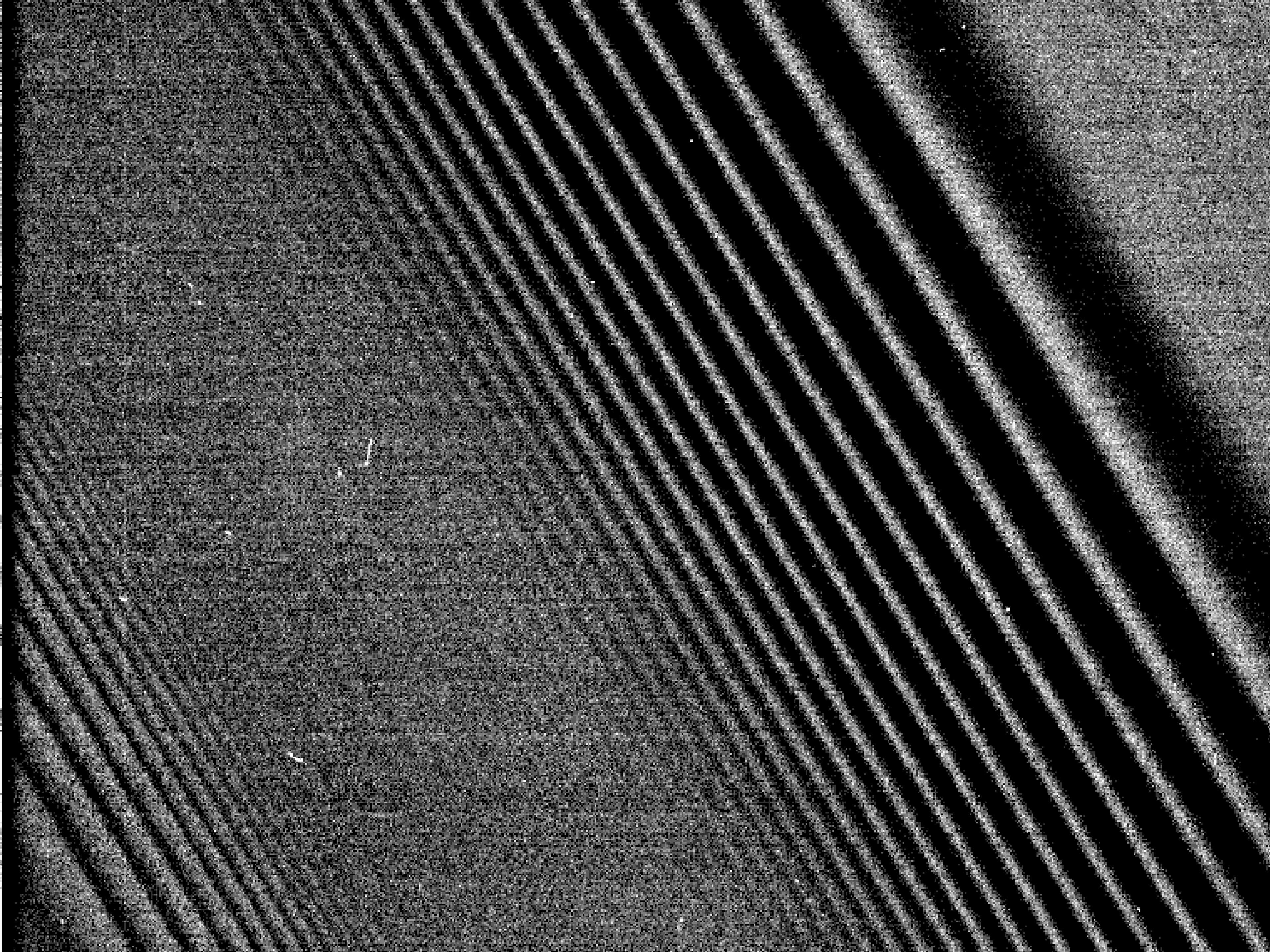
Cassini observations show Saturn's rings may be ancient

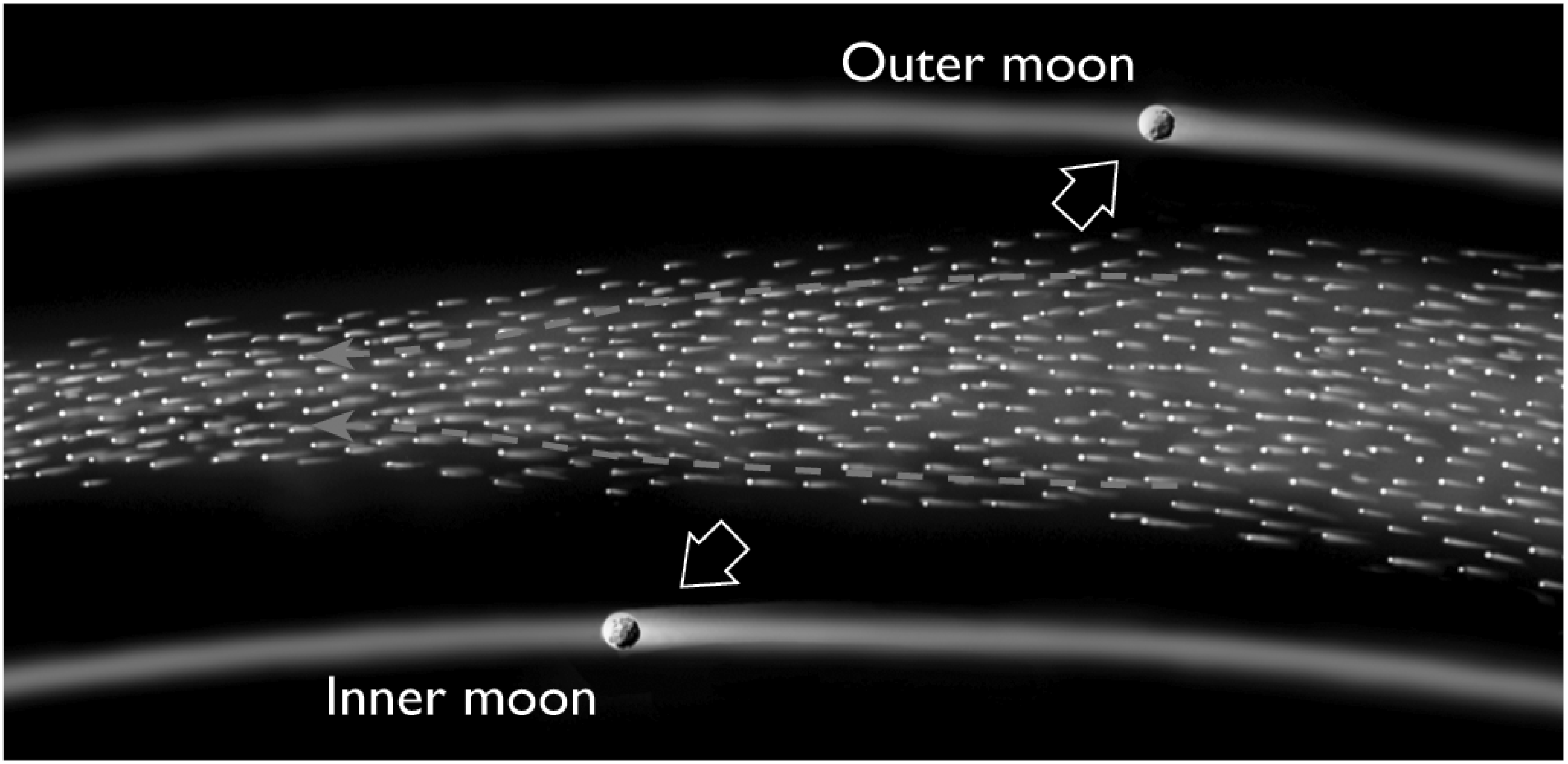
- Saturn's rings are made of billions of small pieces of ice orbiting Saturn, they resemble the planet-forming disks surrounding stars
- Cassini's Ultraviolet Imaging Spectrograph (UVIS) observes light reflected from Saturn's rings and watches stars pass behind the rings
- Voyager observations indicated the rings are youthful, but Cassini shows even younger ages: the range of ages is not consistent with a single event creating Saturn's rings



Saturn’s rings were a 17-th century puzzle …

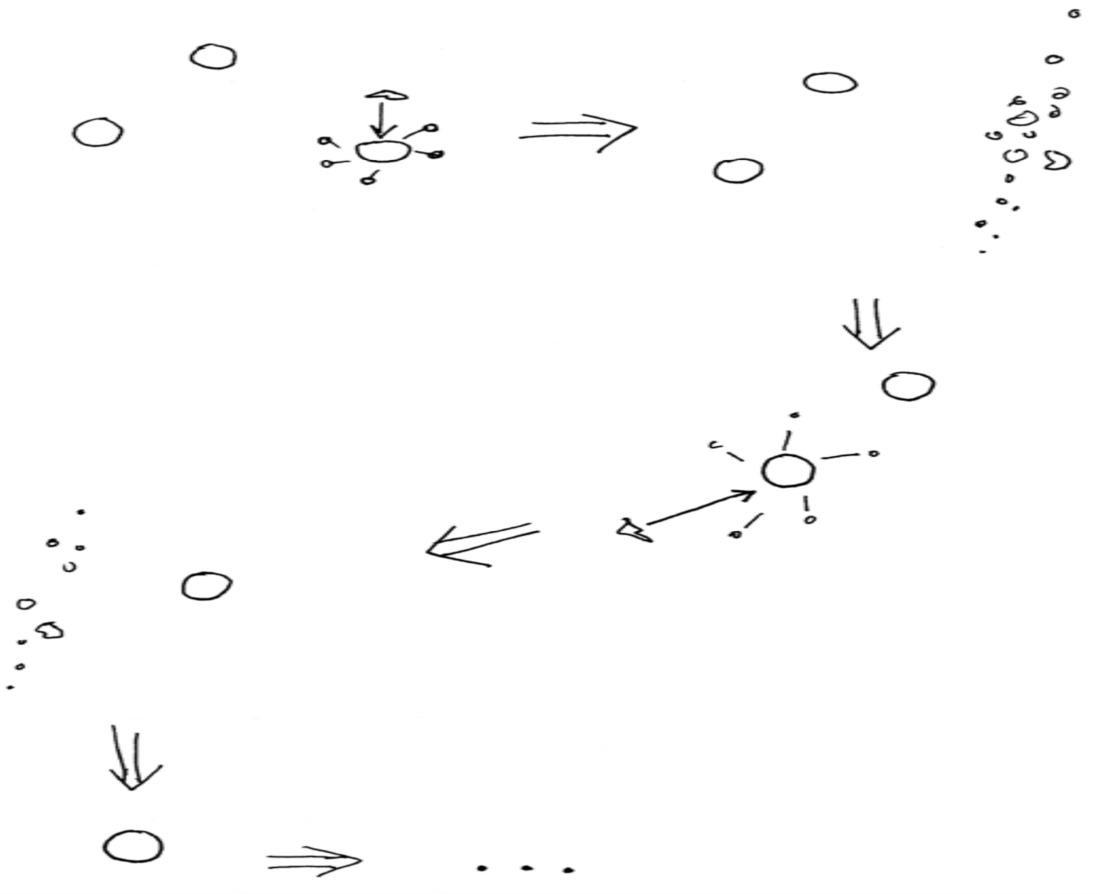




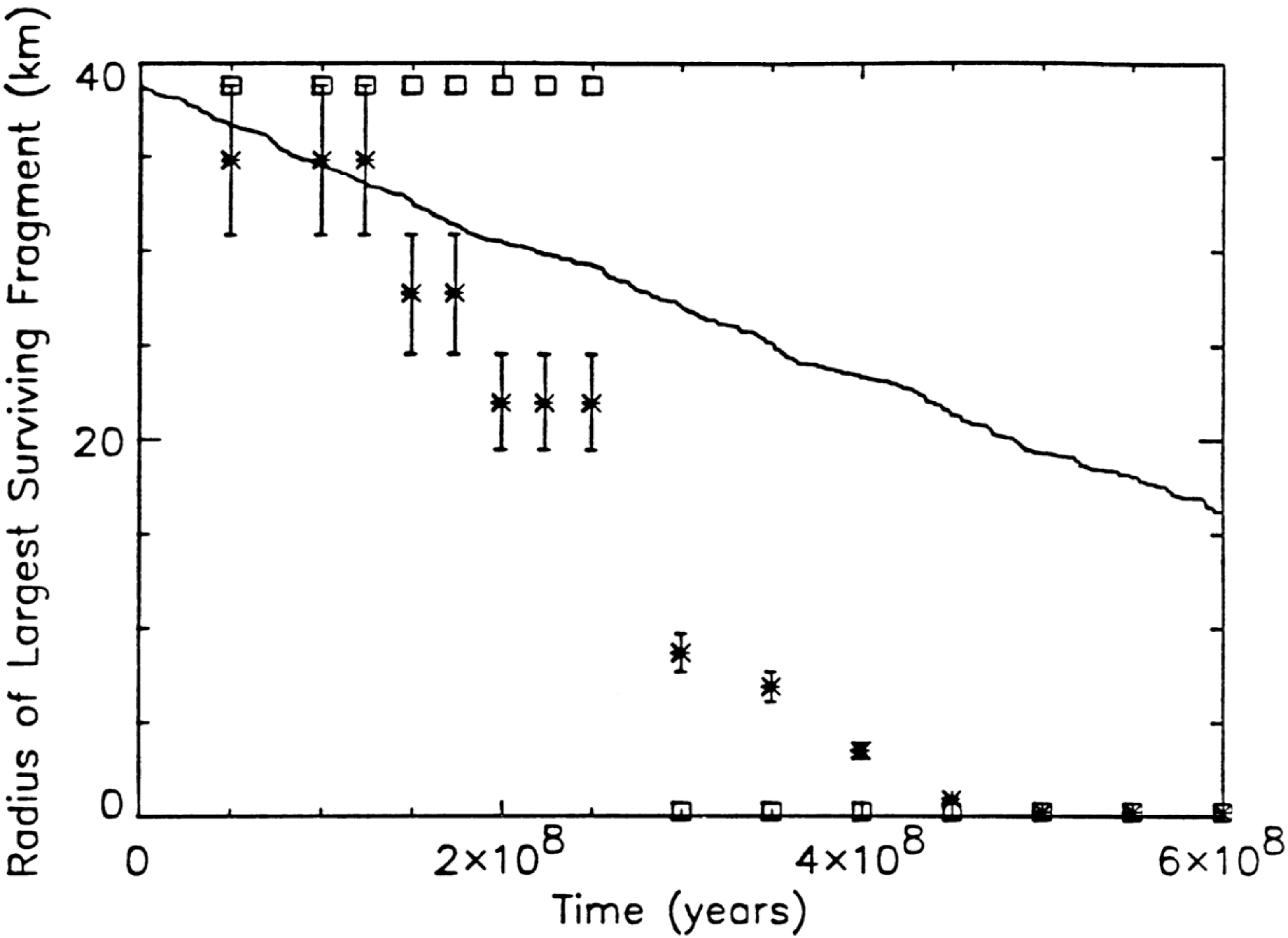


The moons ‘shepherd’ the ring particles

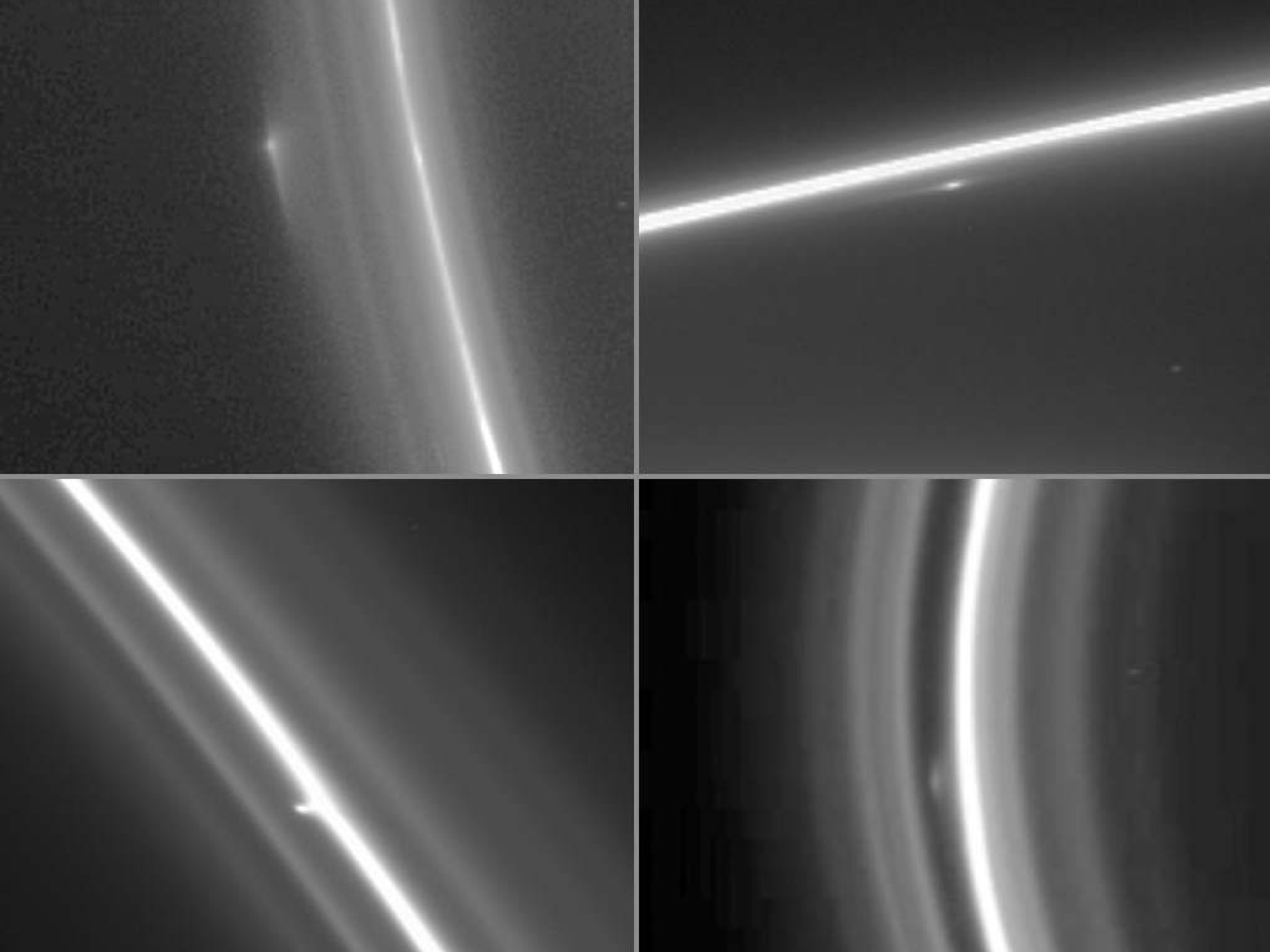
COLLISIONAL CASCADE

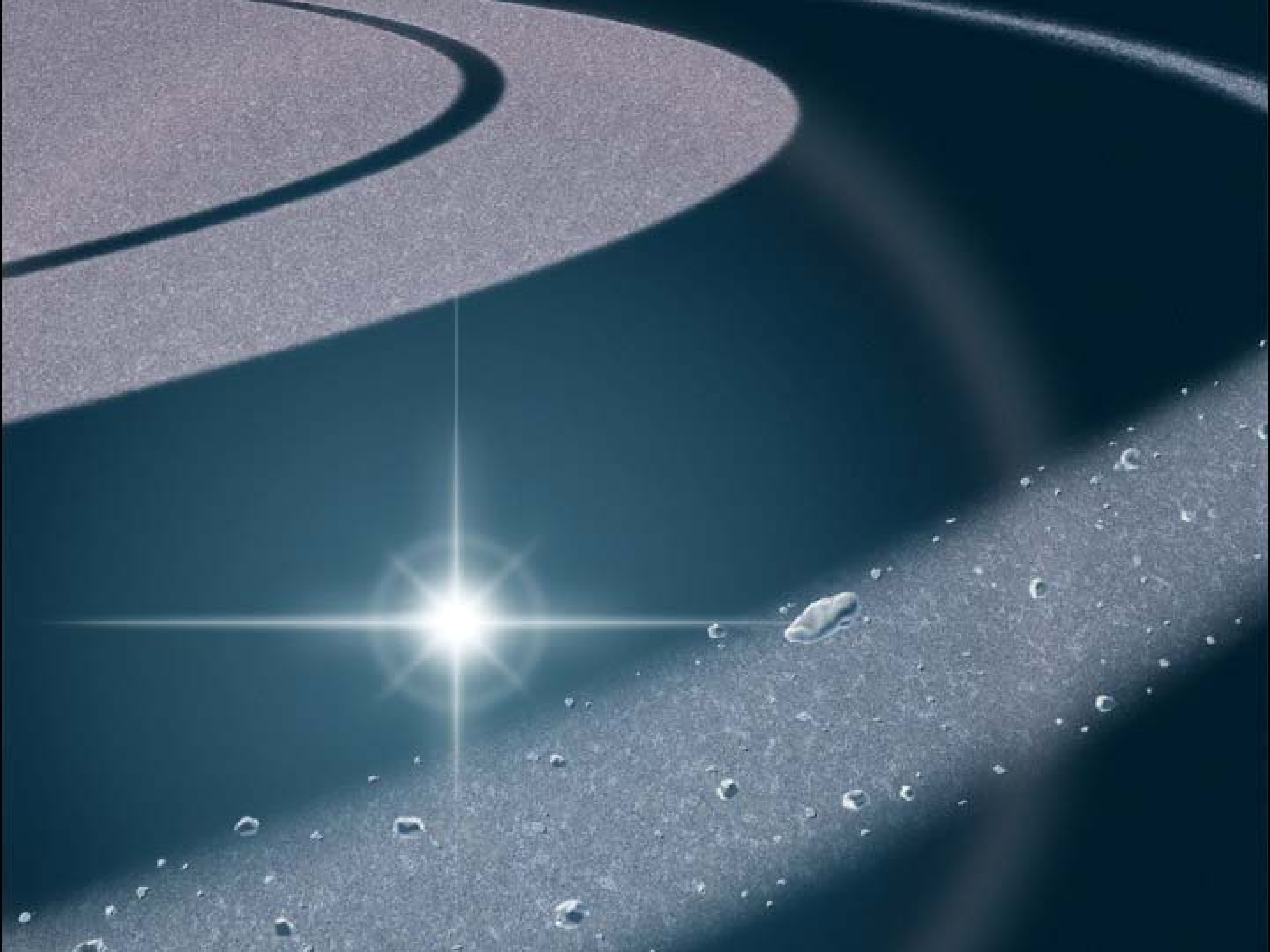


USES UP THE RING MATERIAL TOO FAST!



Collisional evolution shows original material lost



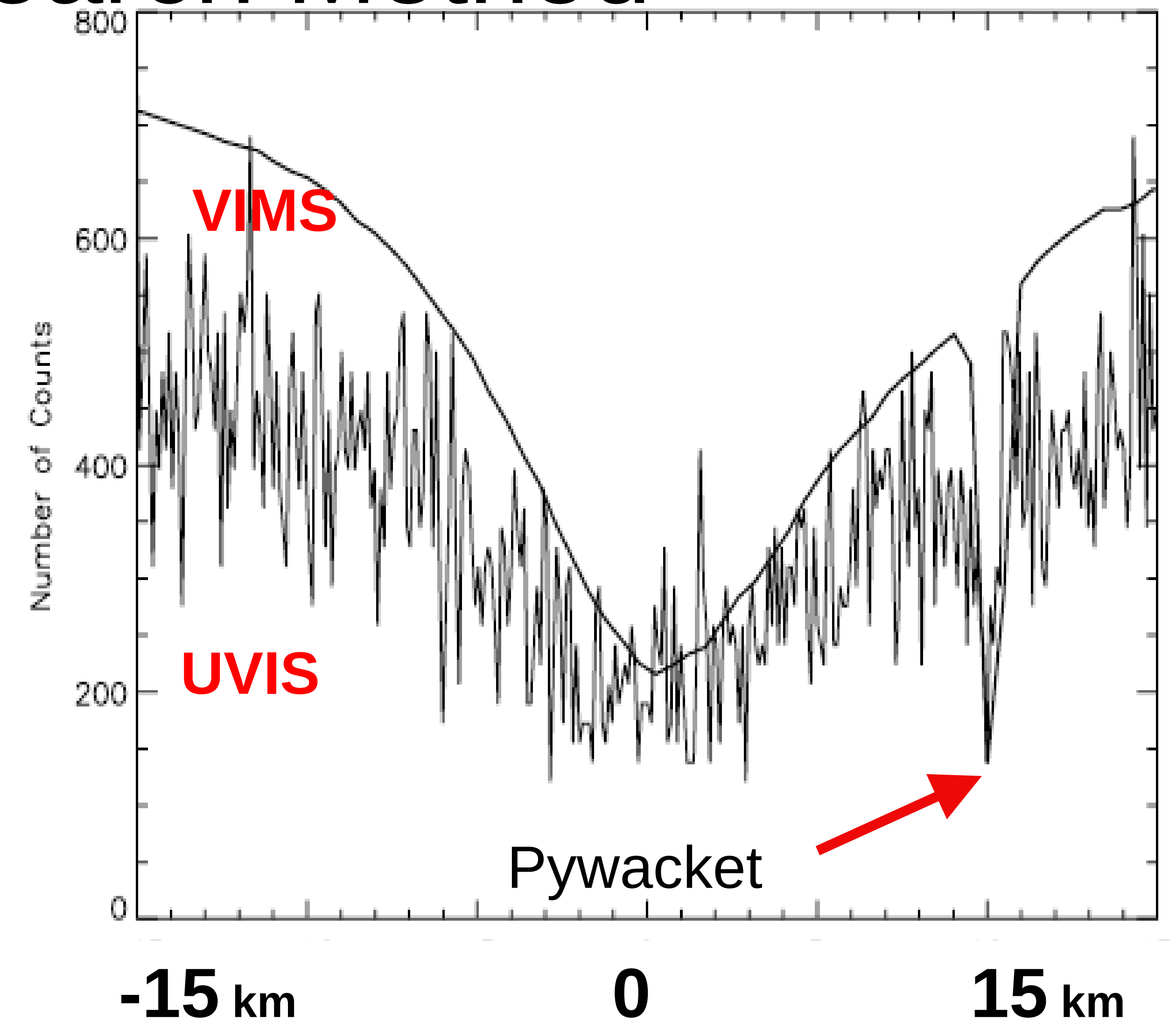


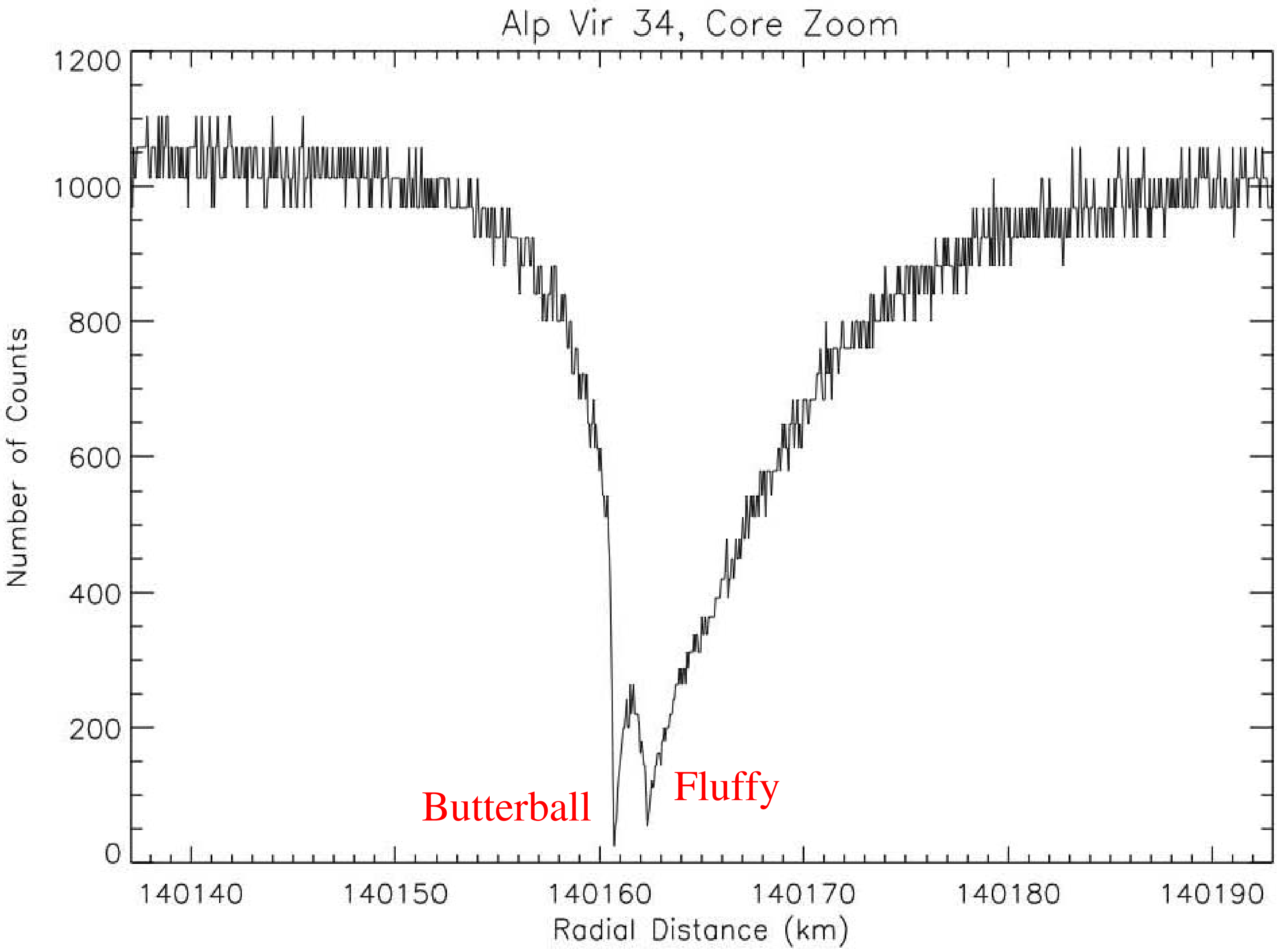
UVIS finds clumps and moonlets in Saturn's F ring

- Cassini detects 13 events: temporary aggregations and one possible moonlet
- These indicate clumping of ring particles that recycles the fragments of shattered moons

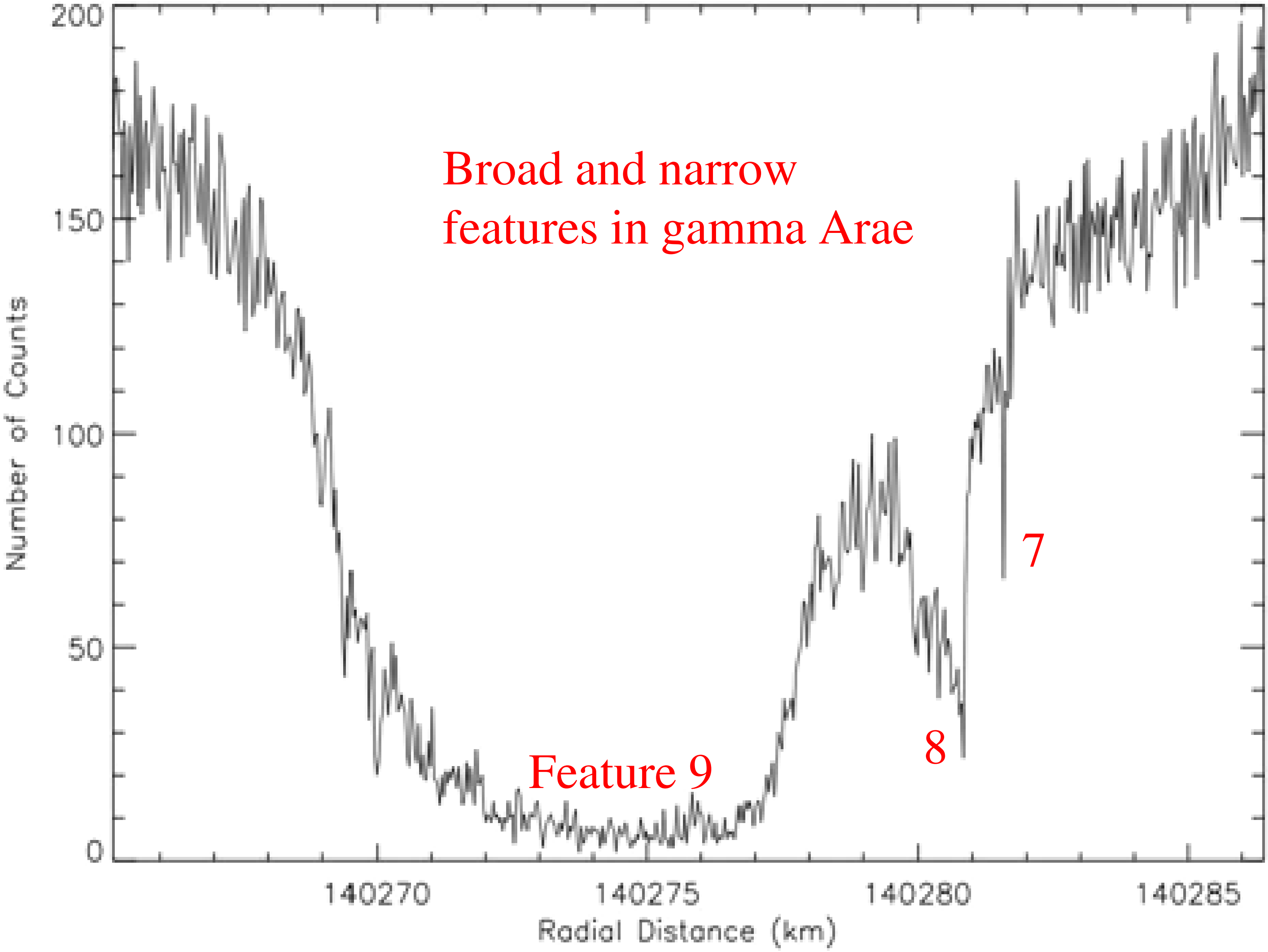
Search Method

- Search tuned for 1 VIMS-confirmed event
  - Optimal data-bin size
  - τ_{min}





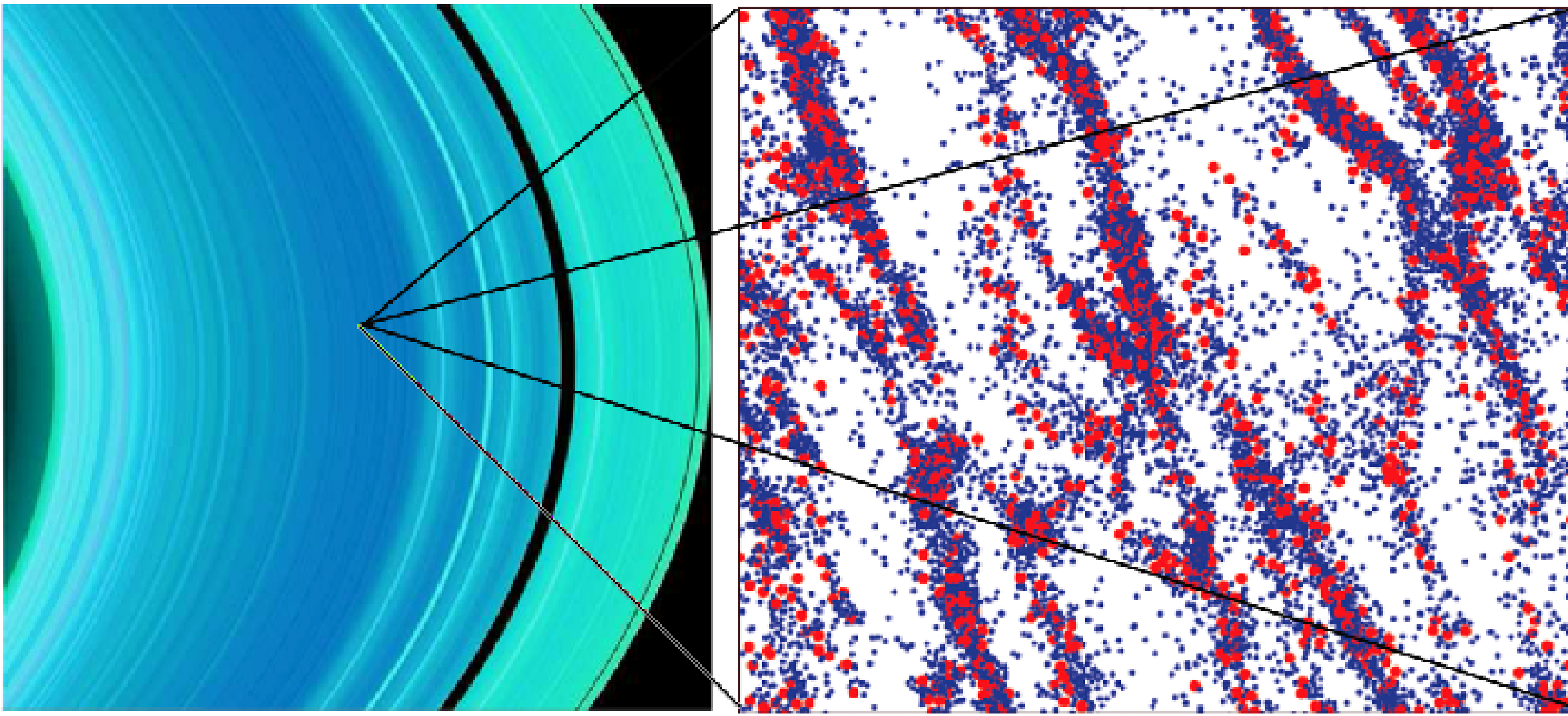
Alp Vir 34, Core Zoom
Number of Counts
0
200
400
600
800
1000
1200
140140
140150
140160
140170
140180
140190
Radial Distance (km)
Butterball
Fluffy

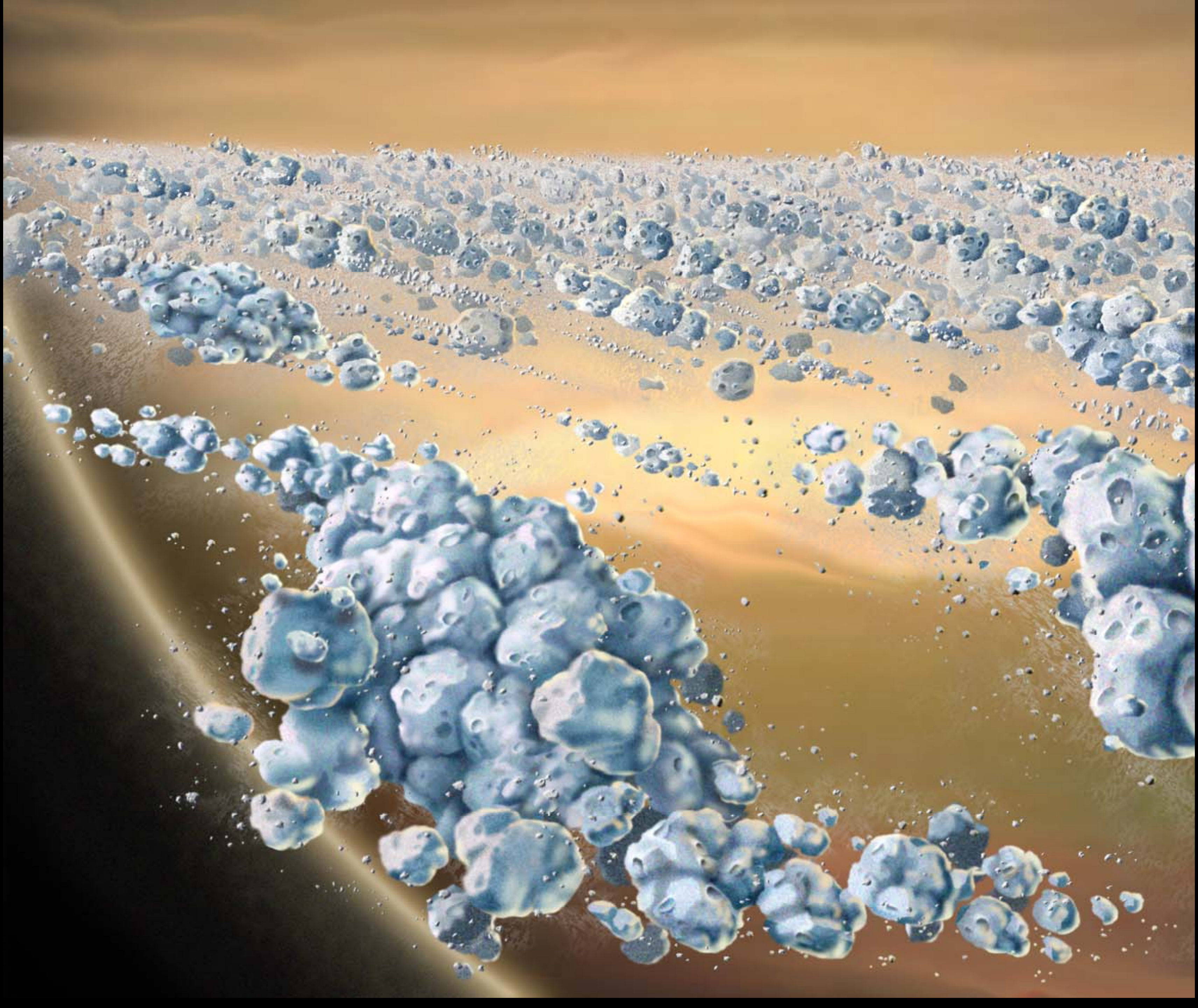


Broad and narrow features in gamma Arae
Feature 9
8
7
Number of Counts
Radial Distance (km)
200
150
100
50
0
140270
140275
140280
140285

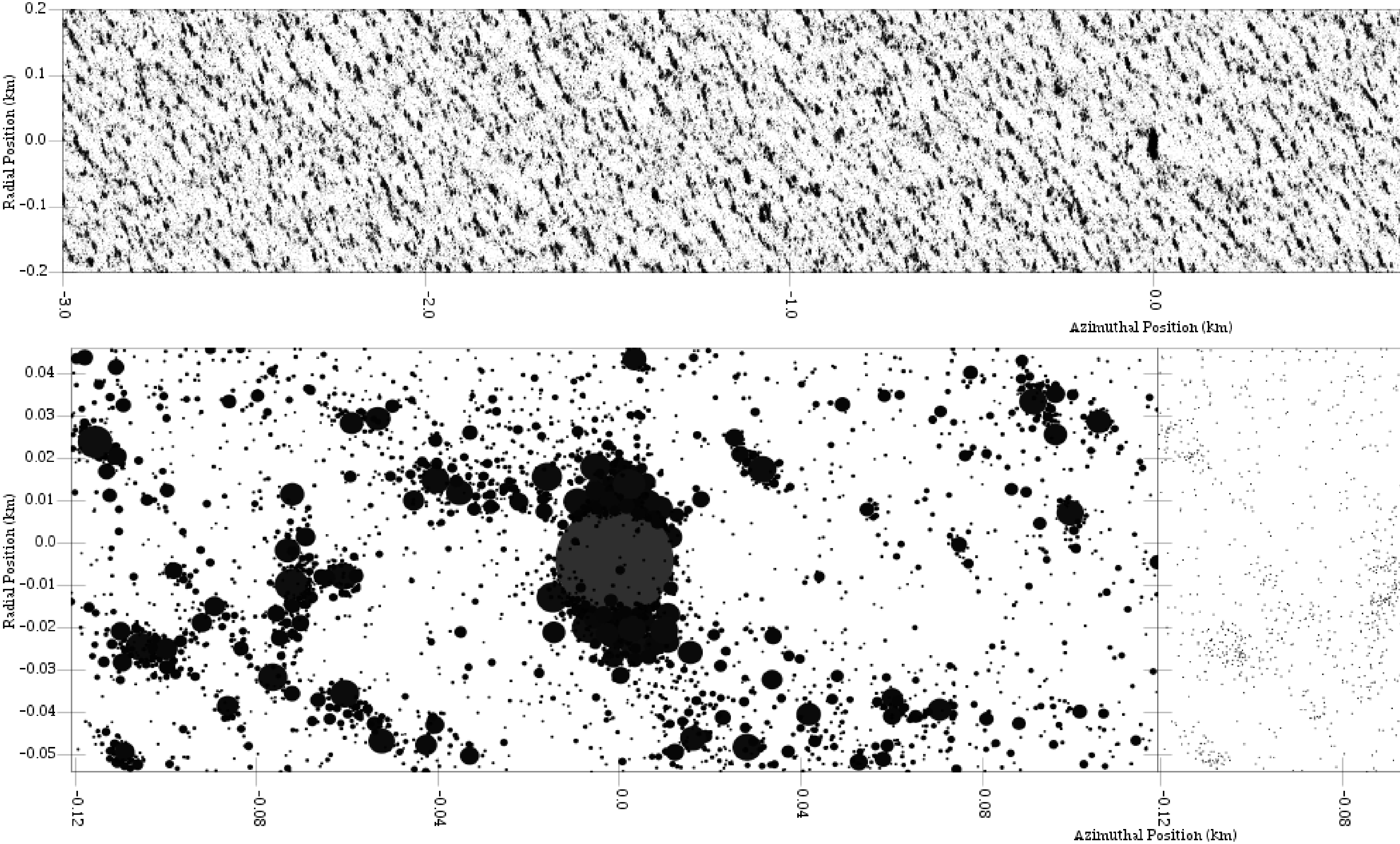
Ring occultations show self-gravity wakes

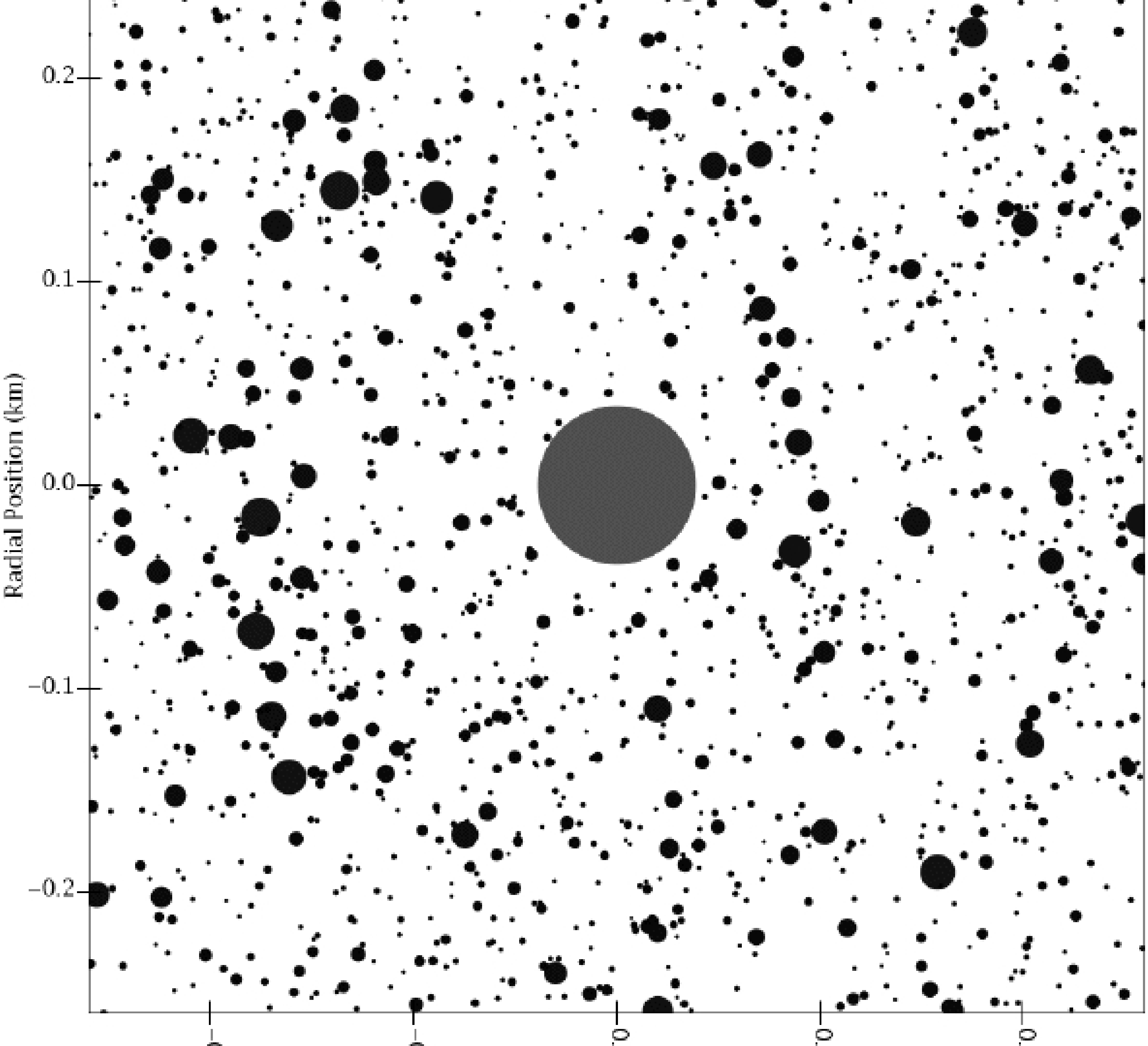
- Multiple occultations provide a tomographic view of ring structures too small to be seen by the cameras
- Autocovariance indicates elongated transient clumps, as predicted in simulations
- We may have greatly underestimated ring heterogeneity, mass and age



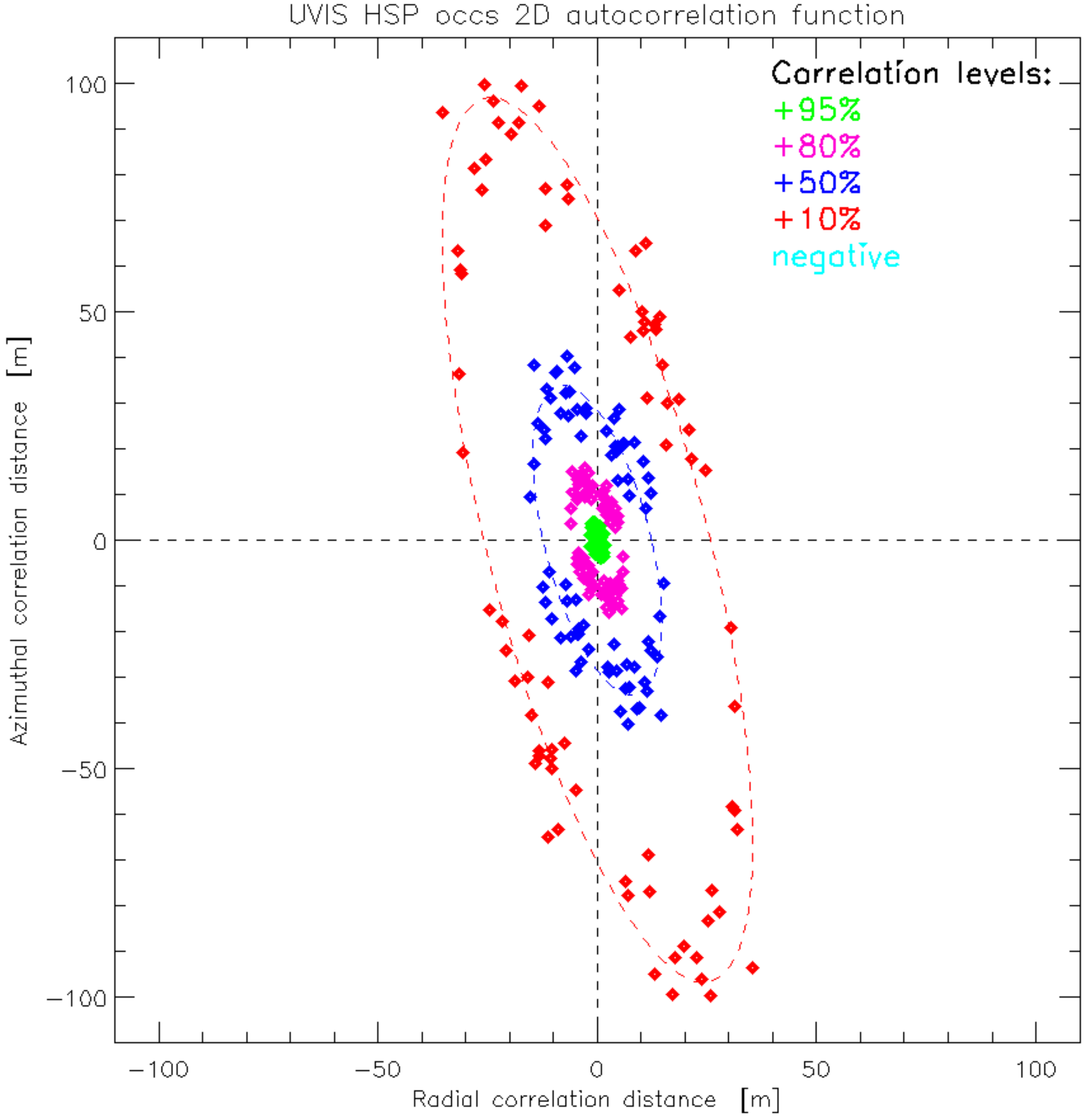


Numerical simulations show collisions and self-gravity effects will create transient elongated trailing structures.



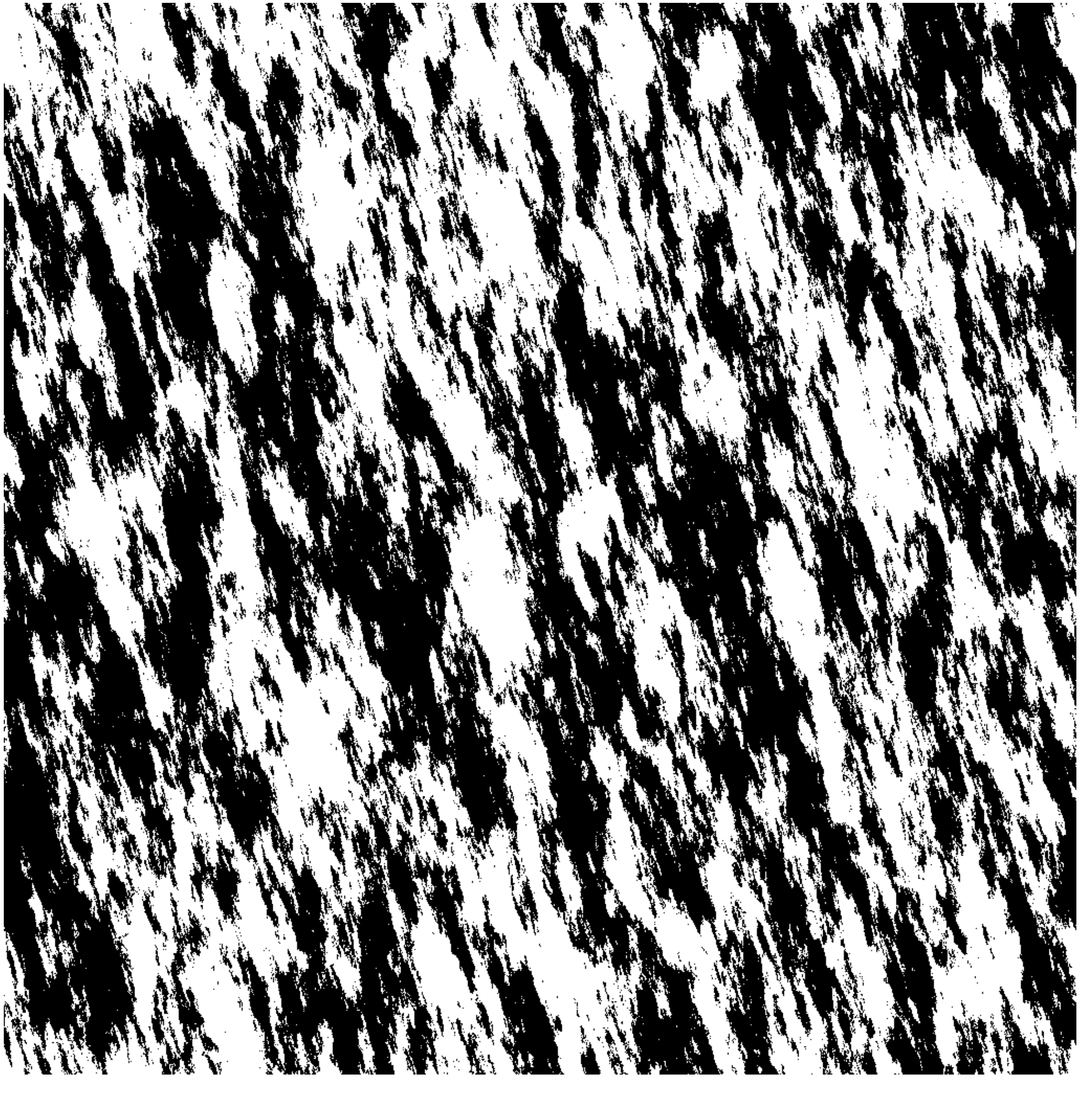

Radial Position (km)
0.2
0.1
0.0
−0.1
−0.2

UVIS HSP 2D autocorrelation

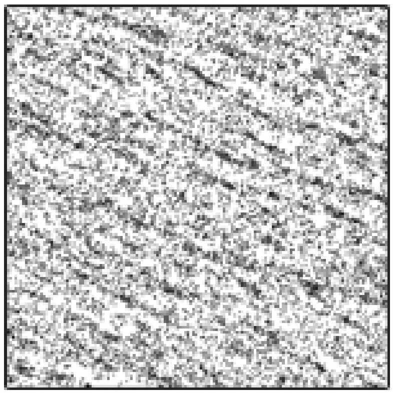


UVIS occs inverted

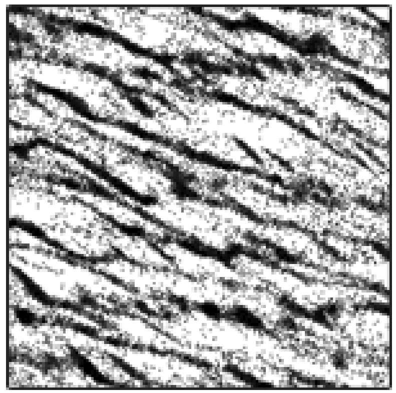
2D autocorrelation => FFT => image



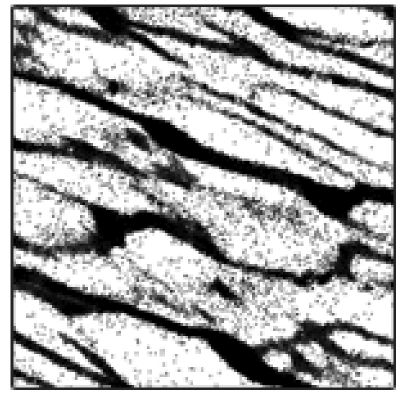
Numerical simulations show a spider-web structure. The ring opacity underestimates mass of the B ring!



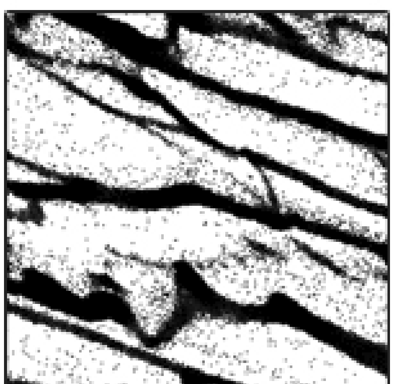
τ = 0.25, 0.25



τ = 0.50, 0.41



τ = 0.75, 0.42



τ = 1.00, 0.43

τ = 1.50, 0.48

τ = 2.00, 0.46

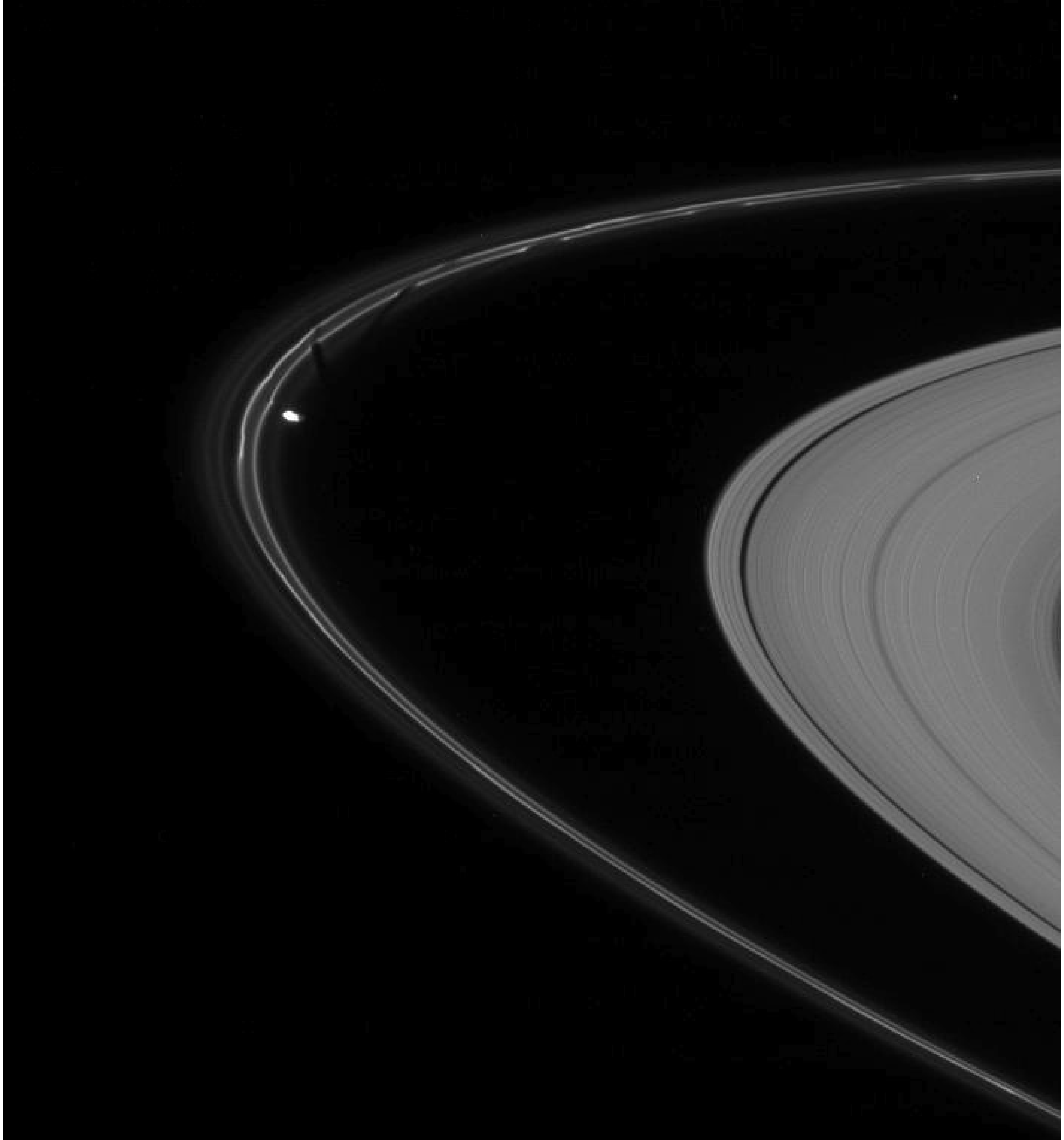
Ring history

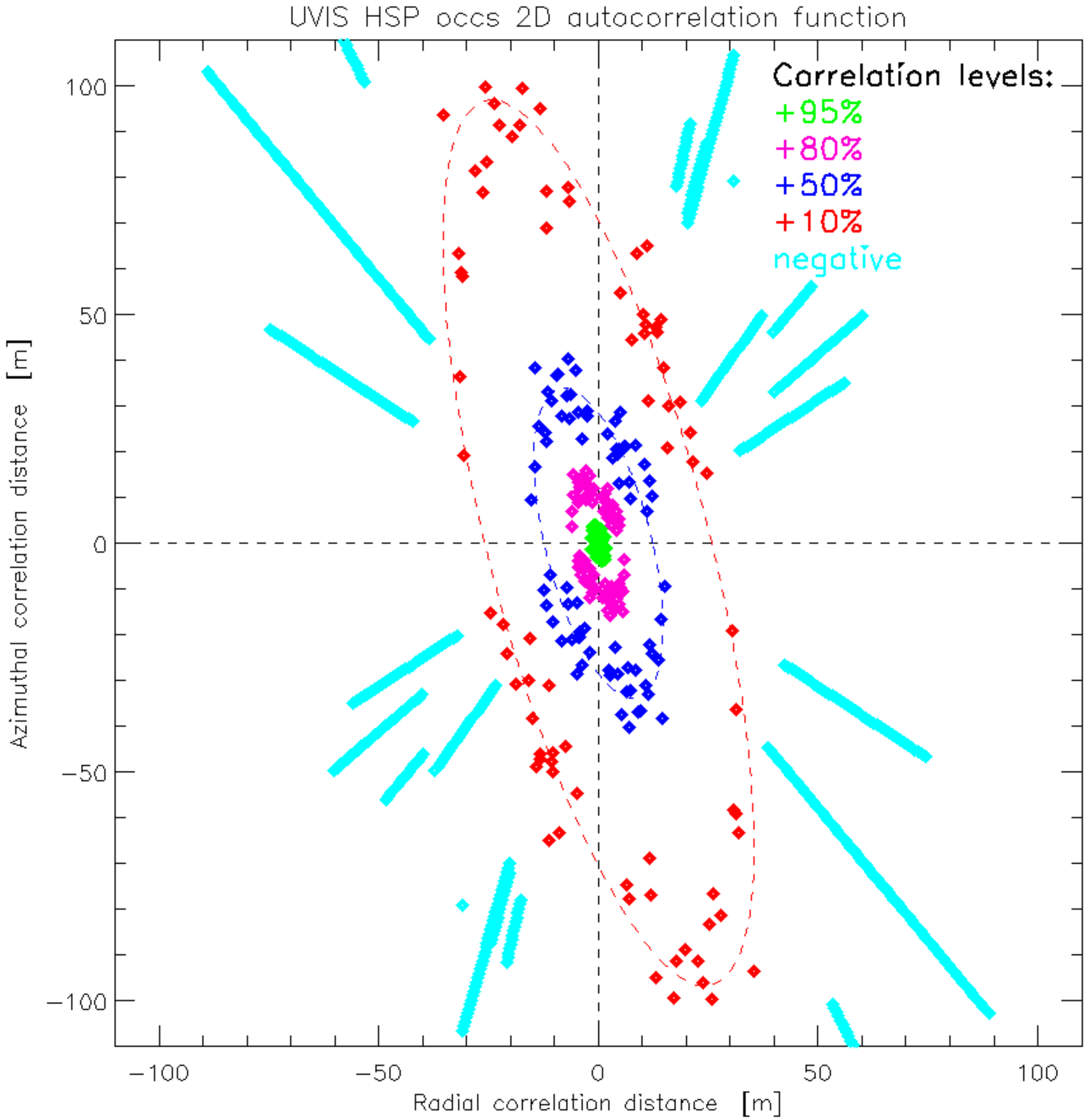
- We believe Saturn’s rings were created when a moon was shattered by a meteorite impact
- The pieces formed a ring around the planet
- But, the pieces can recollect to form new moons
- Which are shattered later, to form new rings, and so on…

Conclusion: Age of Saturn’s rings

- Recycling allows the rings to be as old as the solar system, although continually changing
- Because the rings have more mass than previously thought, their surfaces can still be bright and icy after 4 billion years

Backup Slides

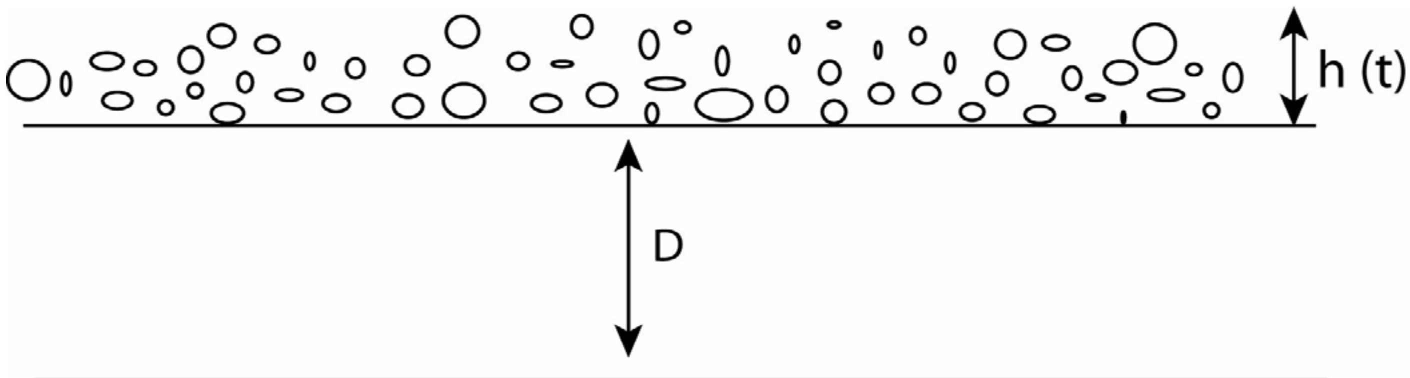




UVIS HSP occs 2D autocorrelation function
Correlation levels:
+95%
+80%
+50%
+10%
negative
100
50
0
−50
−100
Azimuthal correlation distance [m]
−100
−50
0
50
100
Radial correlation distance [m]

Are ancient rings possible? Regolith model for pollution:

Consider an infinite slab of depth, D



The regolith depth at time t: h(t)
For a moonlet or ring particle, D corresponds to the diameter.

Markov chain simulation matches analytic test case

For an impactor size distribution that is a power law of index 3, we can solve the differential equation for *h(t),* assuming all material is excavated:

$$h(t) = H_{max}[1 - exp(-t/T_0)]$$

$$H_{max} = H_1 \, a_{max}$$

$$T_0 = \frac{H_{max}}{F_G Y \dot{m} / \rho}$$

Realistic case for Saturn

- Use Cuzzi and Estrada (1998) impactor size distribution
- Compare to Quaide and Oberbeck (1975) lunar regolith model
- Our Markov chain model result gives depth within a factor of 2 of their values for $10^5 < t < 10^9$ years

This implies young rings?

The fractional pollution of the regolith, f_p, is given by

$$f_p = \frac{F_G \dot{m} t / \rho}{h(t)}$$

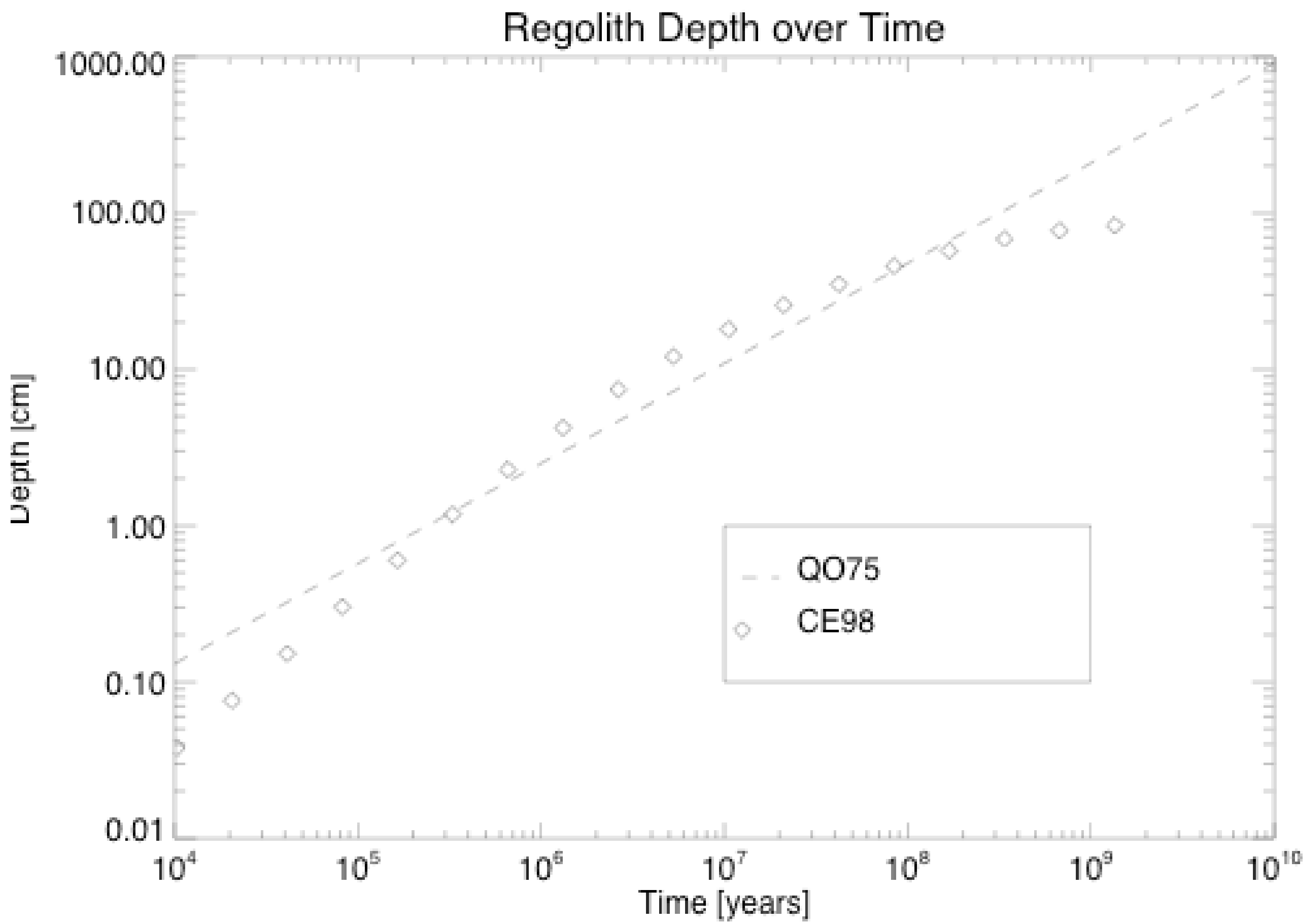
For meter -sized particles, f_p is 0.01 in 10^8 years, a rough upper limit from ring observations at microwave

Estimating ring age from the volume pollution rate

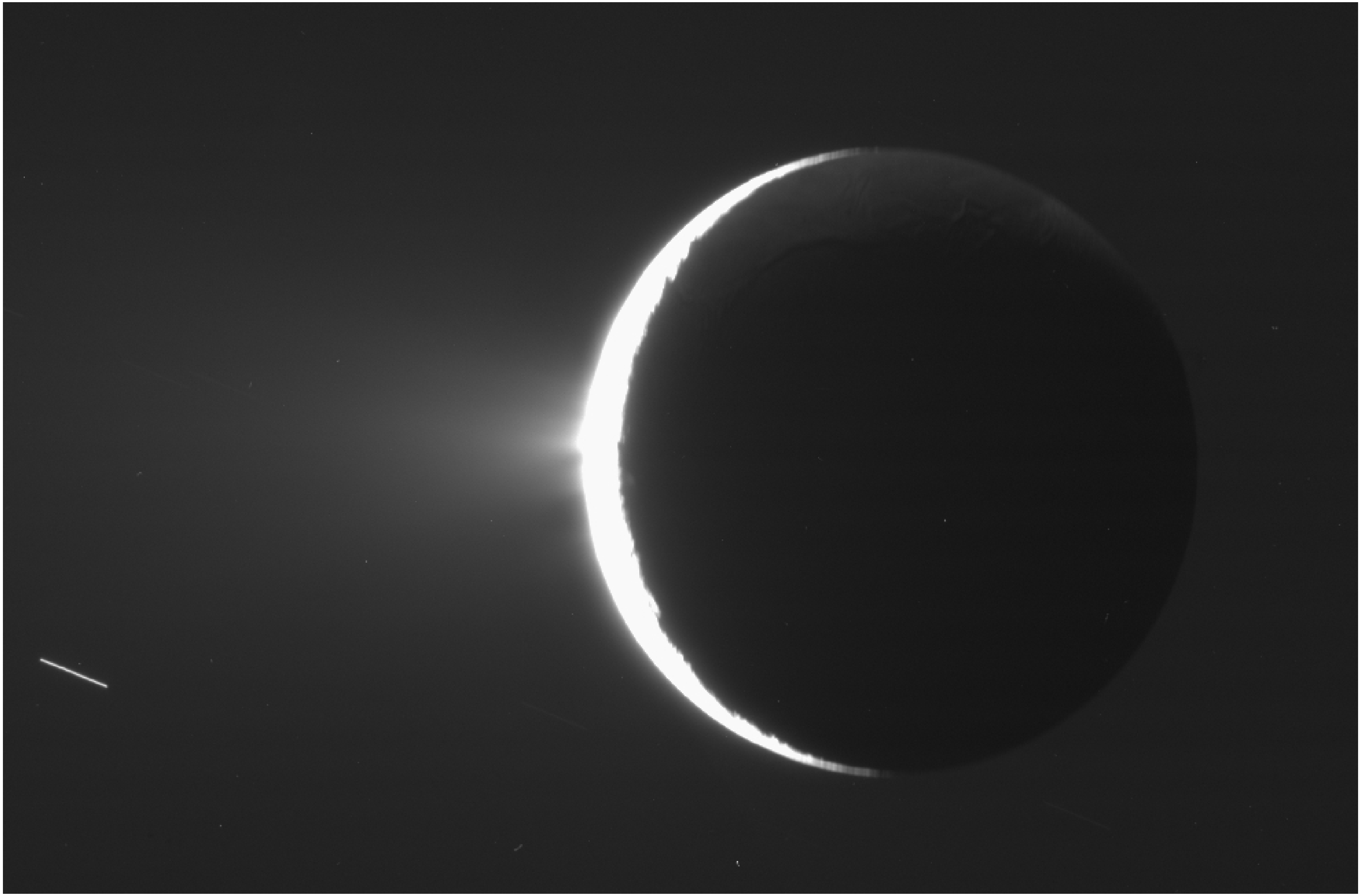
For a ring system with surface mass density, Σ, we have

$$f_p(vol) = \frac{10^{-8}\, g/cm^2/year \cdot t}{\Sigma}$$

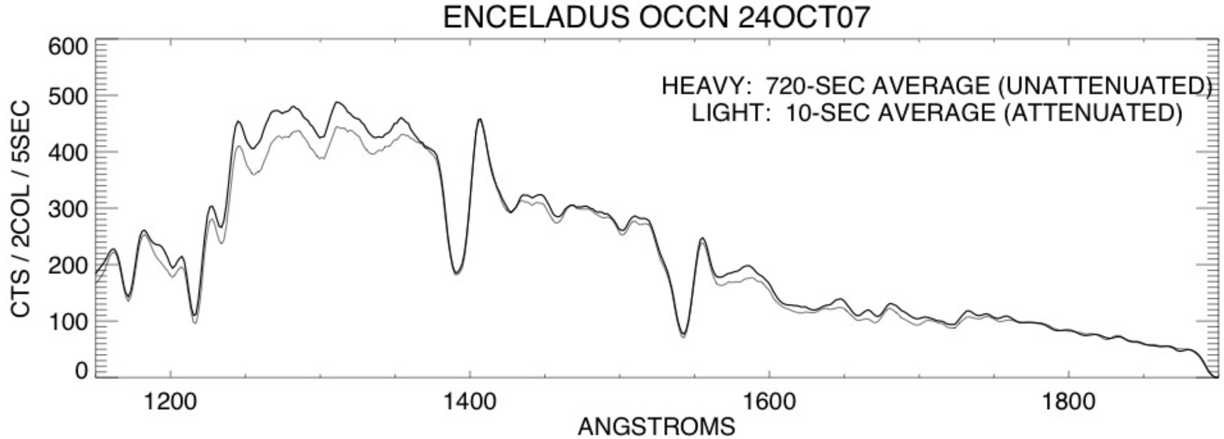
So, f_p(vol) =0.01 and Σ = 100g/cm^2 also gives t=10^8 years, consistent with CE98

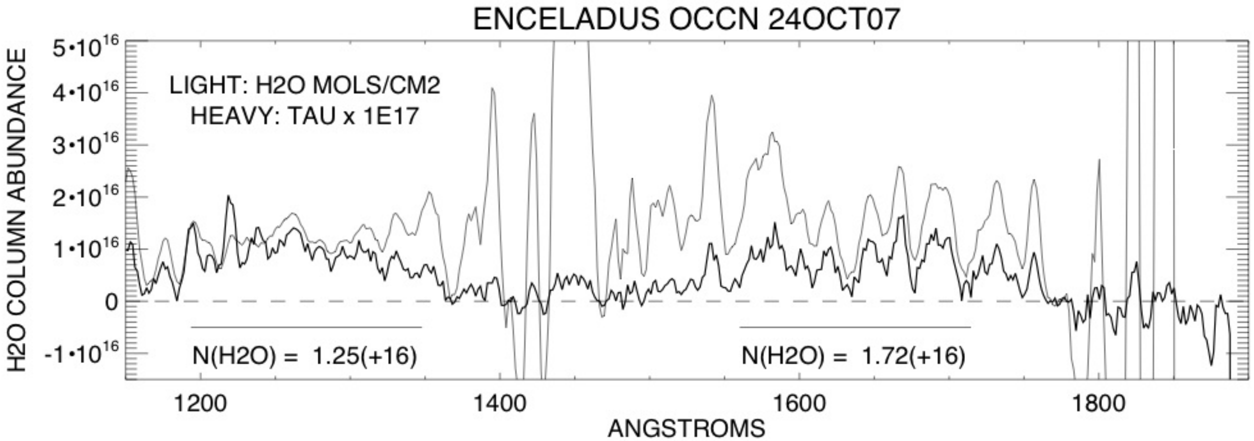


Regolith Depth over Time
1000.00
100.00
10.00
1.00
0.10
0.01
Depth [cm]
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
Time [years]
QO75
CE98



Water column density: FUV



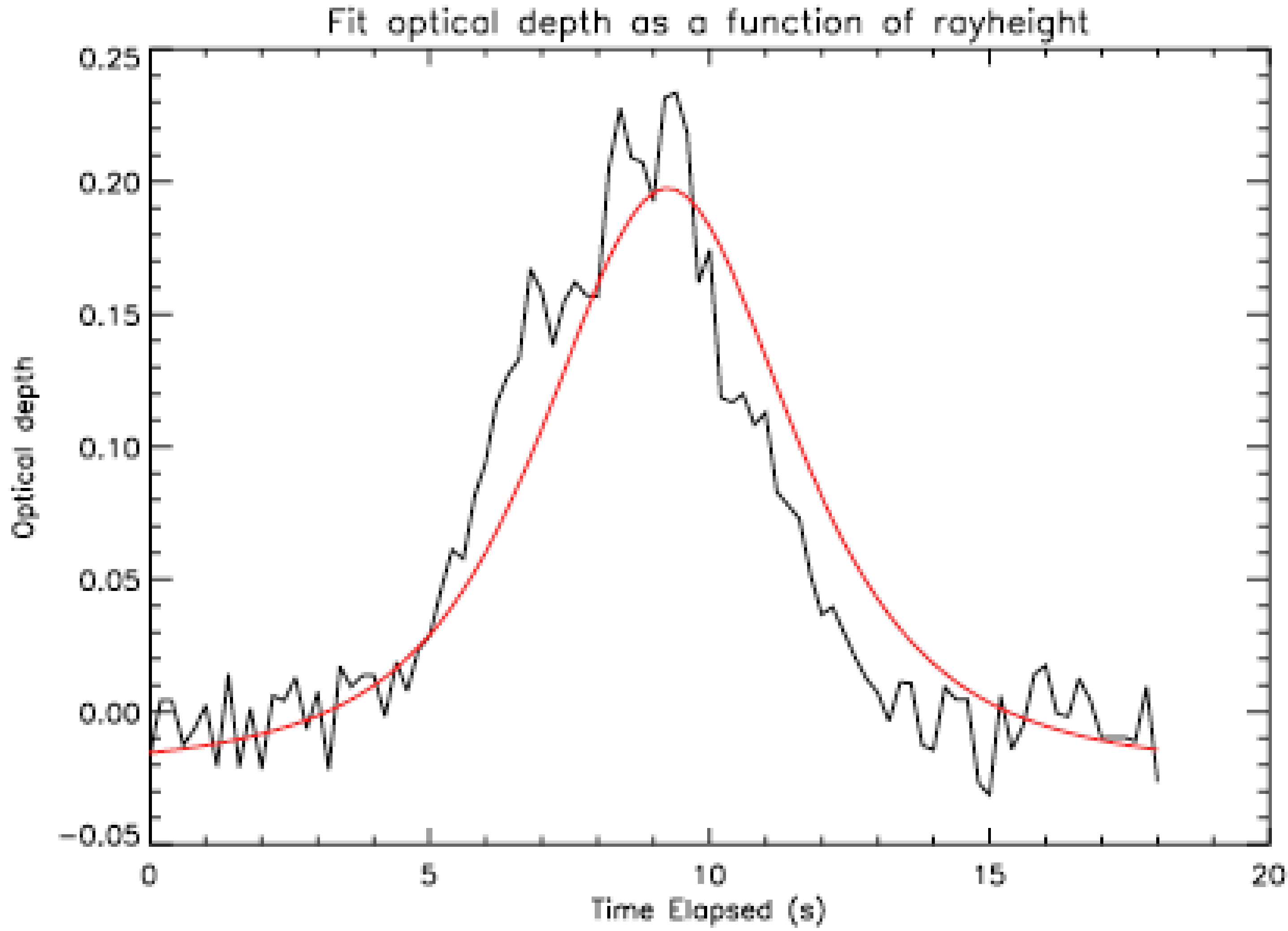


Two occulted time records combined

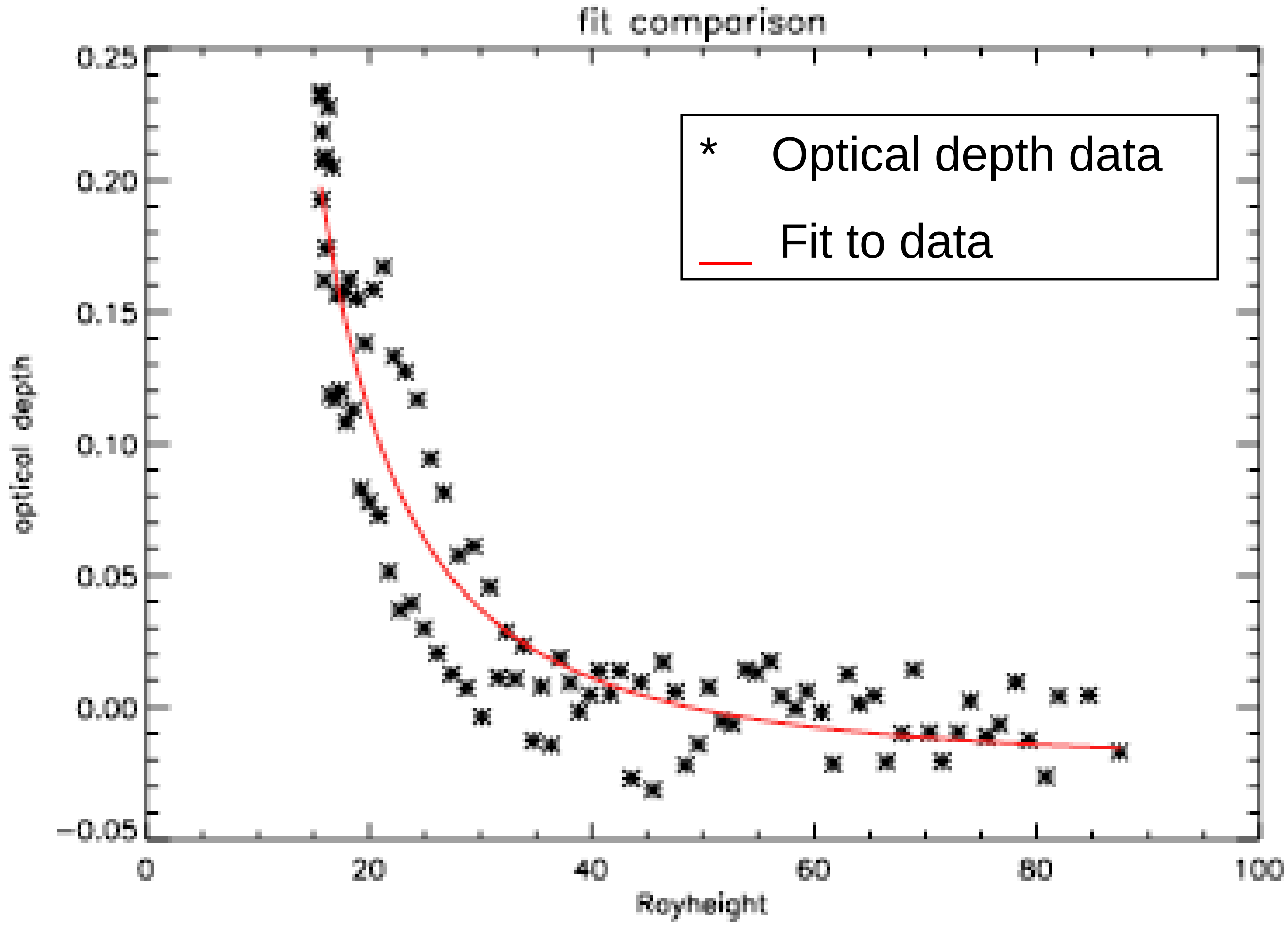
Column density derived from short wavelength region of spectrum and from long wavelength region gives different but similar values

A plausible ring history

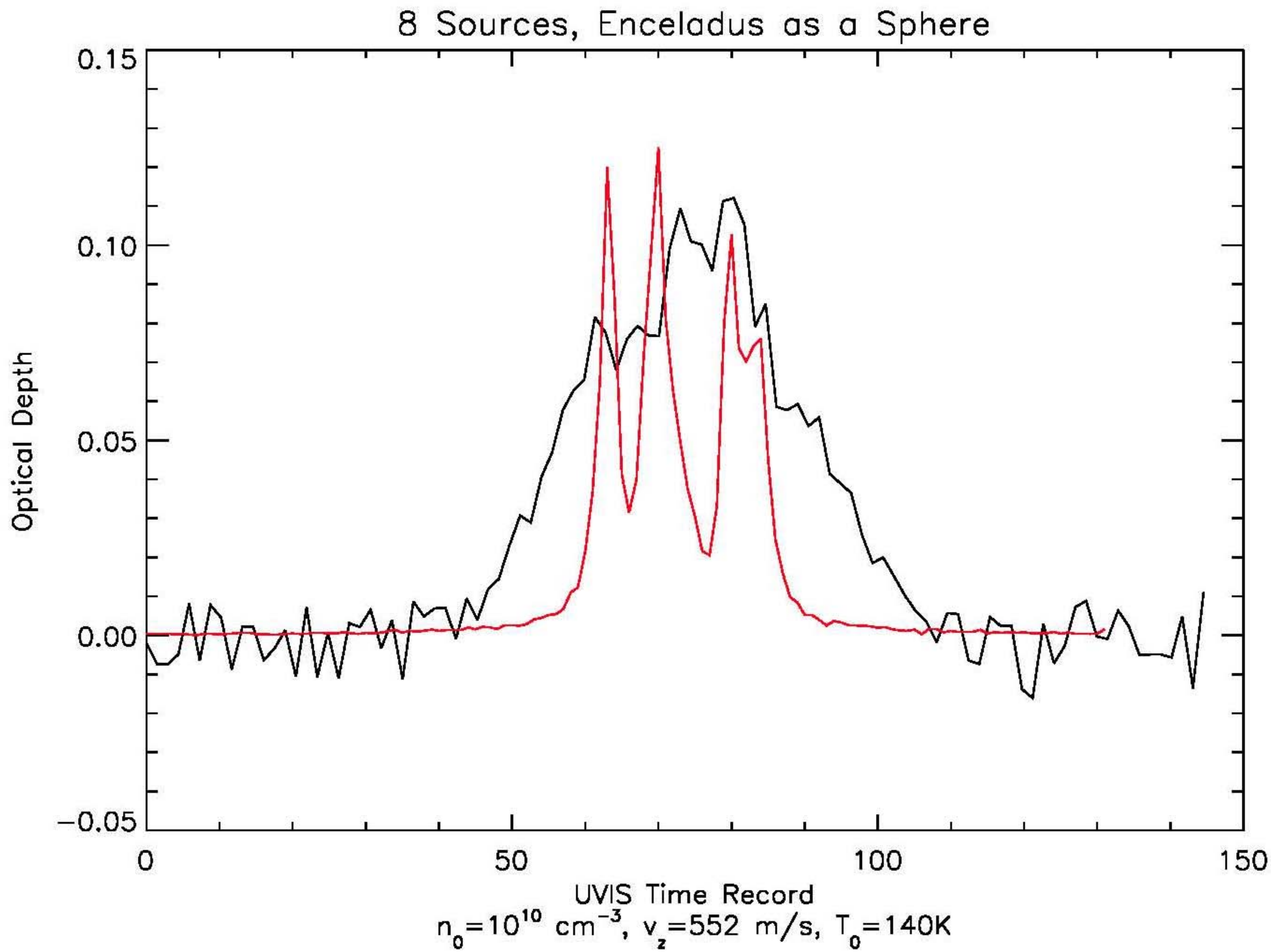
- Interactions between ring particles create temporary aggregations: wakes, clumps, moonlets
- Some grow through fortunate random events that compress, melt or rearrange their elements. Stronger, more compact objects would survive
- Growth rates require only doubling in 10^5 years
- Ongoing recycling resets clocks and reconciles youthful features (size, color, embedded moons) with ancient rings: rings will be around a long time
- Rings can last forever through recycling



$$\tau_{fit} = 54.5\ z^{-2.01} - 0.022$$



$$\tau_{fit} = 54.5\ z^{-2.01} - 0.022$$


8 Sources, Enceladus as a Sphere
Optical Depth
0.15
0.10
0.05
0.00
−0.05
0
50
100
150
UVIS Time Record
$n_0=10^{10}$ cm^{-3}, $v_z=552$ m/s, $T_0=140K$