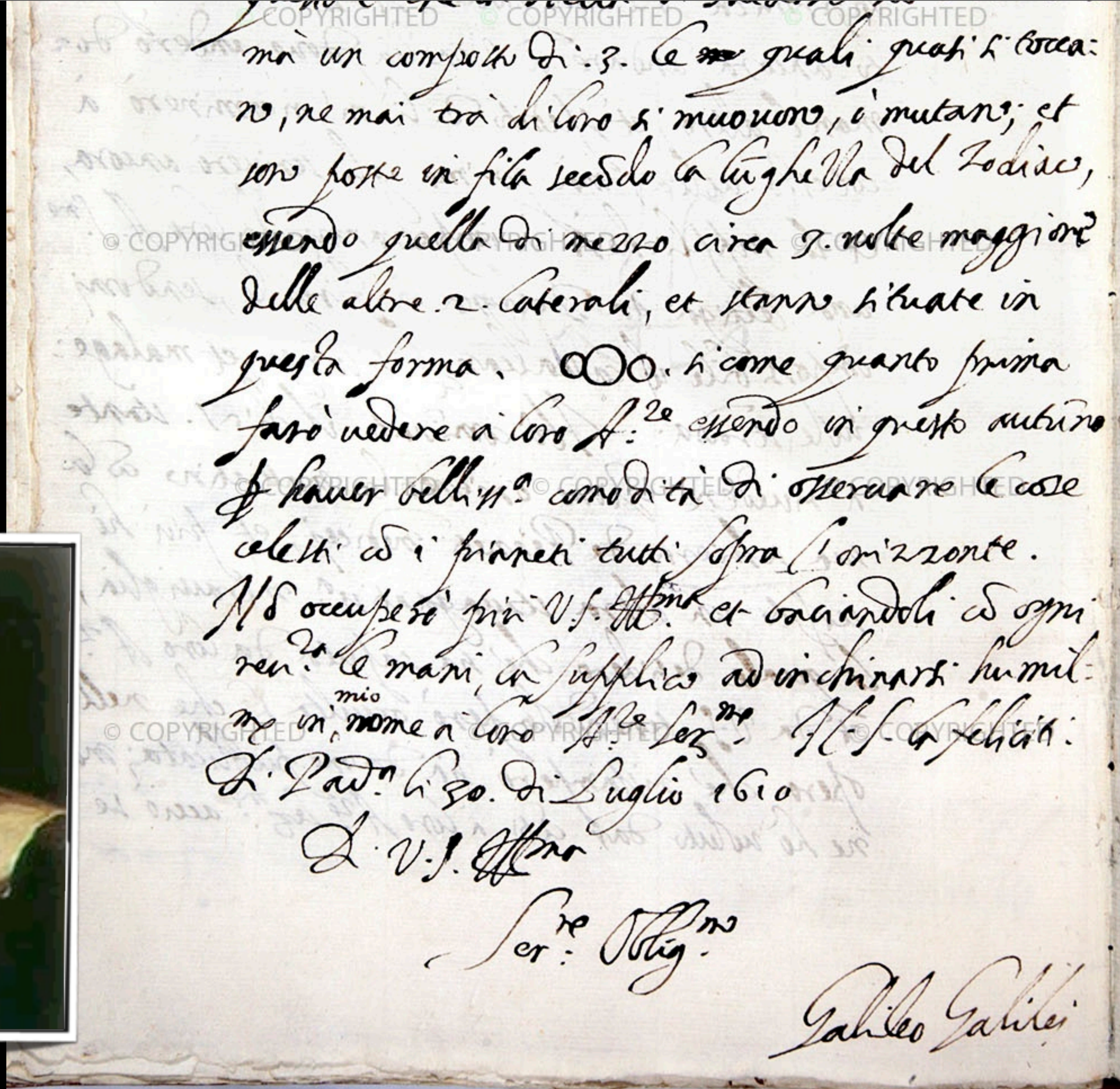
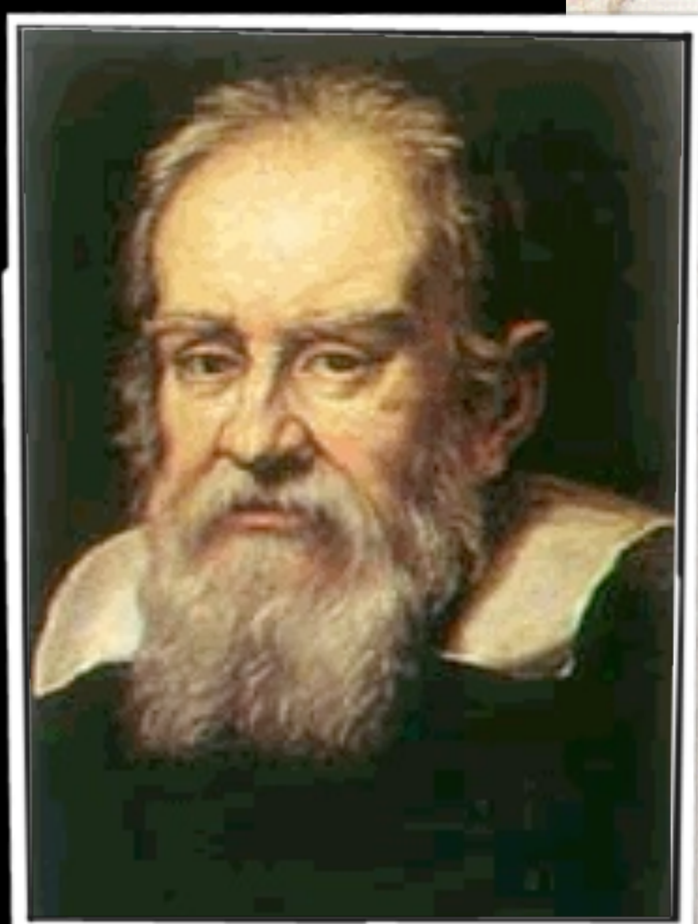
Saturn at Equinox

Mark R. Showalter
SETI Institute

Credit: NASA/STScI/R. G. French, Wellesley

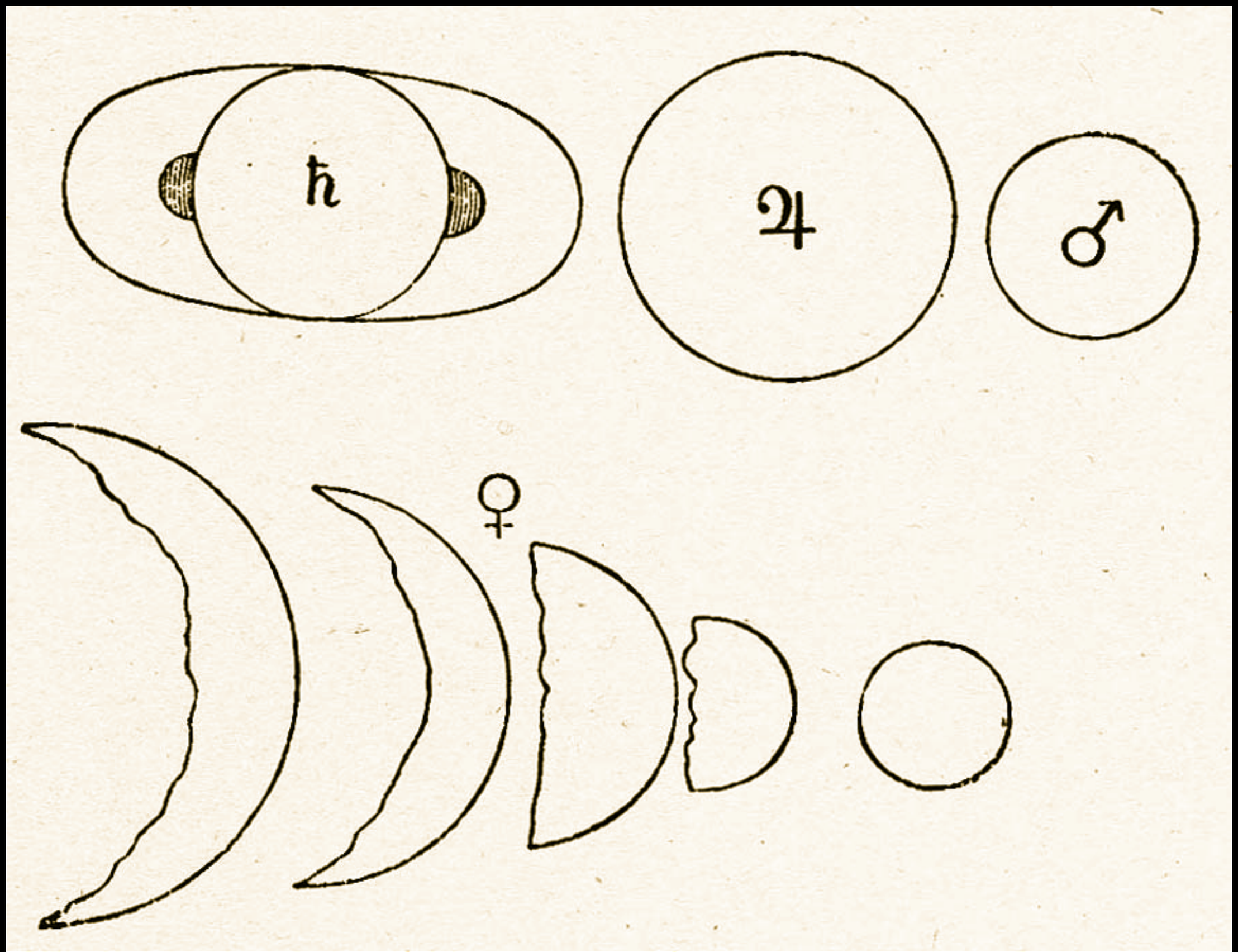
Galileo's Notebooks, 1610


ma un composto di 3. le quali quasi si tocca-
no, ne mai tra di loro si muovono, ò mutano; et
sono poste in fila secondo la lunghezza del Zodiaco,
essendo quella di mezzo circa 3. volte maggiore
delle altre 2. laterali, et stanno situate in
questa forma. oOo. si come quanto prima
farò vedere a loro A.ze essendo in questo autunno
per haver bellissima comodità di osservare le cose
celesti co i pianeti tutti sopra l'orizzonte.
Nè occuperò più V.S. Ill.ma et baciandoli con ogni
reverenza le mani, la supplico ad inchinarmi humil-
mente in mio nome a loro Alt.ze Ser.me N. S. la felicità.
Di Padova li 30. di Luglio 1610
Di V.S. Ill.ma
Ser.re Oblig.mo
Galileo Galilei



no, ne mai tra di loro si muovono, o muta
sono poste in fila secondo la lunghezza del Z
essendo quella di mezzo circa 3. volte m
delle altre .2. laterali, et stanno situat
questa forma. oOo. si come quanto p
farò vedere a loro A.ze essendo in questo
per haver bellissima commodità di osservare
celesti co i pianeti tutti sopra l'orizzon
ld occuperò più V.S. Ill.ma et baciandoli

Galileo, Il Saggiatore, 1623 (The Assayer)

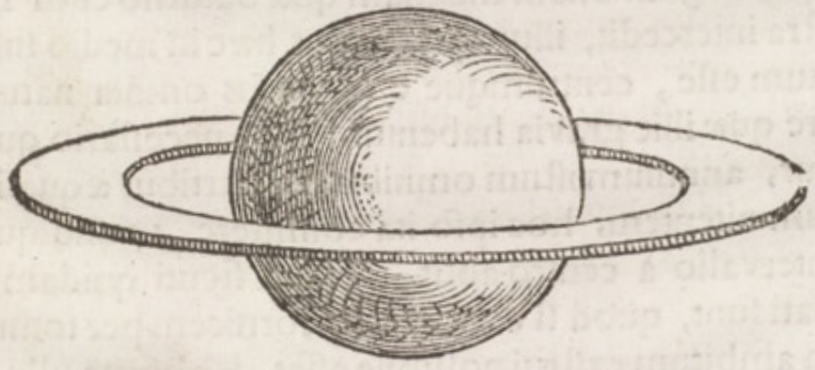


Christiaan Huygens

Systema Saturnium, 1659

ea quam dixi annuli inclinatione, omnes mirabiles Saturni facies ſicut mox demonſtrabitur, eo referri poſſe inveni. Et hæc ea ipſa hypotheſis eſt quam anno 1656 die 25 Martij permixtis literis una cum obſervatione Saturniæ Lunæ edidimus.

Erant enim Literæ a a a a a a a c c c c c d e e e e e g h i i i i i i i l l l l m m n n n n n n n n n o o o o p p q r r s t t t t t u u u u u u; quæ ſuis locis repoſitæ hoc ſignificant, *Annulo cingitur, tenui, plano, nuſquam cohærente, ad eclipticam inclinato.* Latitudinem vero ſpatij inter annulum globumque Saturni interjecti, æquare ipſius annuli latitudinem vel excedere etiam, figura Saturni ab aliis obſervata, certiuſque deinde quæ mihi ipſi conſpecta fuit, edocuit: maximamque item annuli diametrum eam circiter rationem habere ad diametrum Saturni quæ eſt 9 ad 4. Ut vera proinde forma ſit ejuſmodi qualem appoſito ſchemate adumbravimus.



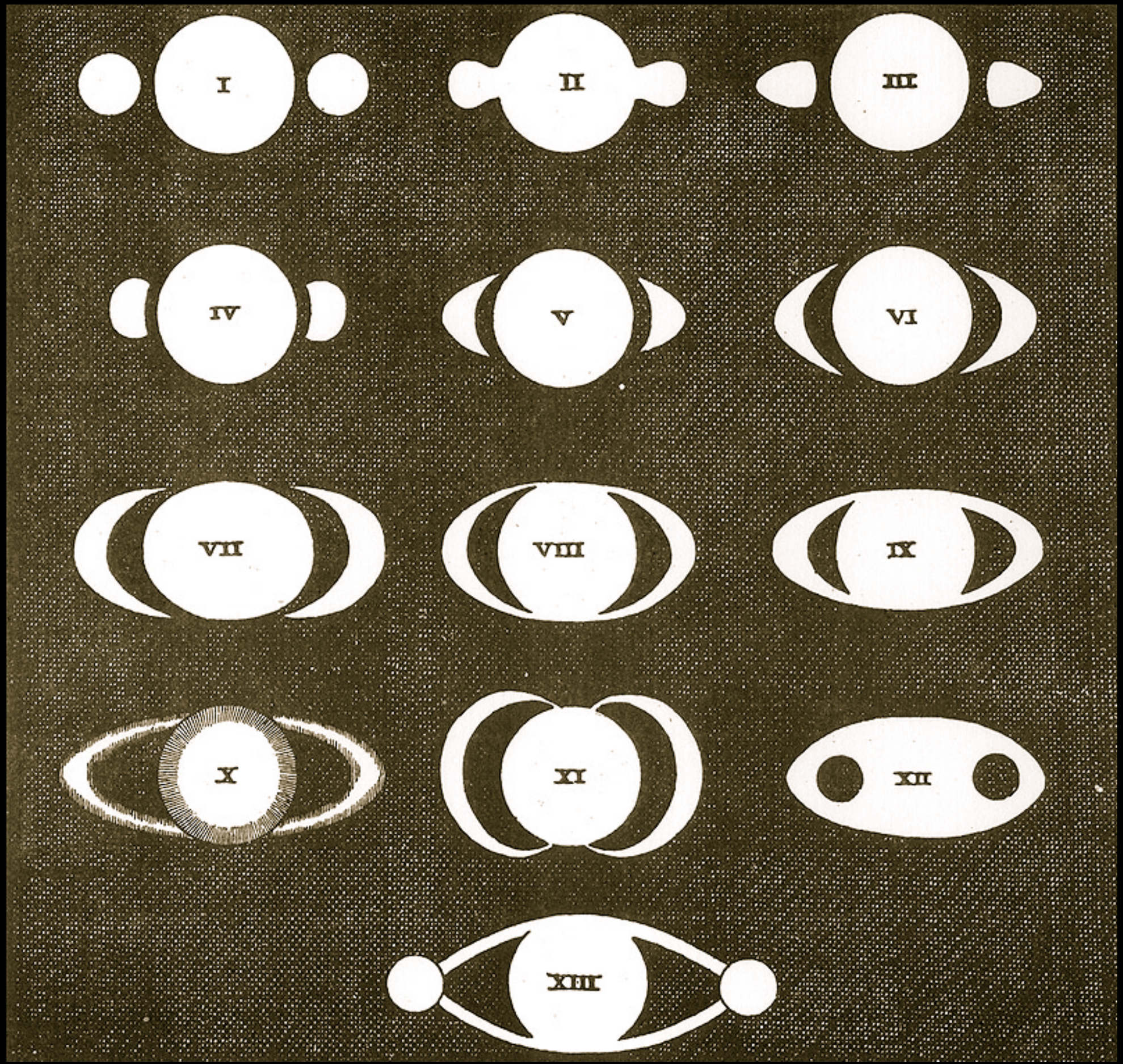
Cæterum obiter hic iis reſpondendum cenſeo, quibus novum nimis ac fortaſſe abſonum videbitur, quod non tantum alicui cæleſtium corporum figuram ejuſmodi tribuam, cui ſimilis in nullo hactenus eorum deprehenſa eſt, cum contra pro certo creditum fuerit, ac veluti naturali ratione conſtitutum, ſolam iis ſphæricam convenire, ſed & quod annulum

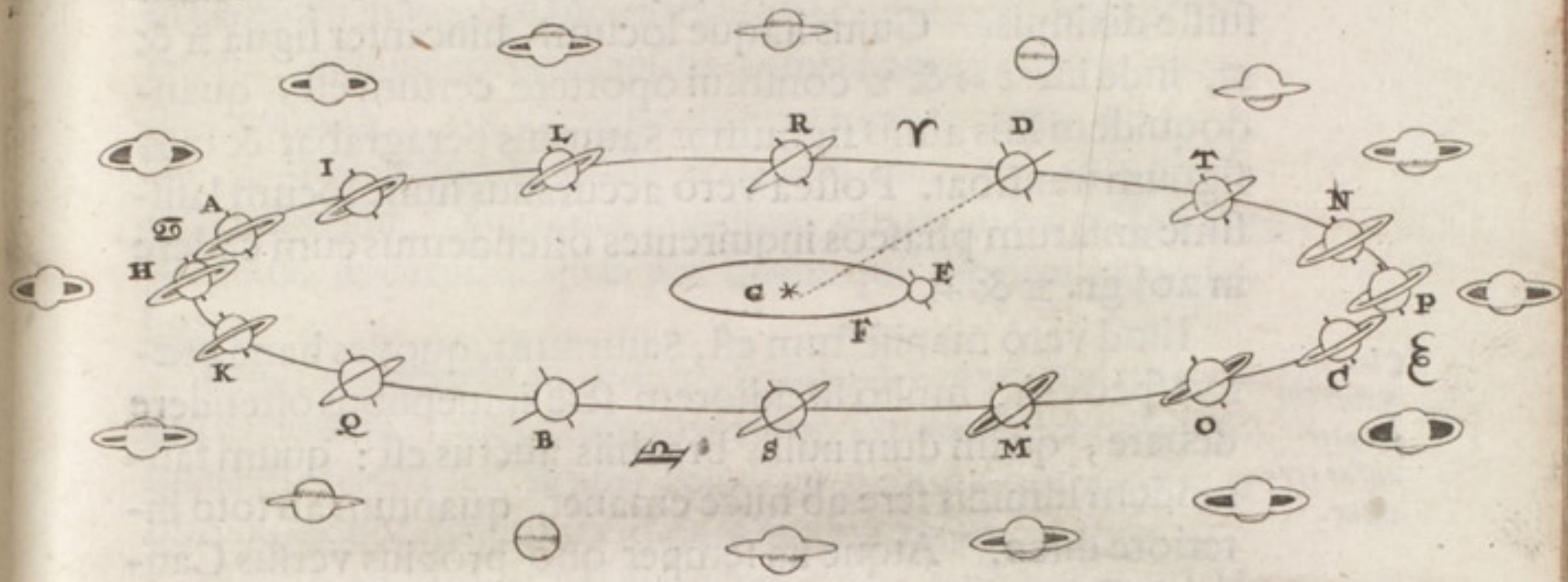
Occurritur iis quæ de annulo objici poſſent.

Erant enim Literæ a a a a a a a c c c c c c d e e e e e e g h i i i i i i i l l l l l m m n n n n n n n n n n o o o o p p q r r s t t t t t u u u u u u; quæ ſuis locis repoſitæ hoc ſignificant, *Annulo cingitur, tenui, plano, nuſquam cohærente, ad eclipticam inclinato.* Latitudinem vero ſpatij inter annulum globum-

The ring
encircles,
is thin,
planar,
nowhere connected,
and inclined to the ecliptic.

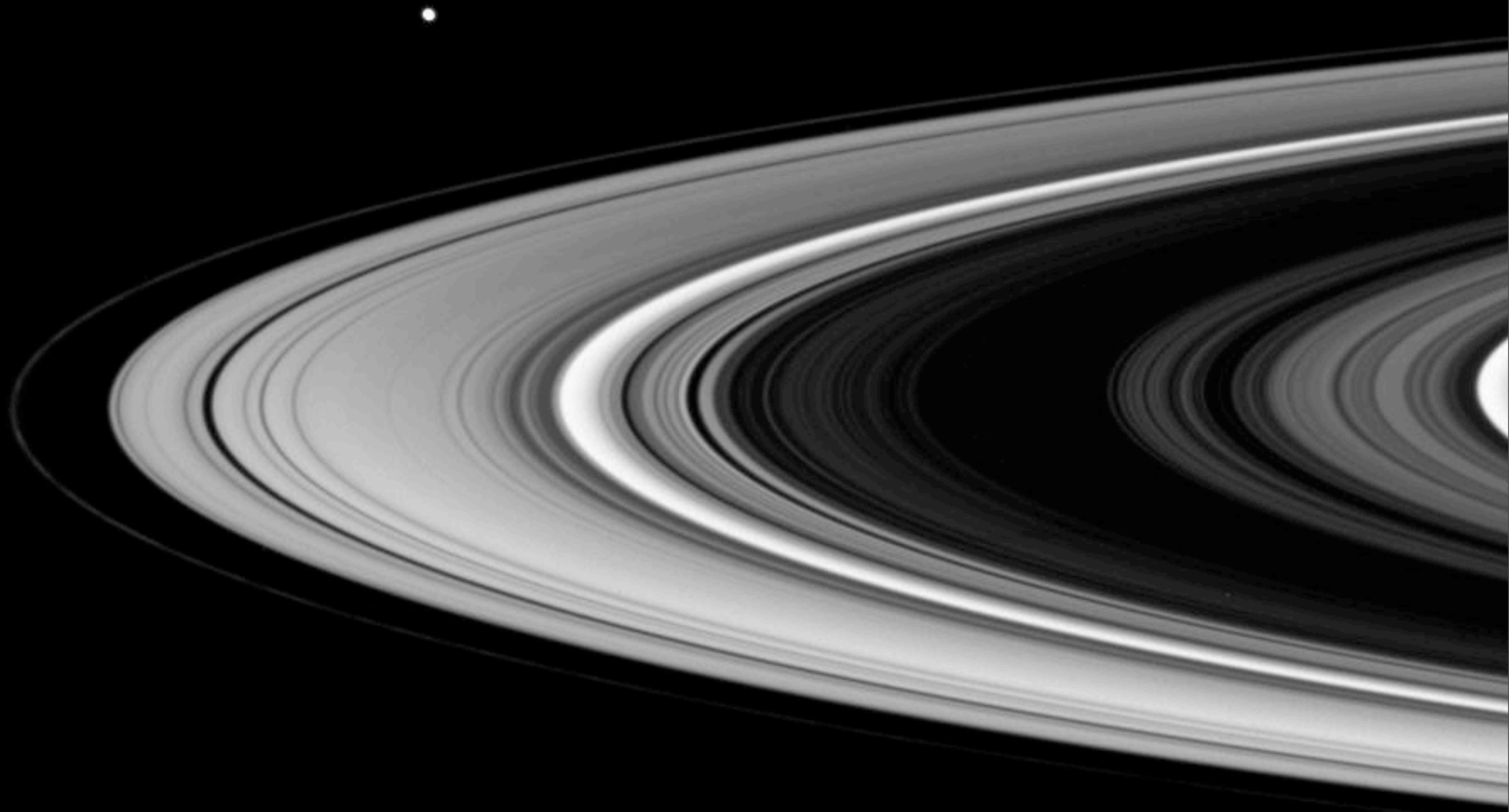
— Christiaan Huygens, 1659


I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII



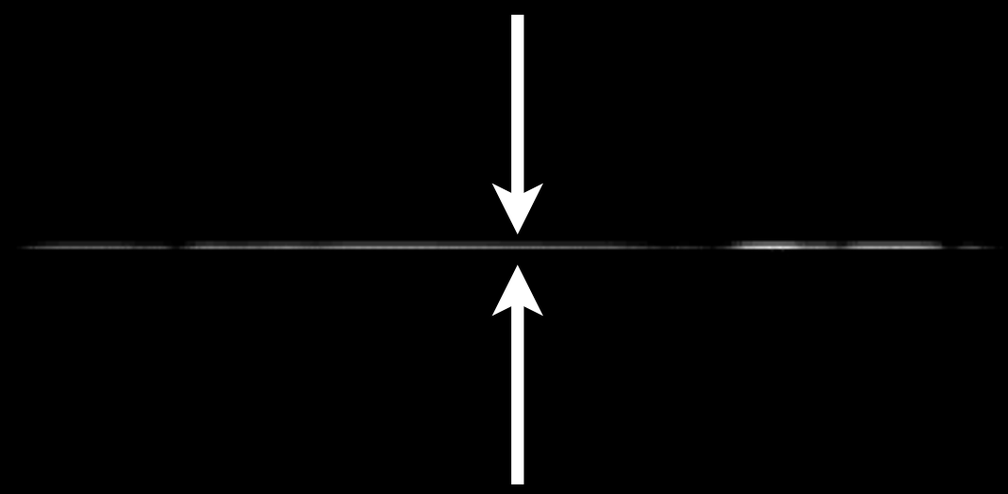
Cujus phaſeos vera proinde forma, ſecundum ea quæ ſupra circa annulum definivimus, ejuſmodi erit qualis hîc delineata cernitur, majori ellipſis diametro ad minorem ſe

Ring Thickness

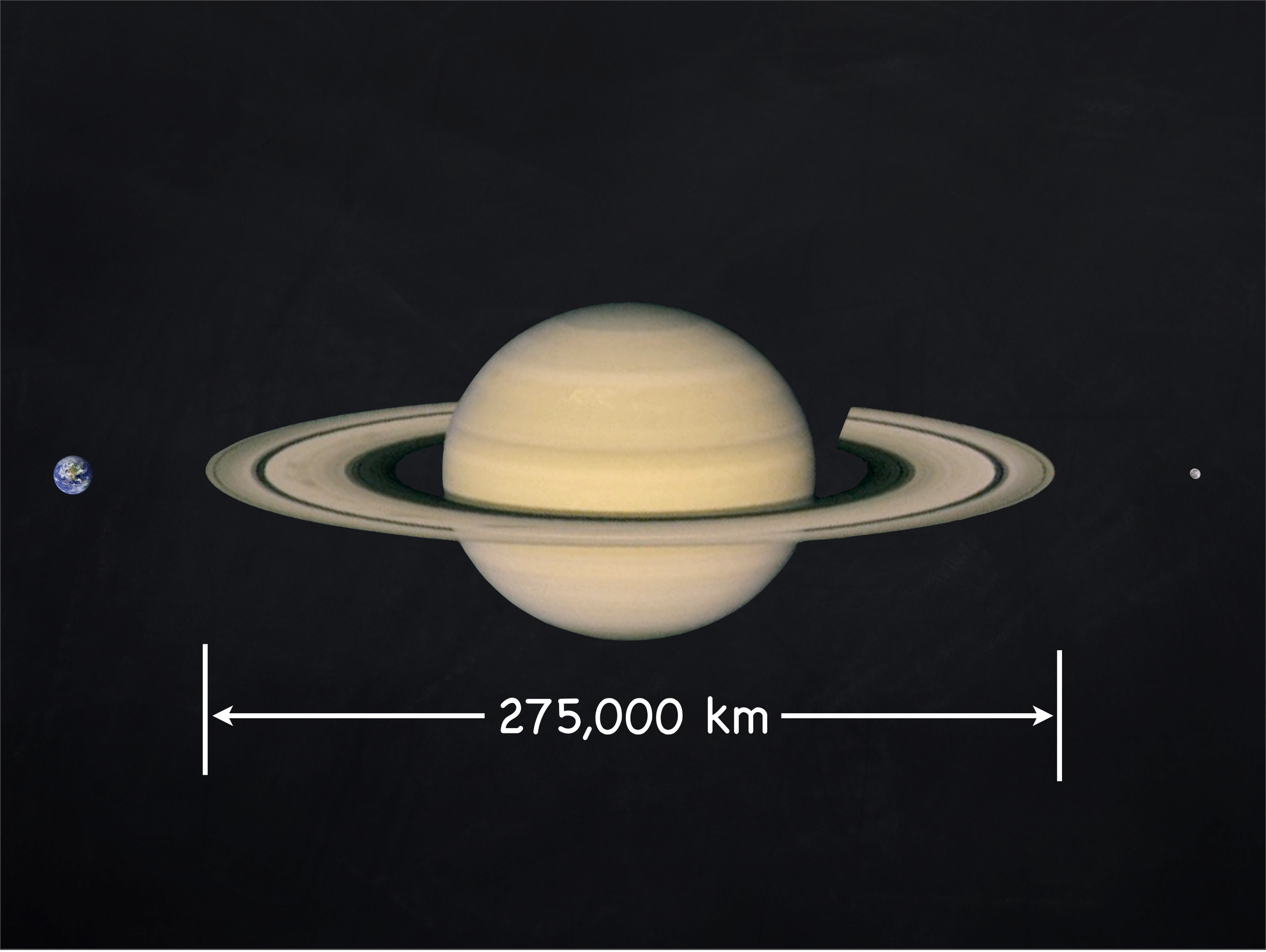


http://photojournal.jpl.nasa.gov/catalog/PIA08356

Ring Thickness



Cassini ISS, PIA08356


275,000 km

Q. Why do equinoxes matter?

A. We get to see phenomena normally lost in the glare of the main rings.
   - Small satellites
   - Faint rings

A. We get to examine the vertical structure of the rings.
   - Thickness
   - Warps & bending waves

A. Satellite shadows, occultations, mutual events.

1966: Saturn's E Ring

NATURE, VOL. 214, MAY 20, 1967

LETTERS TO THE EDITOR

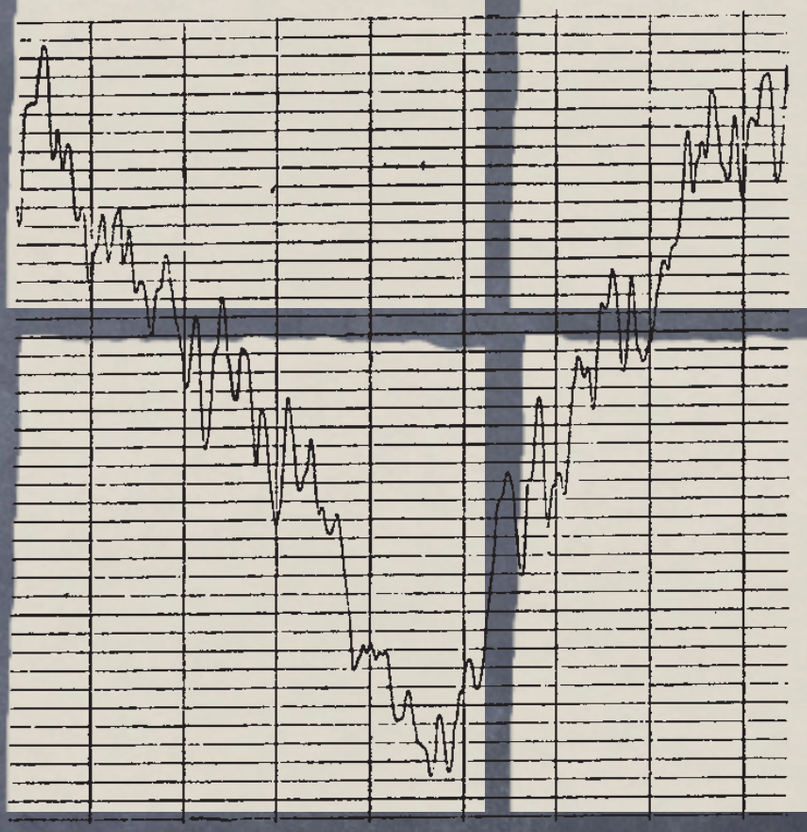
ASTRONOMY

Concerning the "*D*" Ring of Saturn

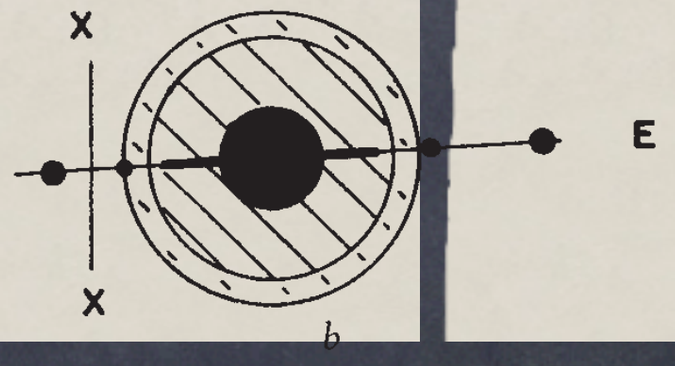
In his excellent chronological review book of observations, *The Planet Saturn*, Alexander[1] compares the outer, "*D*" ring of Saturn to the Loch Ness Monster: some see it, and some do not. During the second half of the nineteenth century a number of visual observations were reported by experienced observers but the issue seems to have been settled by Barnard[2] in 1909, using the 40 in. Yerkes refractor visually and getting negative results. Apparently few, if any, attempts have been made photographically to detect a ring outside the well known *A*, *B* and *C* rings.

The recent edge-on configuration of the ring system was an appropriate time to investigate the problem of the hypothetical "*D*" ring photographically. It is known that when seen nearly edge-on, the *A* ring, normally fainter than the *B* ring, can sometimes appear brighter than *B*. Similarly, an outer "*D*" ring might appear relatively bright at the time, while when in the open position it may be completely unobservable.

Although there are theoretical arguments against the existence of an outer "*D*" ring, for example, the sweeping effect of the inner moons (compare (Alfven[3]), there is at



a



b

Fig. 2. *a*, Microdensitometer trace along path *X*–*X* of Fig. 2*b*. Expo time, 5 min, December 12, 1966. Other data as in Fig. 1*a*. *b*, Aspec

1966: Janus

Circular No. 1987

Central Bureau for Astronomical Telegrams
INTERNATIONAL ASTRONOMICAL UNION
Postal Address: Central Bureau for Astronomical Telegrams
Smithsonian Astrophysical Observatory, Cambridge, MA 02138, U.S.A.
Cable Address: SATELLITES, NEWYORK
Western Union: RAPID SATELLITE CAMBMASS

PROBABLE NEW SATELLITE OF SATURN

Dr. Audouin Dollfus, Meudon Observatory, reports the discovery of a probable new satellite of Saturn. The satellite, of magnitude 14, is very close to the edge of the ring and moves in an orbit of estimated diameter 315 000 km. The provisional revolution period is 18 hours. The object was observed on three plate: at eastern elongation on December 15 and at western elongatin on December 16 and 17. Dr. Dollfus states that further observations are needed.

COMET RUDNICKI (1966e)

Dr. Axel V. Nielsen, Ole Romer Observatory, points out that at its descending node Comet Rudnicki passes very near the orbit of the earth. Its heliocentric distance would then be 1.02 AU. He suggests the possibility of observing meteors associated with the comet on about 1967 June 7.

Further precise positions have been reported as follows:

1966 UT	R.A. (1950)	Decl.	Mag.	Observer
Nov. 16.81487	1 13 14.71	- 6 54 55.1		Milet
16.82318	1 13 12.28	- 6 55 08.3		"
Dec. 1.03499	0 06 33.99	-11 24 24.3	9.0	Pereyra

1979: Epimetheus, Helene, Telesto, Calypso

ICARUS 47, 288–290 (1981)

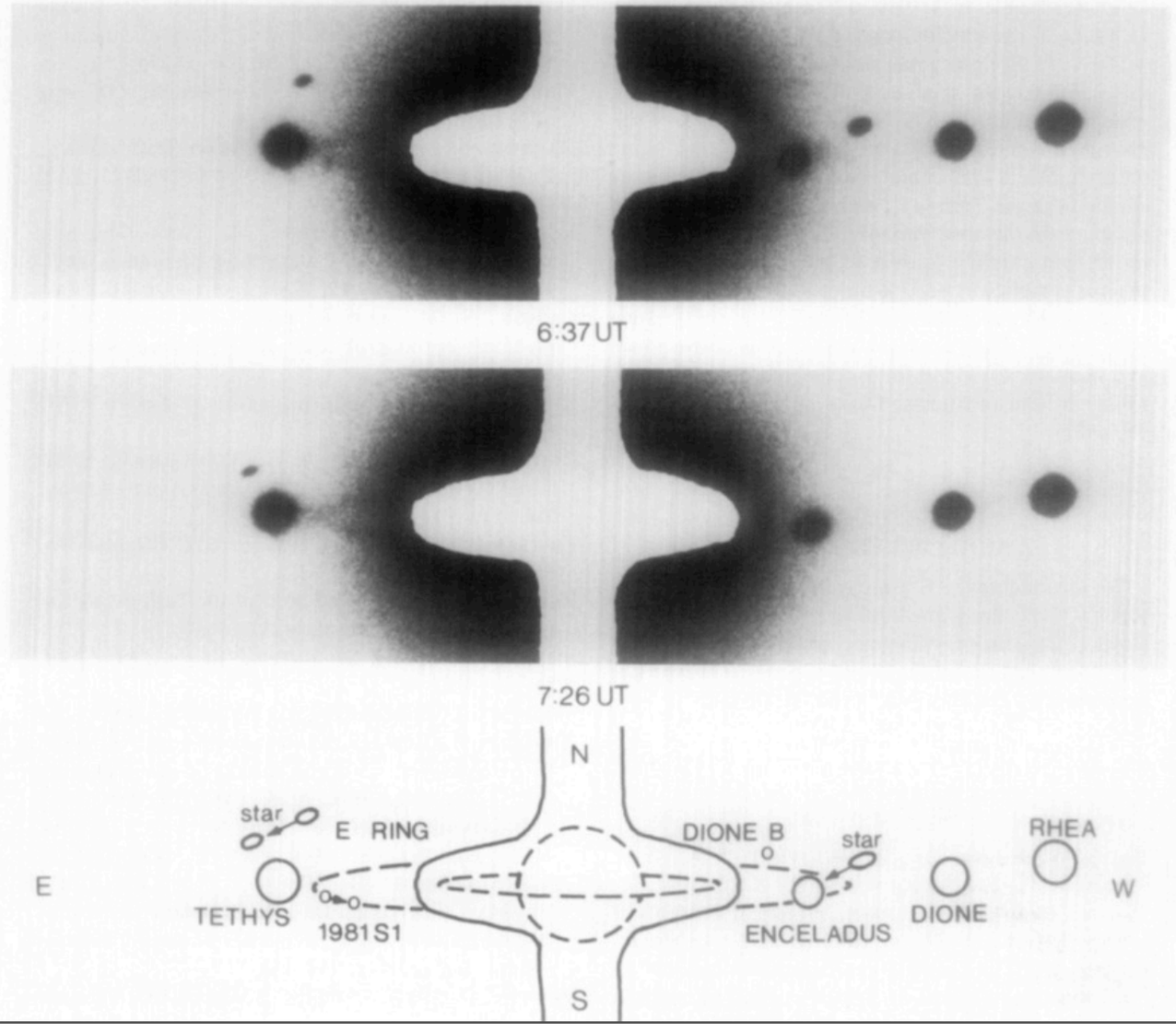
NOTES

Observations of the Saturn E Ring and a New Satellite

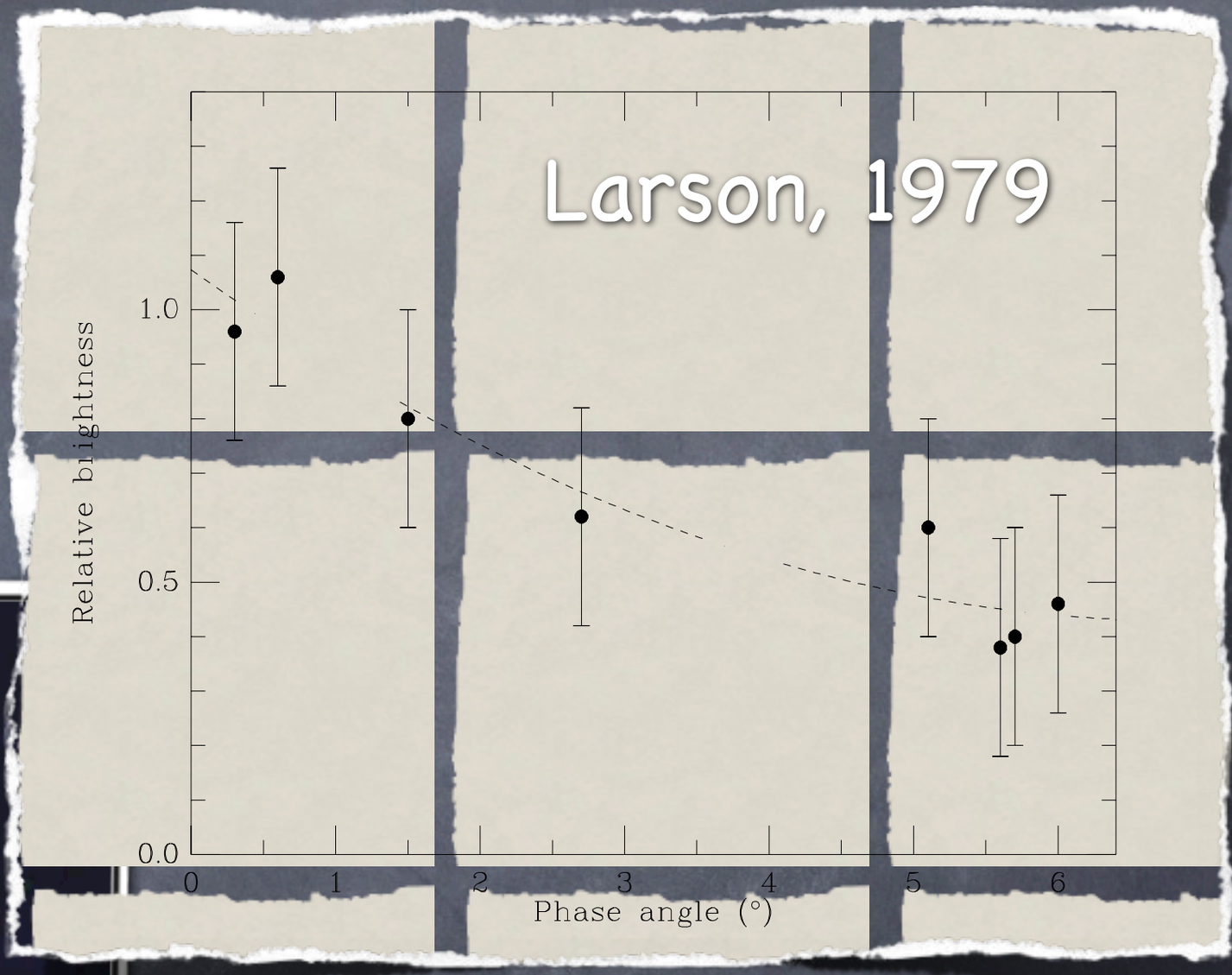
S. M. LARSON, J. W. FOUNTAIN, B. A. SMITH, AND H. J. REITSEMA

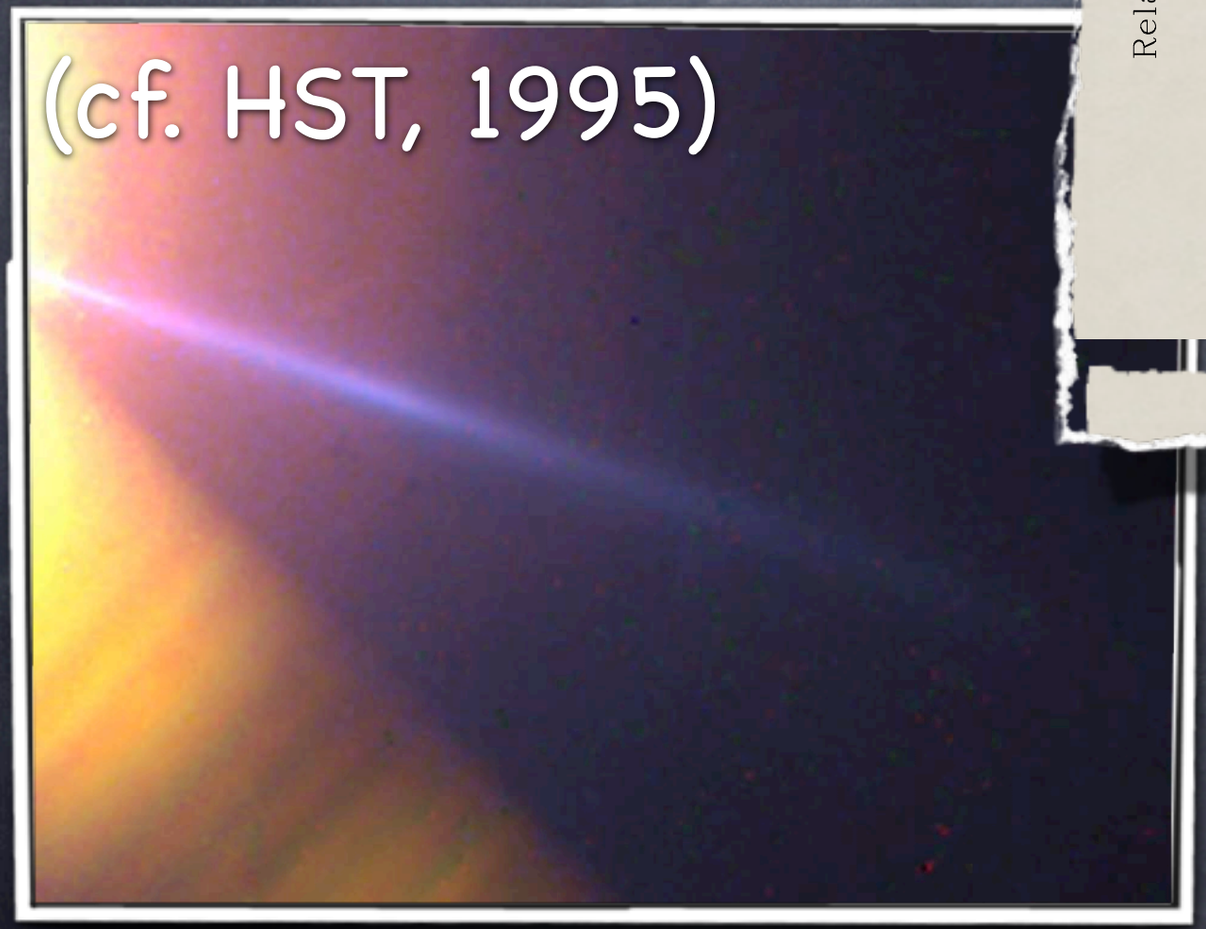
Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona 85721

Received May 22, 1981; revised June 29, 1981



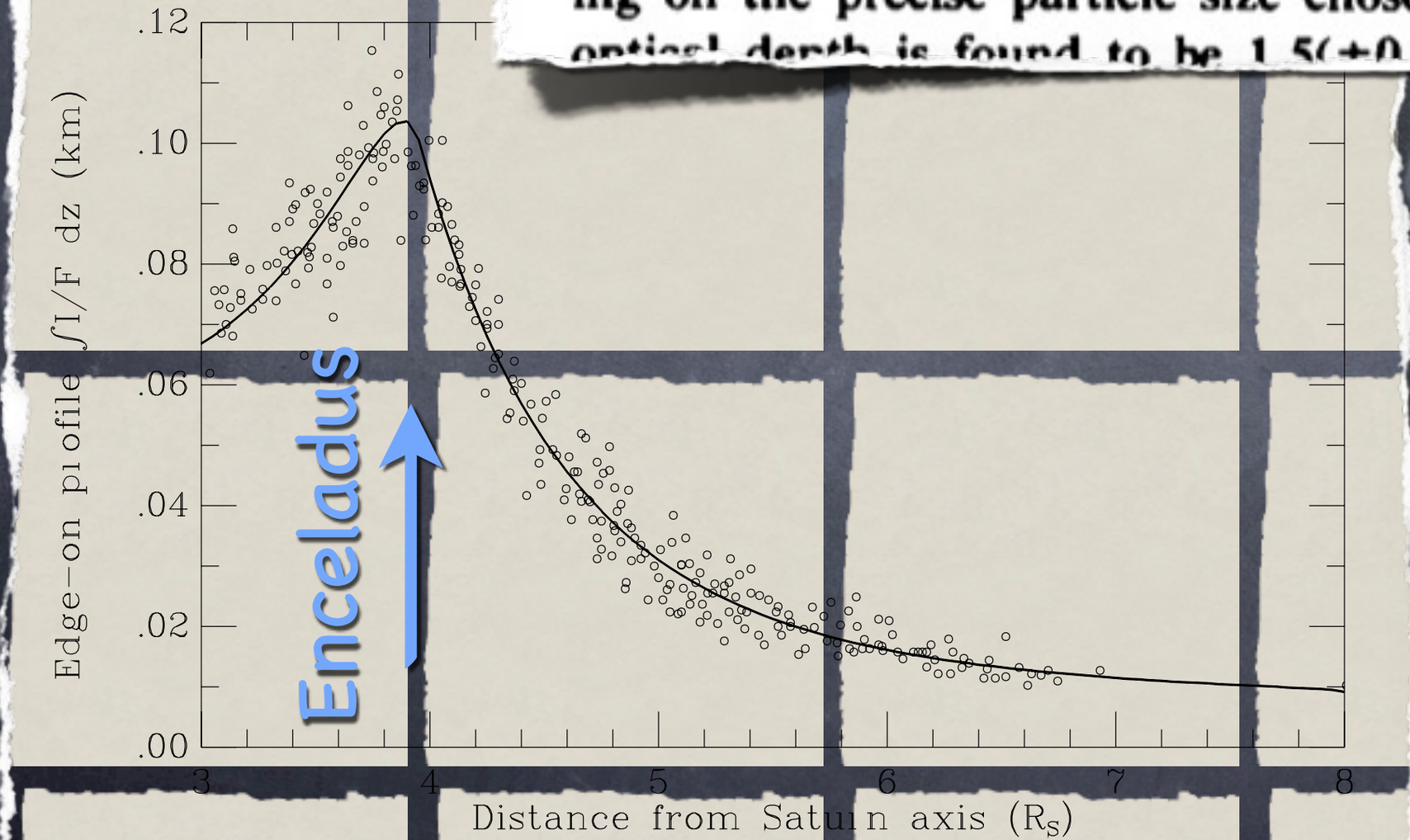
1979: The E Ring is Blue!





1979: E Ring's Connection to Enceladus

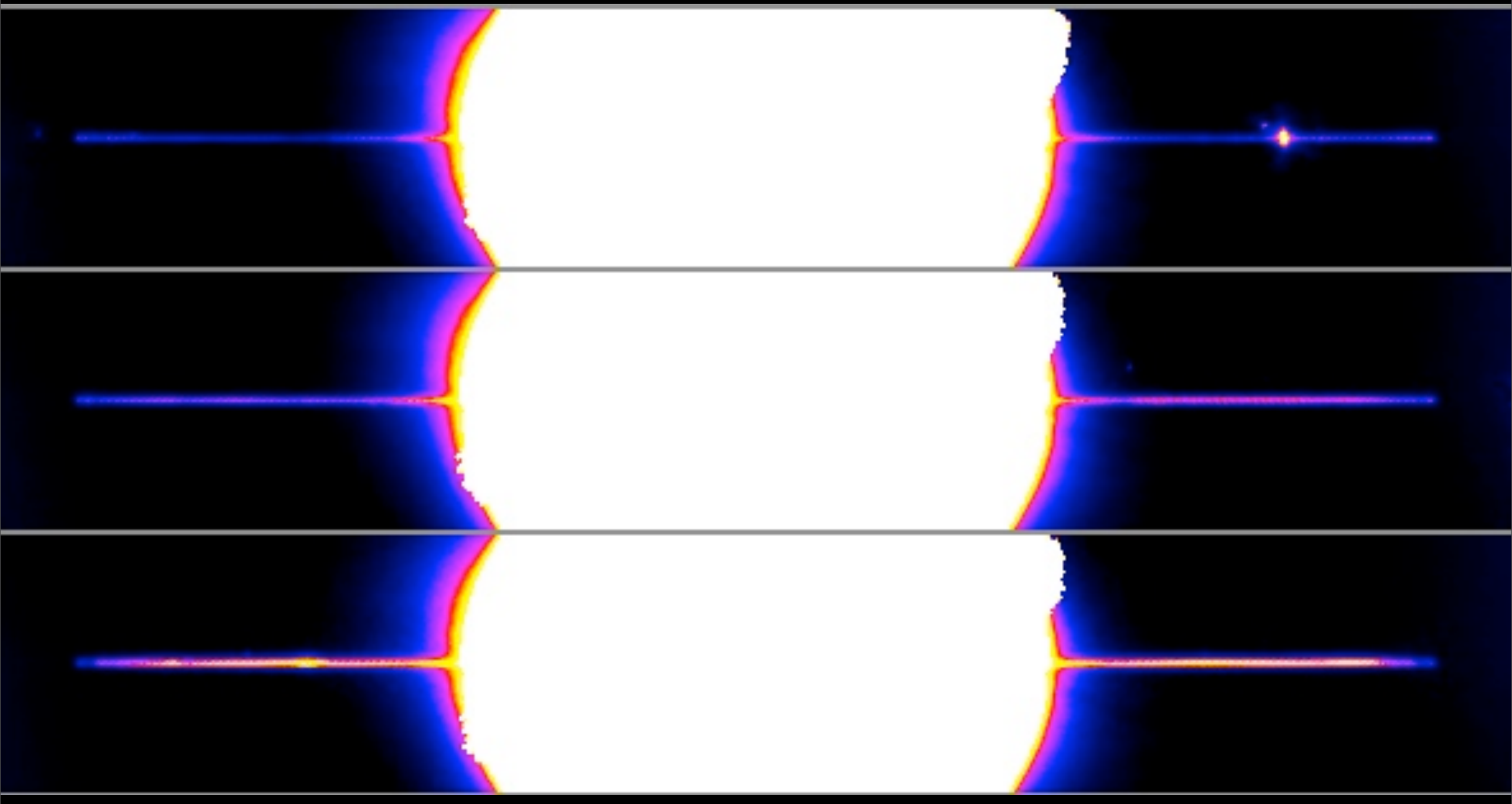
does not originate from collisional or disruptive processes, and is therefore unlike any other known ring. Hence, we can give some credence to the possibility that the E Ring originates in "geyser-like" eruptions from the surface of Enceladus. Depending on the precise particle size chosen, the ring's peak normal optical depth is found to be 1.5(±0.4) × 10⁻⁵



Showalter et al 1991. Icarus **94**, 451-473.

November 27, 2005
Cassini ISS, PIA07758

1995: Warps in the Ring Plane



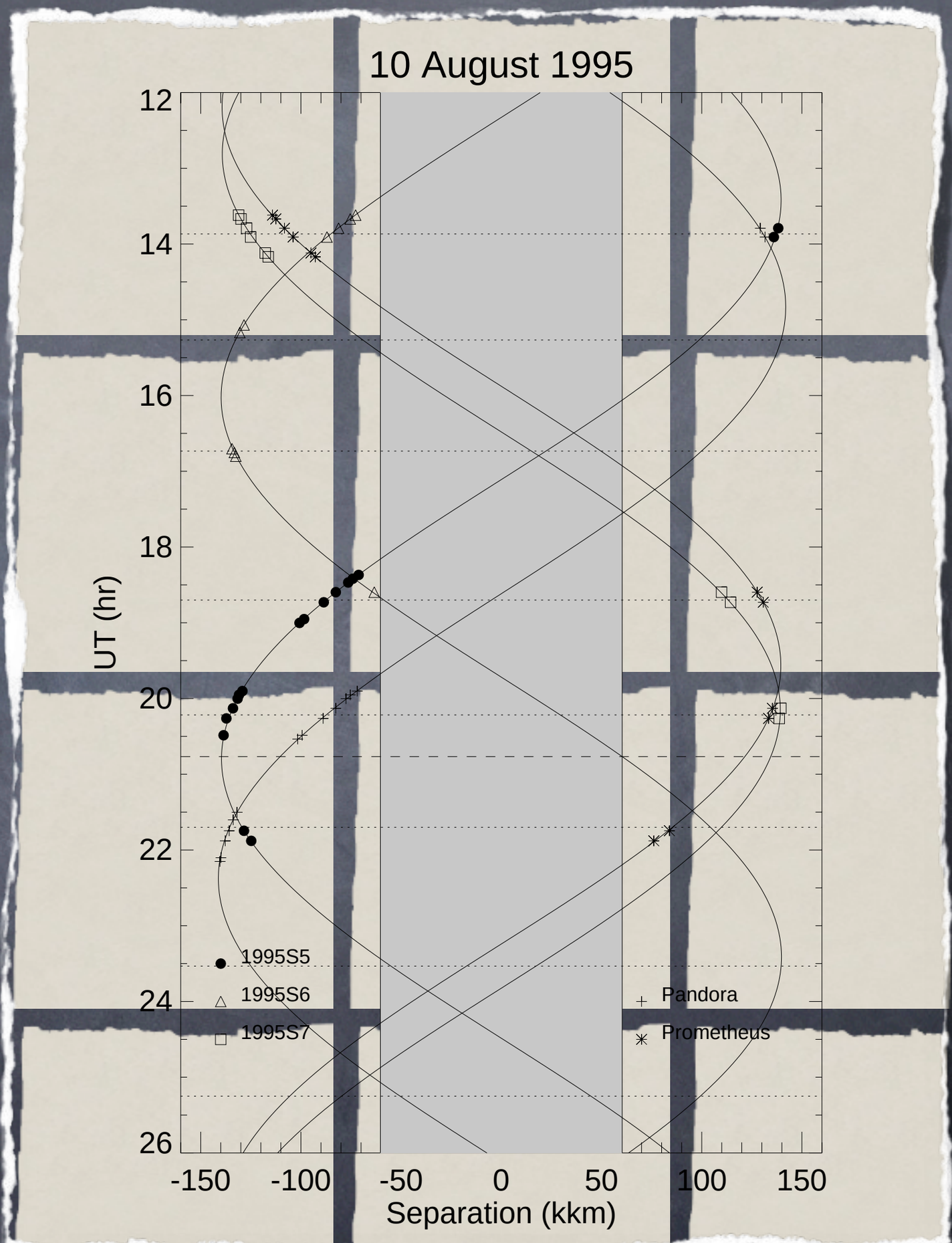
Credit: NASA/STScI/P. D. Nicholson, Cornell

1995: Vertical thickness of the F Ring

Image Credit: NASA/STScI/P. D. Nicholson, Cornell

1995:

- Chaotic interaction between Prometheus and Pandora.
- Dispersion of the F Ring's clumps.



Nicholson et al., 1996. Science 272, 453–616

Earth-based Discoveries

- 1966
  - E Ring
  - Janus

13 y

- 1979–1980
  - Epimetheus, Helene, Telesto, Calypso
  - E Ring color & association with Enceladus

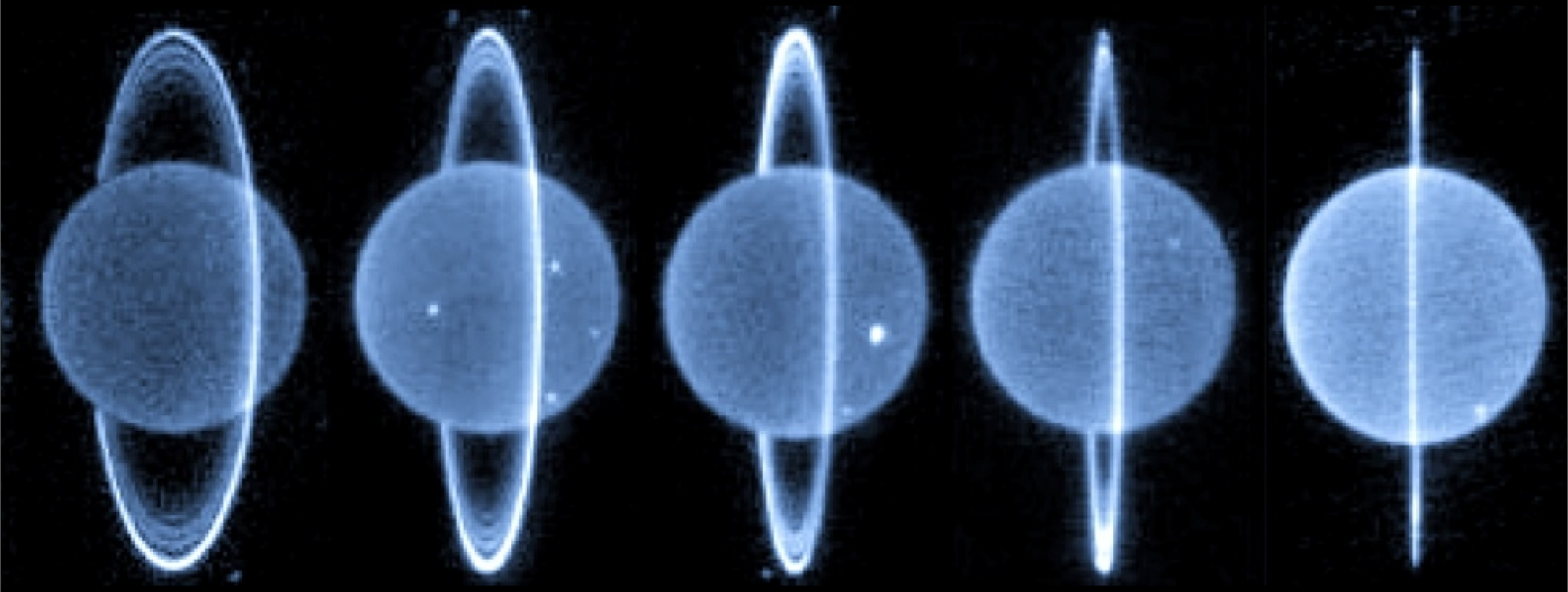
16 y

- 1995
  - Prometheus/Pandora chaotic interactions
  - Vertical warps in the ring plane
  - F Ring thickness

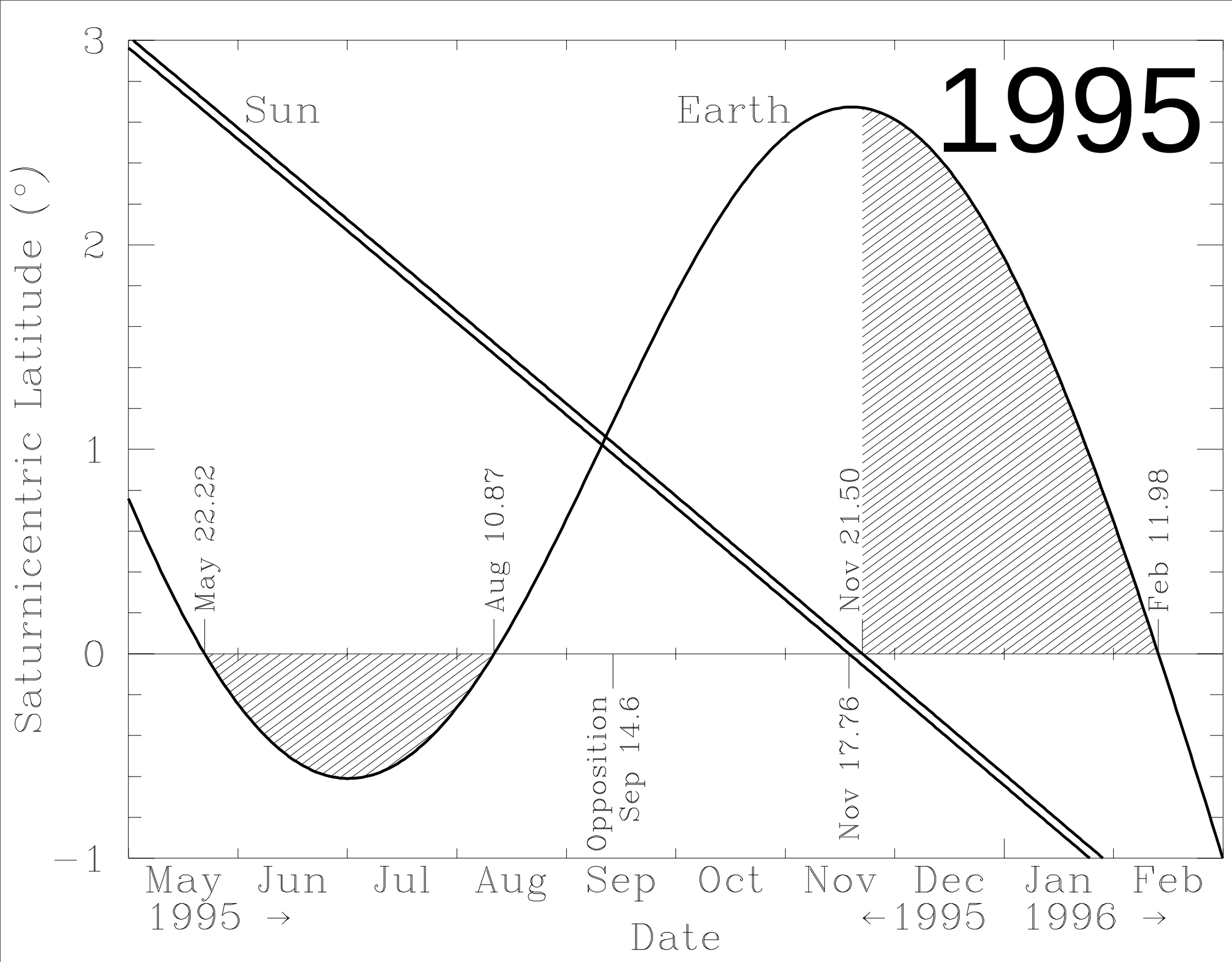
14 y

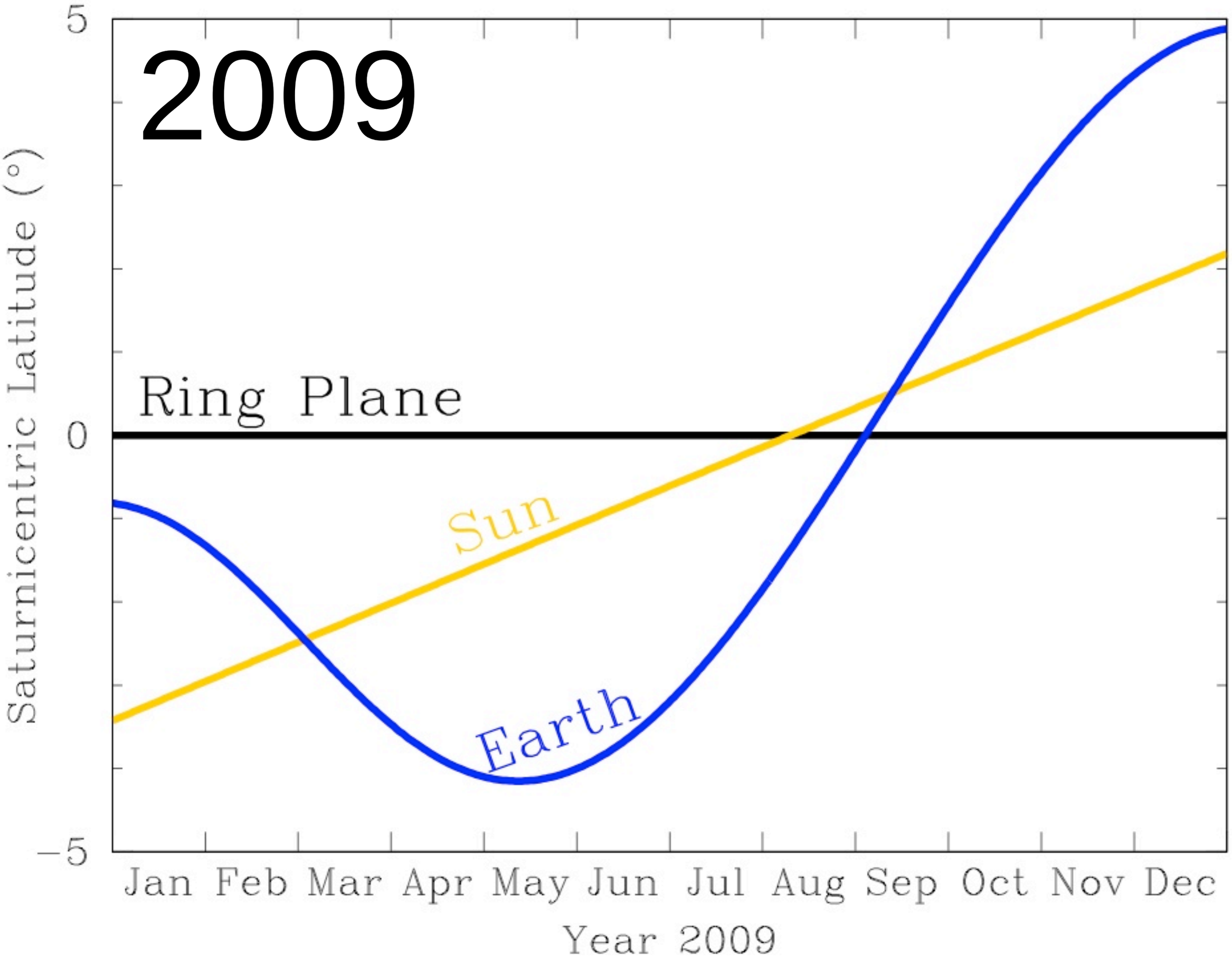
- 2009

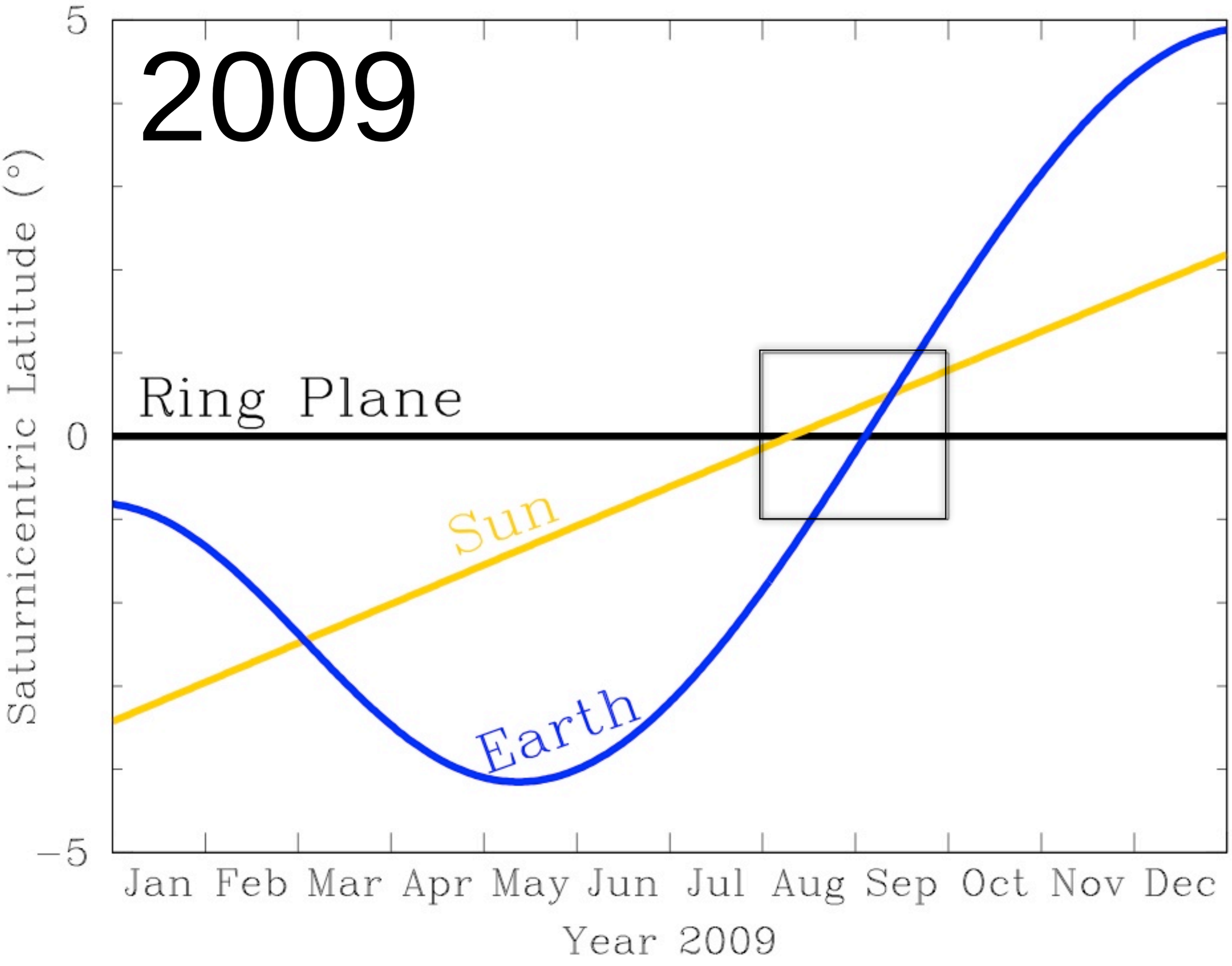
Uranian Equinox, December 2007

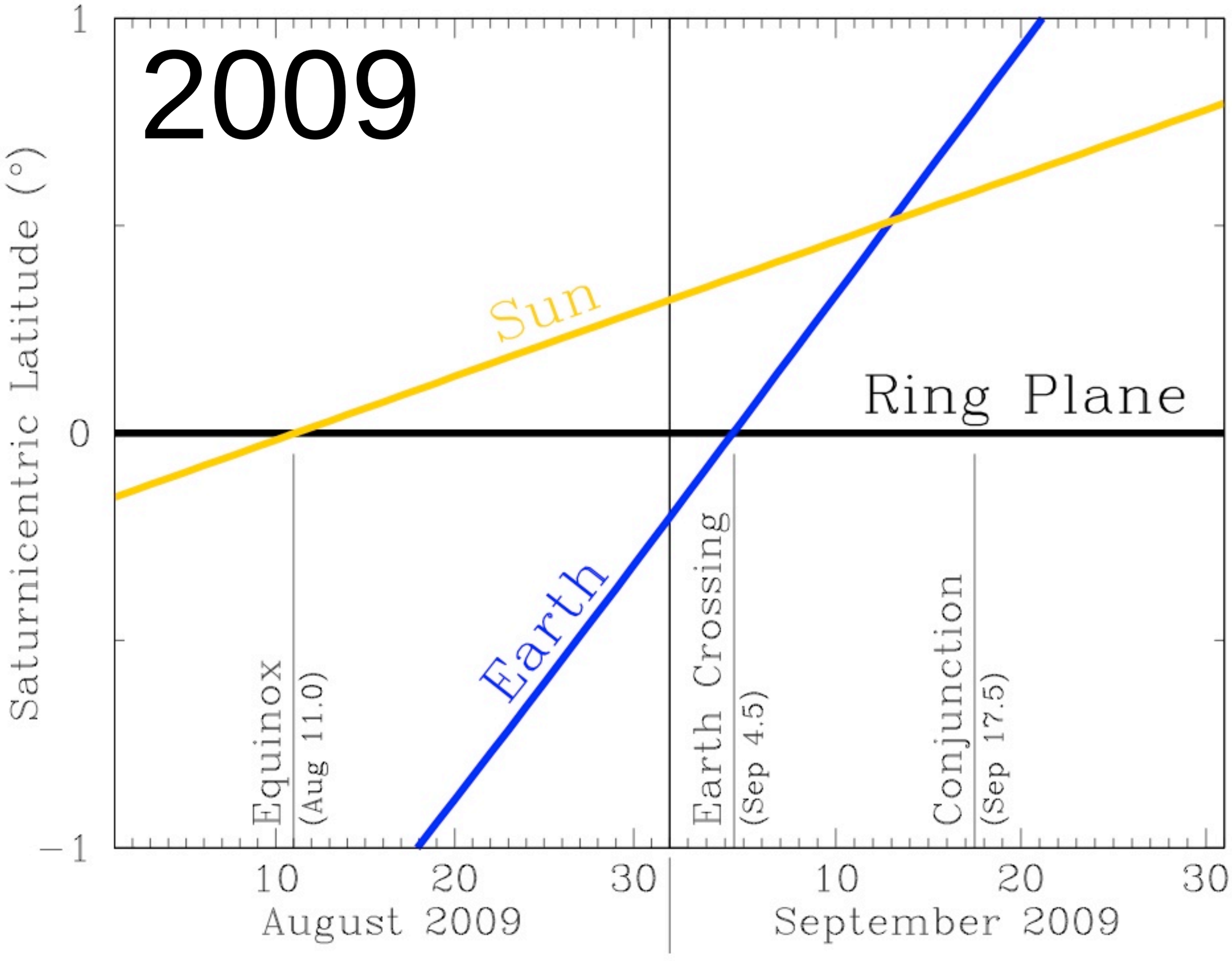


Credit: I. de Pater, U. C. Berkeley/W. M. Keck Telescope

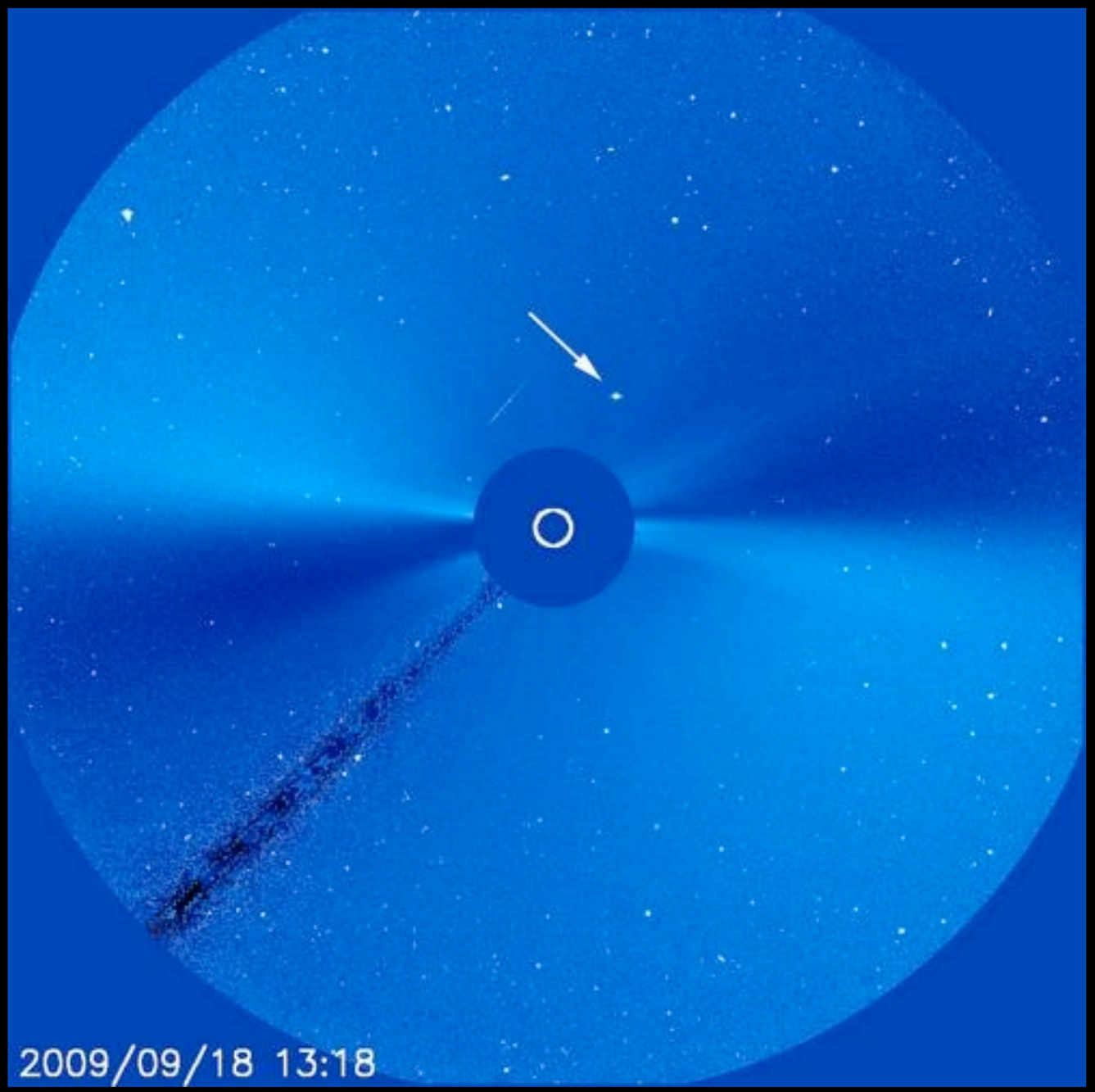

1995
Sun
Earth
Saturnicentric Latitude (°)
3
2
1
0
−1
May 22.22
Aug 10.87
Nov 21.50
Feb 11.98
Opposition
Sep 14.6
Nov 17.76
May Jun Jul Aug Sep Oct Nov Dec Jan Feb
1995 →
←1995 1996 →
Date


2009
Ring Plane
Sun
Earth
5
0
−5
Saturnicentric Latitude (°)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Year 2009


2009
Ring Plane
Sun
Earth
5
0
−5
Saturnicentric Latitude (°)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Year 2009


2009
Sun
Earth
Ring Plane
Saturnicentric Latitude (°)
1
0
−1
Equinox
(Aug 11.0)
Earth Crossing
(Sep 4.5)
Conjunction
(Sep 17.5)
10
20
30
August 2009
10
20
30
September 2009

2009: Slim pickins' for Earth-based Observers

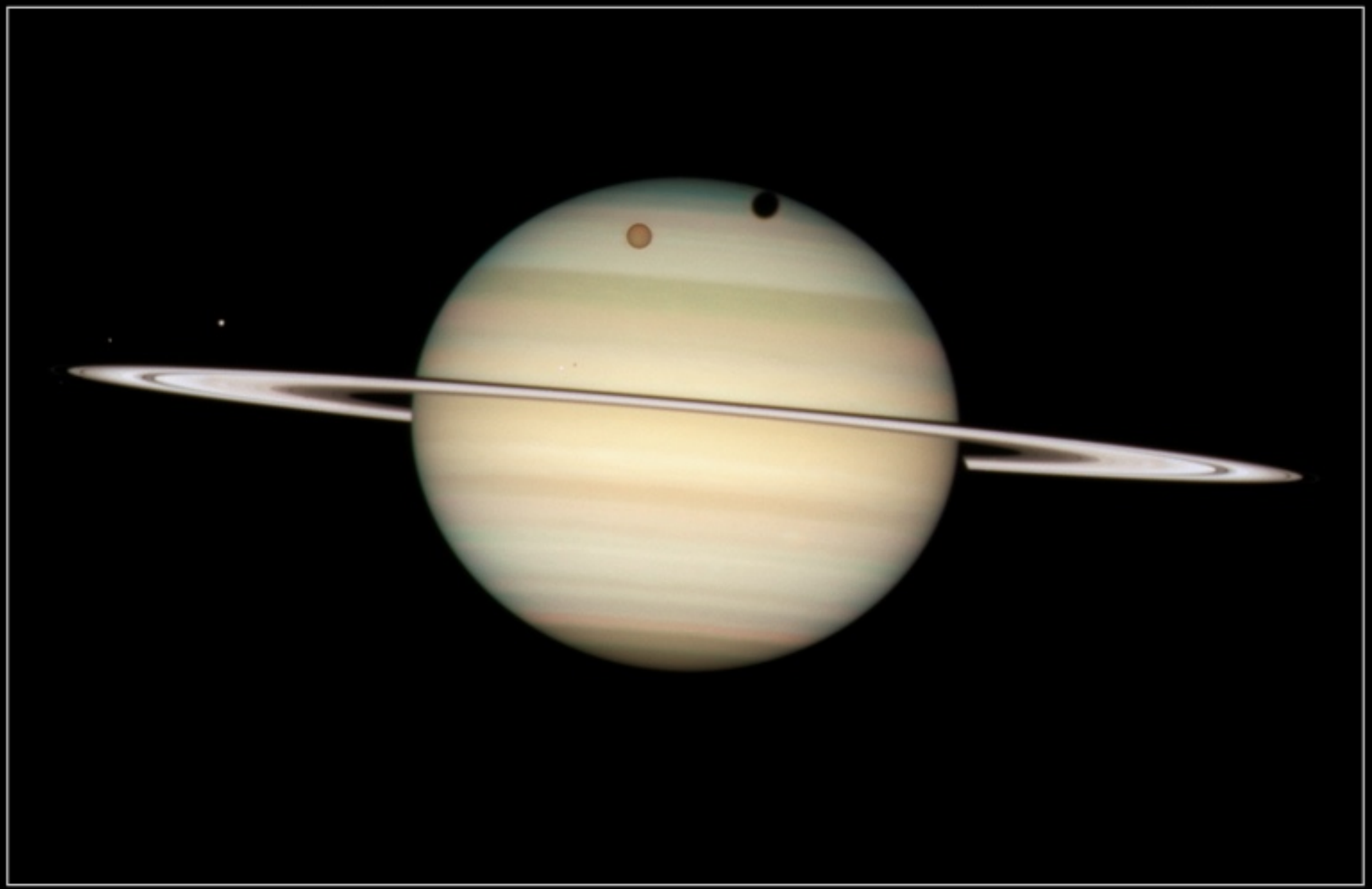


Solar & Heliospheric Observatory (SOHO)

September 18, 2009

Credit: SOHO - http://sohowww.nascom.nasa.gov

Saturn • February 24, 2009 12:46UT *Hubble Space Telescope* WFPC2



NASA, ESA, and the Hubble Heritage Team (STScI/AURA) STScI-PRC09-12a

B Ring "Spo

Voyager ISS, August

vie, see

g/saturn/animations/saturn_spoke.mov

Cassini's First Spoke

September 5, 2005

Cassini ISS, PIA07731

Spokes, November 2008

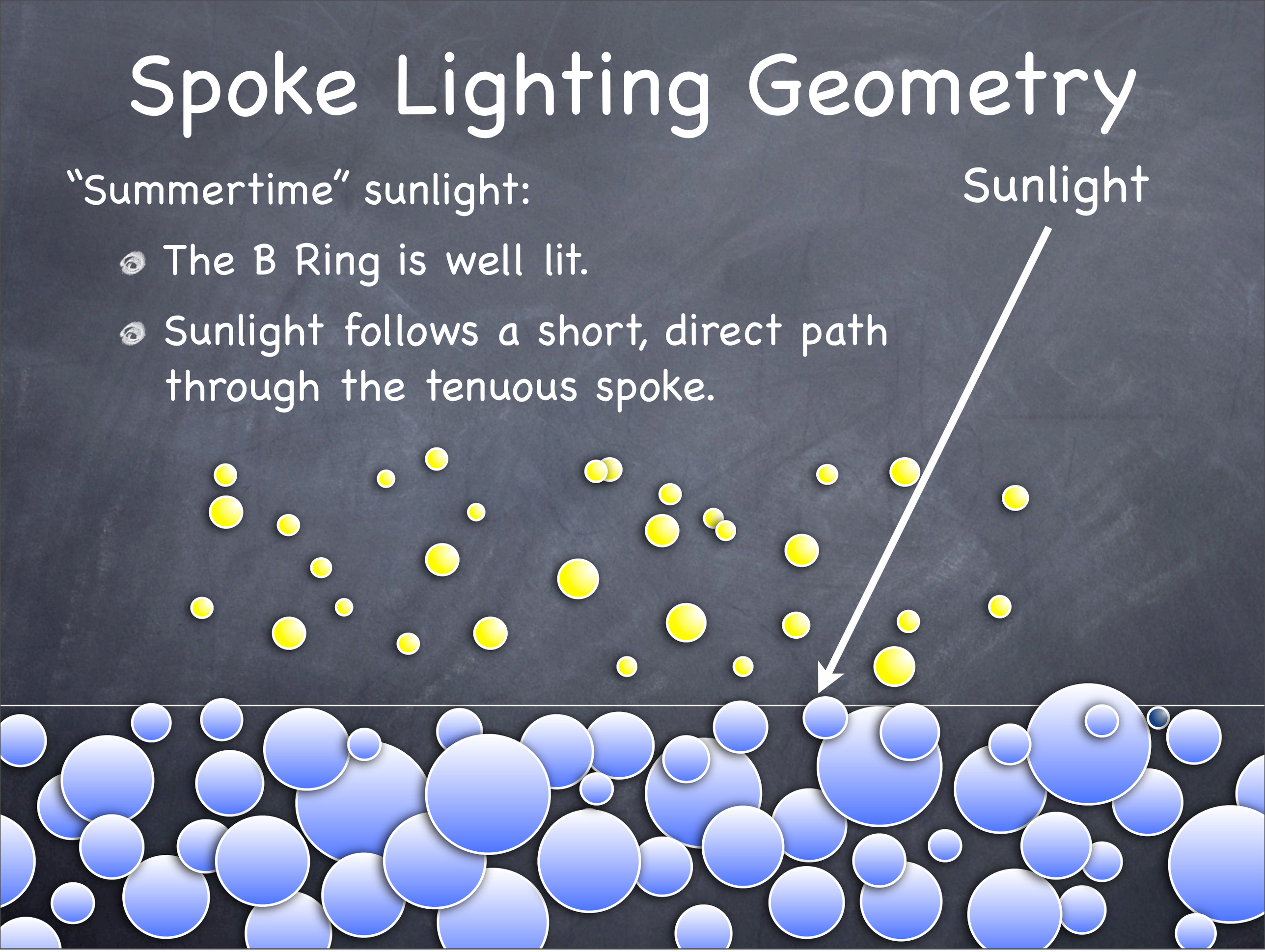
PIA10561

Spokes, February 2009
PIA11470

Spoke Lighting Geometry

"Summertime" sunlight:

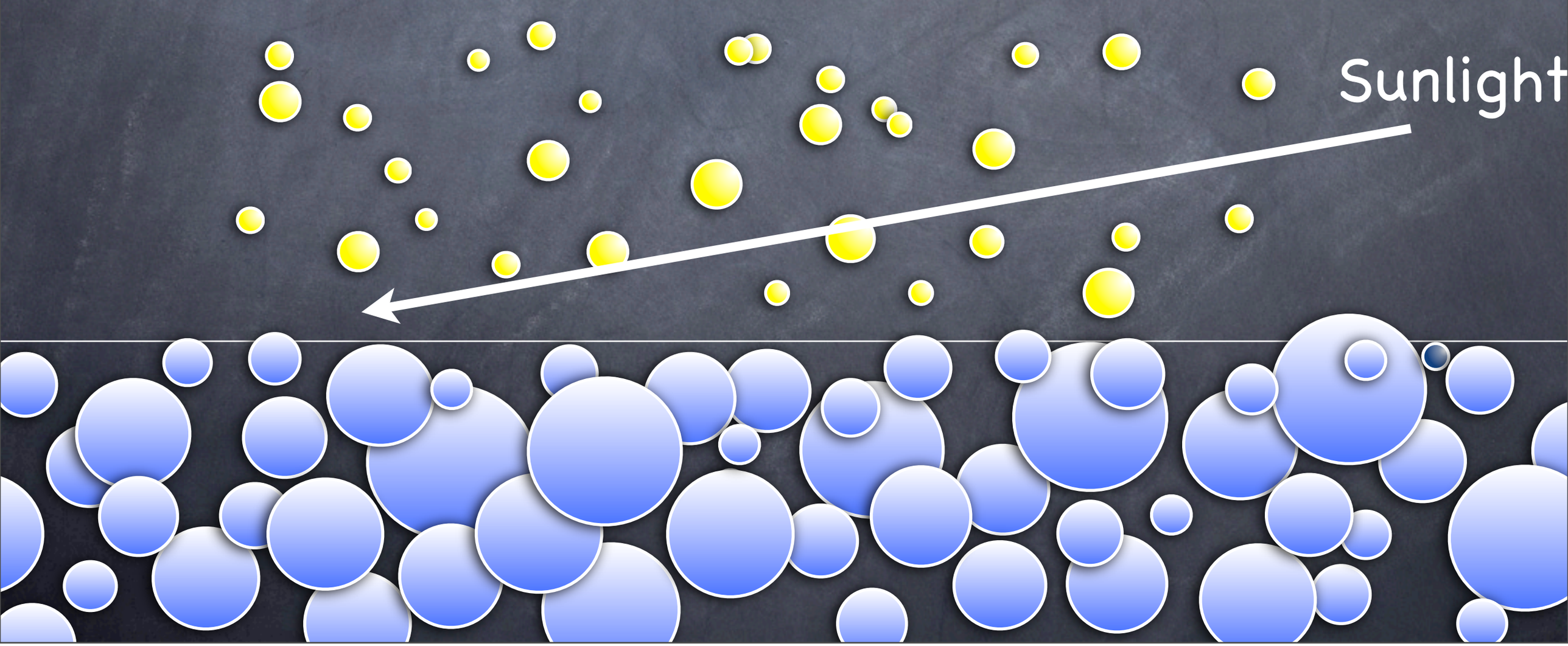
- The B Ring is well lit.
- Sunlight follows a short, direct path through the tenuous spoke.



Spoke Lighting Geometry

"Springtime" sunlight:

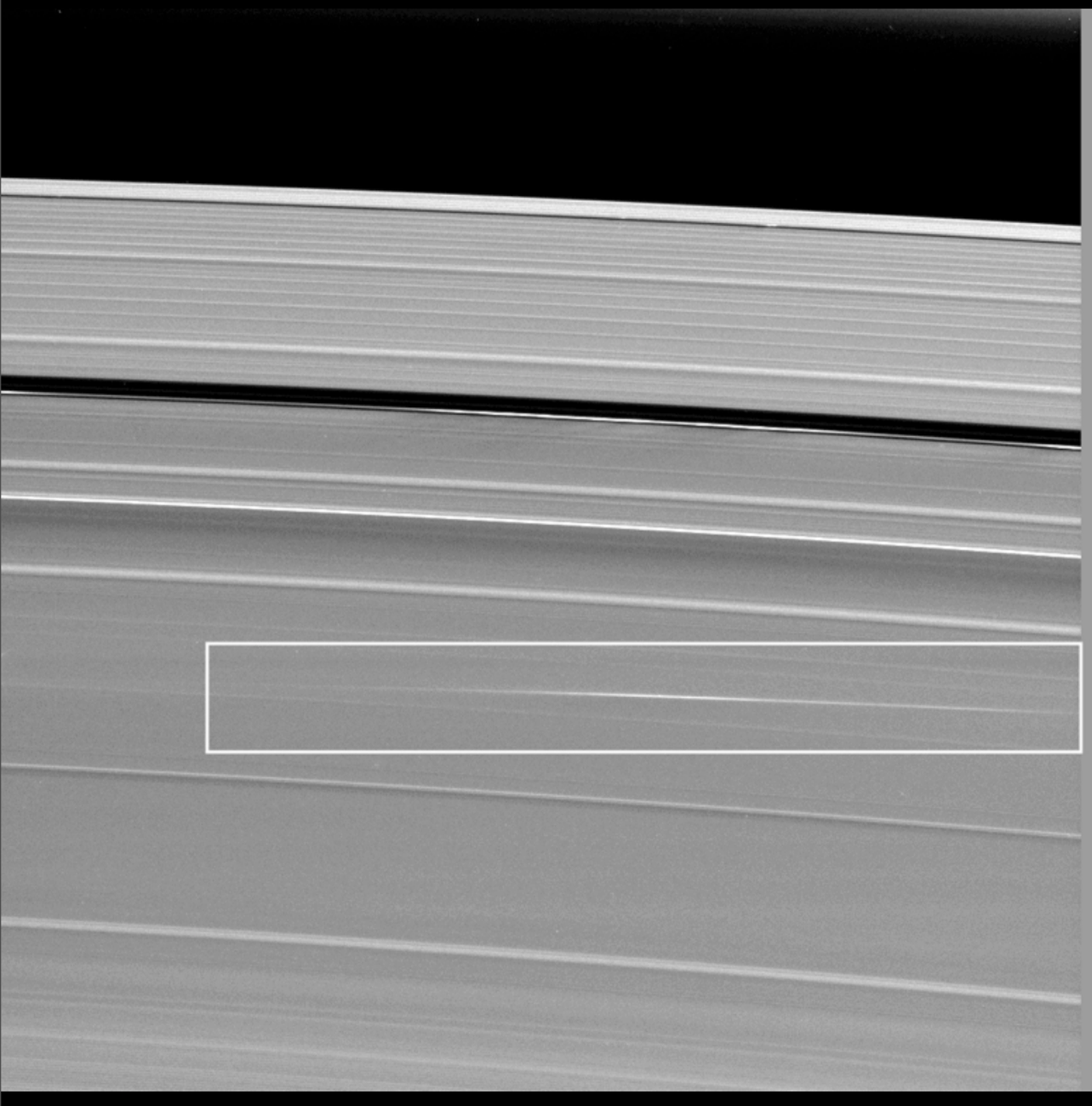
- Grazing sunlight makes the B Ring darker.
- A longer path through the tenuous cloud makes the spoke more visible.

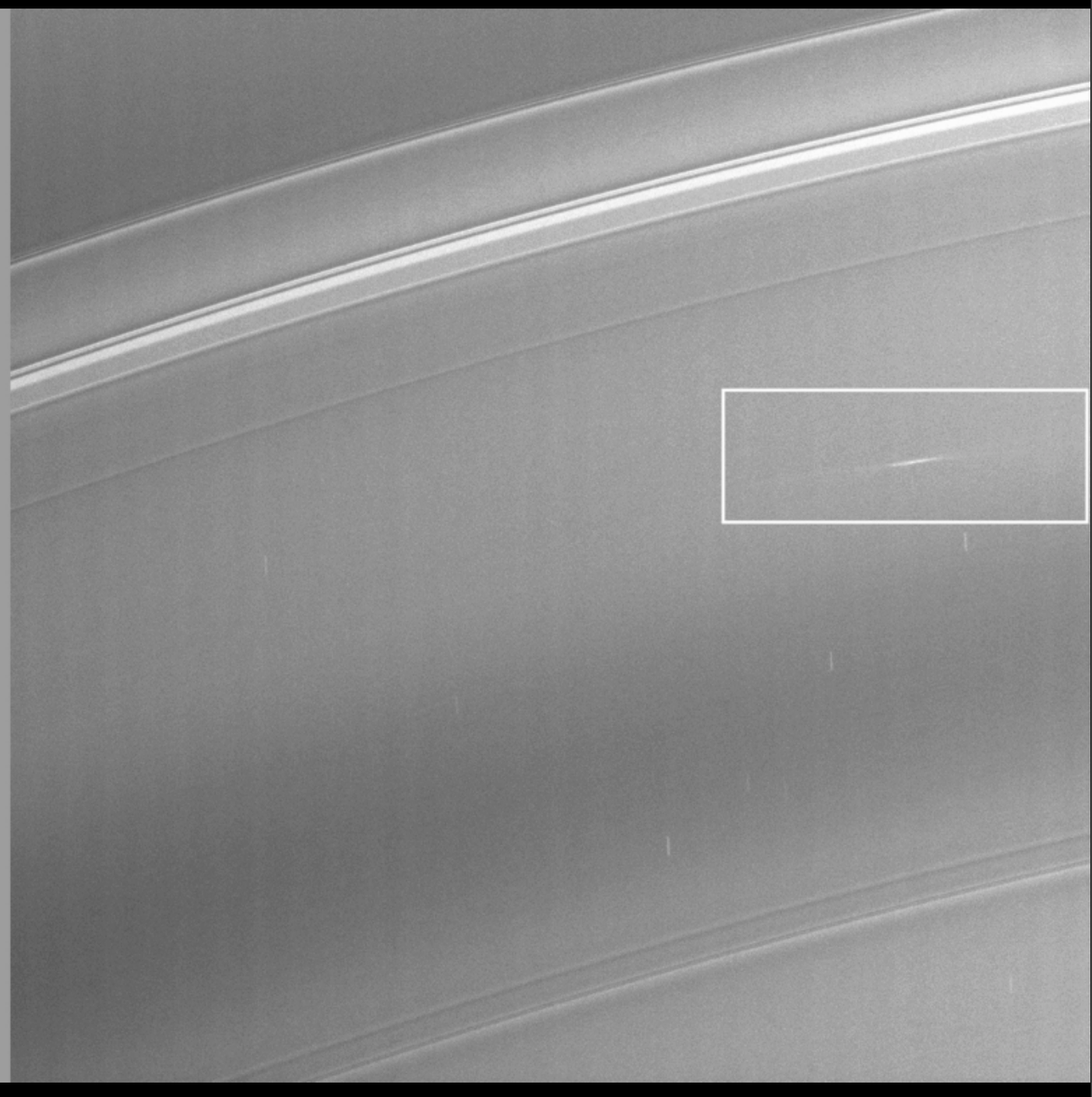


Impacts into the Rings (?)

August 11 & 13, 2009

PIA11674



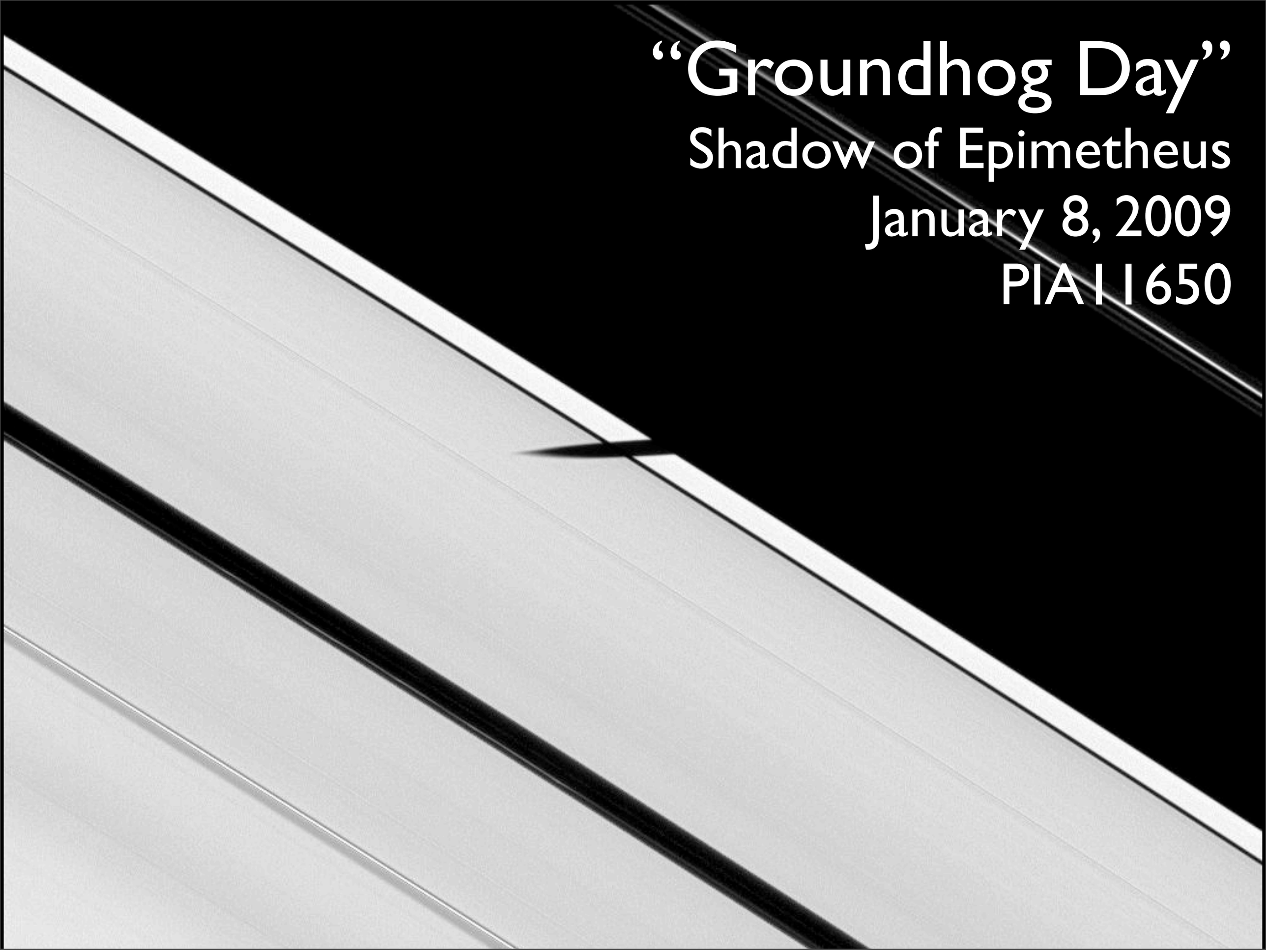


“Groundhog Day”

Shadow of Epimetheus

January 8, 2009

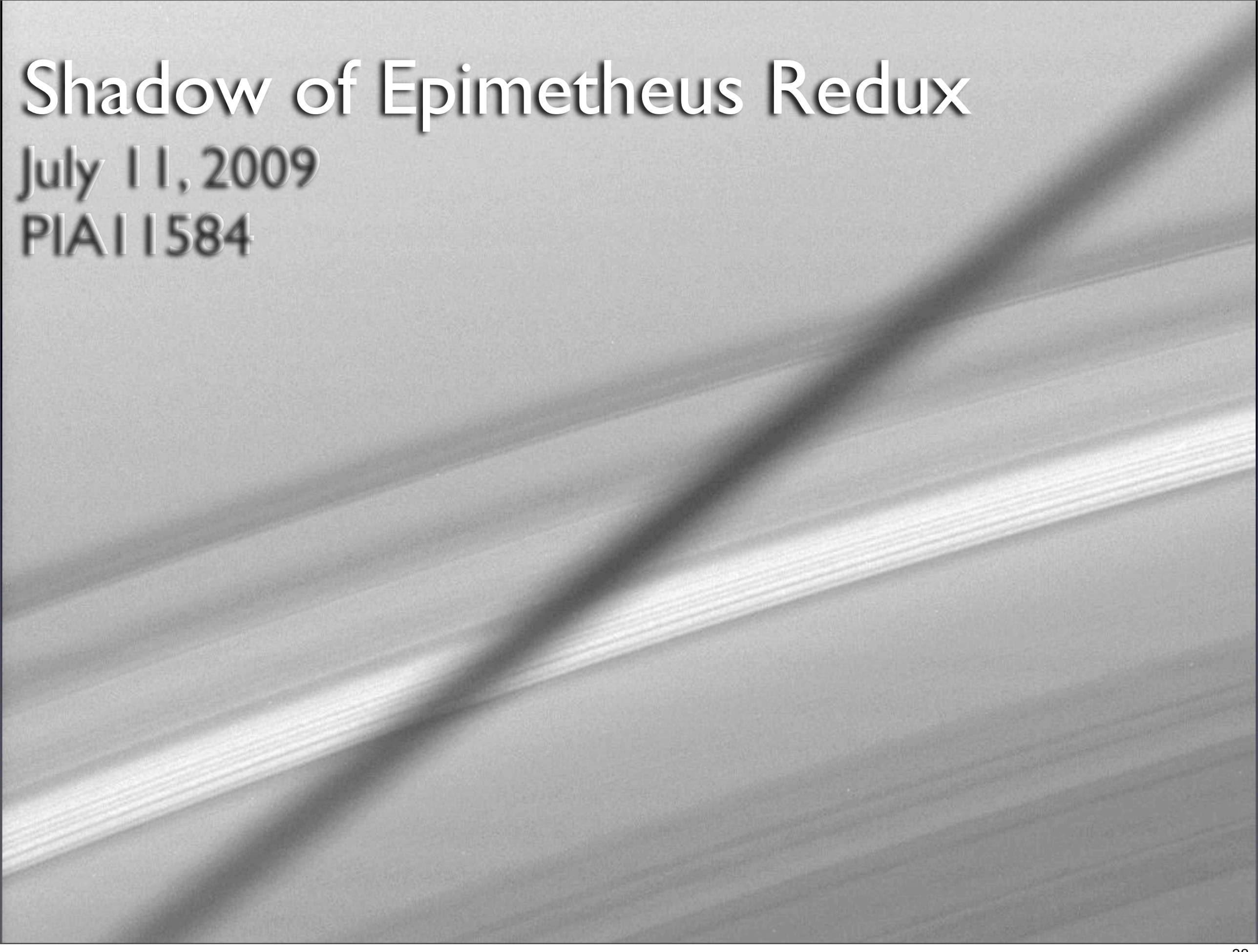
PIA11650



Shadow of Epimetheus Redux

July 11, 2009

PIA11584



Shadow of Tethys

May 20, 2009

PIA11525

Shadow of Pan

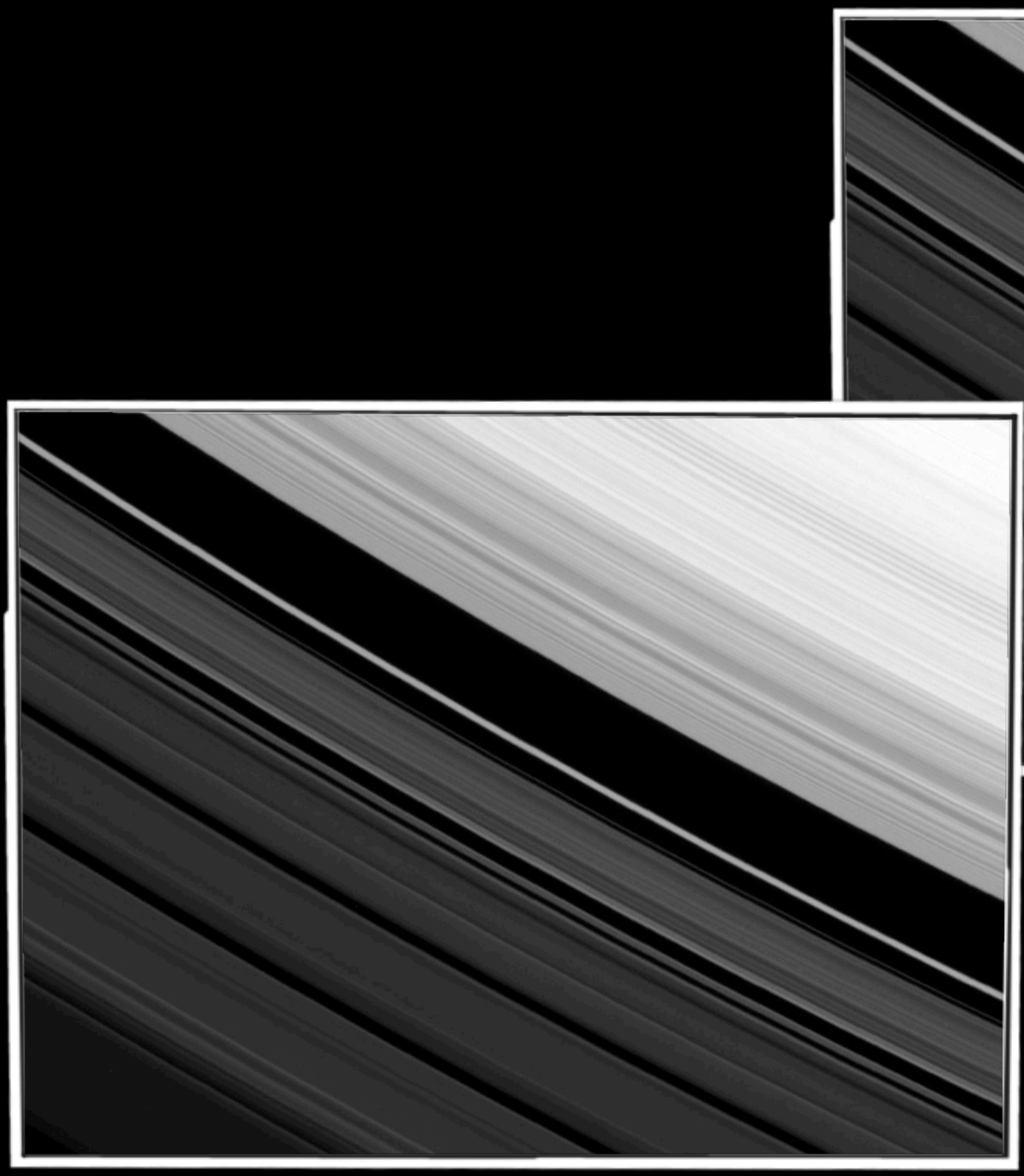
July 27, 2009

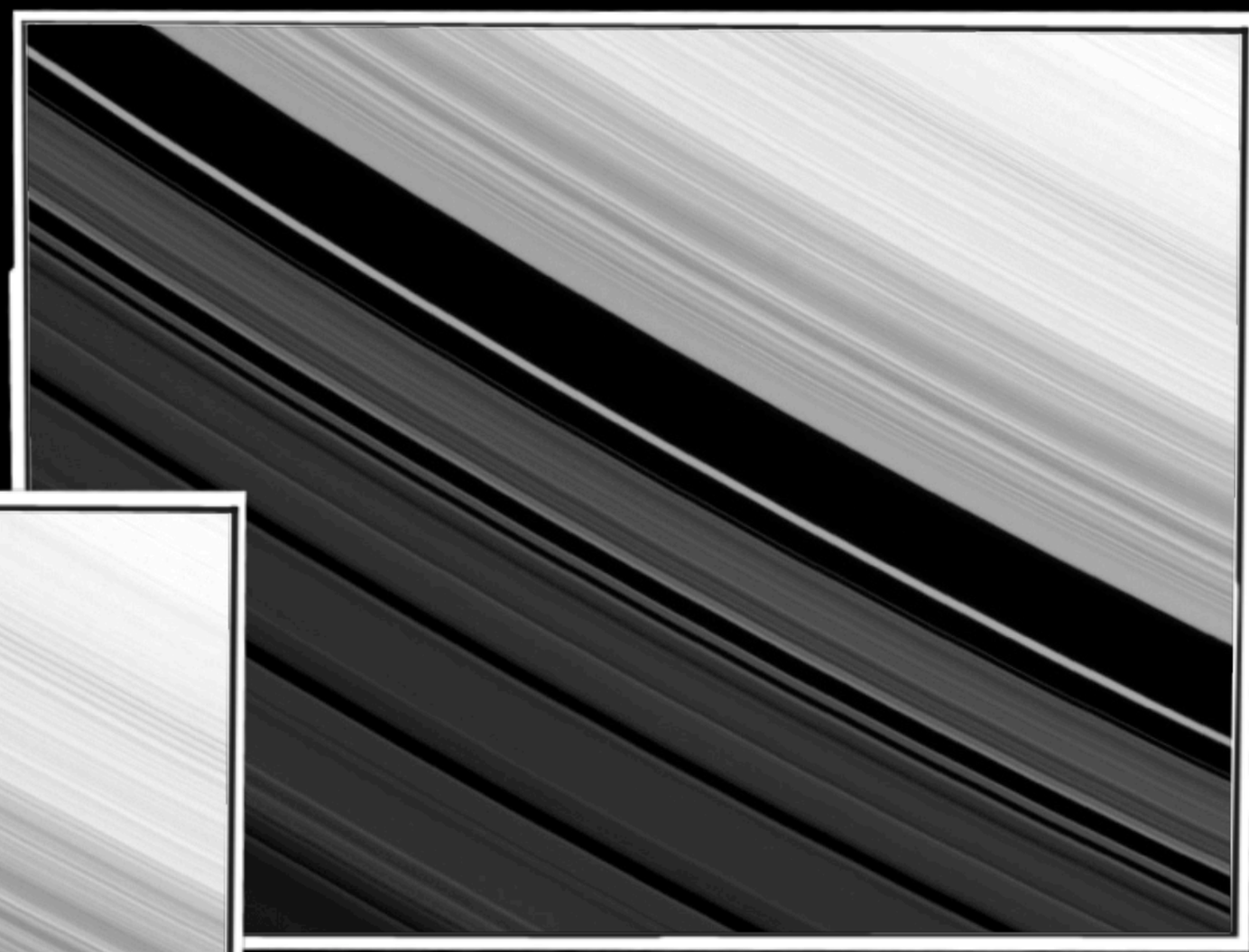
PIA11581

B Ring edge

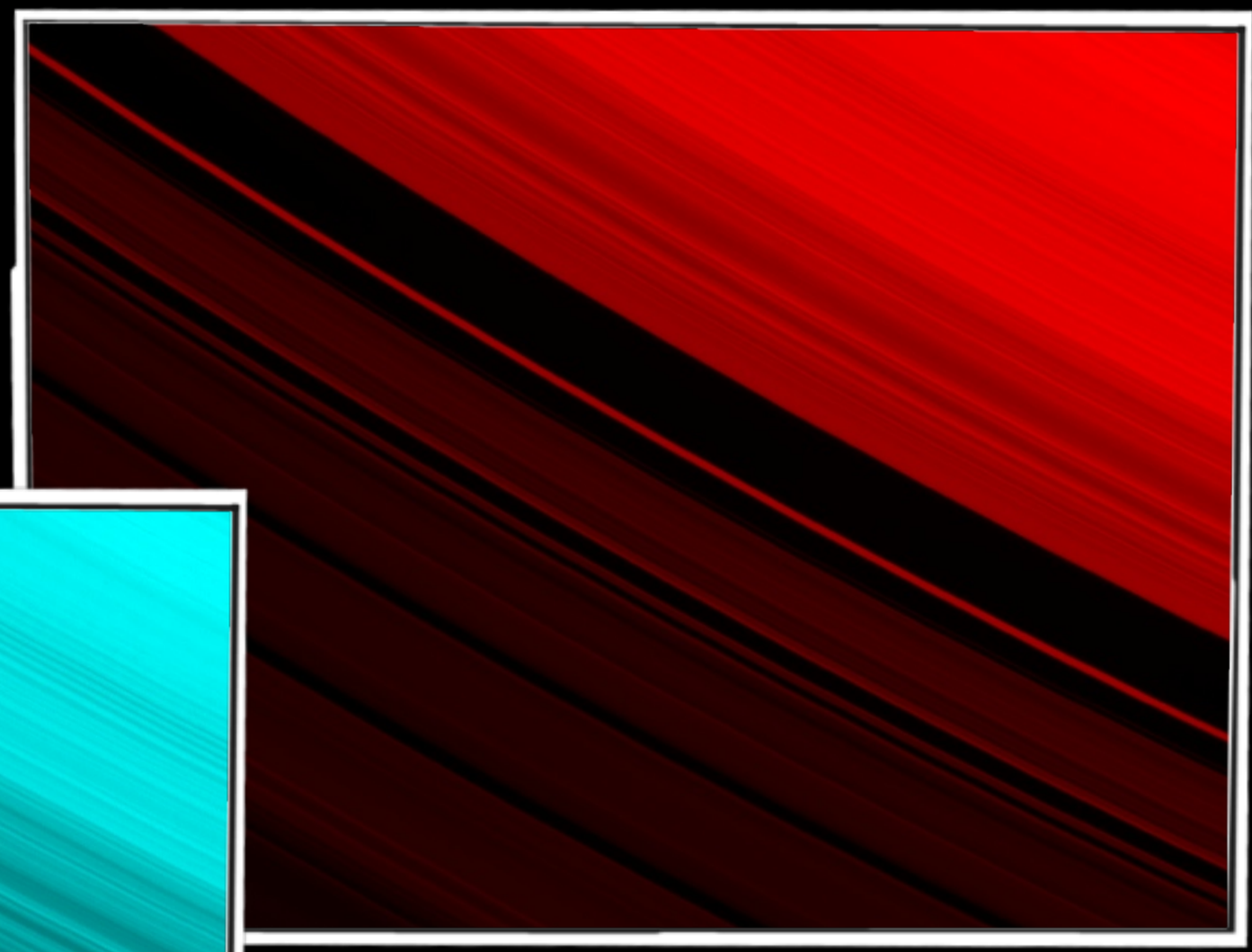
April 9, 2009

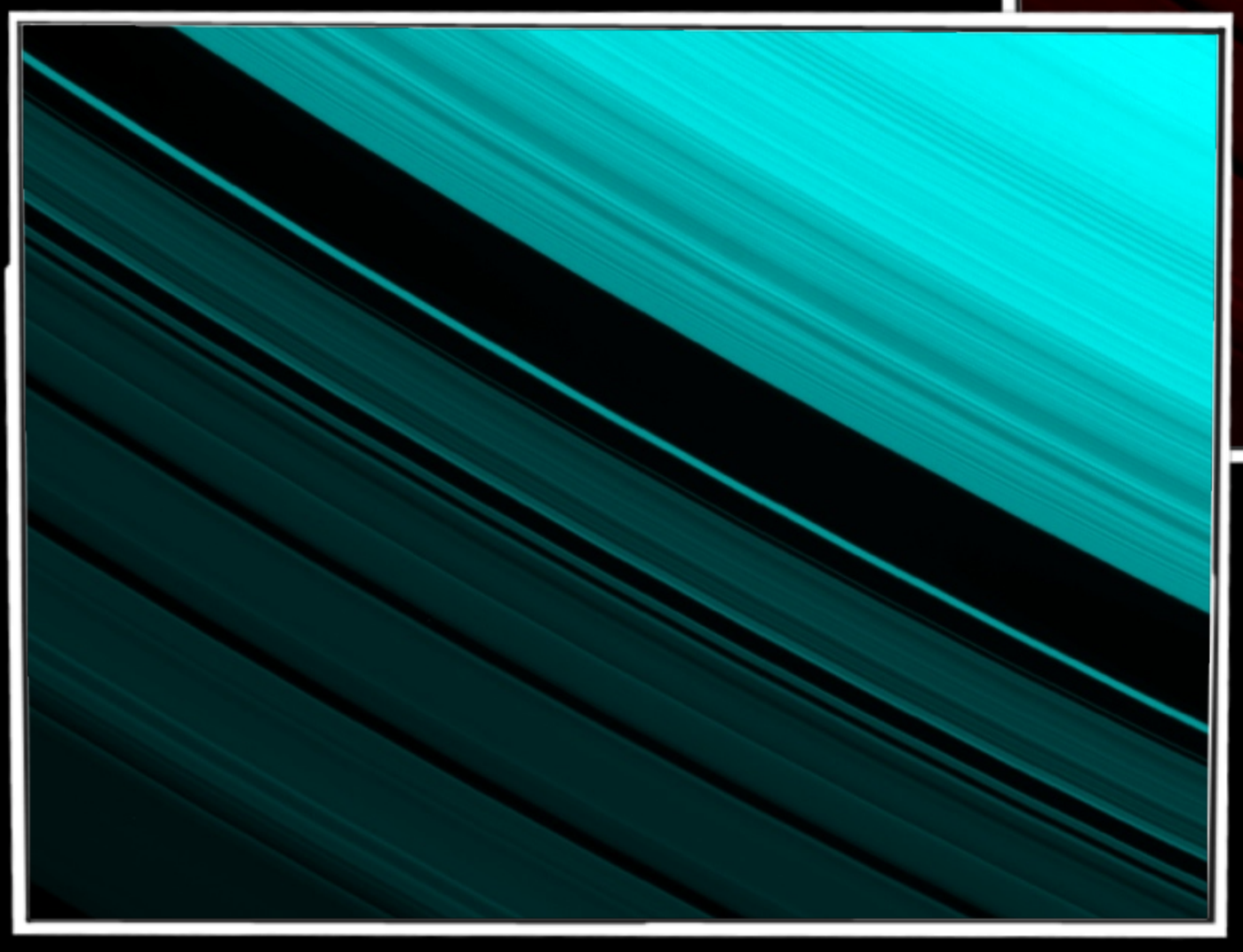
Two Images of the B Ring Edge



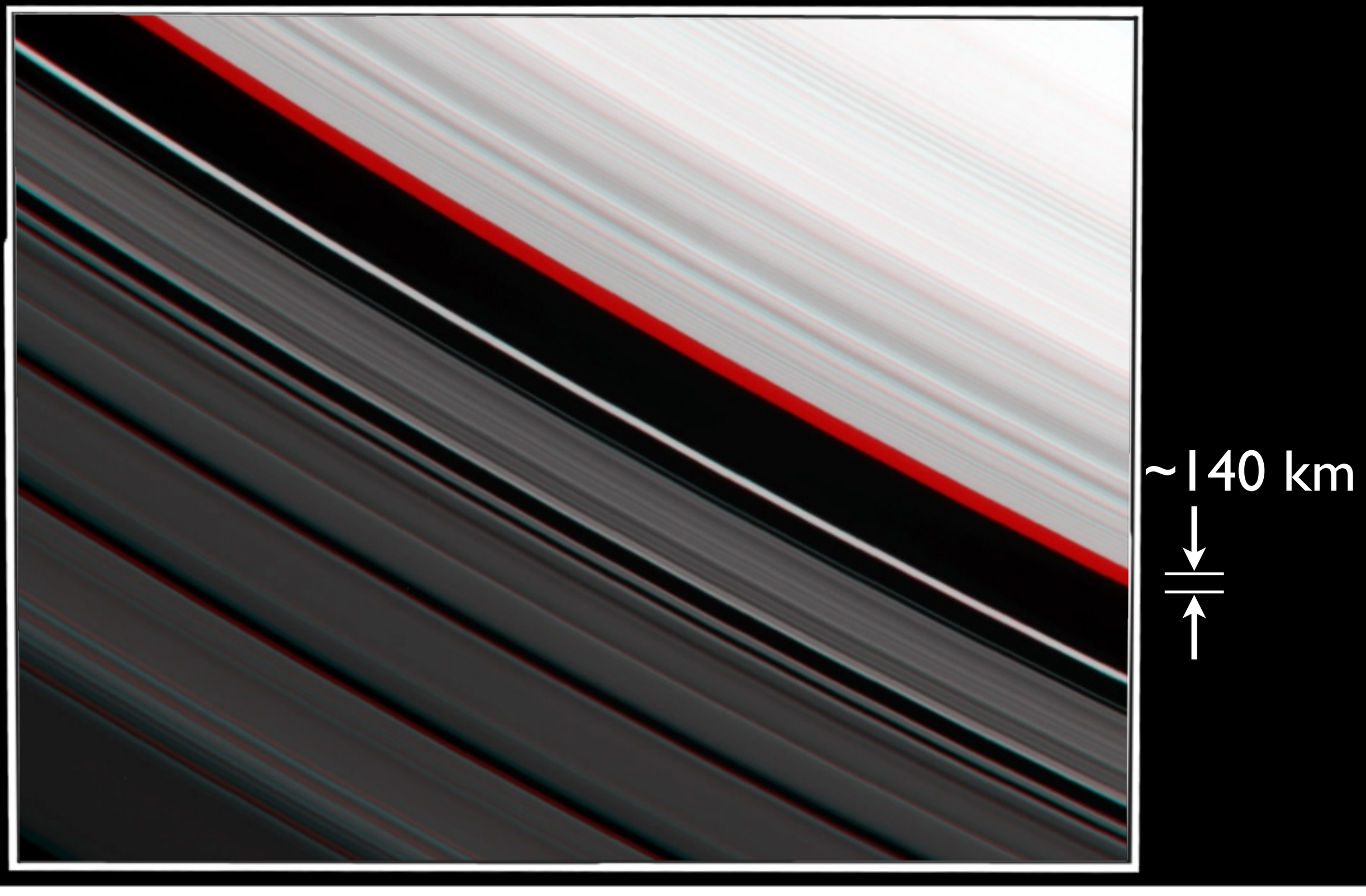


Two Images of the B Ring Edge

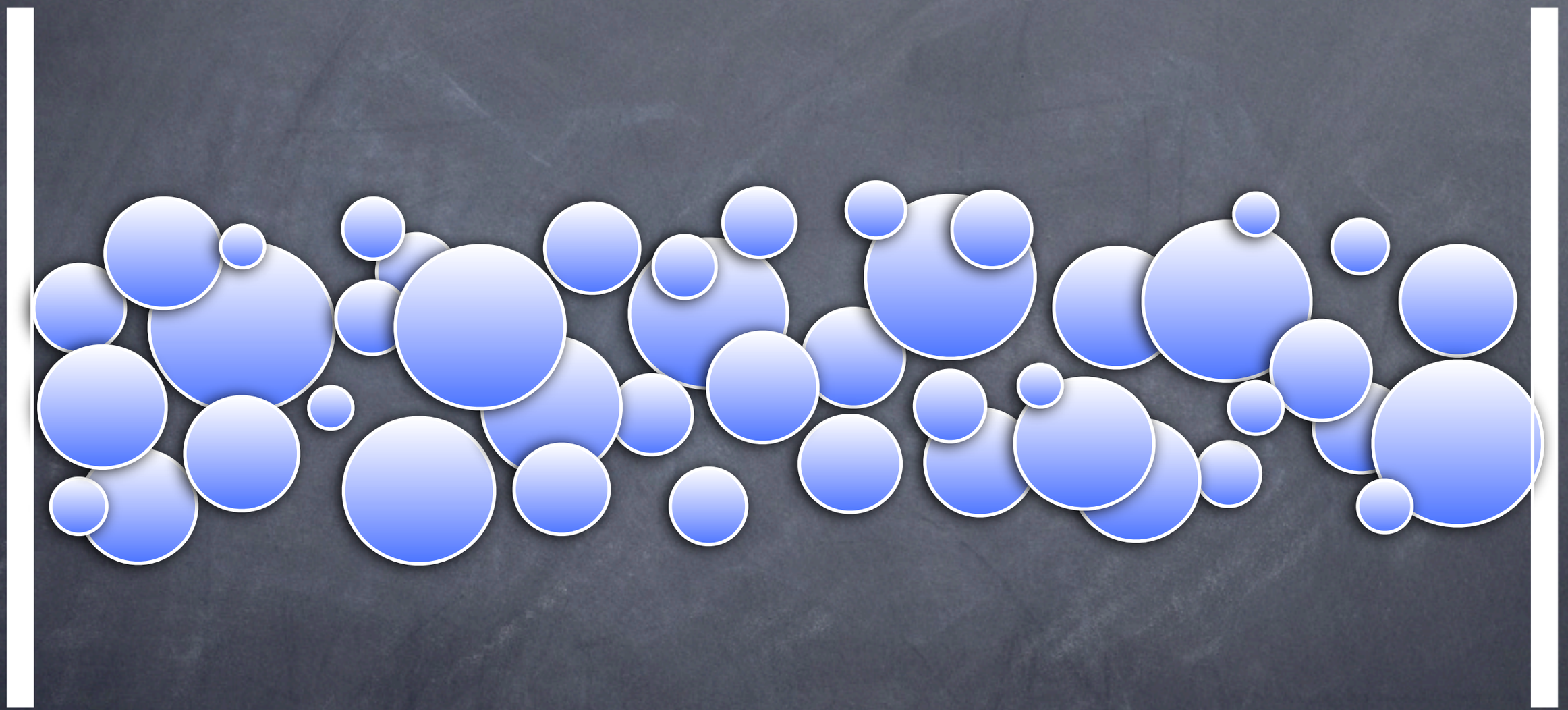




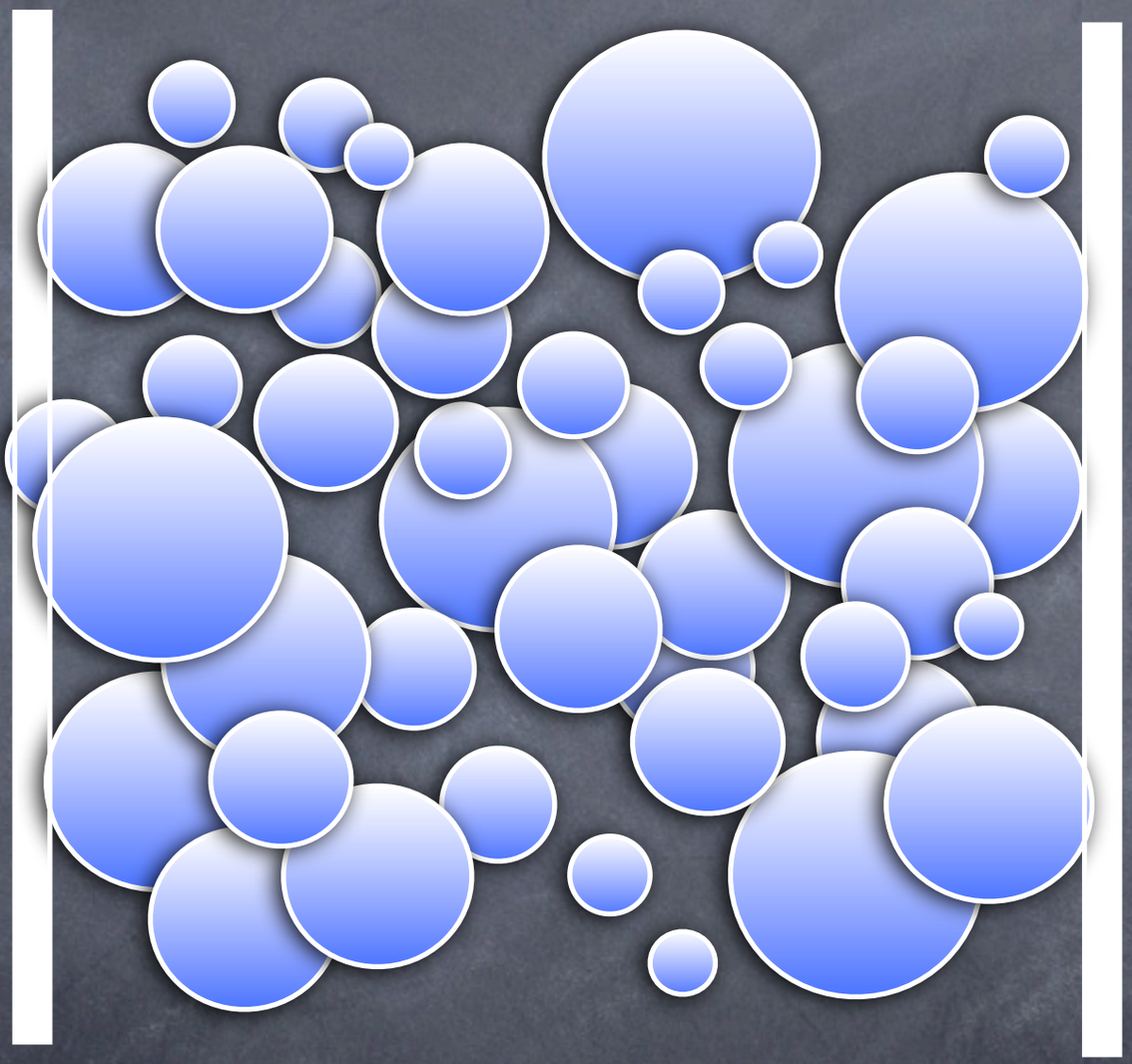
Two Images of the B Ring Edge



"Before"



"After"



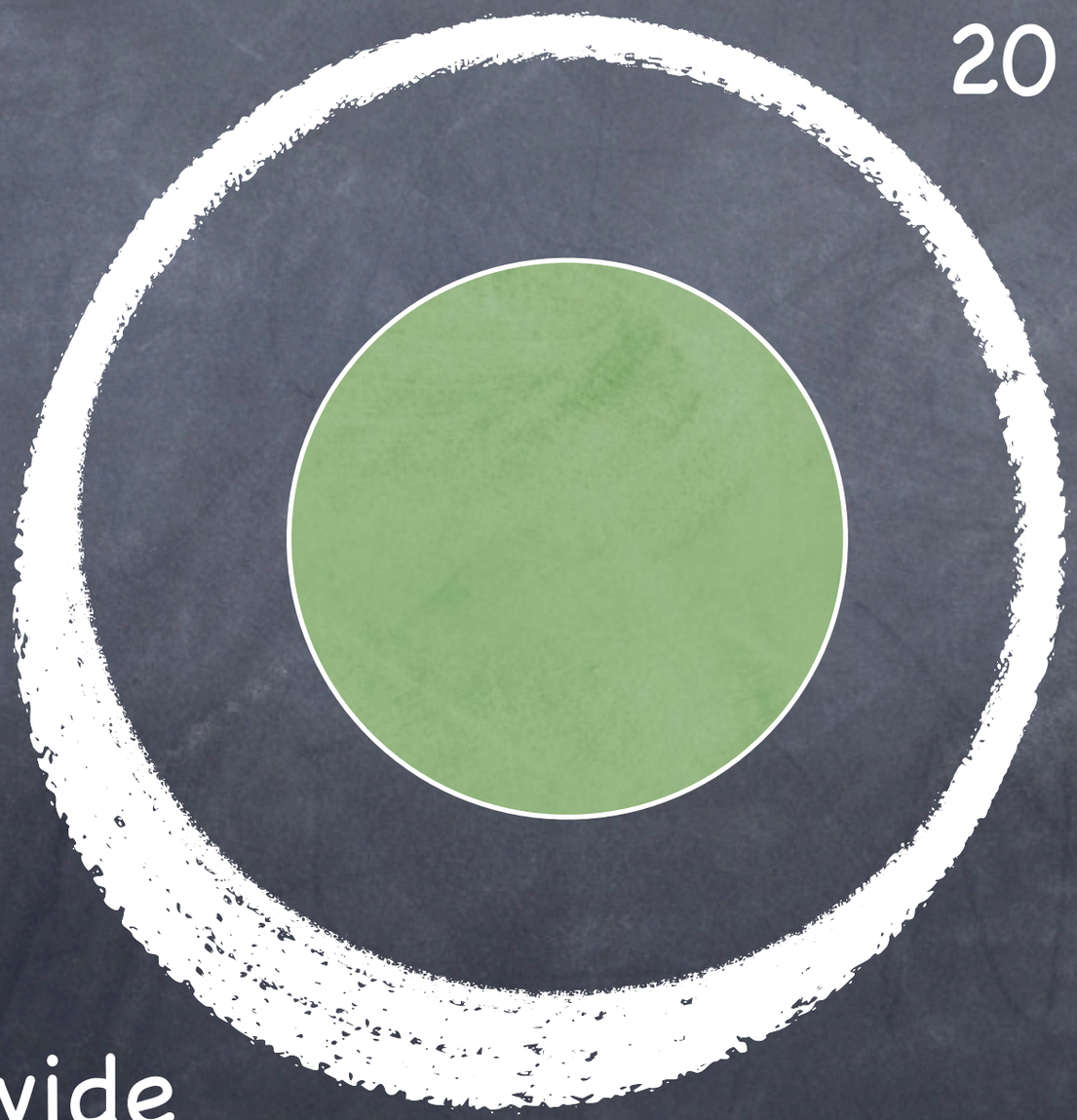
Hypothesis: Densely packed ring material, when squeezed together, has nowhere to go but "up".

B Ring edge

April 9, 2009

Someday, we'll see this in the Uranian ε ring!

20 km wide

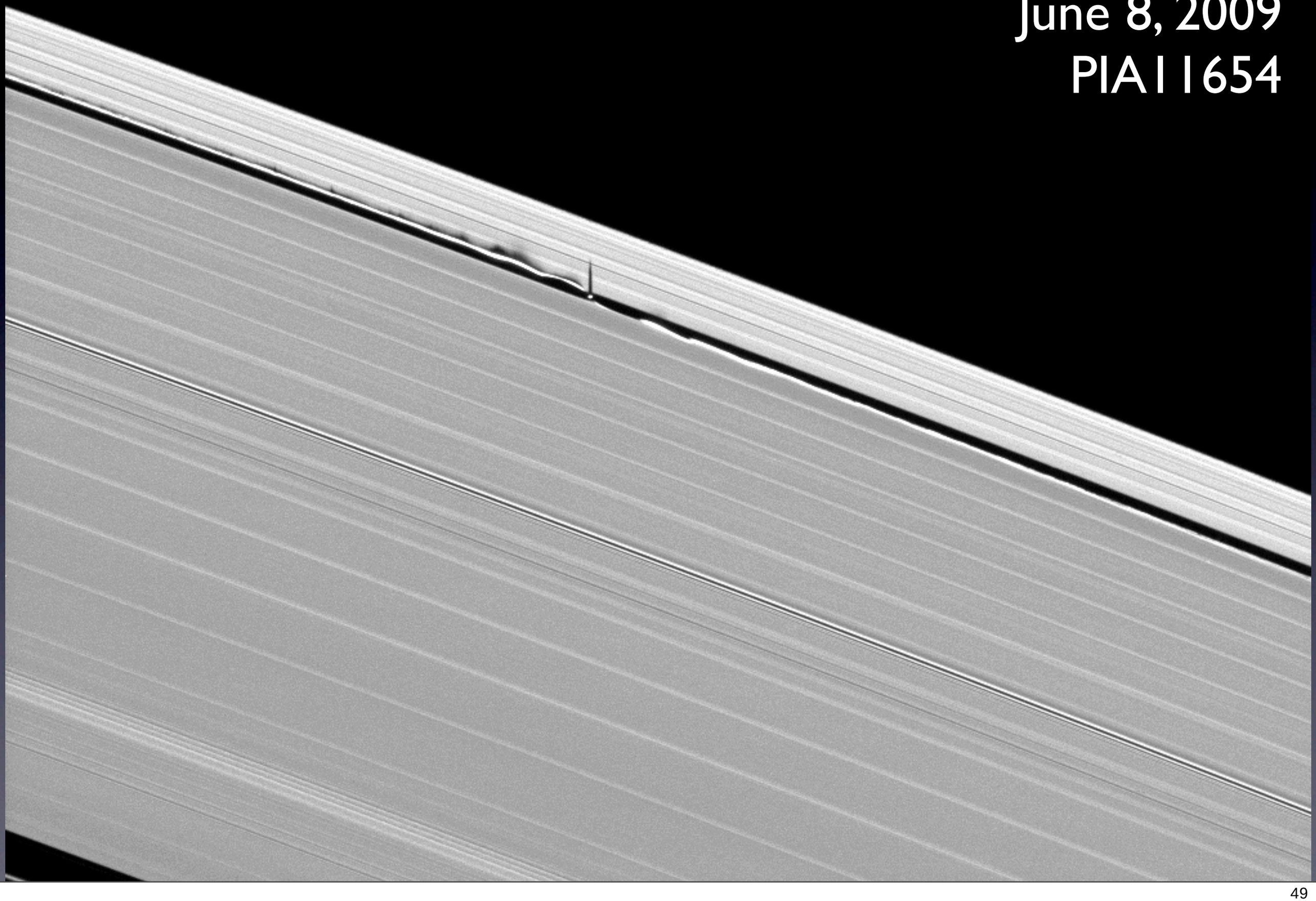


100 km wide

Daphnis and its "Wake"

June 8, 2009

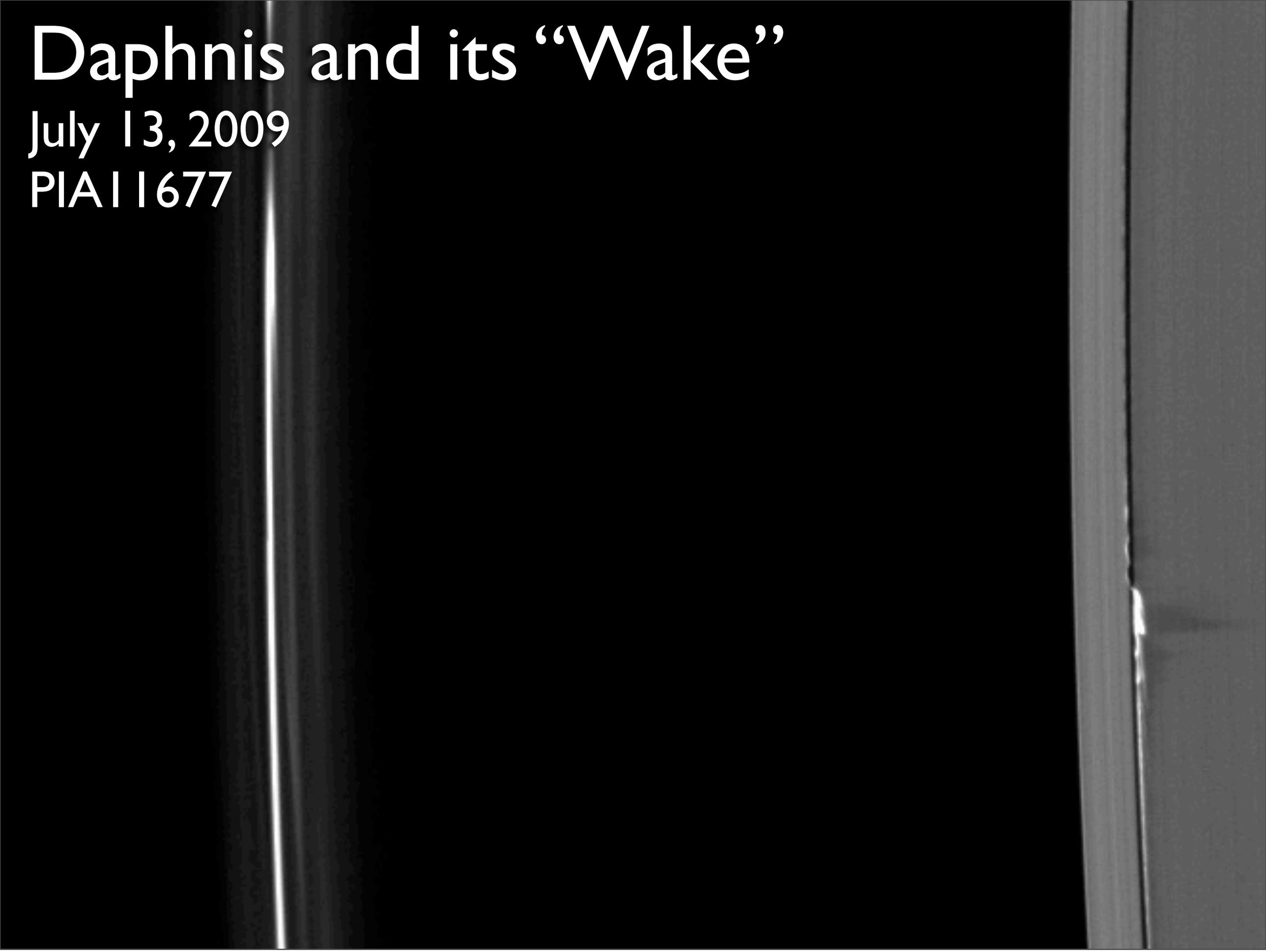
PIA11654



Daphnis and its "Wake"

July 13, 2009

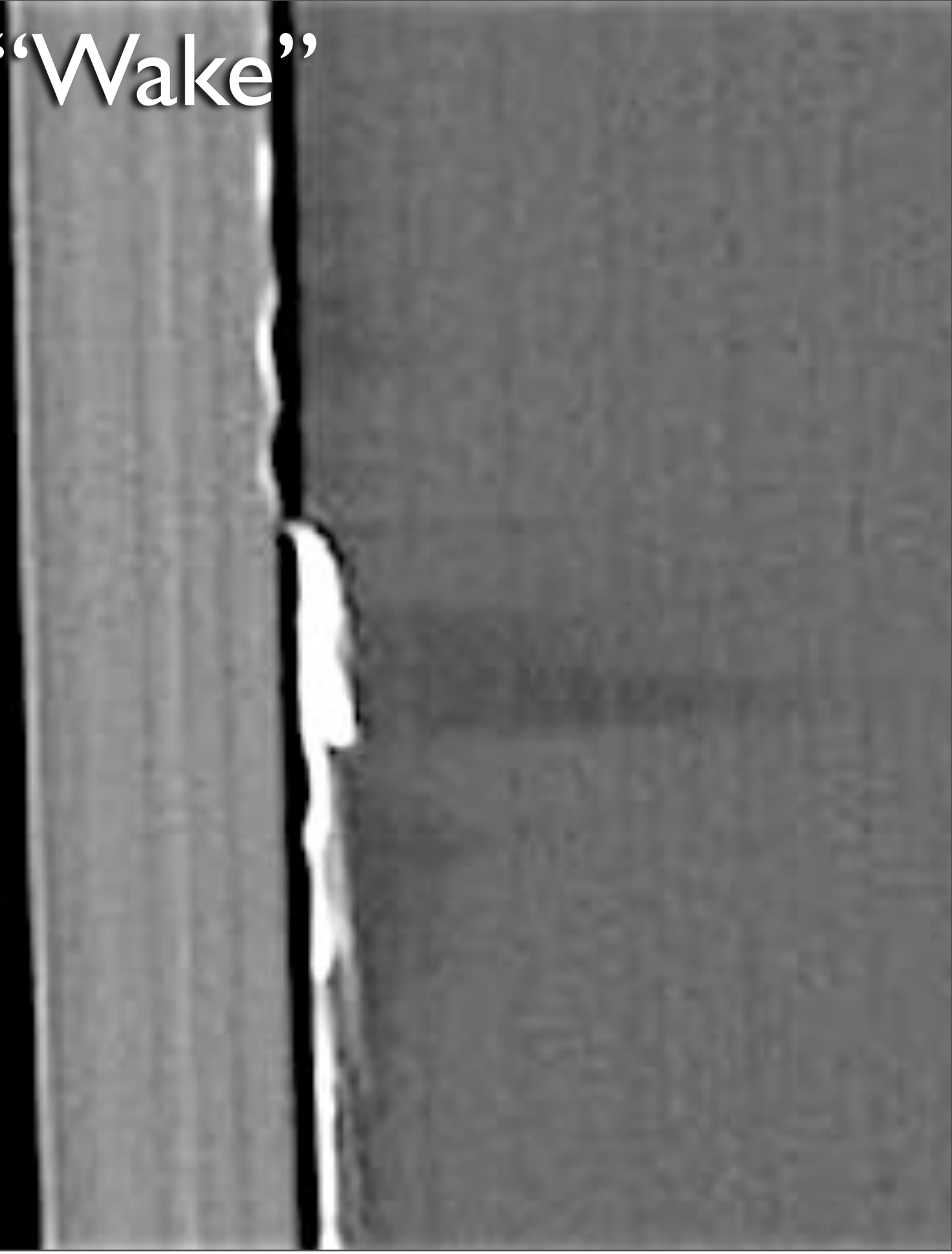
PIA11677



Daphnis and its "Wake"

July 13, 2009

PIA11677



Sharpened and enhanced

“Something” in the F Ring

June 11, 2009

PIA11662

F Ring "moonlets"

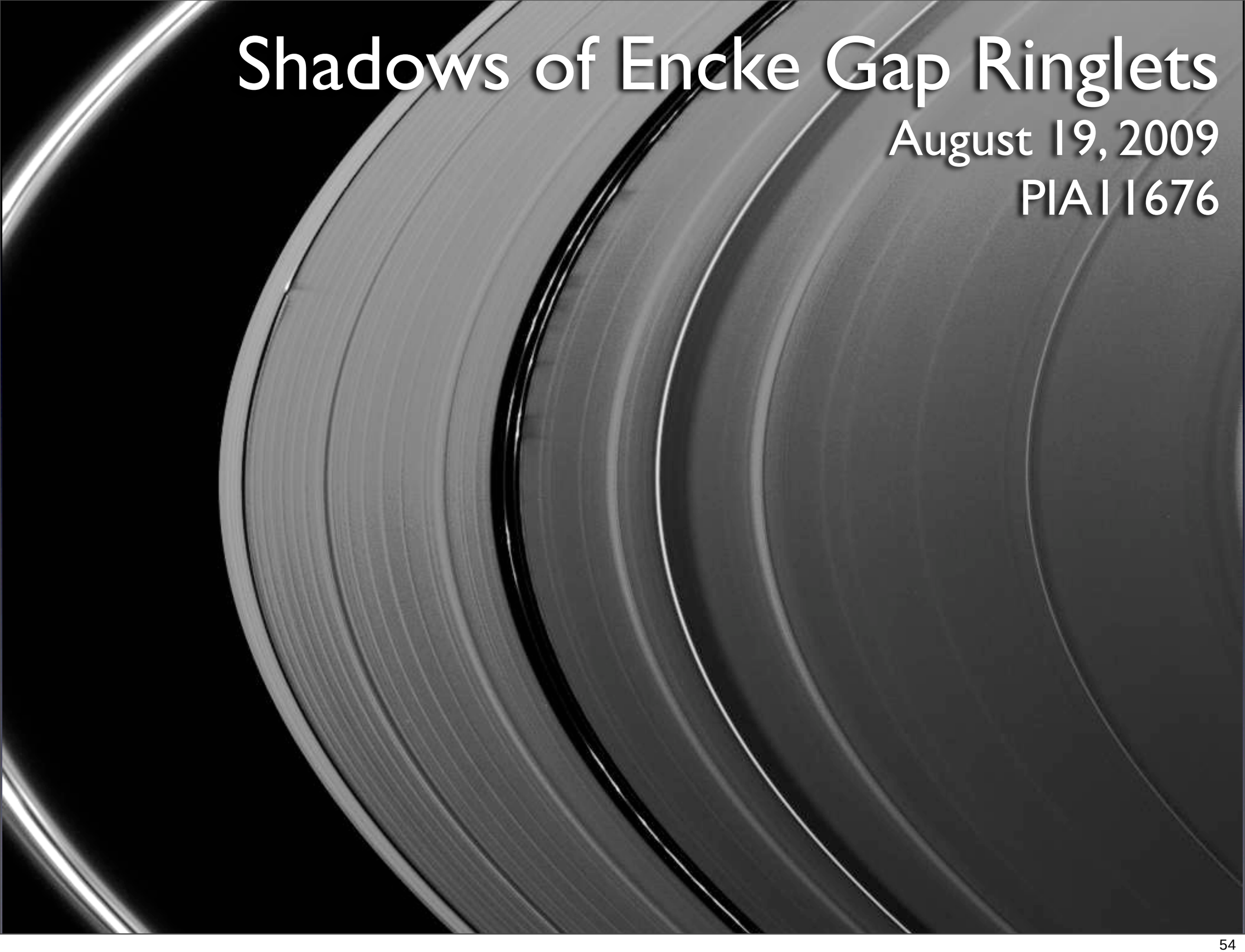
April–August, 2005

PIA07716

Shadows of Encke Gap Ringlets

August 19, 2009

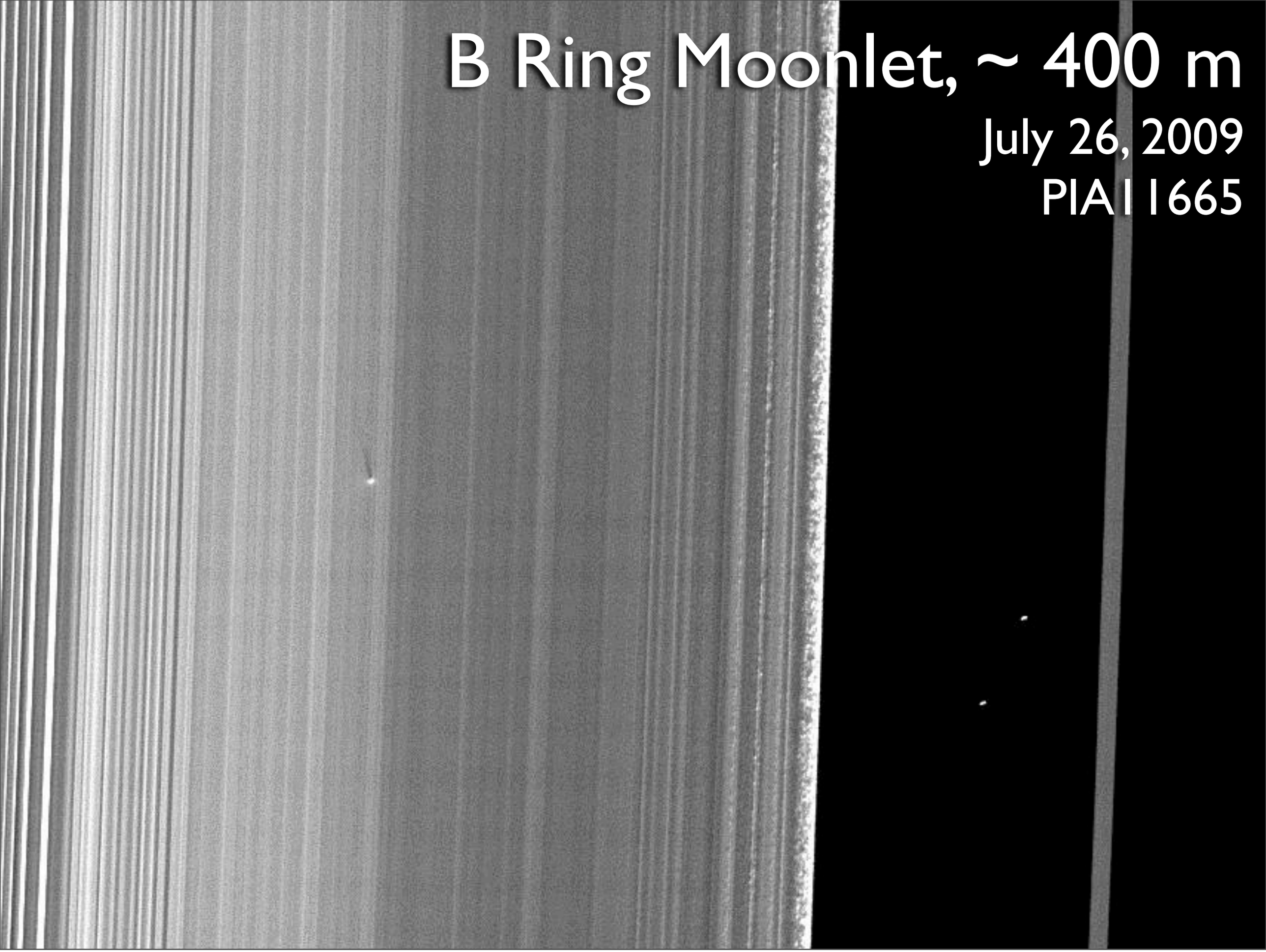
PIA11676



B Ring Moonlet, ~ 400 m

July 26, 2009

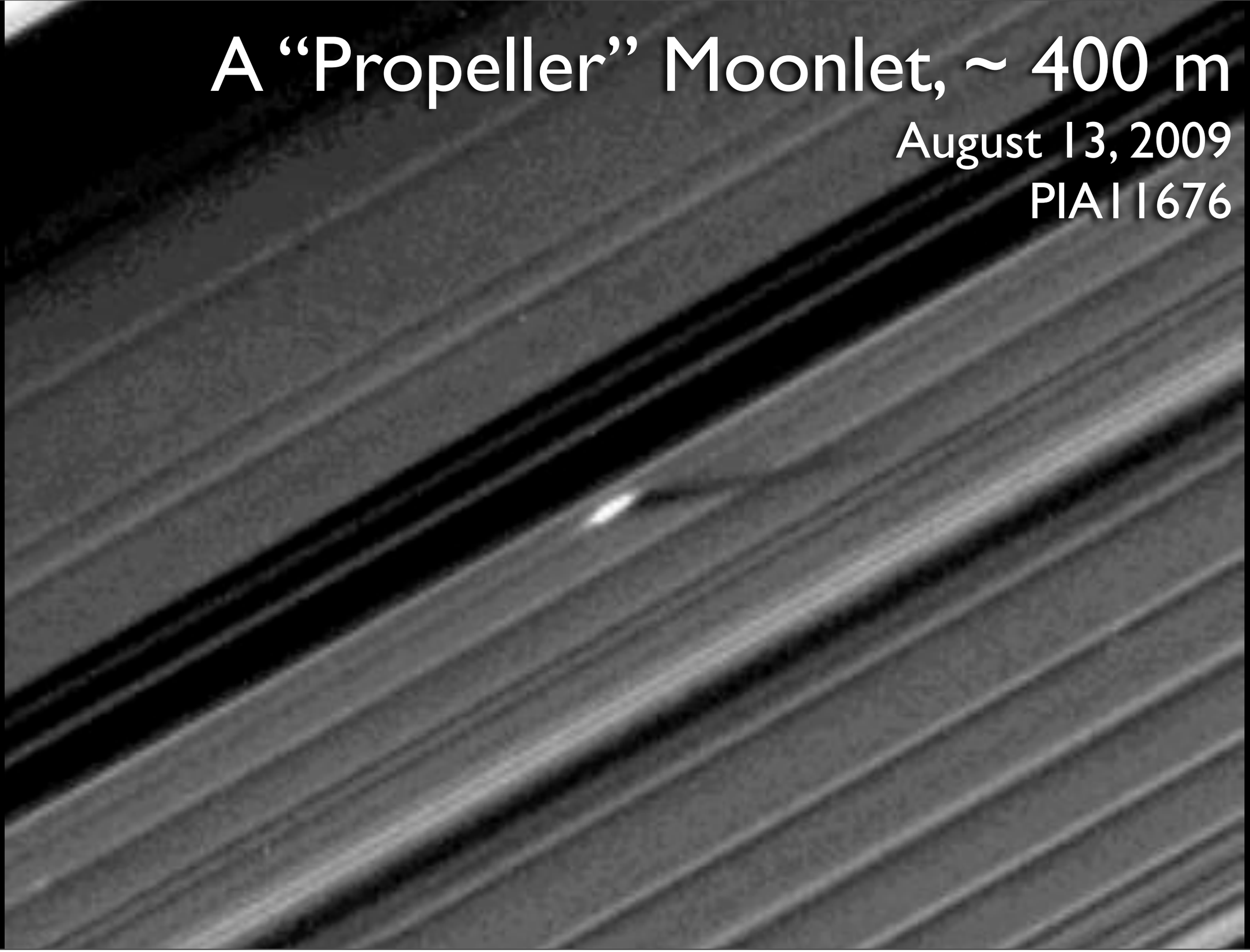
PIA11665



A "Propeller" Moonlet, ~ 400 m

August 13, 2009

PIA11676



Ripples in the C Ring

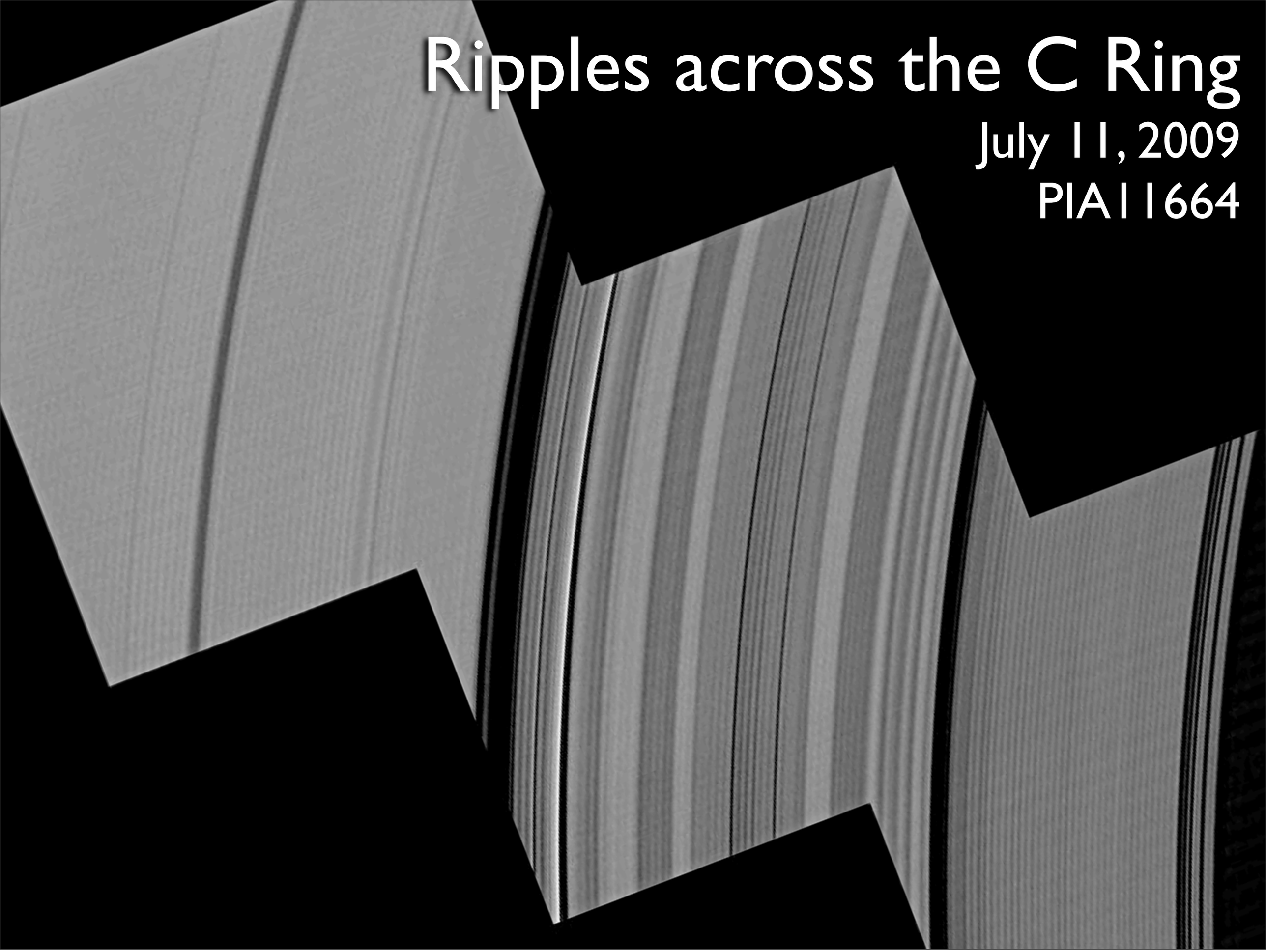
August 10, 2009

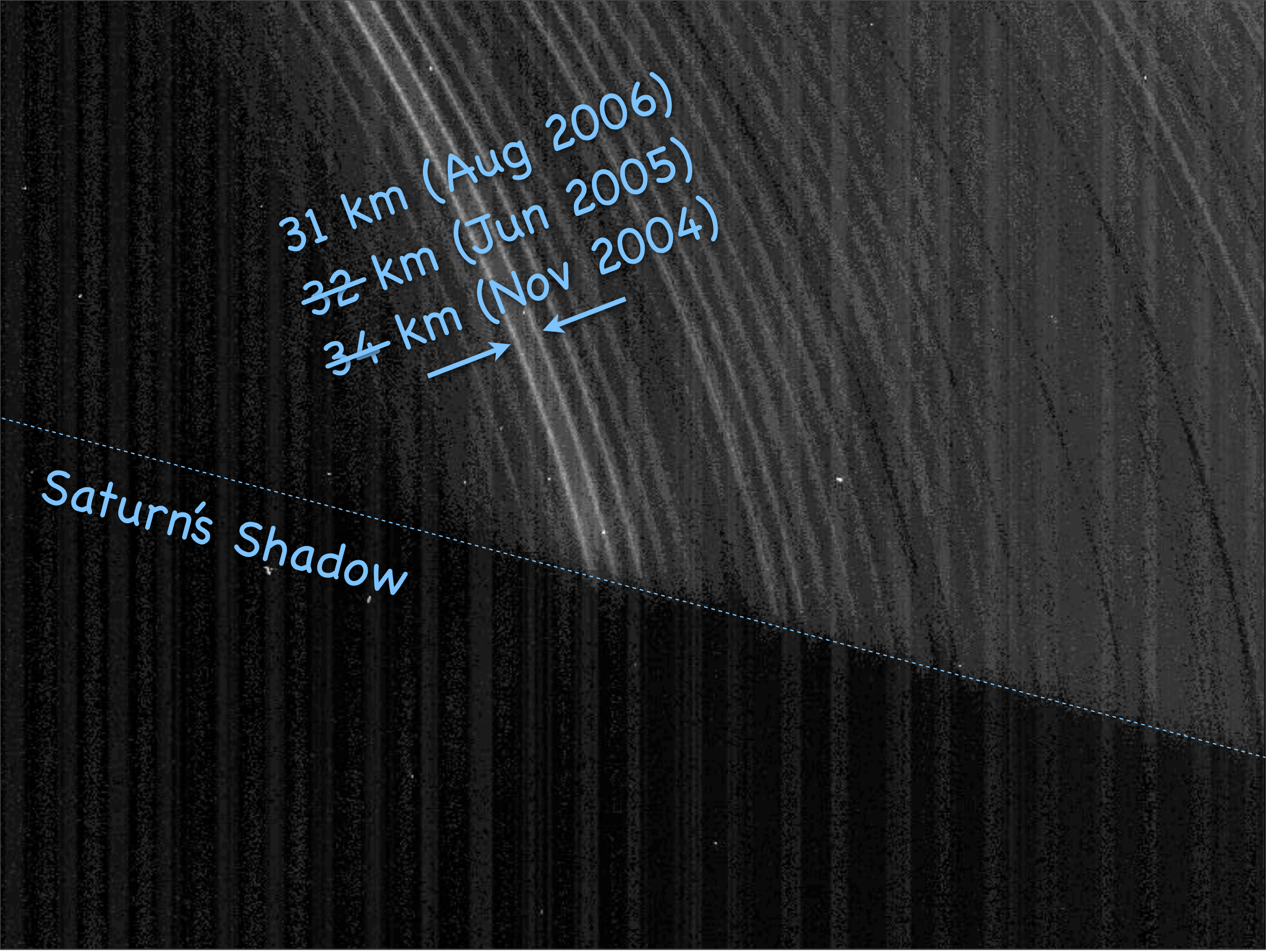
PIA11671

Ripples across the C Ring

July 11, 2009

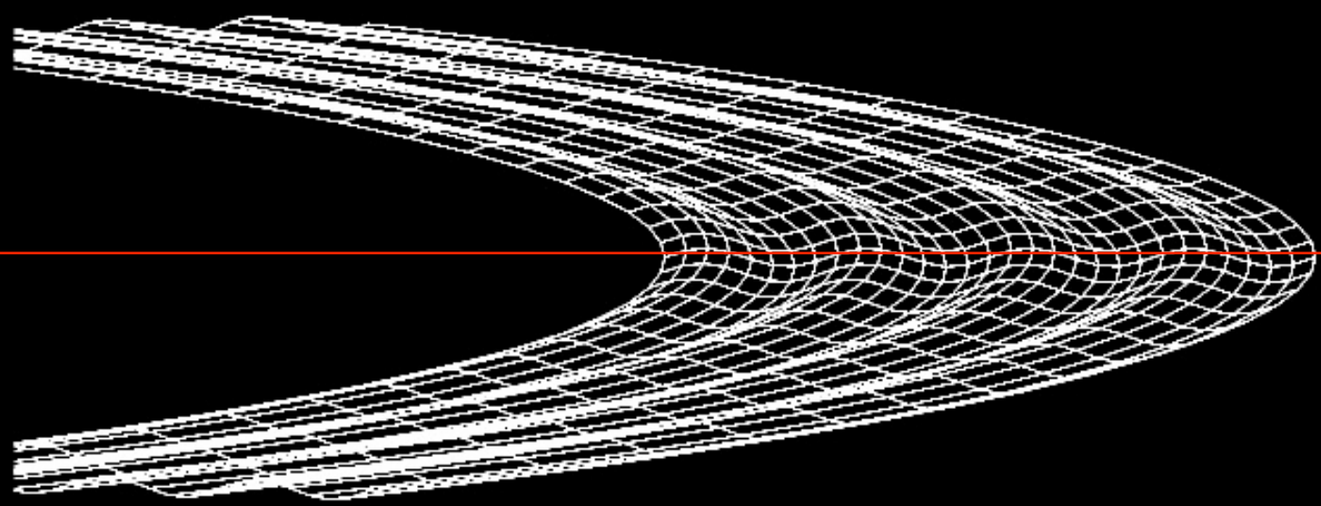
PIA11664




31 km (Aug 2006)
~~32~~ km (Jun 2005)
~~34~~ km (Nov 2004)
Saturn's Shadow

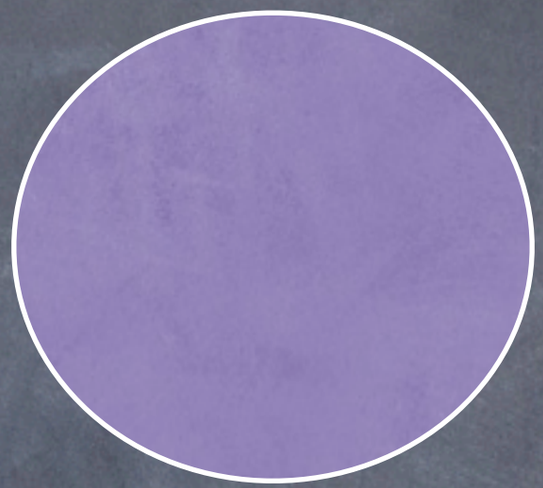
From Hedman et al. 2007.

Icarus **188**, 89–107



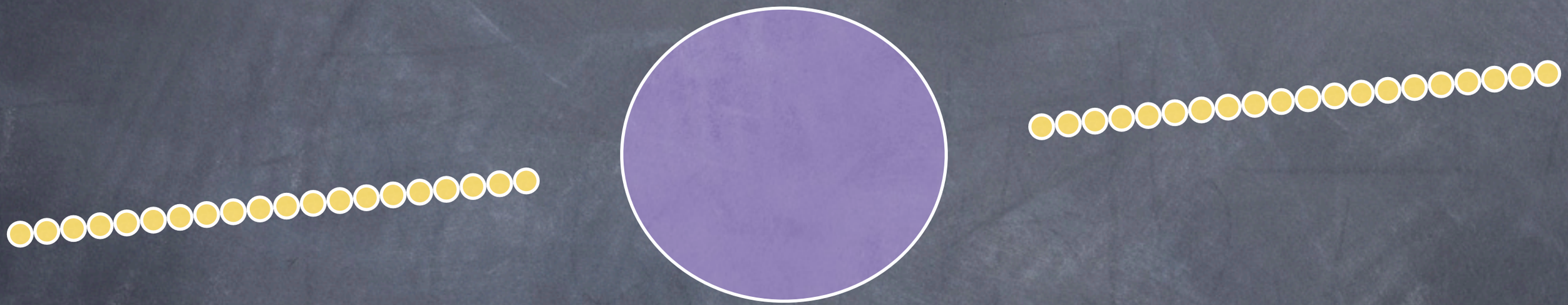
Ripples in the D & C Rings

"Cut-away" view of the rings



Ripples in the D & C Rings

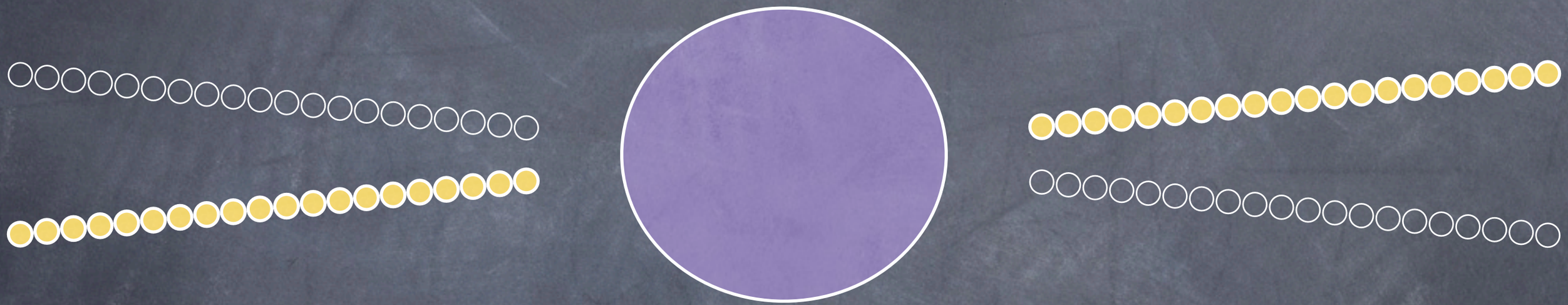
"Cut-away" view of the rings



- "Something" tilts the ring plane slightly in spring 1984.

Ripples in the D & C Rings

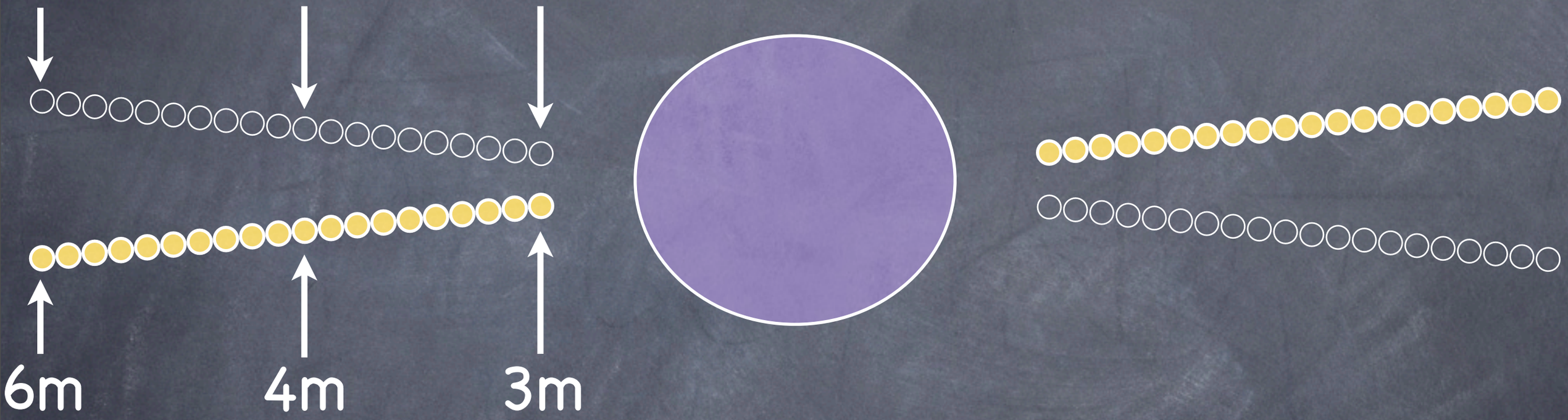
"Cut-away" view of the rings



- "Something" tilts the ring plane slightly in spring 1984.
- Oblateness causes inclined orbits to "wobble."

Ripples in the D & C Rings

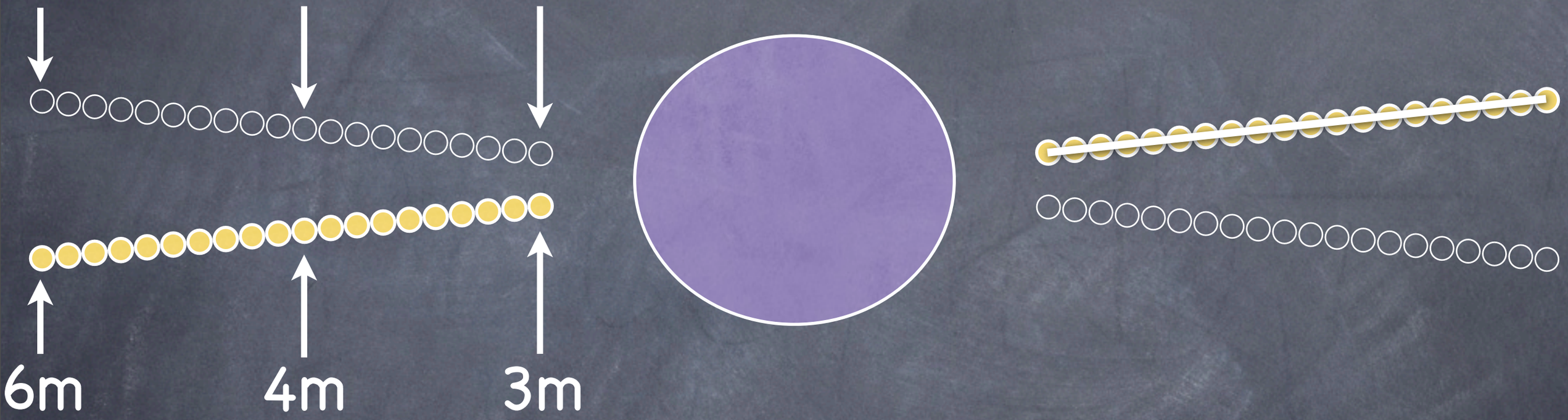
"Cut-away" view of the rings



- "Something" tilts the ring plane slightly in spring 1984.
- Oblateness causes inclined orbits to "wobble."
- Inner orbits wobble faster than outer ones.

Ripples in the D & C Rings

"Cut-away" view of the rings

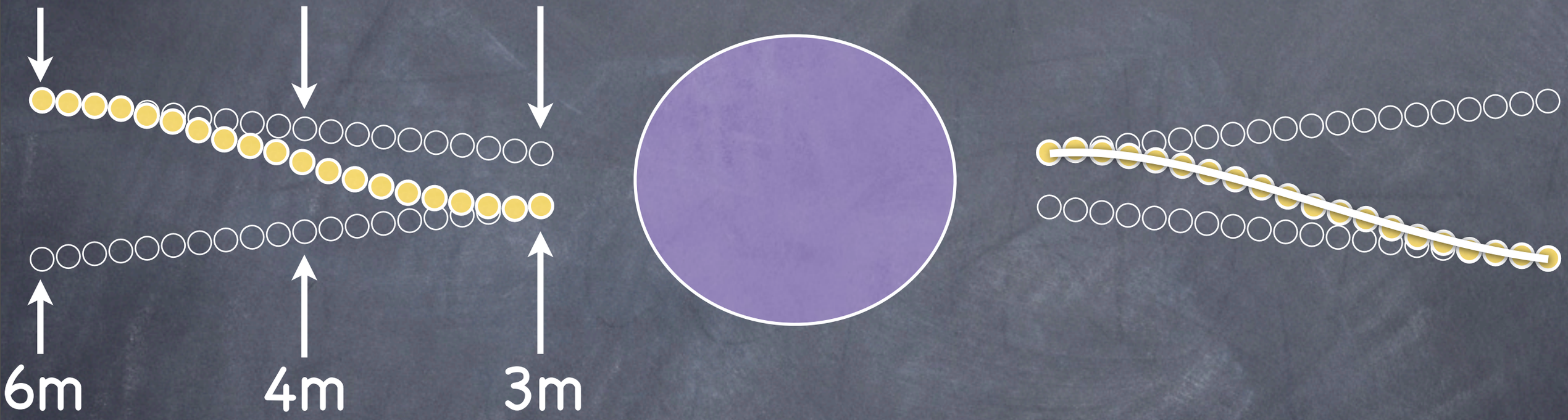


0 months

April 1984

Ripples in the D & C Rings

"Cut-away" view of the rings

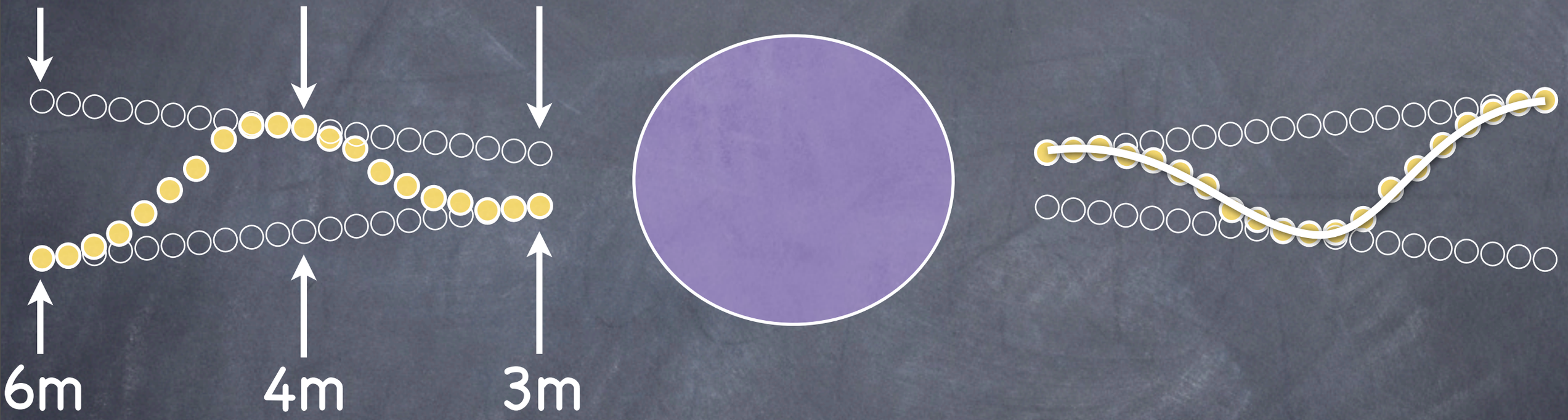


3 months

July 1984

Ripples in the D & C Rings

"Cut-away" view of the rings

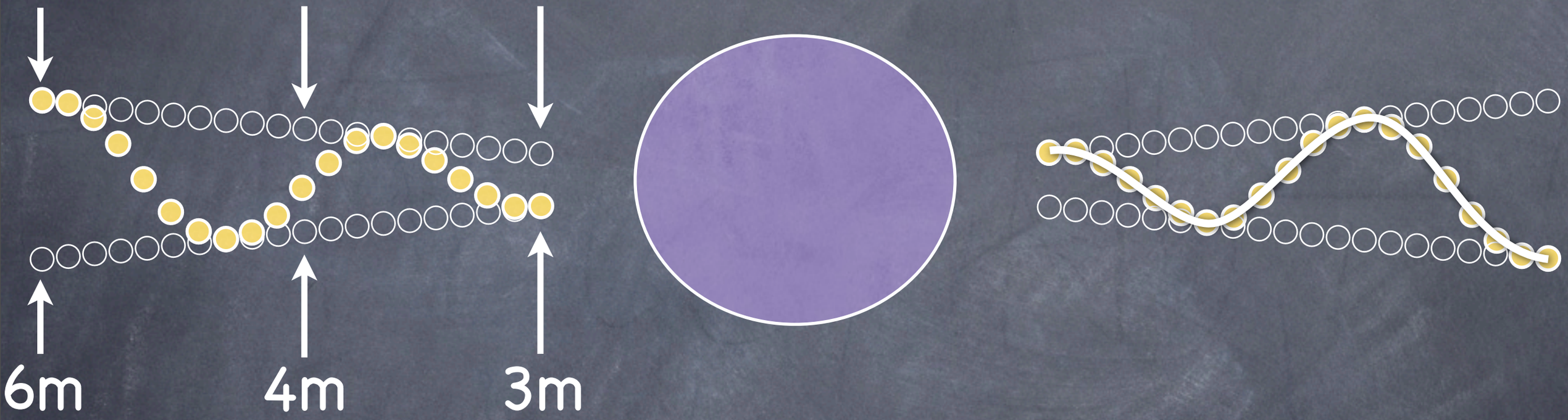


6 months

October 1984

Ripples in the D & C Rings

"Cut-away" view of the rings

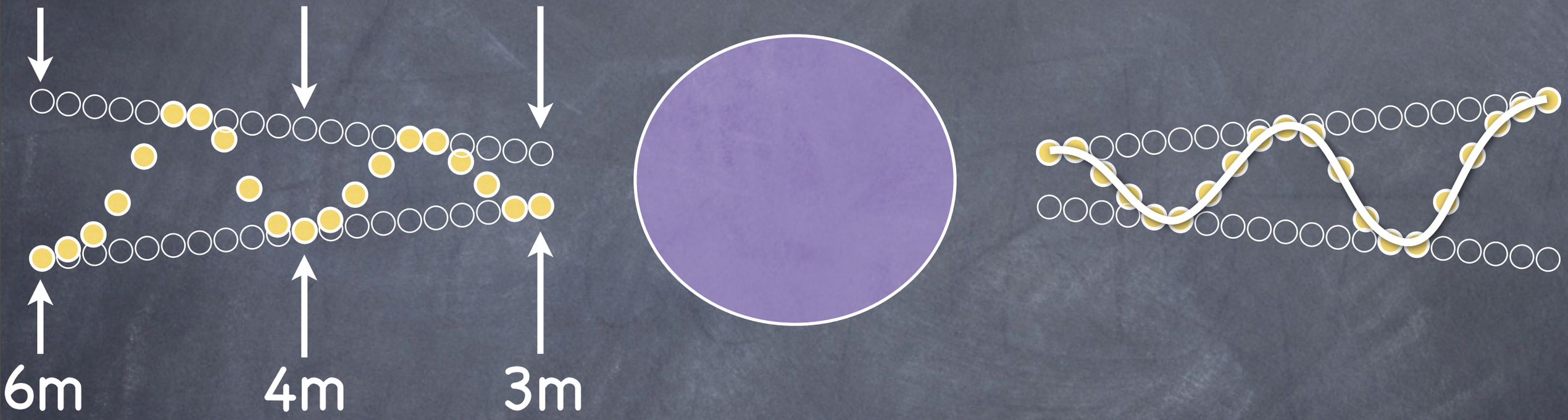


9 months

January 1985

Ripples in the D & C Rings

"Cut-away" view of the rings

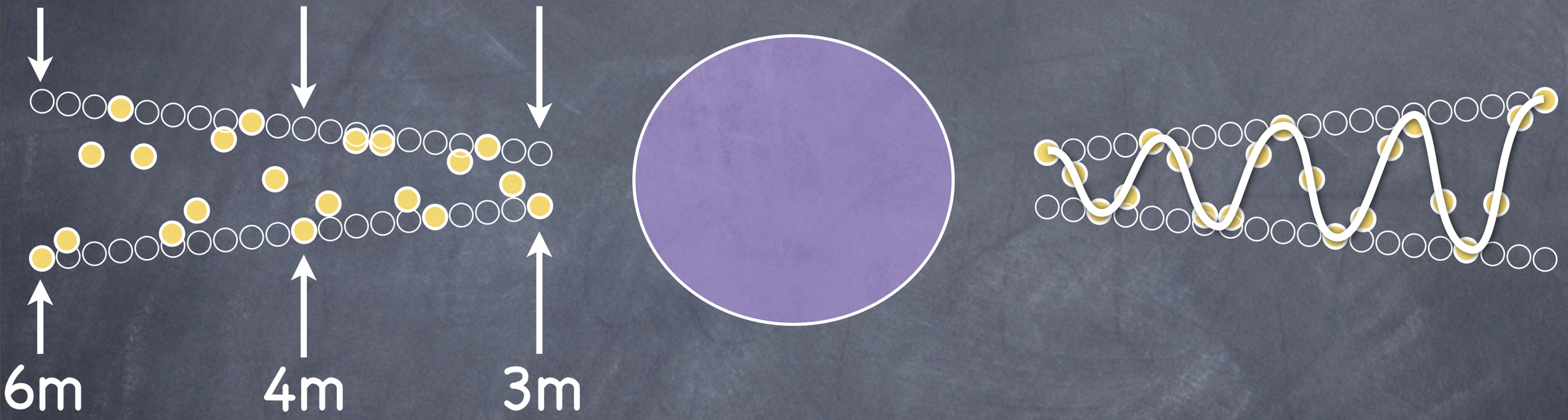


12 months

April 1985

Ripples in the D & C Rings

"Cut-away" view of the rings

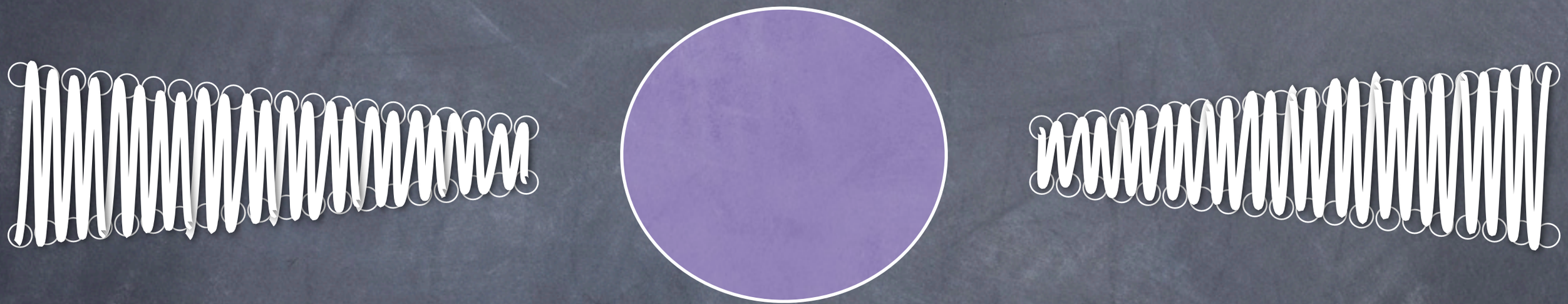


48 months

April 1986

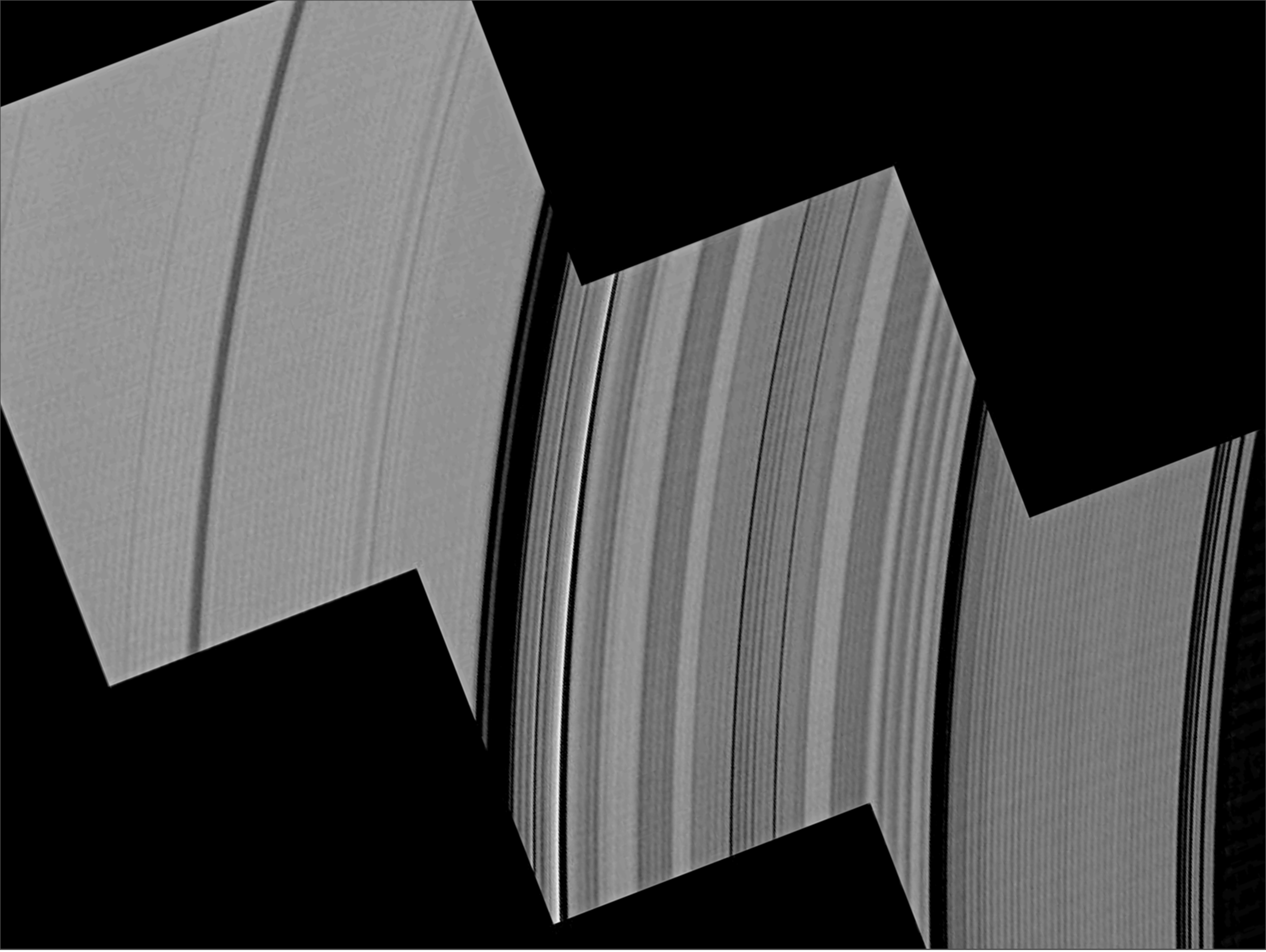
Ripples in the D & C Rings

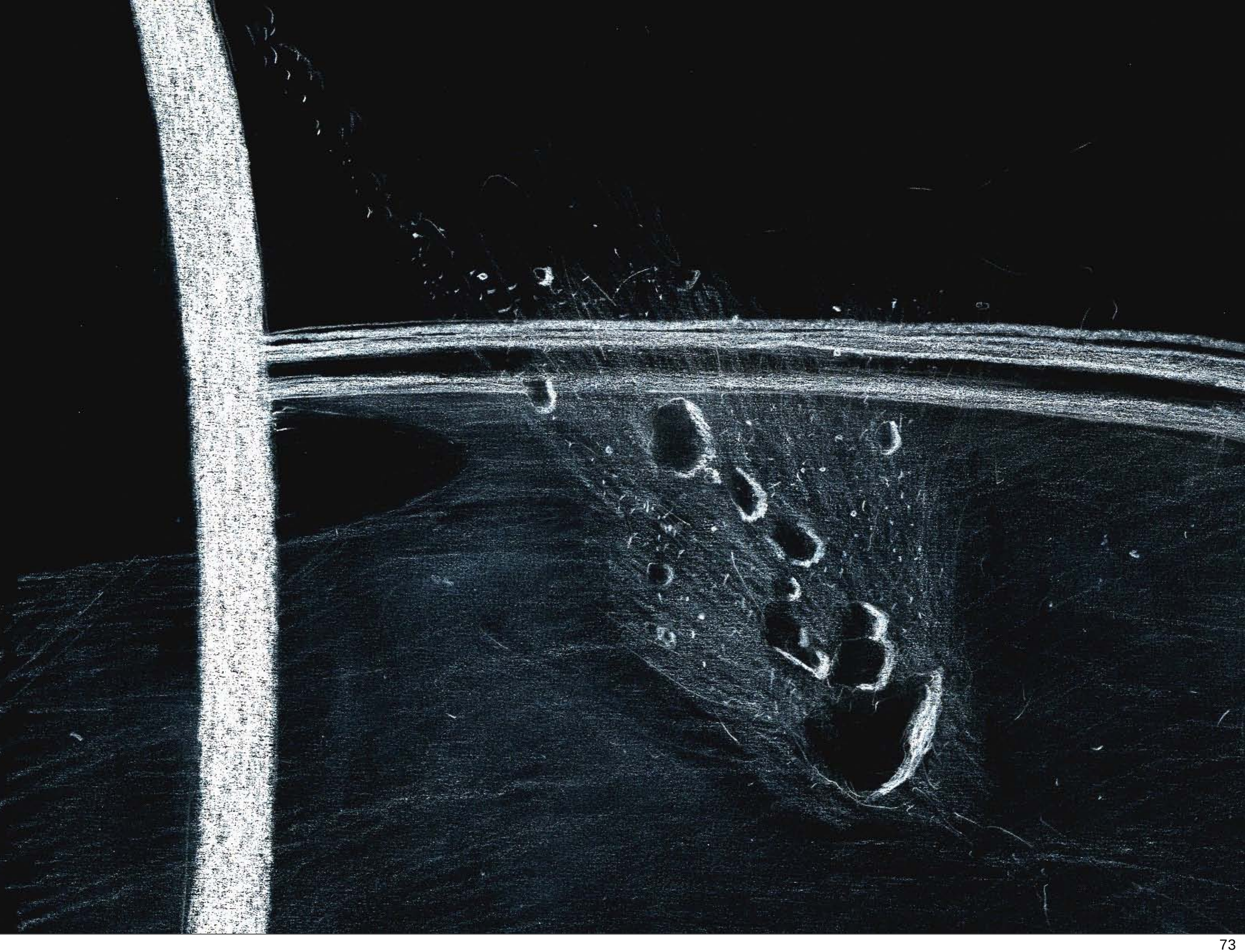
"Cut-away" view of the rings



281 months

September 2009





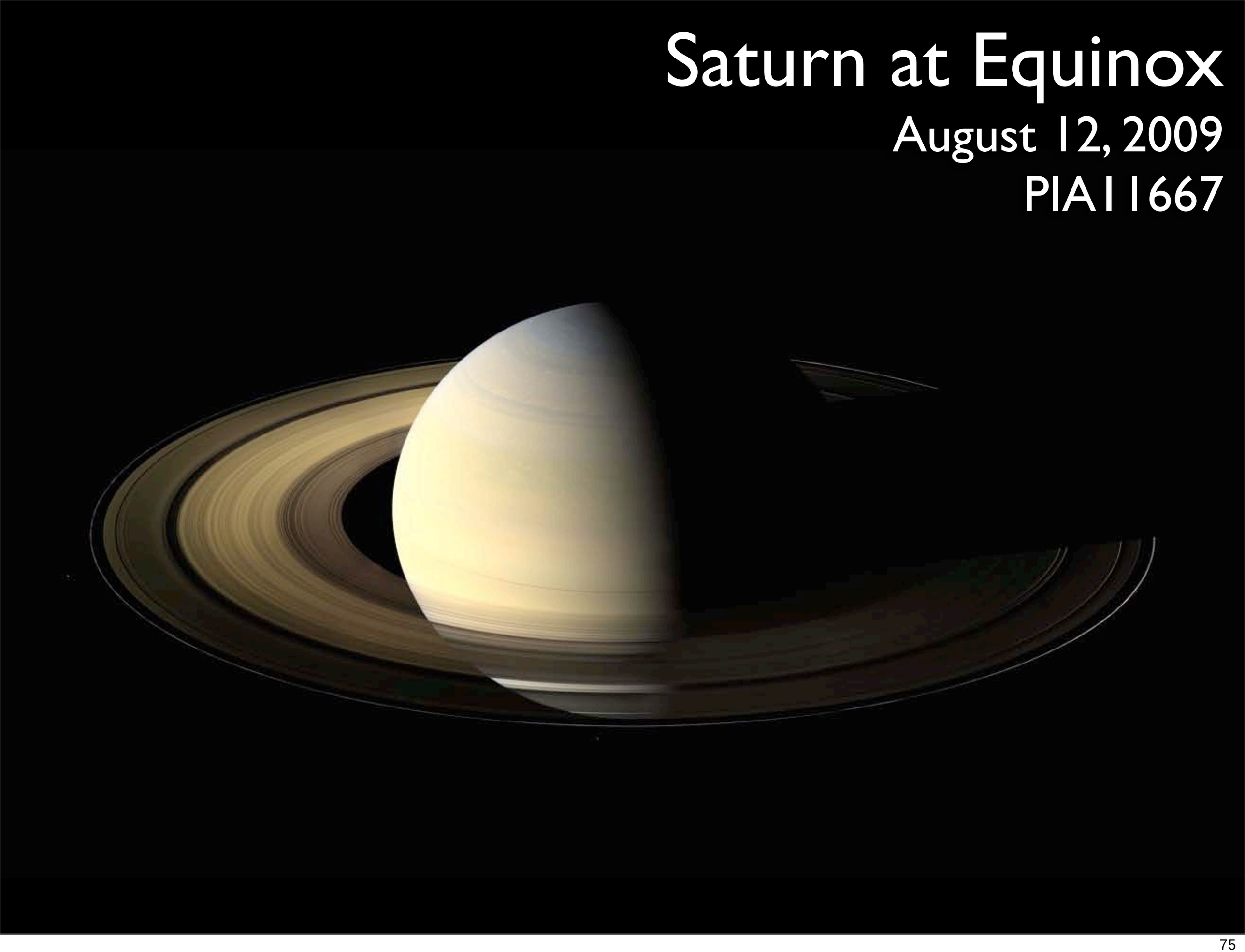
The Problem...

- We still know that "something" happened in spring 1984.
  - The pattern still unwinds to a particular moment.
- That "something" affected 17,000 km of the ring, not just a small region of the low-mass D ring.
  - It was a much larger event than we had imagined.

Saturn at Equinox

August 12, 2009

PIA11667



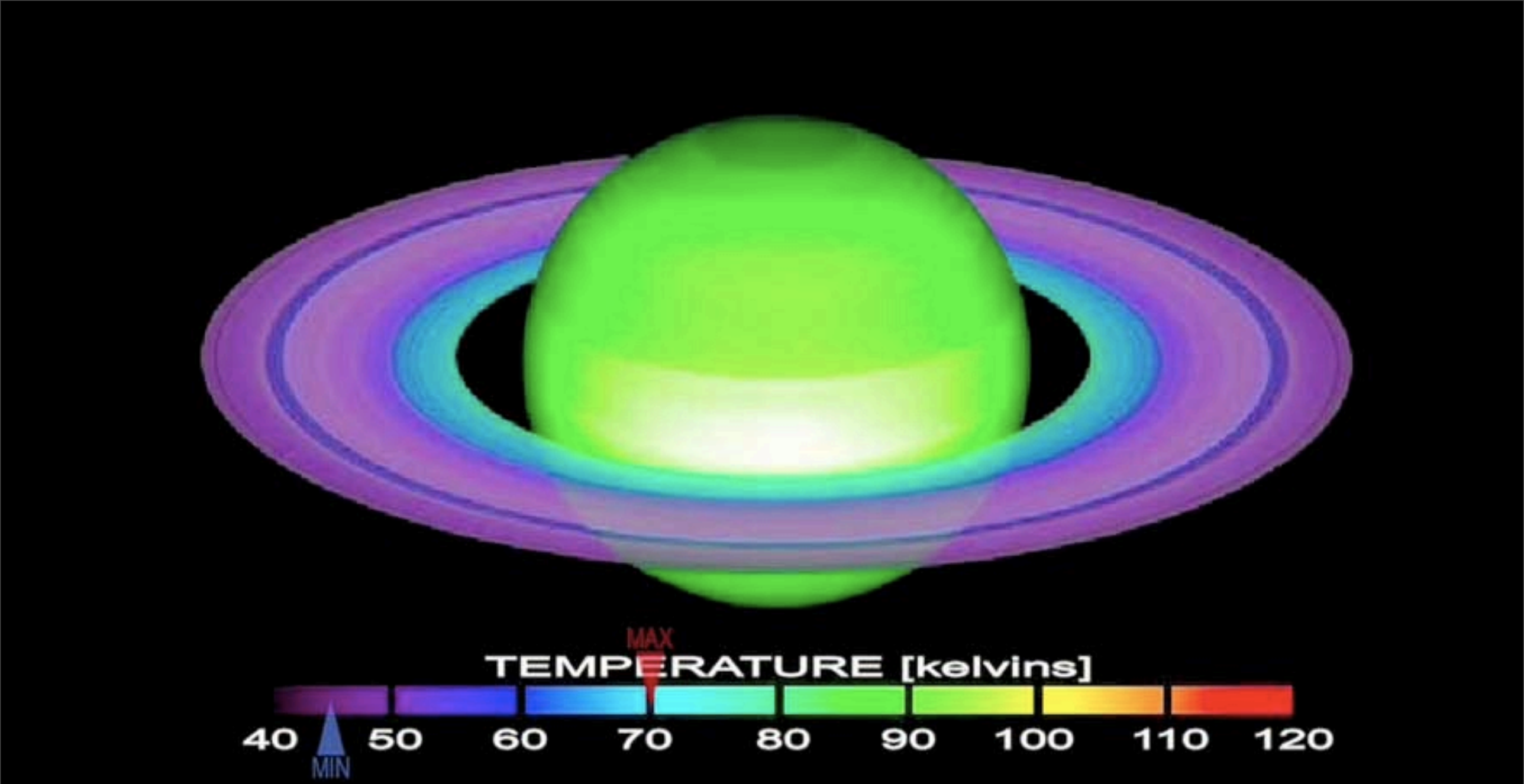
Saturn at Equinox

August 12, 2009

PIA11667

Rings illuminated primarily by Saturn-shine

Only the F Ring is still glowing
(...as was noted in HST data from 1995)

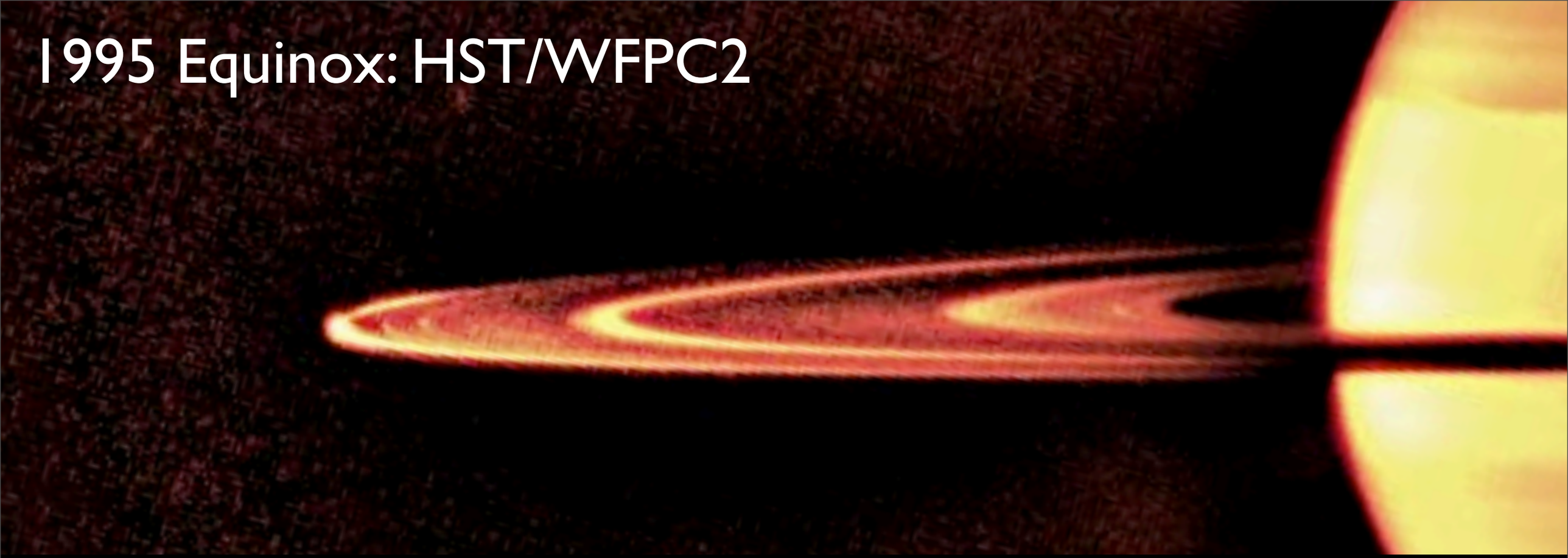


http://saturn.jpl.nasa.gov/video/videodetails/?videoID=195

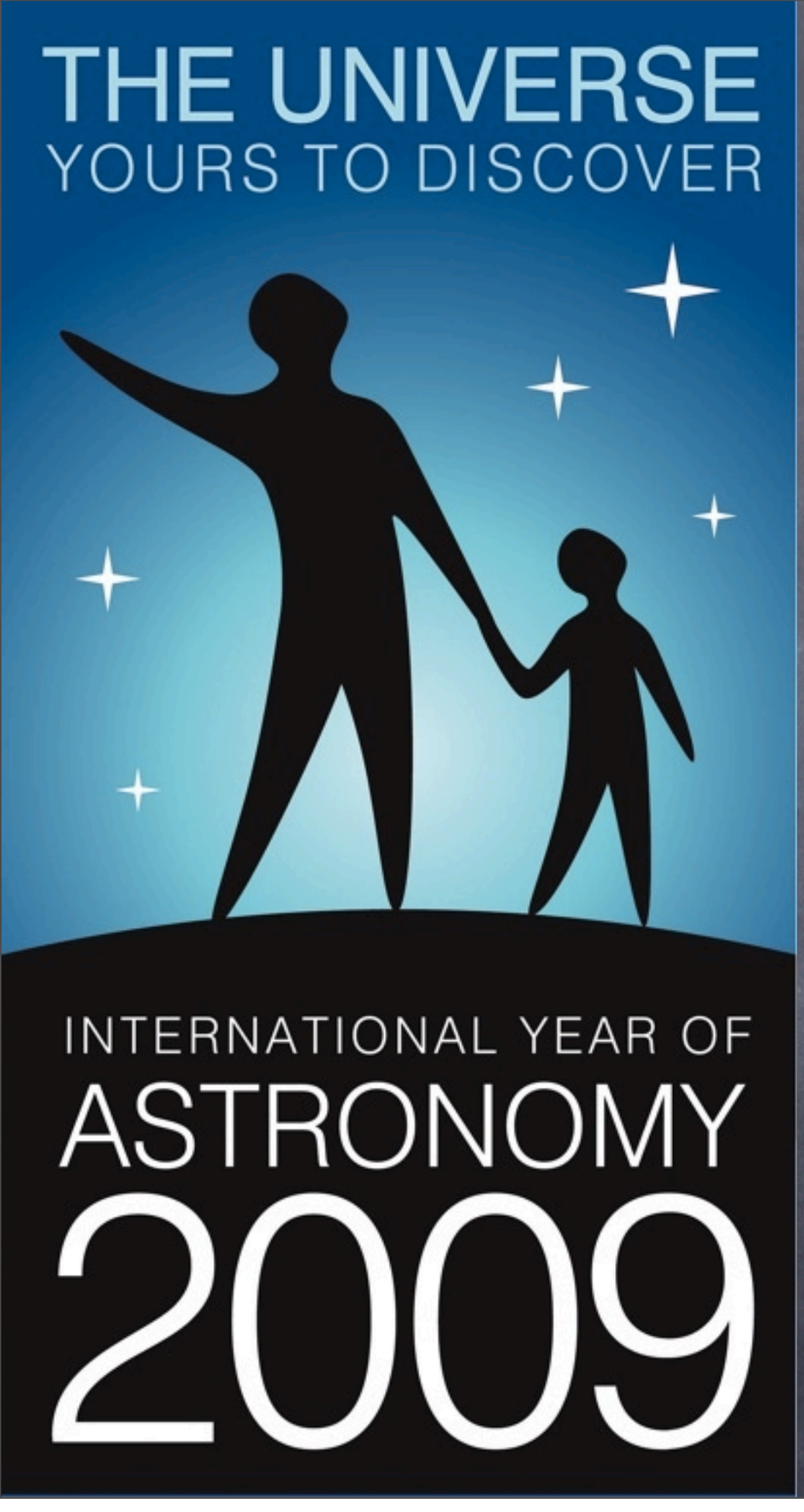
Suggestion: Advance to 1:14 in the movie

NASA/JPL/Alberto Flandes & the CIRS team

1995 Equinox: HST/WFPC2



2009 Equinox: Cassini ISS



- 400 years of telescopic astronomy.
- 399 years from Galileo's first look at Saturn.
- 350 years since the publication of Huygens' Systema Saturnium.
- Heyday of the Cassini Mission.
- Saturn's equinox.