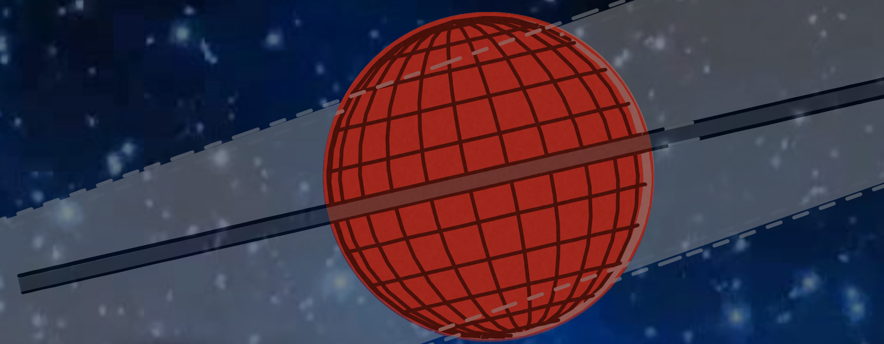

Dust Rings of Mars: Dynamical Models and Observational Limits

Mark Showalter
SETI Institute

Thursday, January 12, 2017
DAP-2017 Boulder, Colorado

Nix and Hydra:
Five Years after Discovery

May 11–12, 2010

NEW HORIZONS

APL
The Johns Hopkins University
Applied Physics Laboratory

SPACE TELESCOPE SCIENCE INSTITUTE
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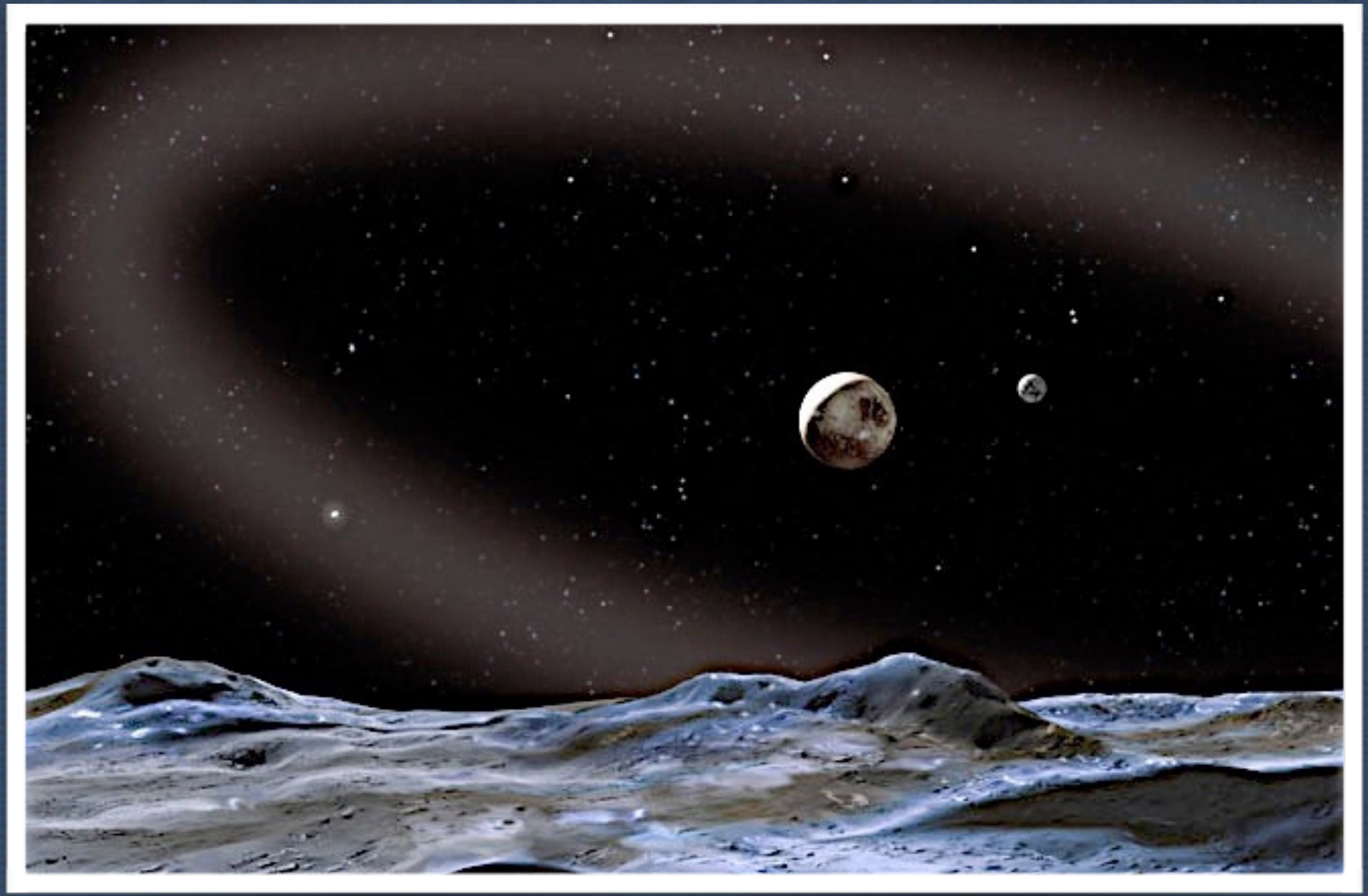
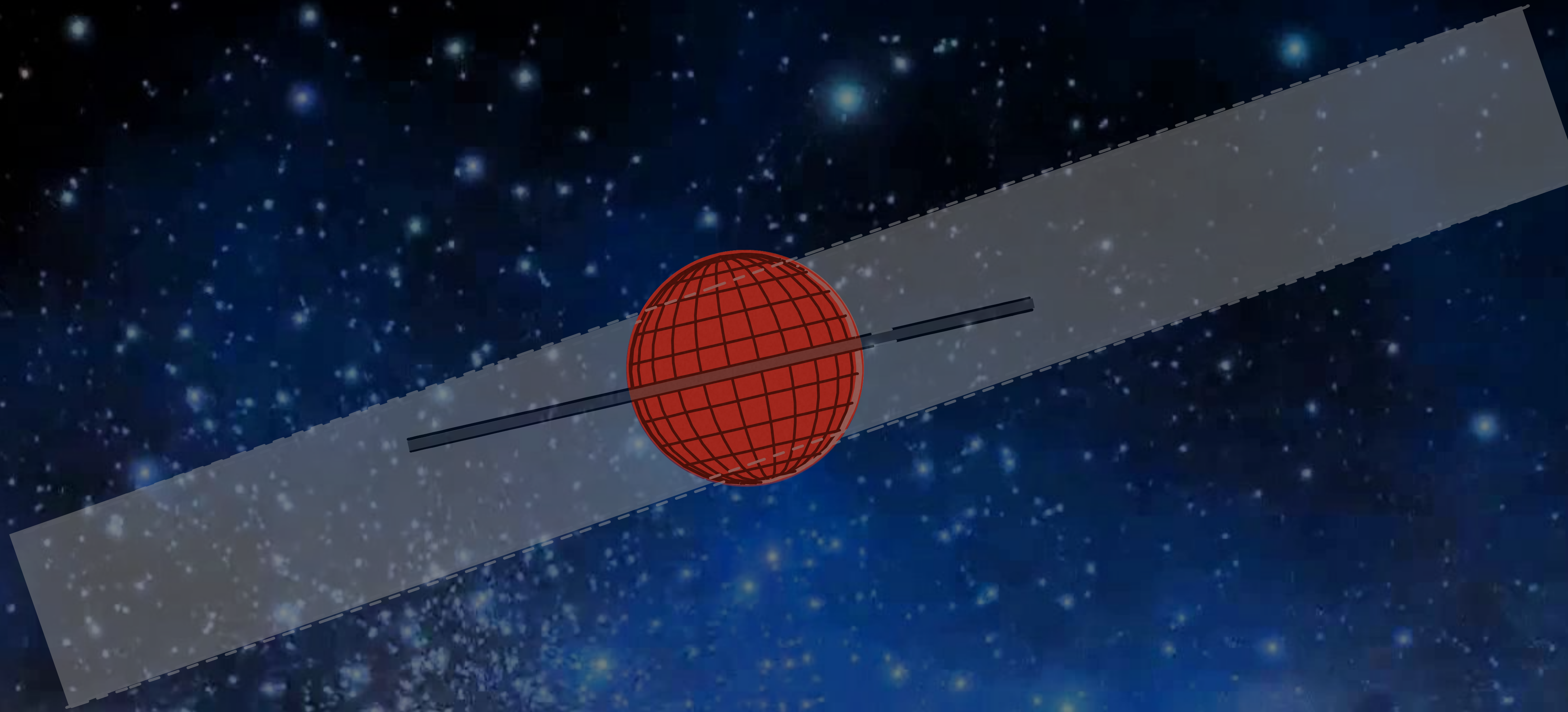


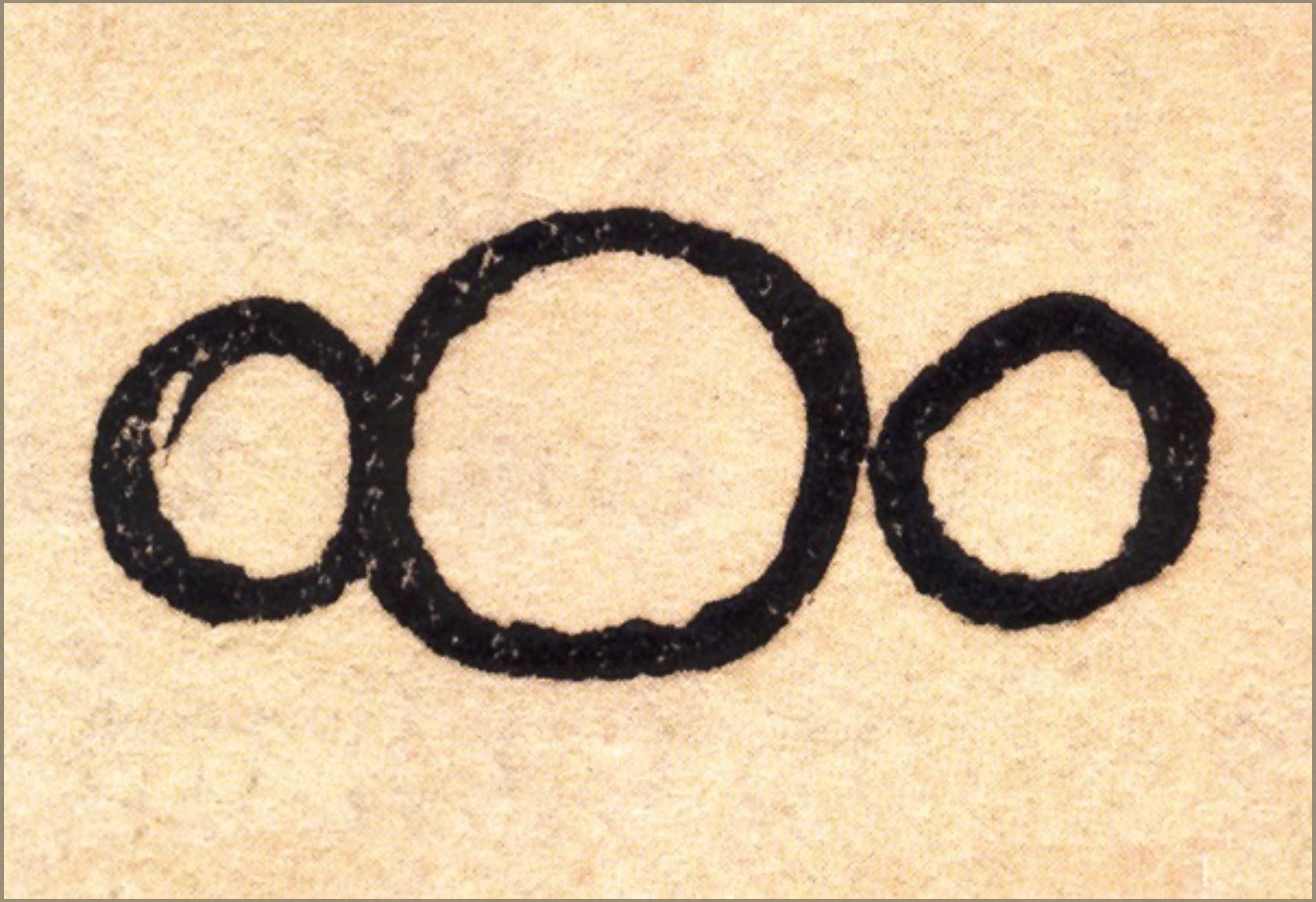
Prospects for Rings around Pluto
Observational Perspectives

Mark R. Showalter, mshowalter@seti.org
Doug Hamilton, hamilton@astro.umd.edu



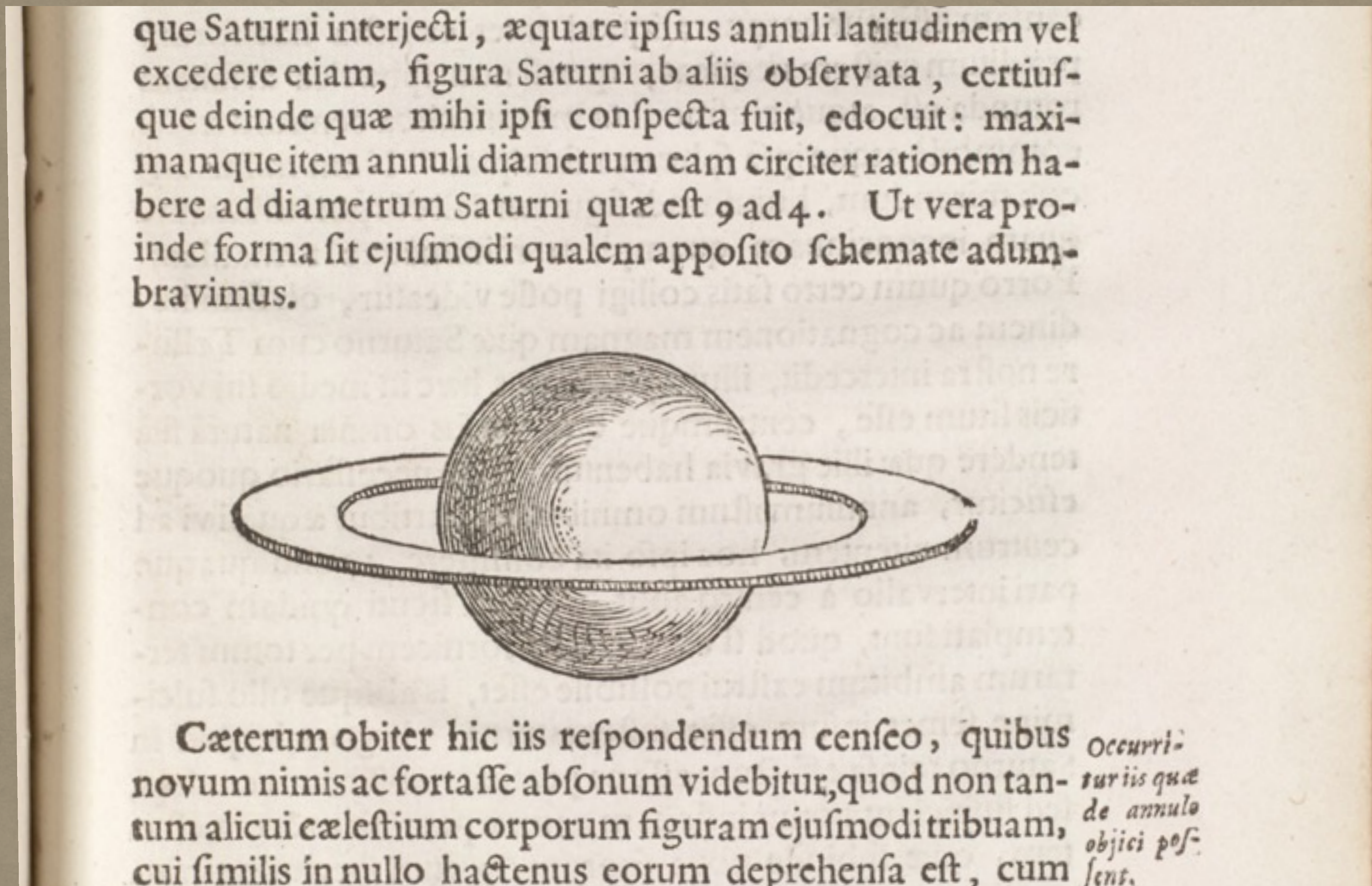
Q. Why are we even discussing Martian rings?

Galileo, 1610



1. Discovery of rings

Huygens, 1659



que 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

Occurritur iis quæ de annulo objici poſſent.

1. Discovery of rings

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 least one modern observation of a belated and gradual emergence of the satellite Iapetus from the shadow of the *A* ring[4], suggesting an extension or at least a gradual tapering of the outer edge of the *A* ring.

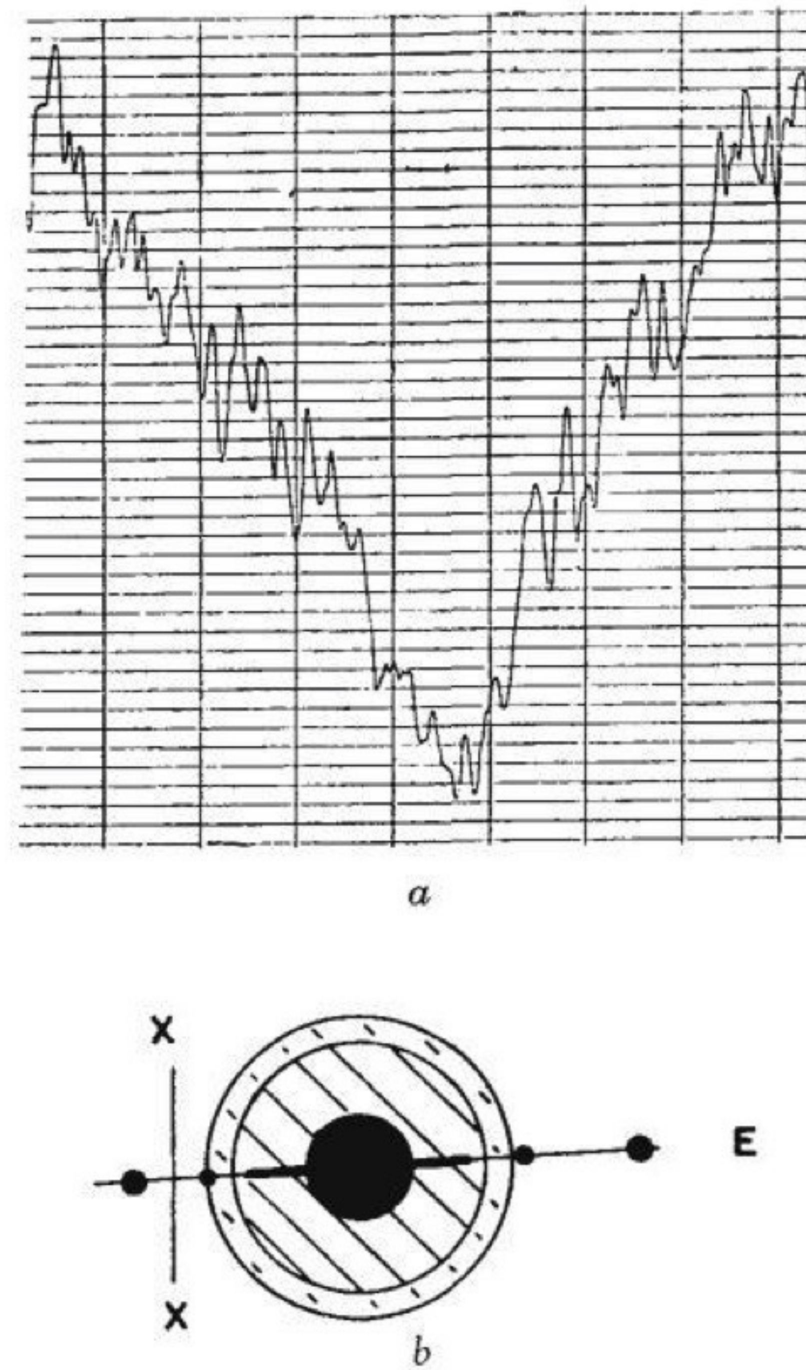


Fig. 2. *a*, Microdensitometer trace along path *X–X* of Fig. 2*b*. Exposure time, 5 min, December 12, 1966. Other data as in Fig. 1*a*. *b*, Aspect of Saturn, December 12, 1966.

On six nights between October 27, 1966, and January 16, 1967, about fifty photographs of Saturn of considerable length were taken with the 30 in. refractor at the Allegheny Observatory of the University of Pittsburgh. On all moderately long (5–10 min) and very long (30 min) exposures on backed Kodak '103*a*-0' without filter

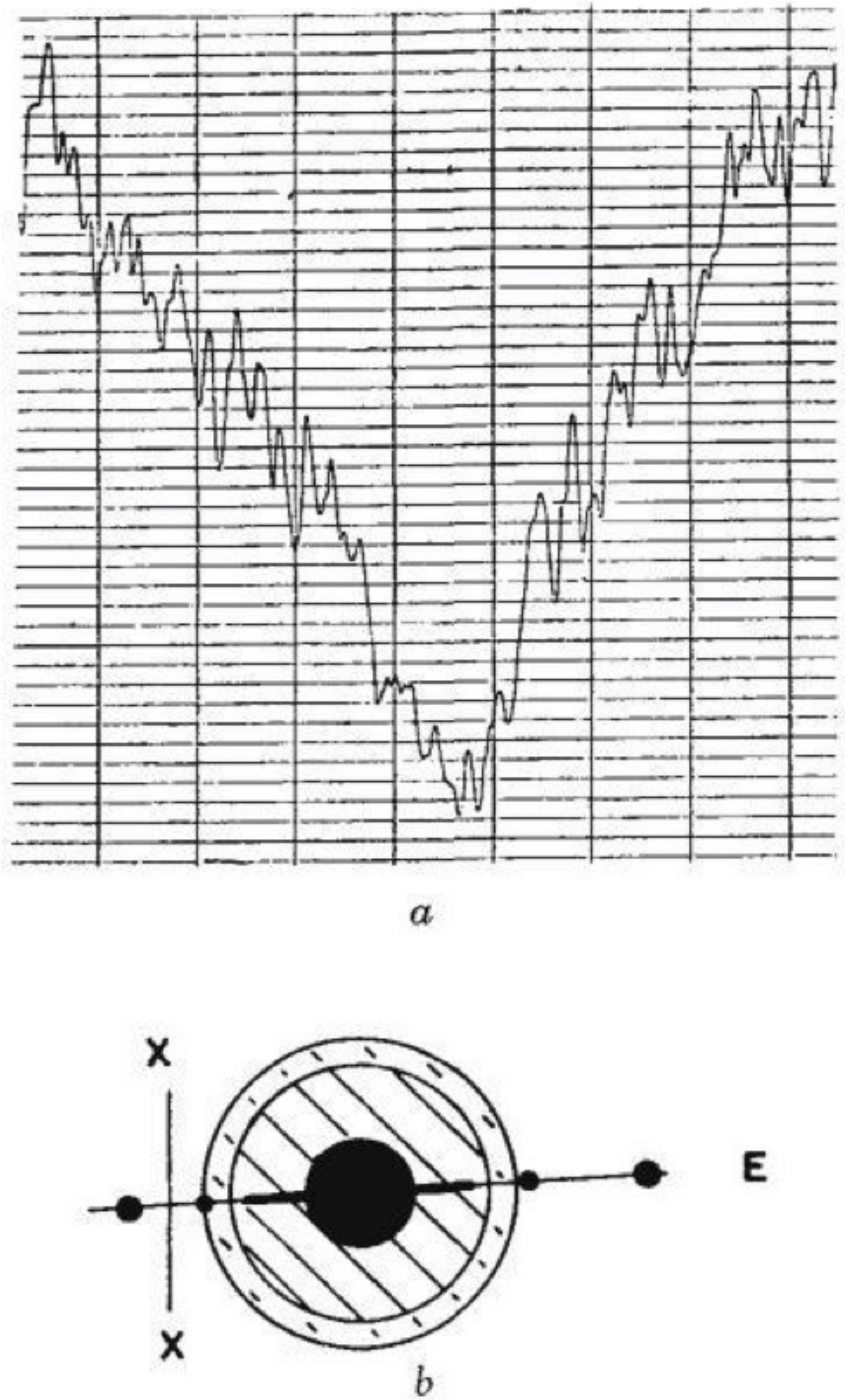
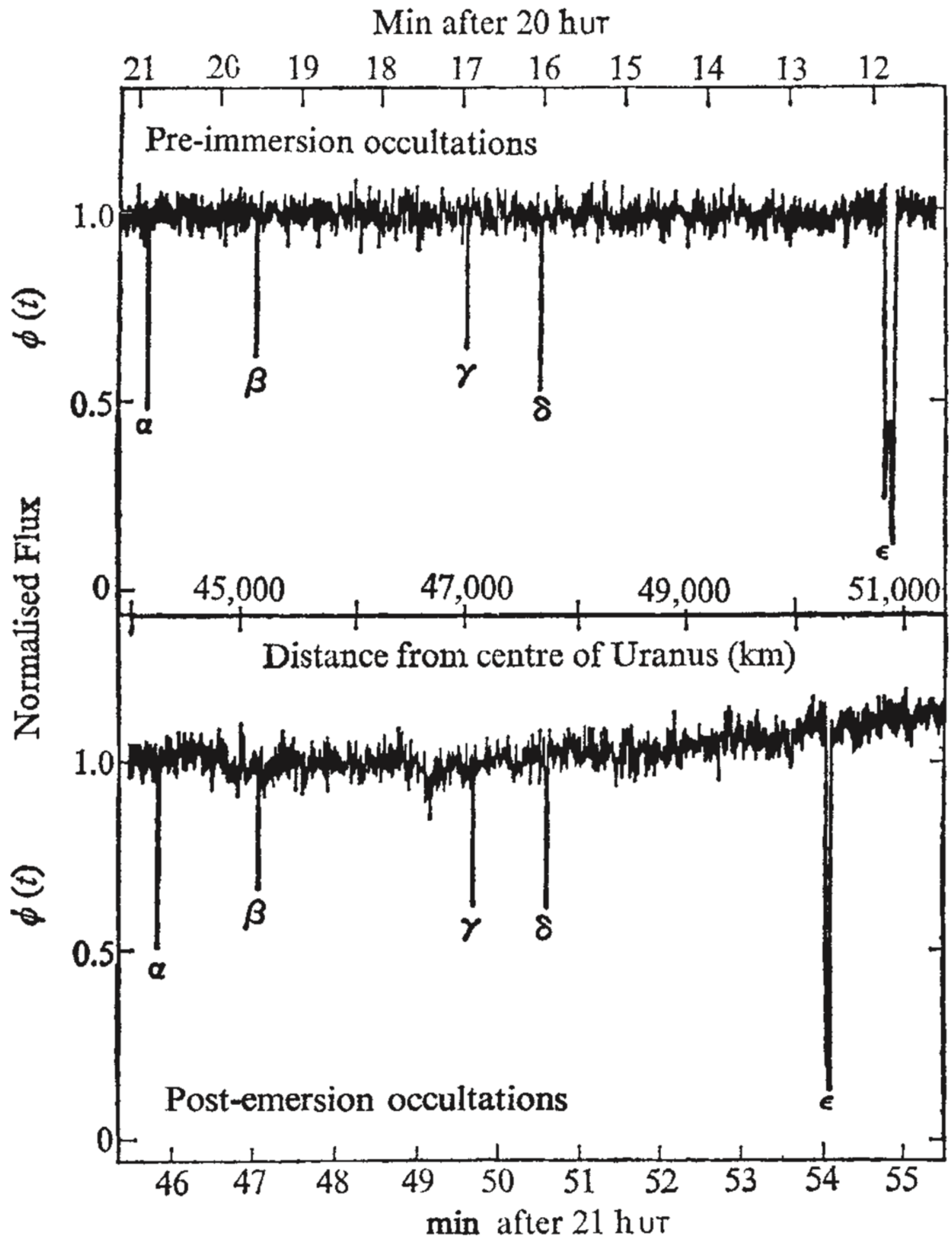


Fig. 2. *a*, Microdensitometer trace along path *X–X* of Fig. 2*b*. Exposure time, 5 min, December 12, 1966. Other data as in Fig. 1*a*. *b*, Aspect of Saturn, December 12, 1966.

Feibelman, 1967

2. Discovery of a faint ring.



Elliot et al., 1977

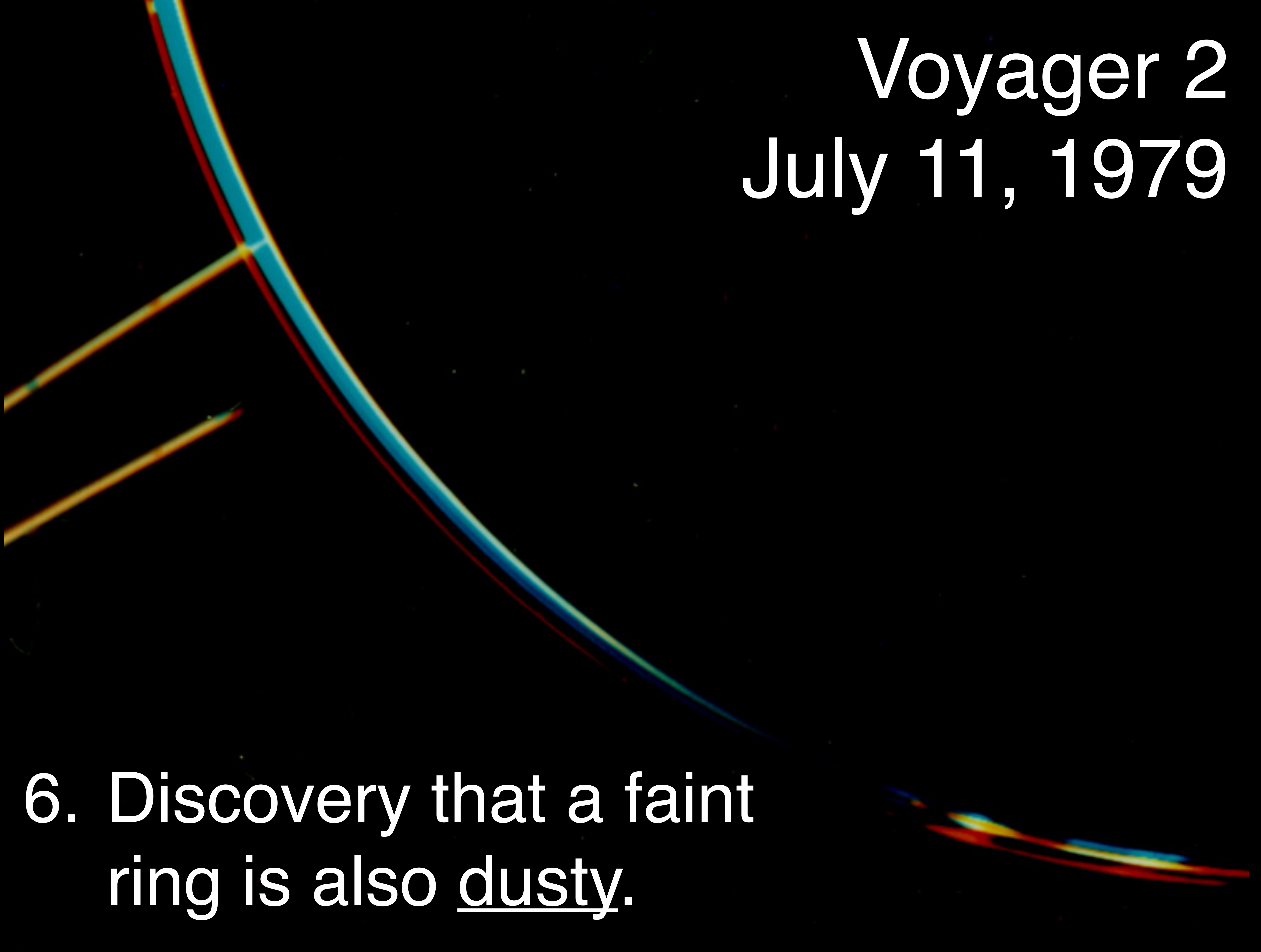
3. Discovery of rings <u>not at Saturn</u>.

Voyager 1 at Jupiter
March 4, 1979

4. Discovery of a faint ring not at Saturn.

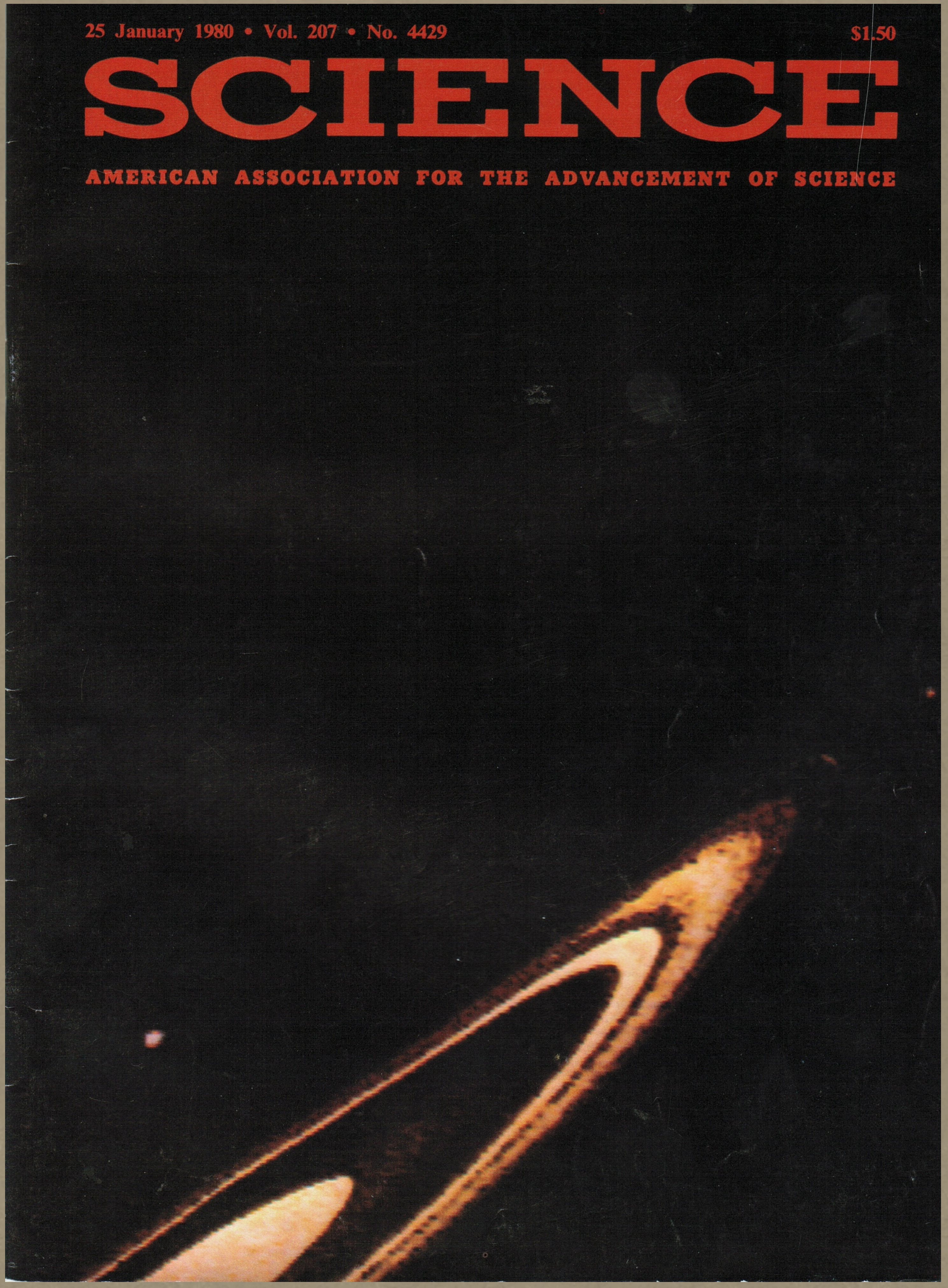

Voyager 2
July 8, 1979
Adrastea
5. Discovery of a faint ring associated with a small moon.

Voyager 2
July 11, 1979



6. Discovery that a faint ring is also <u>dusty</u>.

Pioneer 11
September 1, 1979



7. Discovery of <u>another</u> faint ring of Saturn

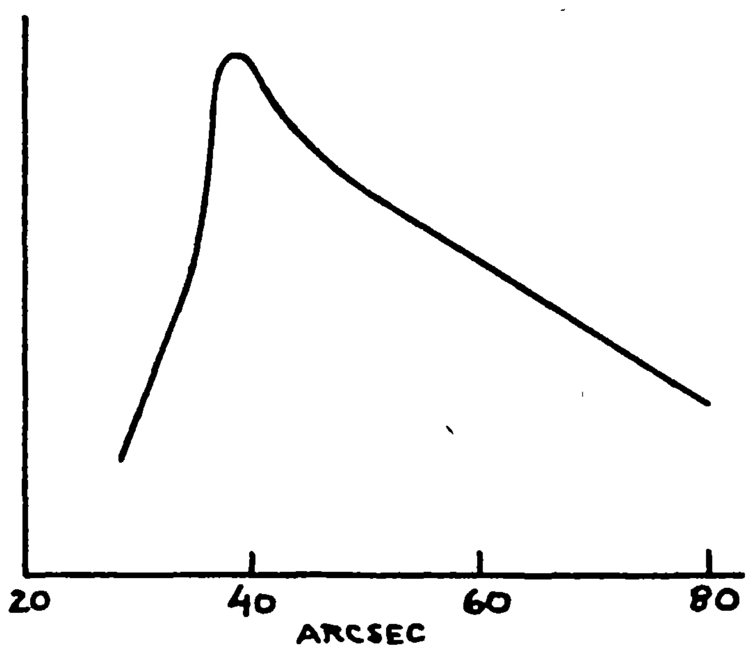
maxima of density near 4.4 and 5.7 Saturn's radii.

9.13 Profile of Saturn's E Ring. W. A. BAUM and T. KREIDL, Lowell Observatory; J. A. WESTPHAL and G. E. DANIELSON, California Institute of Technology; P. K. SEIDELMANN and D. PASCU, U. S. Naval Observatory; and D. G. CURRIE, University of Maryland. - The tenuous E ring of Saturn is found to have a maximum "density" at about 40 arcseconds from the center of Saturn, evidently coinciding with the orbit of the satellite Enceladus and presumably controlled by it. The radial distribution of

Baum et al., 1980

12TH ANNUAL D

material in the ring has approximately the following form if the material is assumed to be homogeneous. This form suggests that the E ring may be of recent origin. It was obtained by inverting a preliminary edge-on brightness profile of the E ring derived from images recorded in March (1980) with a CCD camera attached to the 1.5-meter reflector of the U. S. Naval Observatory at Flagstaff. The developmental camera, built at Cal Tech for ground-based training of the Space Telescope Wide-Field/Planetary Camera Team, utilizes a TI 500x500 thinned CCD operated at -120°C. In addition to a coronagraphic technique for suppressing diffracted light, we used a complex focal-plane mask for blocking direct light from individual satellites, as well as from Saturn and the A+B rings. This system permitted very "deep" exposures that provided a clear E-ring signal out to about eight Saturn radii.



8. Discovery that Saturn's E ring is also associated with a moon.

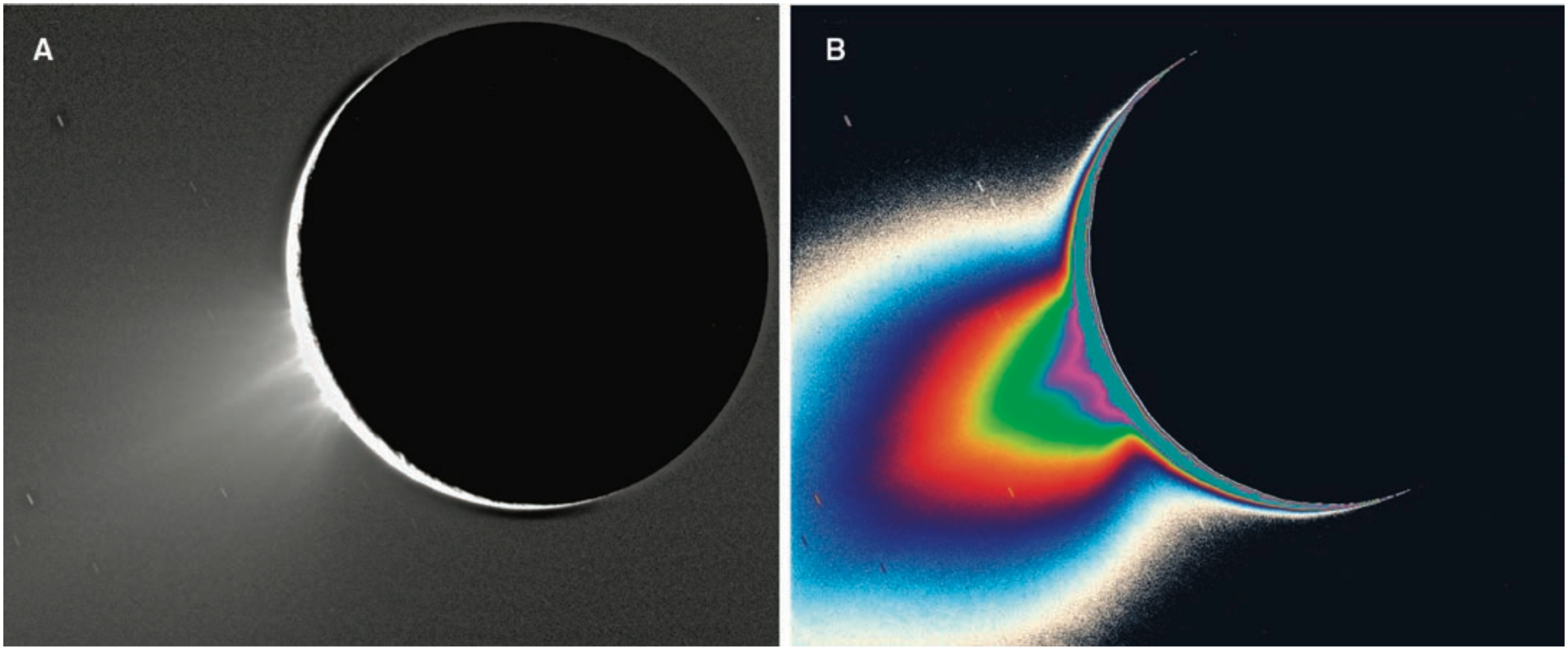
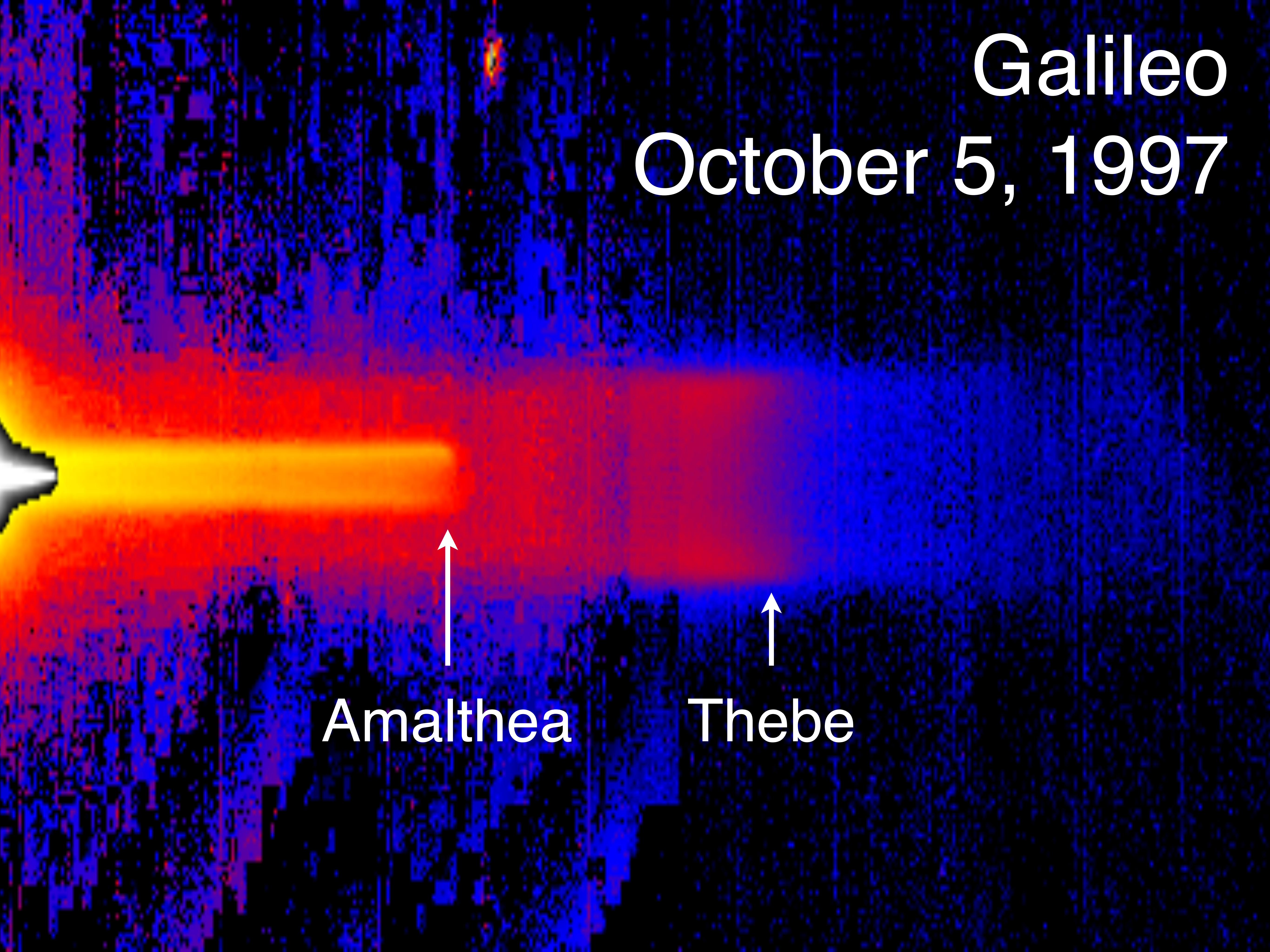
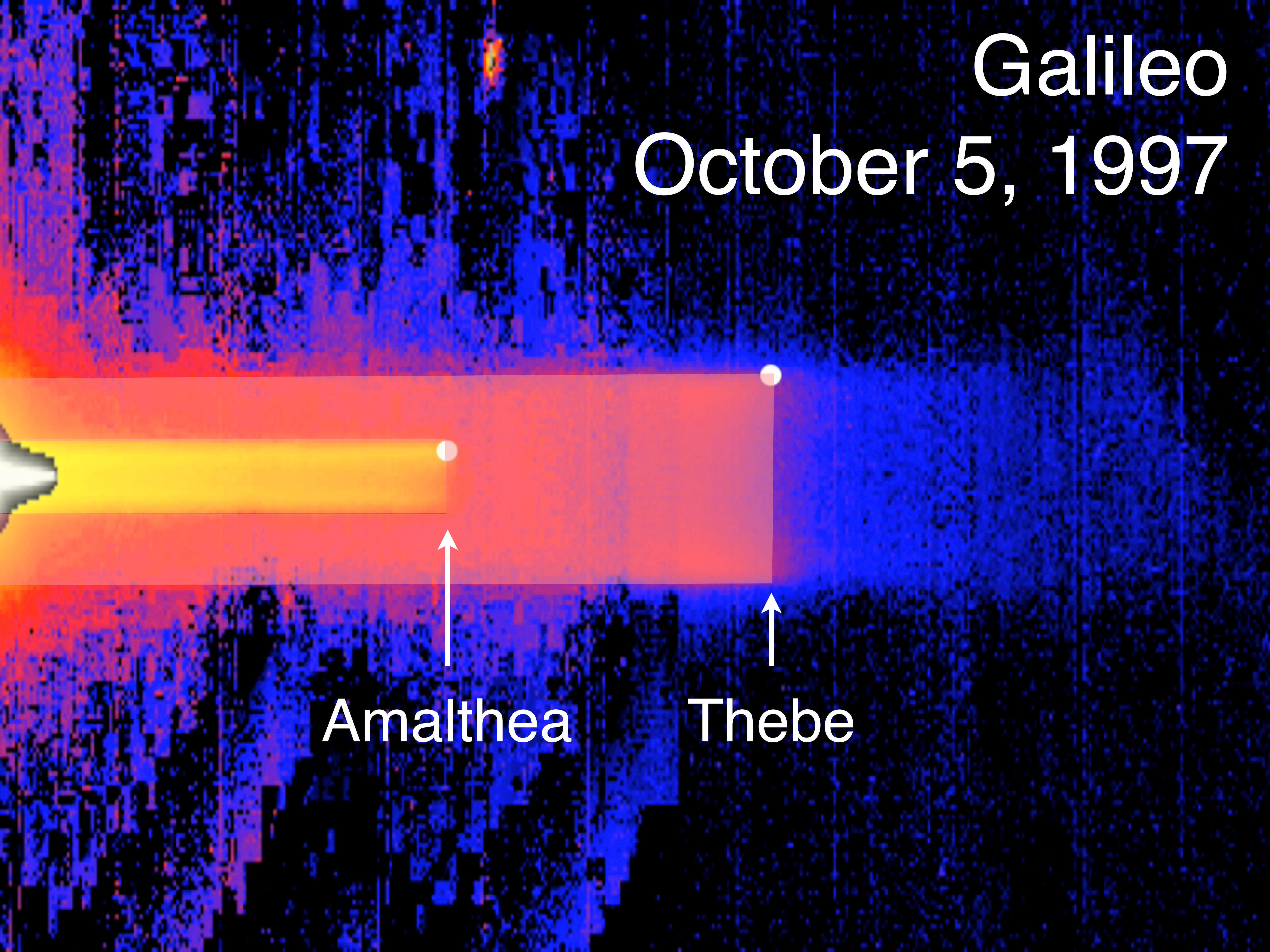


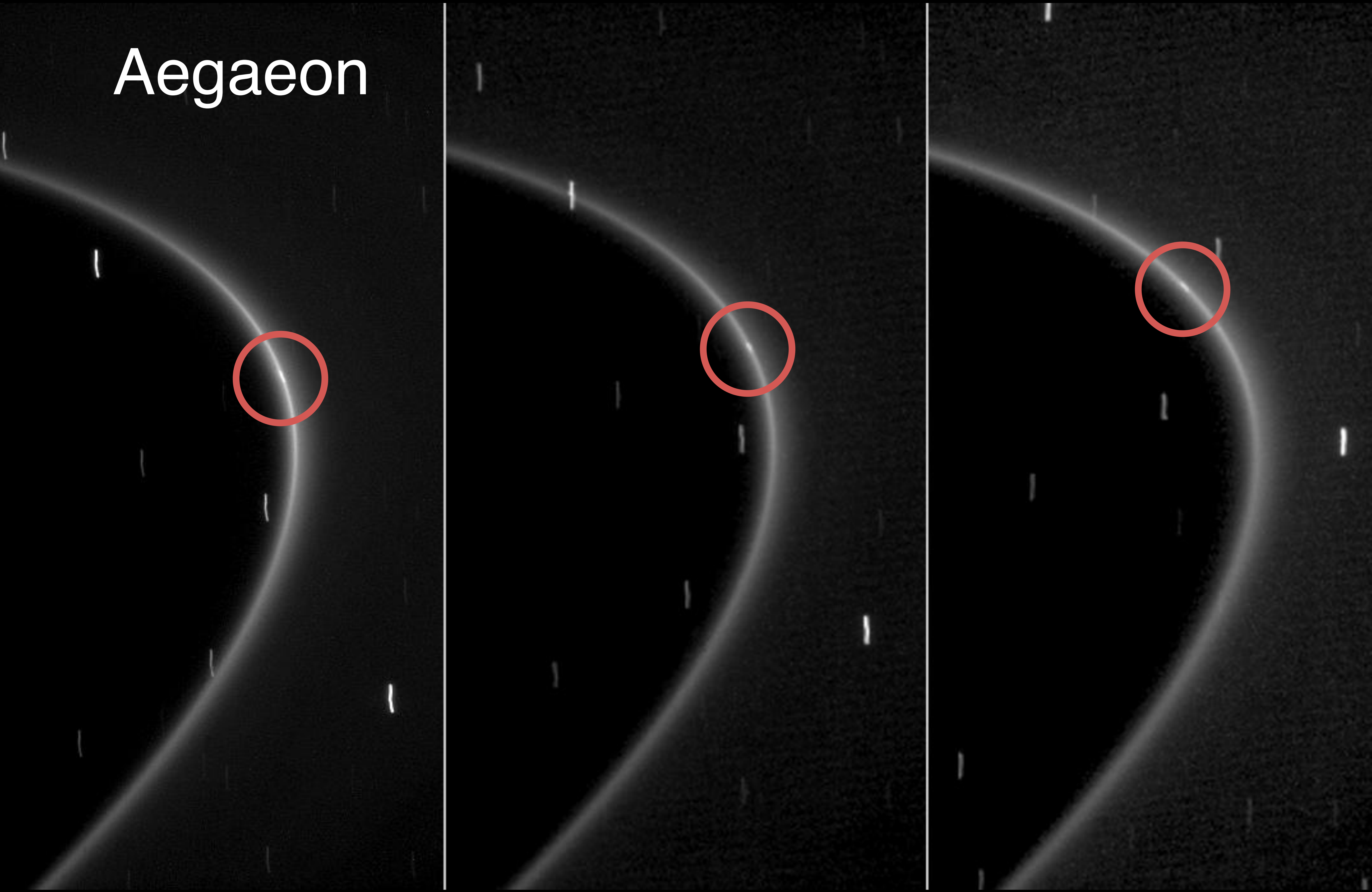
Fig. 6. (**A**) An ISS NAC clear-filter image (*12*) of Enceladus′ near-surface plumes (which can be resolved into individual jets) taken on 27 November 2005 at a phase angle of 161.4° with an image scale of ~0.89 km/pixel. The subspacecraft latitude was +0.9°; the view on this day was also broadside to the tiger stripes (Fig. 1). The south pole is pointing toward the lower left. (**B**) A color-coded version of (A), in which faint light levels were assigned different colors to enhance visibility, shows the enormous extent of the fainter component above the south polar region.

By the early 1980s…

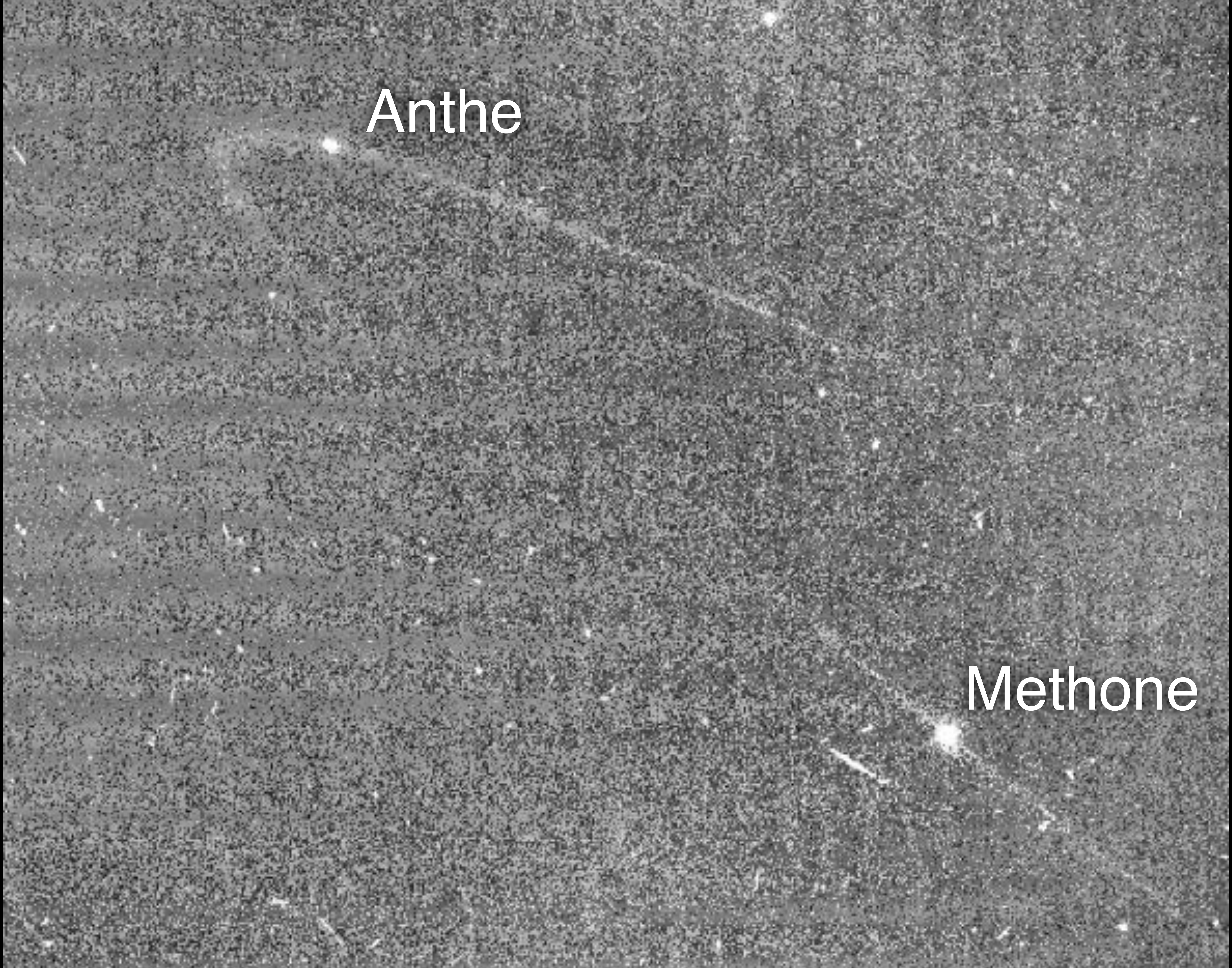
- We are aware of five faint rings:
  - The main ring of Jupiter.
  - The D, E, F, and G rings of Saturn.
- We know that all are dominated by micron-sized dust.
- We recognize that fine dust grains have limited lifetimes and must be replenished continuously.
- We know that at least two of the faint rings coincide with the orbits of moons.
- The idea that meter-sized and larger embedded bodies must be the sources of dusty rings is well established.

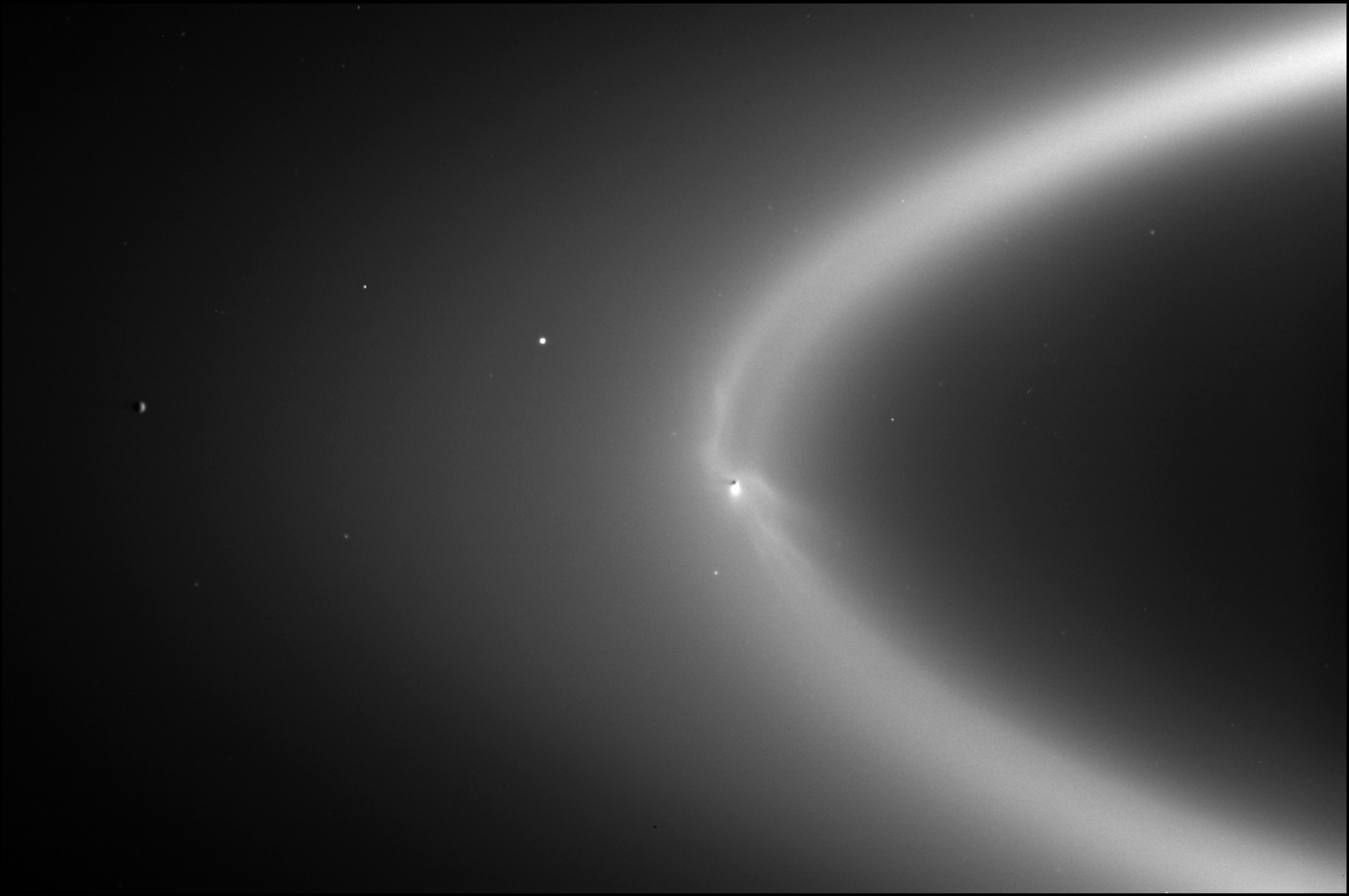

Galileo
October 5, 1997
Amalthea
Thebe


Galileo
October 5, 1997
Amalthea
Thebe

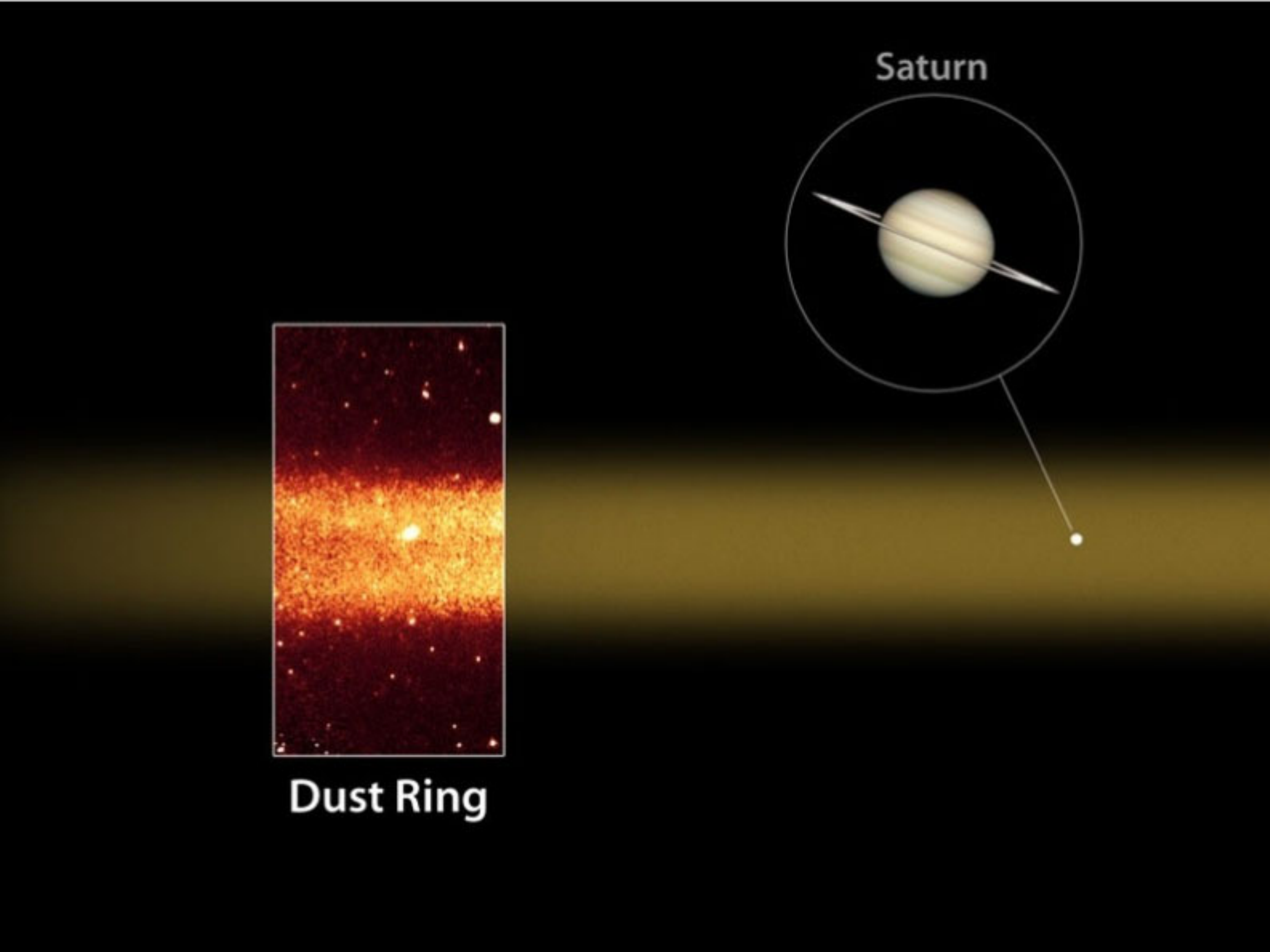

Aegaeon


Anthe

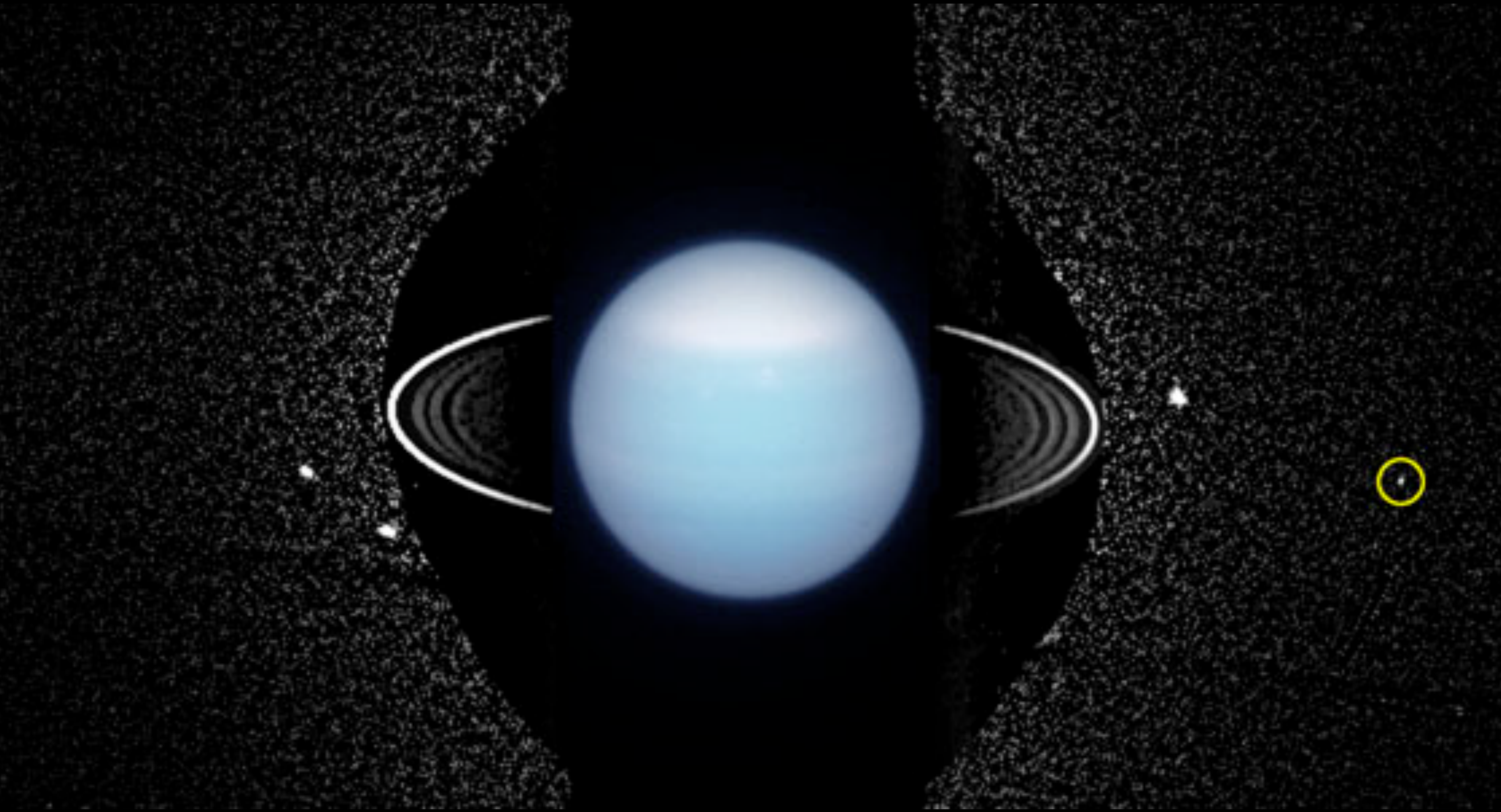

Anthe
Methone

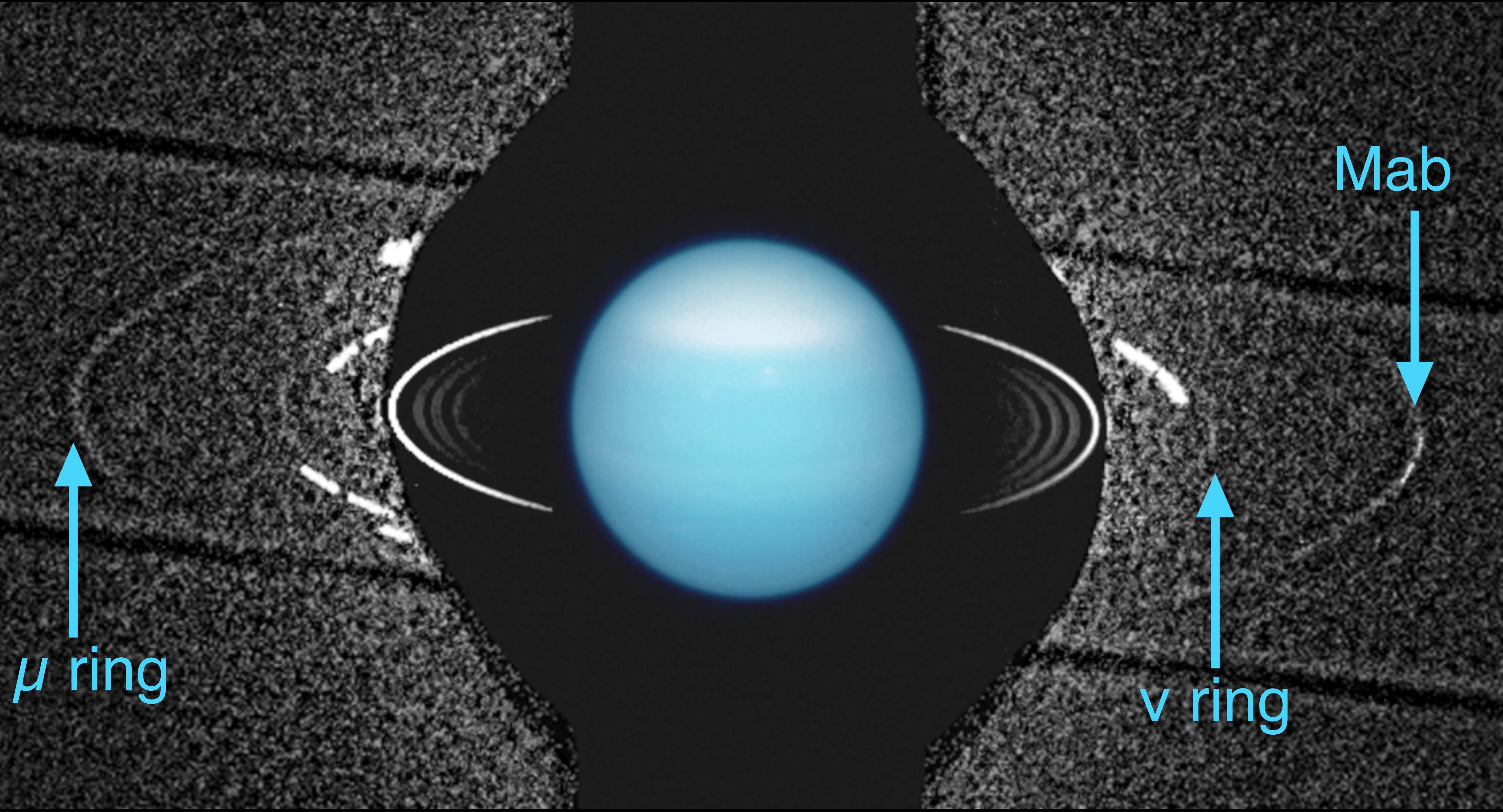


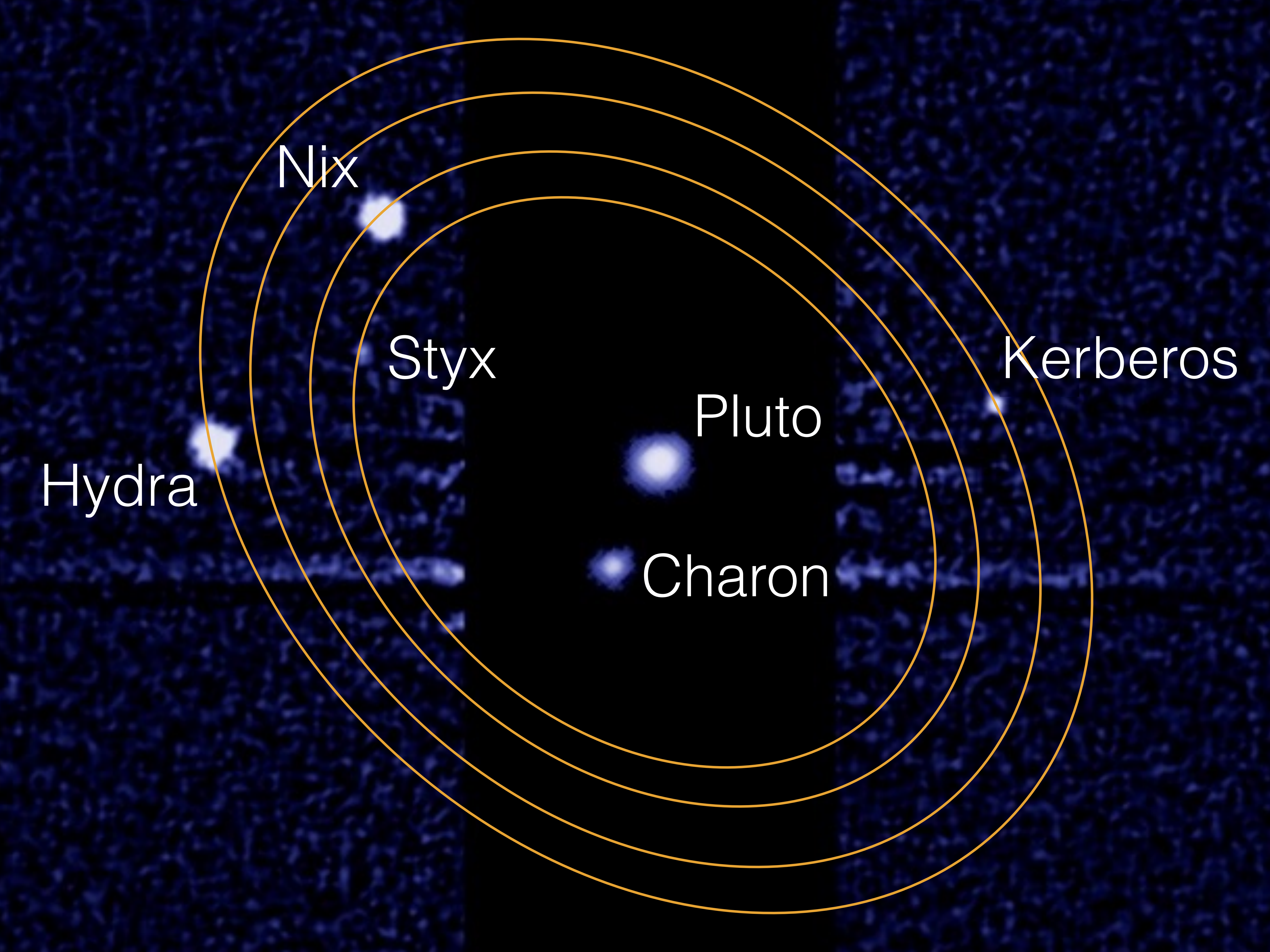
Methone


Saturn
Dust Ring

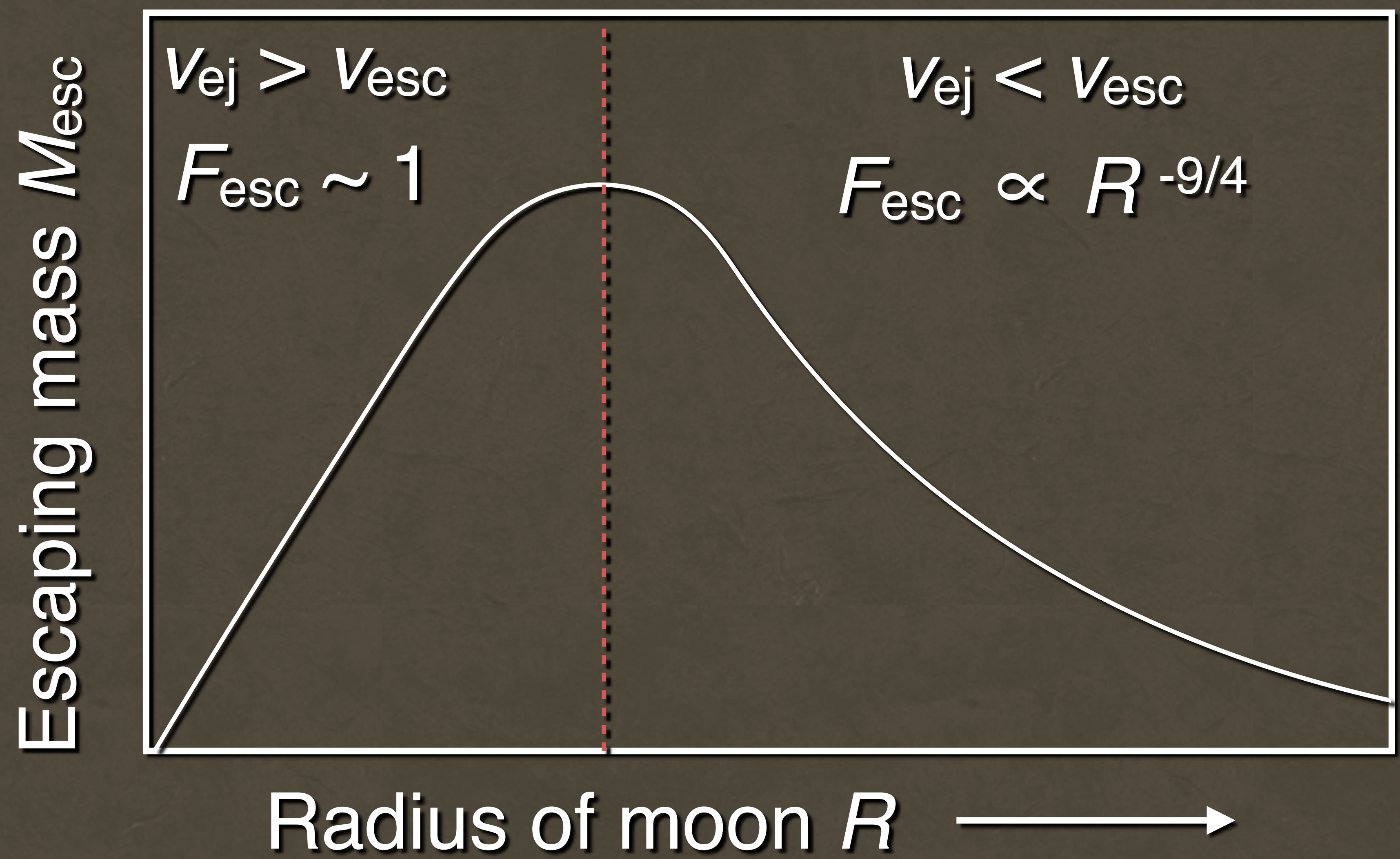
Discovery of "Mab"




Mab
μ ring
ν ring

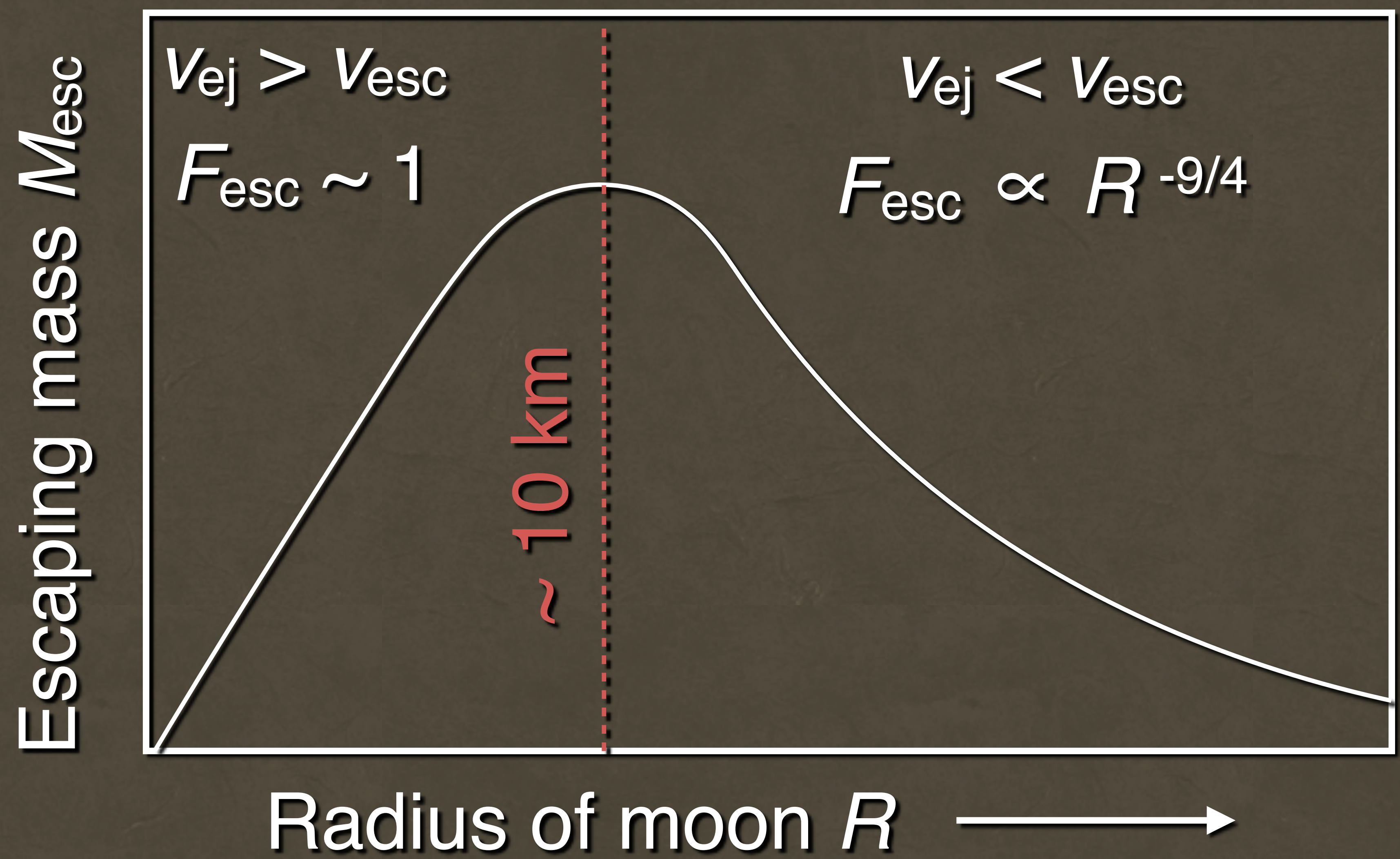

Nix
Styx
Kerberos
Pluto
Hydra
Charon

Moon Size vs. Dust Production



- v_{ej} = typical ejecta velocity from impact
- v_{esc} = escape velocity, $\propto R$
- F_{esc} = fraction of ejecta that escapes
- From Burns et al. chapter, *Planetary Rings*, 1984.

Moon Size vs. Dust Production



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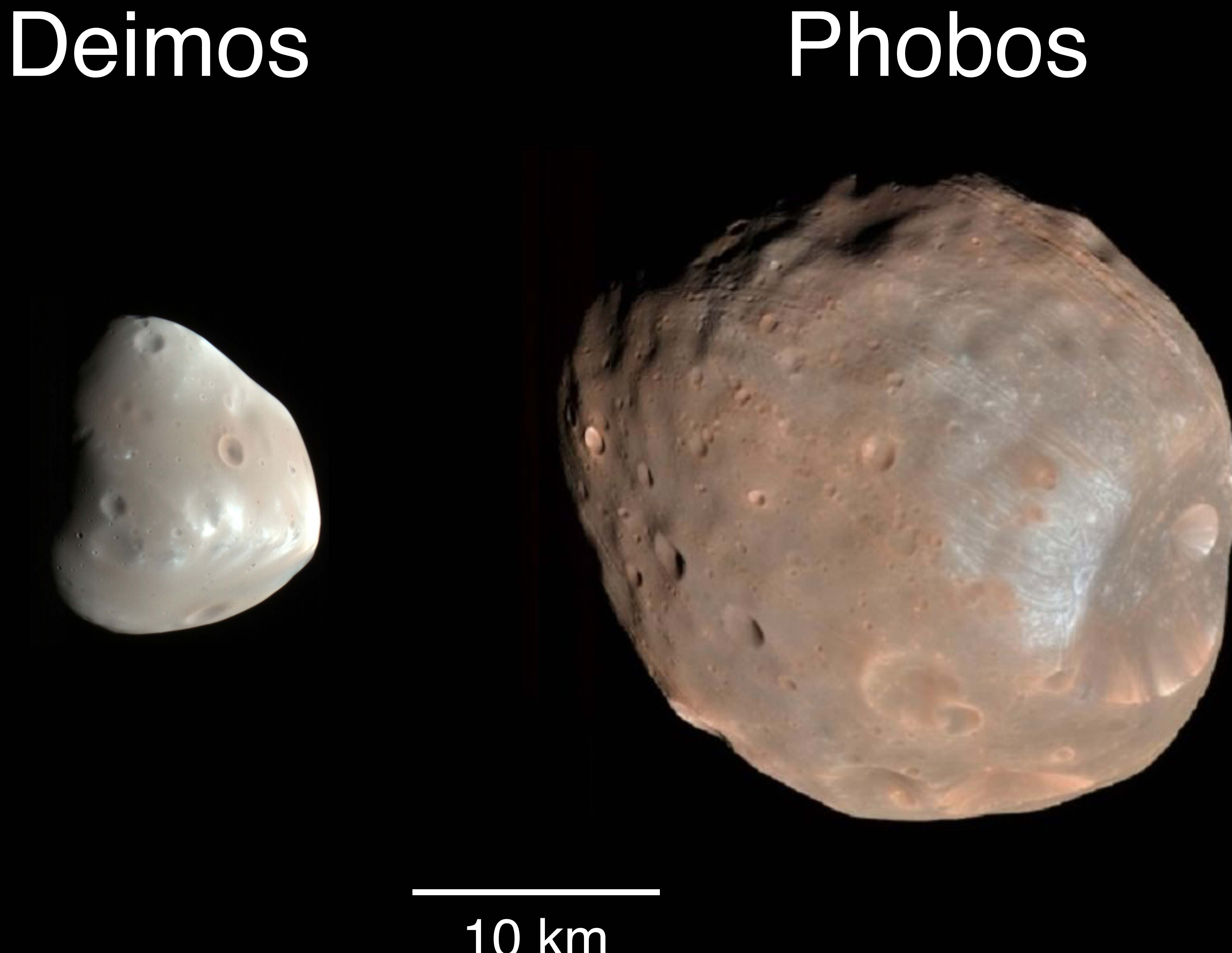
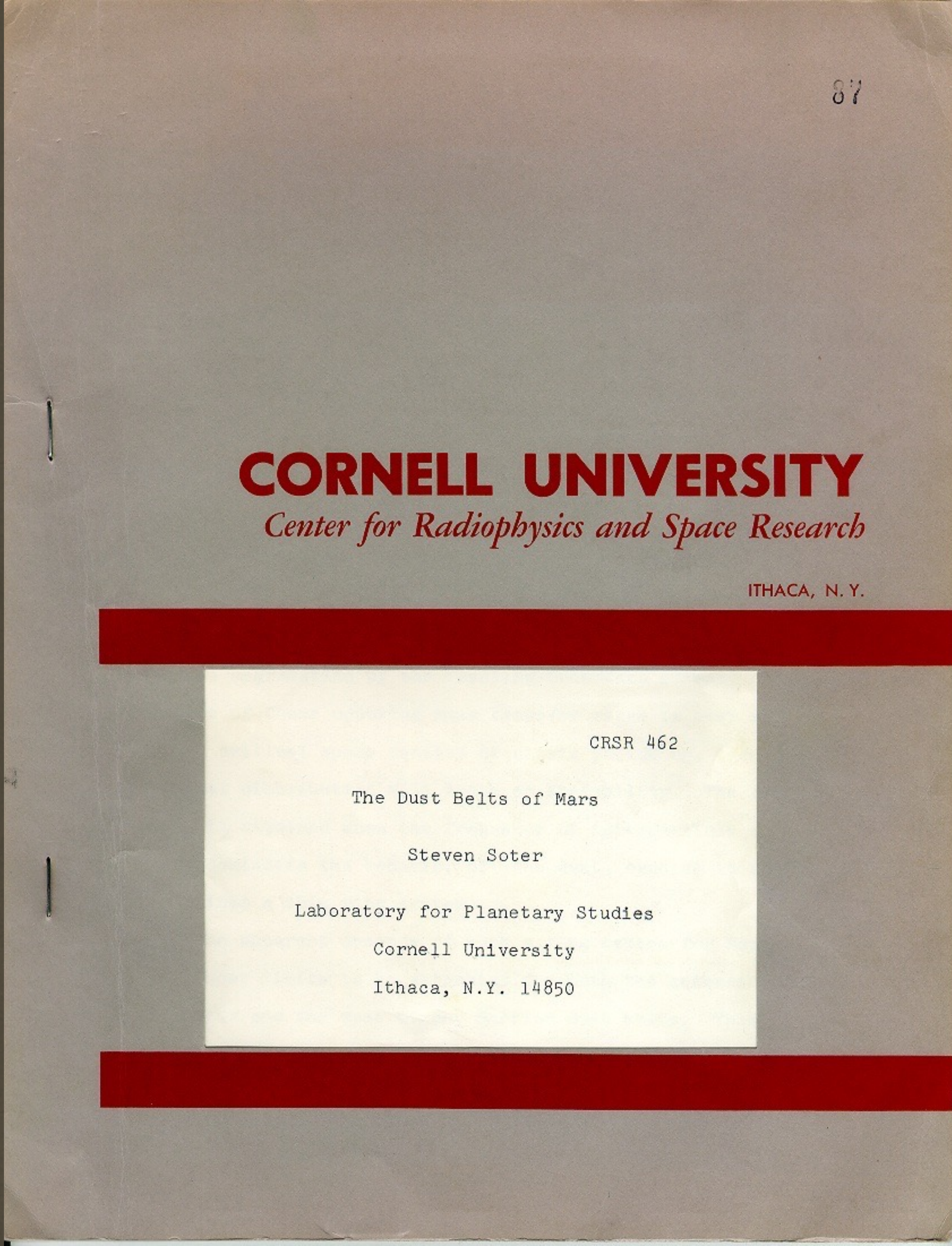

Deimos
Phobos
10 km


87

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Center for Radiophysics and Space Research
ITHACA, N. Y.

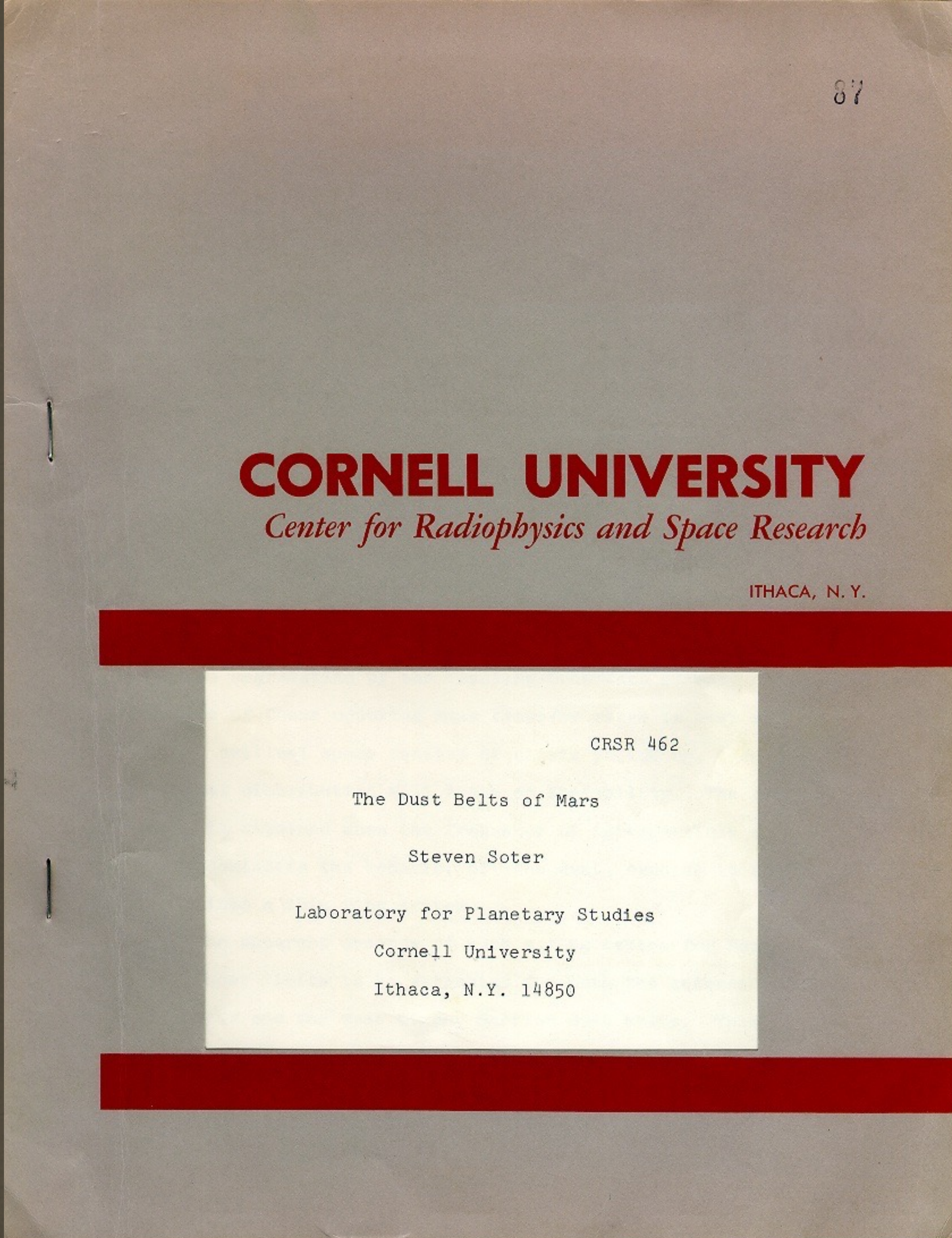
CRSR 462

The Dust Belts of Mars

Steven Soter

Laboratory for Planetary Studies
Cornell University
Ithaca, N.Y. 14850

Abstract. From the unrelated facts that Mars is subjected to a flux of asteroidal projectiles and that it has two very small satellites, an elementary analysis leads to the proposition that the planet possesses an orbiting dust belt system, previously unsuspected. Furthermore, the satellites themselves should have surfaces resembling that of the Moon. Factors bearing on the evolution of an orbiting debris system are discussed, leading to some speculations concerning the origin and structure of the rings of Saturn.


87

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1971

WHY NOT GIVE MARS A RING LIKE THAT OF SATURN?

M. W. Chiplonkar

925/B-3, Yashoda, Fergusson College Road, Poona 411 004

(Received April 17, 1978; revised May 20, 1978)

Abstract

With a view to test the famous Roche hypothesis, it is suggested that, in the near future space programme, Phobos, the inner satellite of Mars, be pushed inside by a properly arranged atomic explosion so as to cross the Roche limit of Mars. Phobos is uniquely suitable for this field experiment in astronomy, since its present orbit is not far outside this Roche limit nor its mass too great for the push of an atomic explosion.

Recent reports of the discussions arranged in London and Washington on the occasion of the Hundredth anniversary of the discovery of Phobos and Deimos have very aptly highlighted the shift in the emphasis of future space probes from Mars to its two tiny satellites (Hughes 1977). Speculations regarding their origin are numerous, no doubt, but the strong possibility of their having first formed as asteroids in the space between Mars and Jupiter and then by chance moved near to Mars to be caught by it and retained as its own permanent satellites, is worth considering. Similar conjectures also exist in respect of most of the non-Galilean satellites of Jupiter, those of Saturn except the giant Titan, and also those of Neptune except the massive Triton. On the other hand, Pluto, the outermost

km and a period of 7 hours 29 minutes to an orbit of radius of 8,700 km and a period of 6 hours 39 minutes 30 seconds. This would necessitate the least of effort when properly manipulated.

The duration of travel along this path may be a few hours only, and will offer an opportunity for a continuous watch of the events. After this new orbit is achieved, it would, most probably, depend upon the structure of Phobos, how long it would take for it to break up into numerous pieces and to form a ring around Mars. The exact prediction of time perhaps need not bother us for the present but perhaps a fair guess could be made based on the strength of the material of typical meteorites available to us and the rate

ICARUS 76, 160–162 (1988)

1988

Mars: Satellite and Ring Search from Viking

THOMAS C. DUXBURY AND ADRIANA C. OCAMPO

M.S. 183-501, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California 91109

Received October 15, 1987; revised February 12, 1988

A search for satellites and rings of Mars was made in 1980 using imaging data taken from the Viking Orbiter 1 spacecraft. A region inside of the orbit of Phobos and ±350 km about the Mars Equatorial plane was searched. No evidence of rings or other satellites was found in this region about Mars.

- Upper limit on ring normal *I/F* = 3×10^{-5}
  - Comparable to the main Jovian ring (if physically thin!)
- No additional moons larger than R ~ 50 m

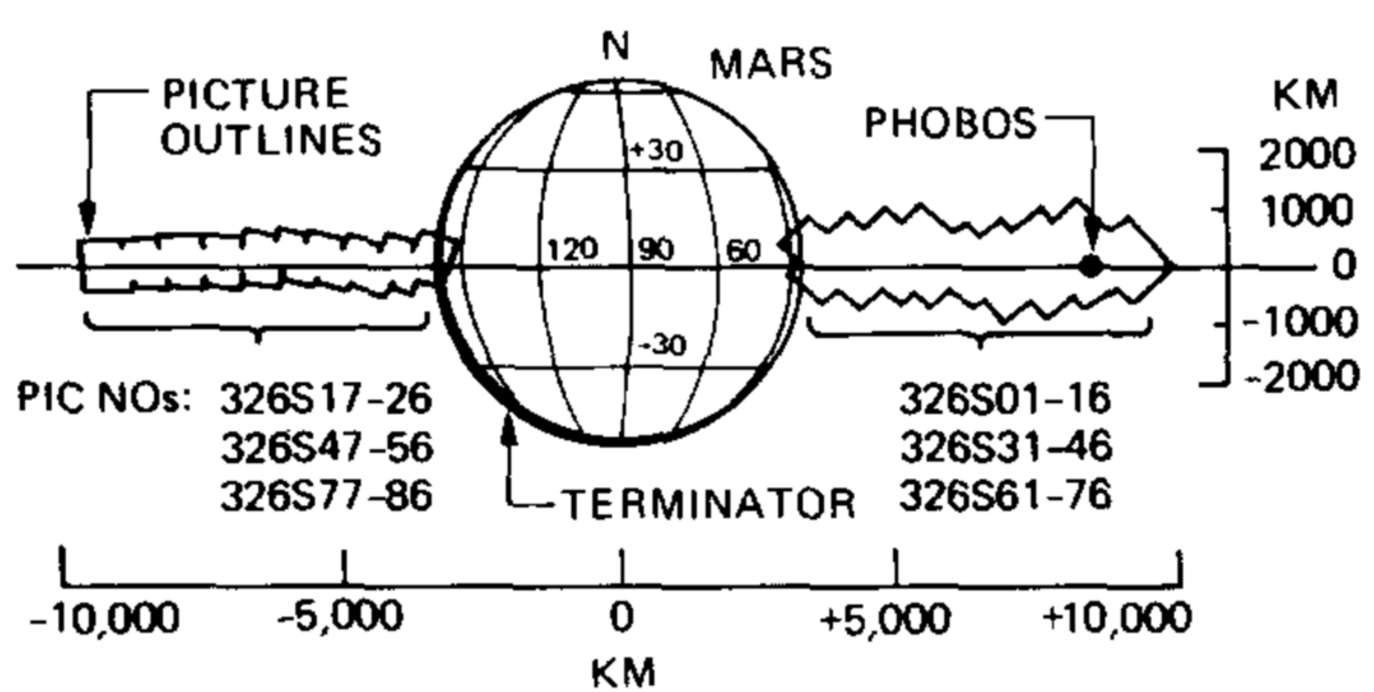


FIG. 1. Typical imaging search sequence.

Modeling starting in the 1990s: Not your typical "dust" rings!

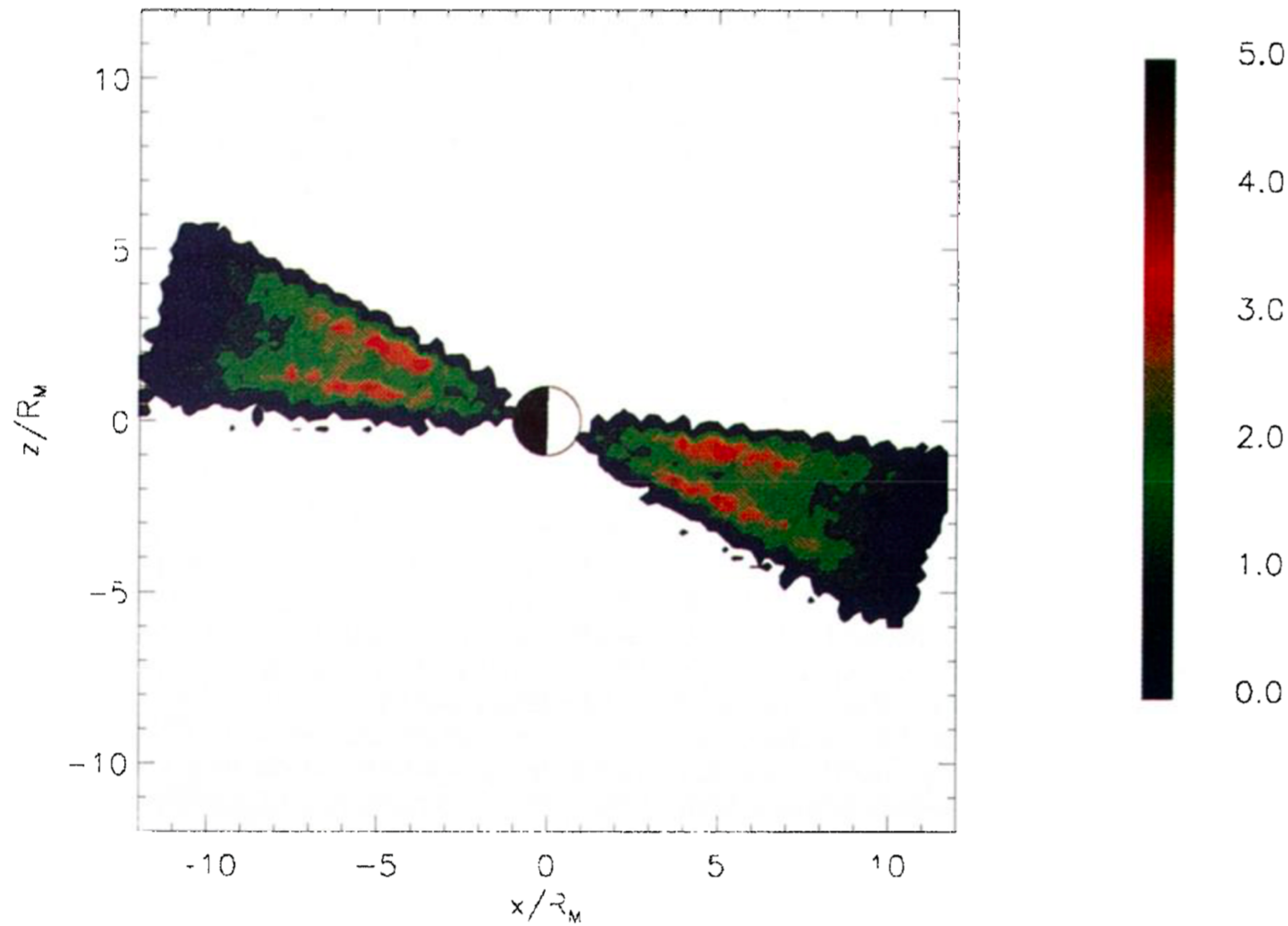
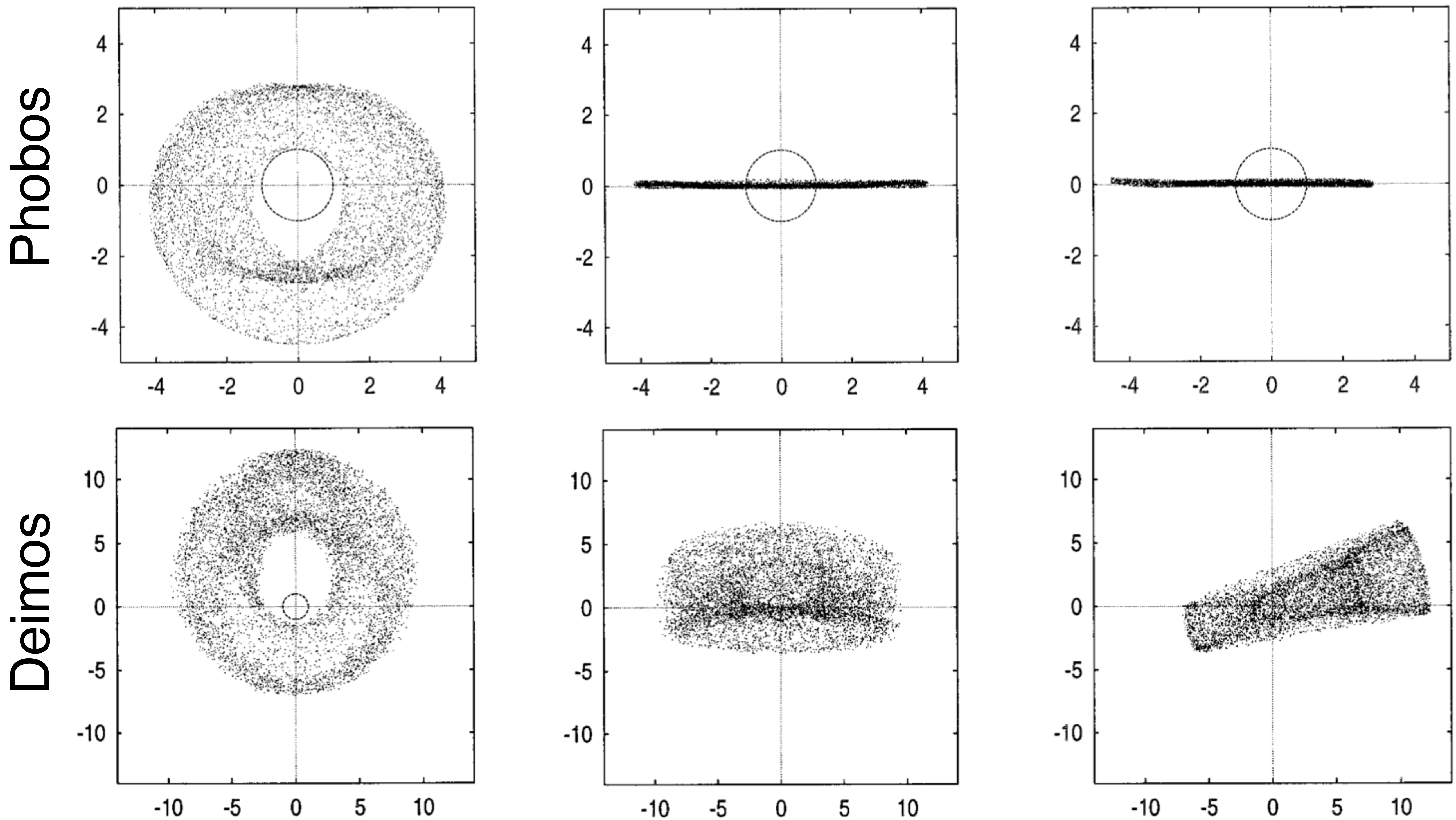


Plate 1. The number density distribution of the dust torus in the X, Z plane in units of 10^{-12} cm^{-3}.

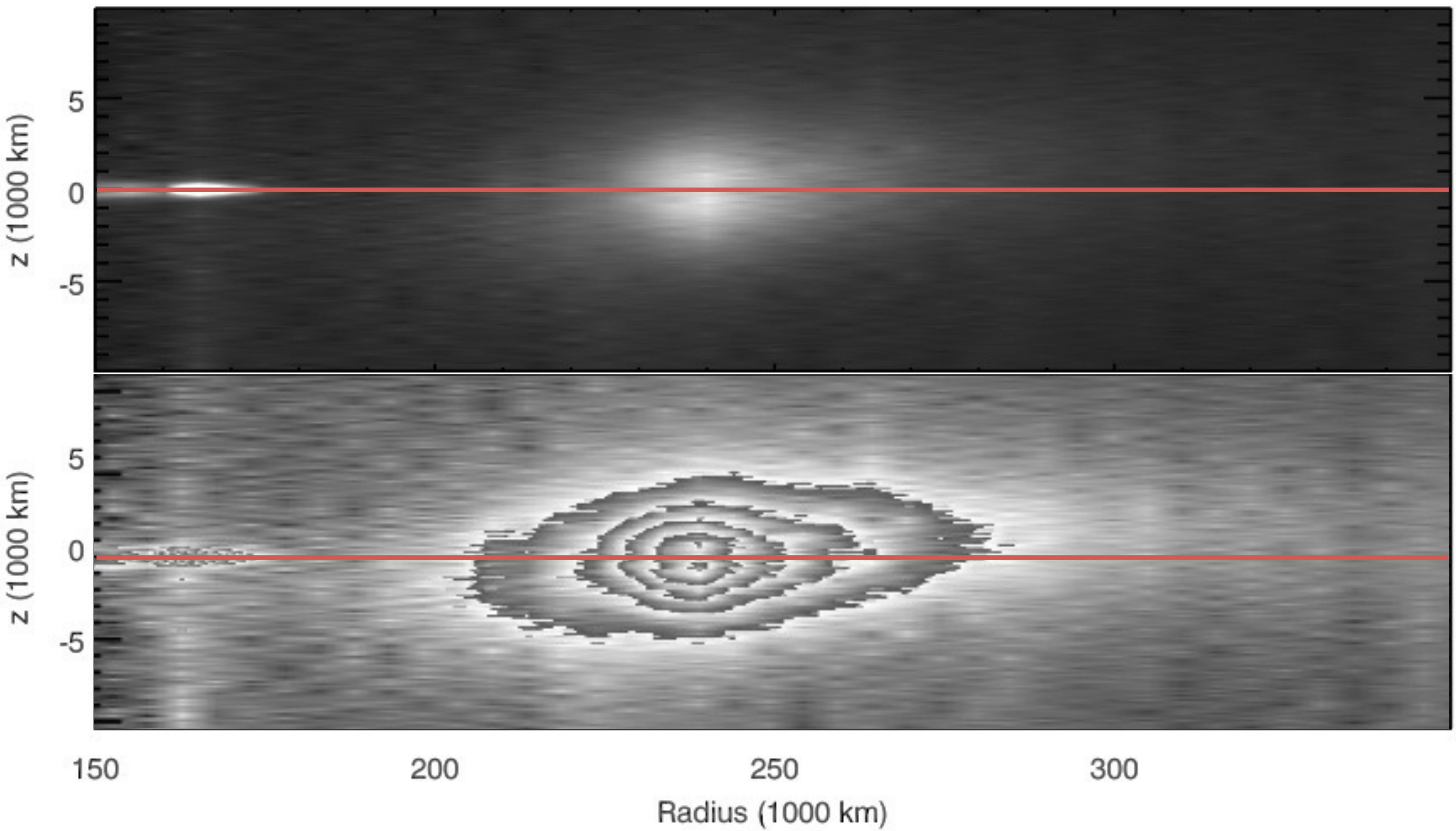
Juhász & Horányi, JGR 100, 1995.

Sample Models in Projection



Krivov & Hamilton, Icarus 128, 1997.

E Ring Comparison



Courtesy of Matt Hedman

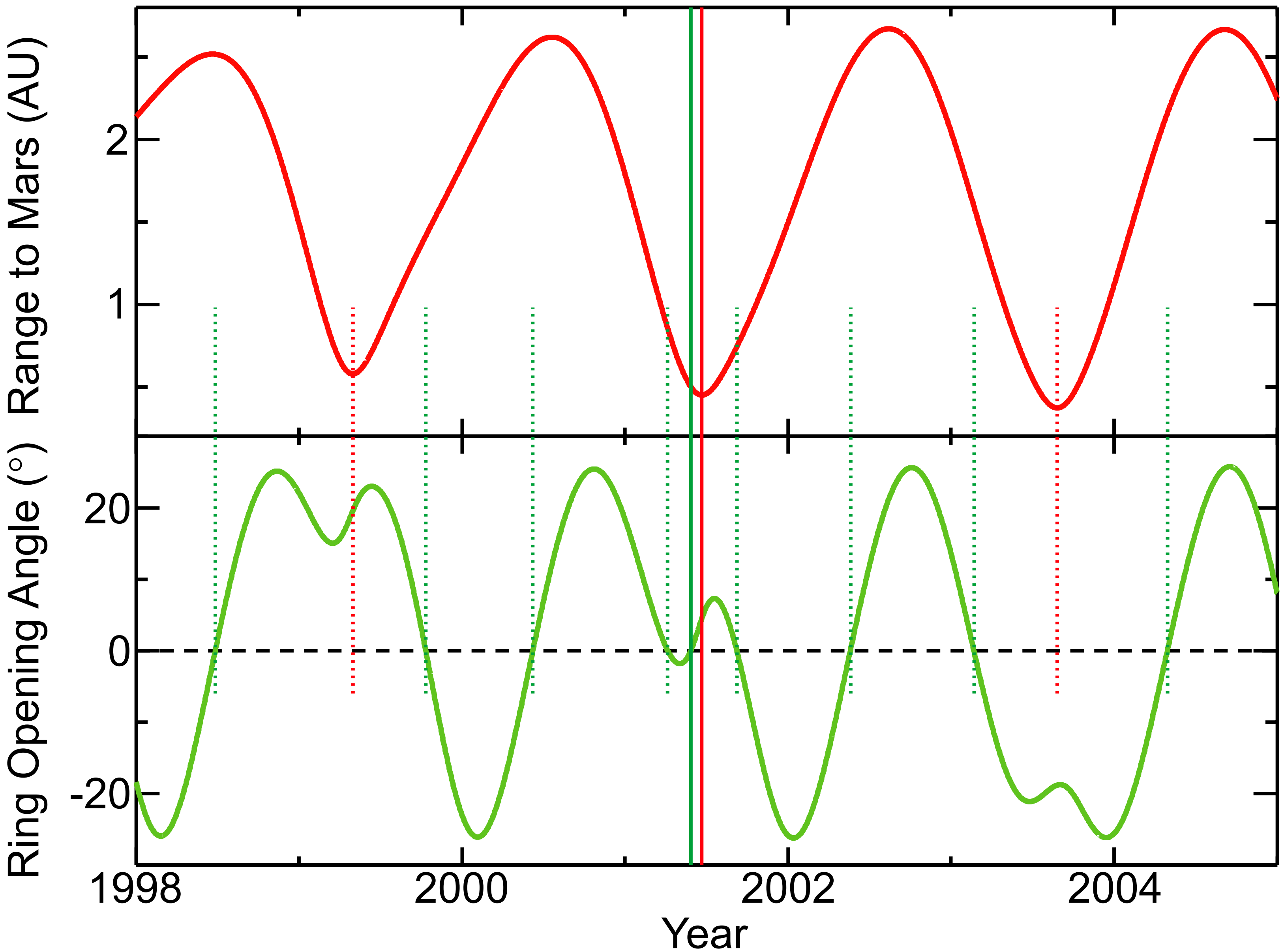
Predicted Ring Properties

- Rings are dominated by particles tens of microns in size.
  - Smaller grains are lost quickly due to solar radiation pressure.
- Remote observing strategies have to change accordingly.
  - High phase angles are not beneficial.
- Note: Methane absorption bands are extremely helpful for Earth-based viewing of rings around the giant planets, but they will also not help us for Mars.
  - In 1997, Brad Smith et al. attempted to use a CO_2 band with HST NICMOS, but had no success.

Predicted Ring Properties

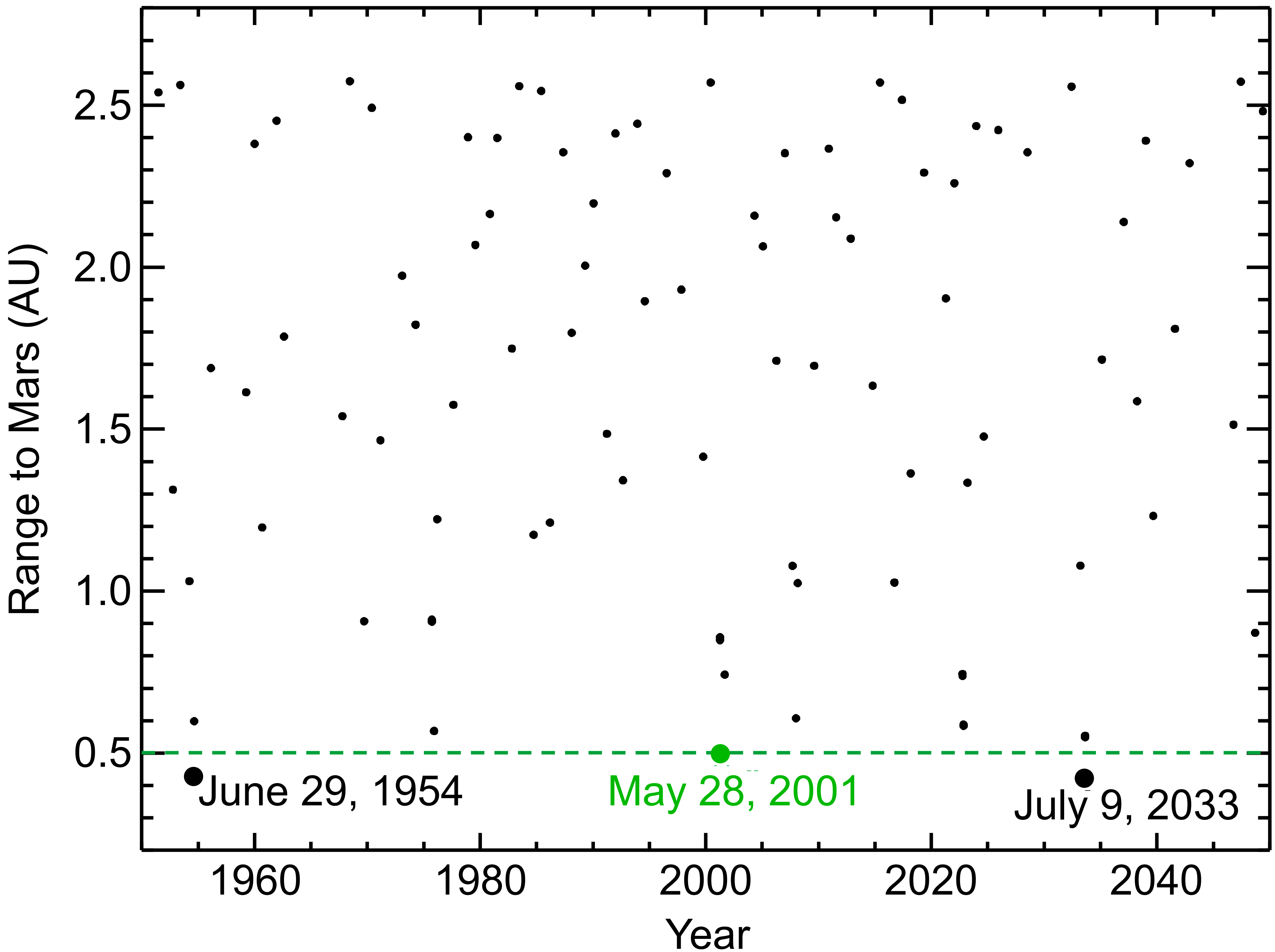
- The rings are not necessarily thin or equatorial.
  - Solar radiation pressure induces vertical thickness and creates warps.
  - The Deimos ring is especially thick.
  - Detailed structure is seasonally variable.
- The rings are displaced radially.
  - The Deimos ring is displaced away from the Sun; The Phobos ring is displaced toward the Sun.
- Optical depths depend on highly uncertain lifetimes, making quantitative predictions of ring detectability difficult.
  - Estimated $\tau \sim 10^{-5}$ to 10^{-9}

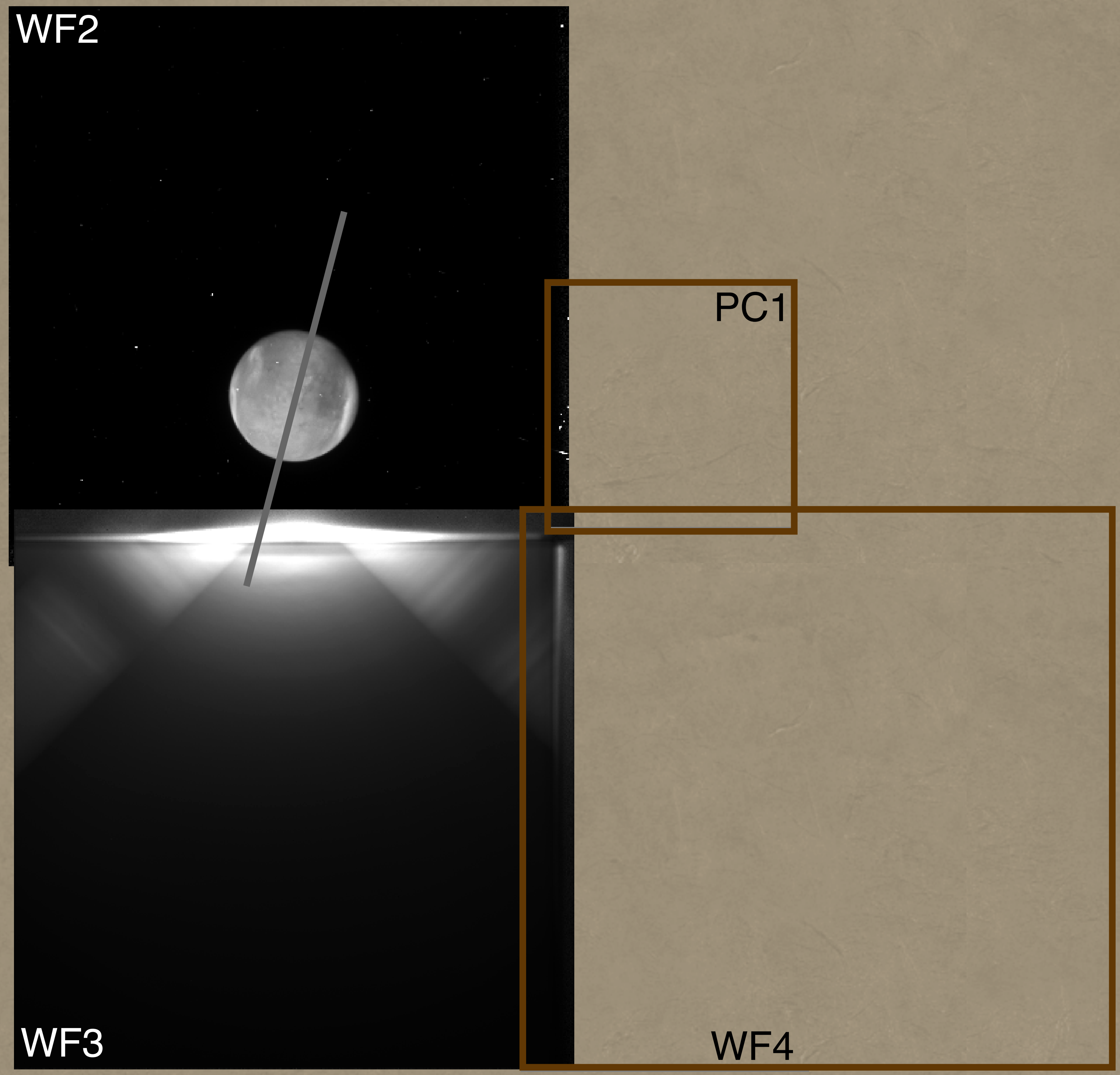
Mars Viewing Geometry 1998–2005

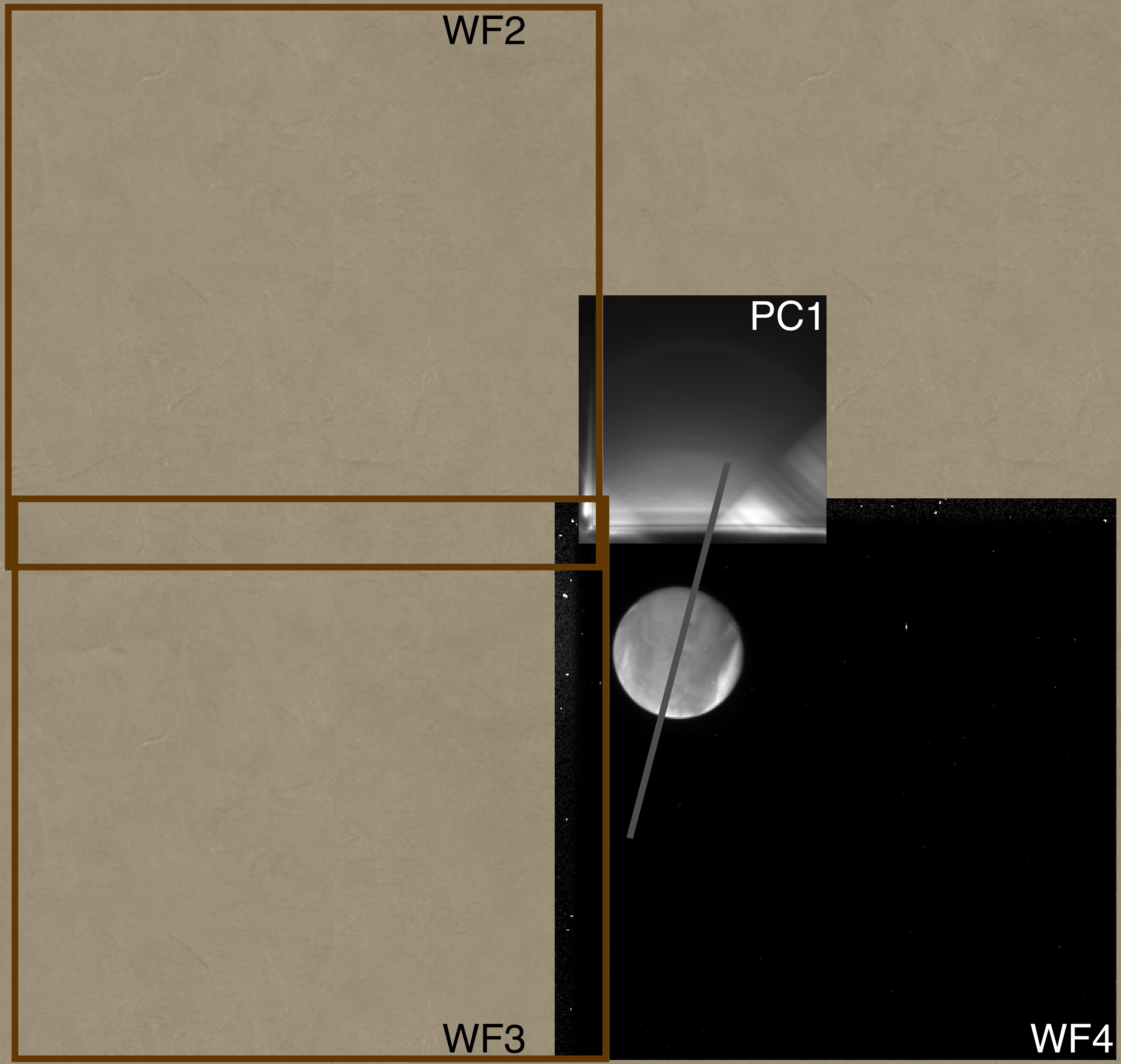


- Ring plane crossing: May 28, 2001
- Mars opposition: June 22, 2001

Mars Viewing Geometry 1950–2050

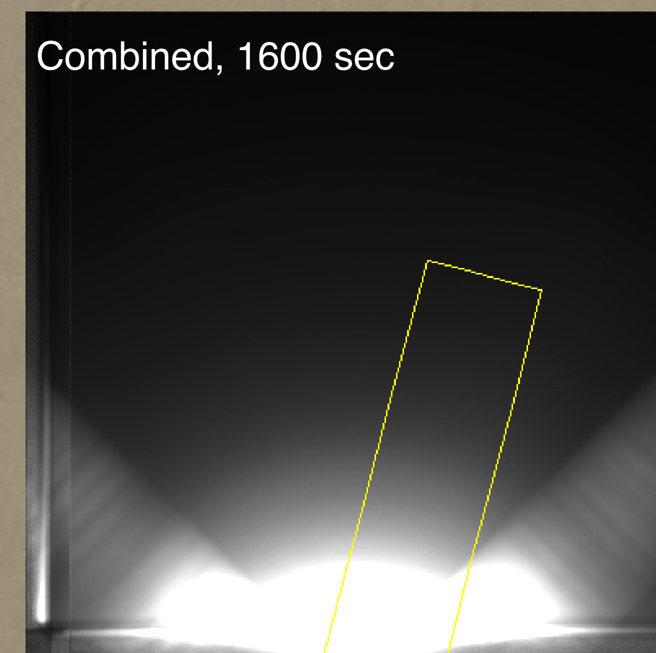



WF2
PC1
WF3
WF4


WF2
PC1
WF3
WF4

Deimos Ring Search

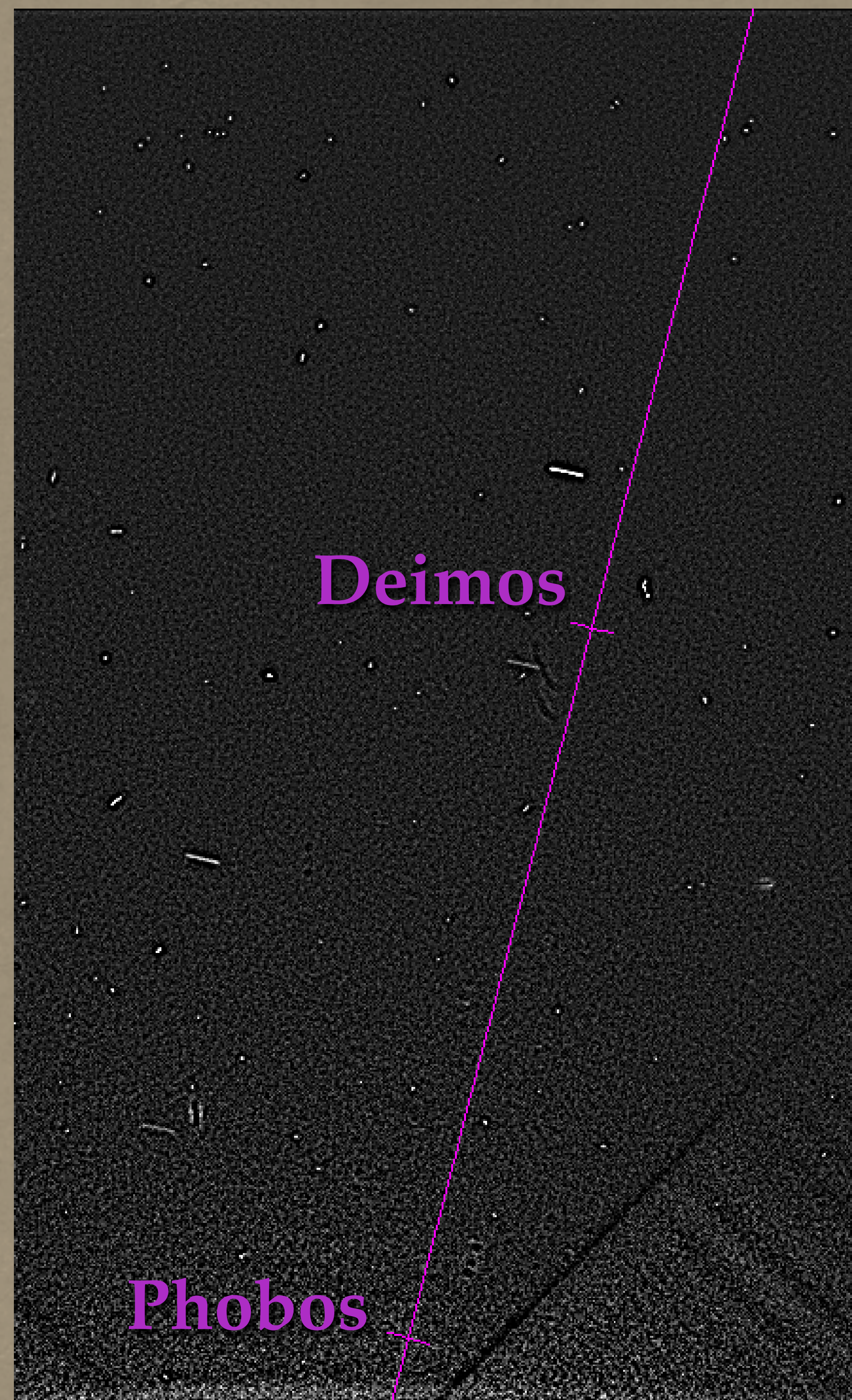
Coadd every image, regardless of filter.



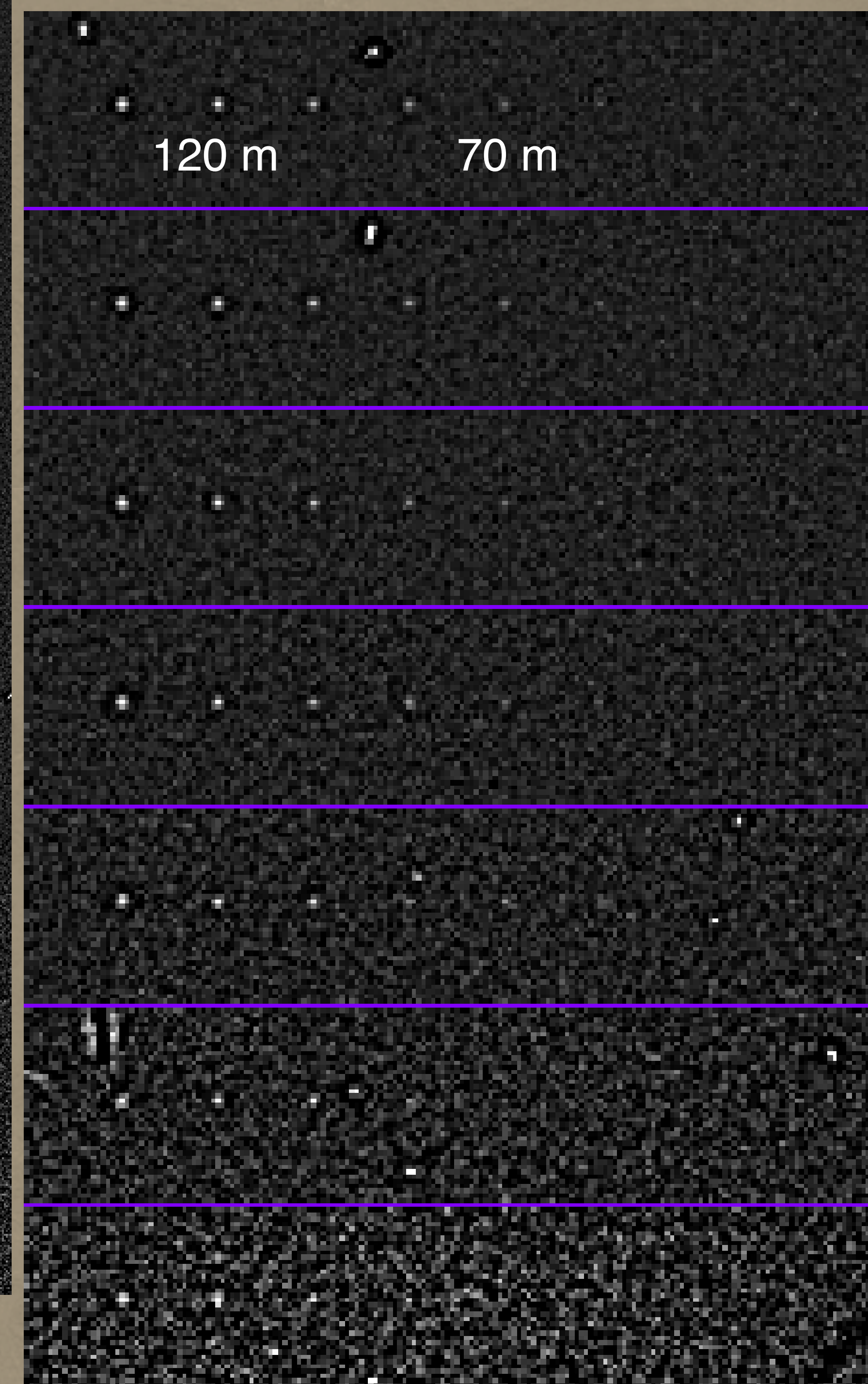
Search for Tiny Moons

Raw Image

High-Pass Filtered



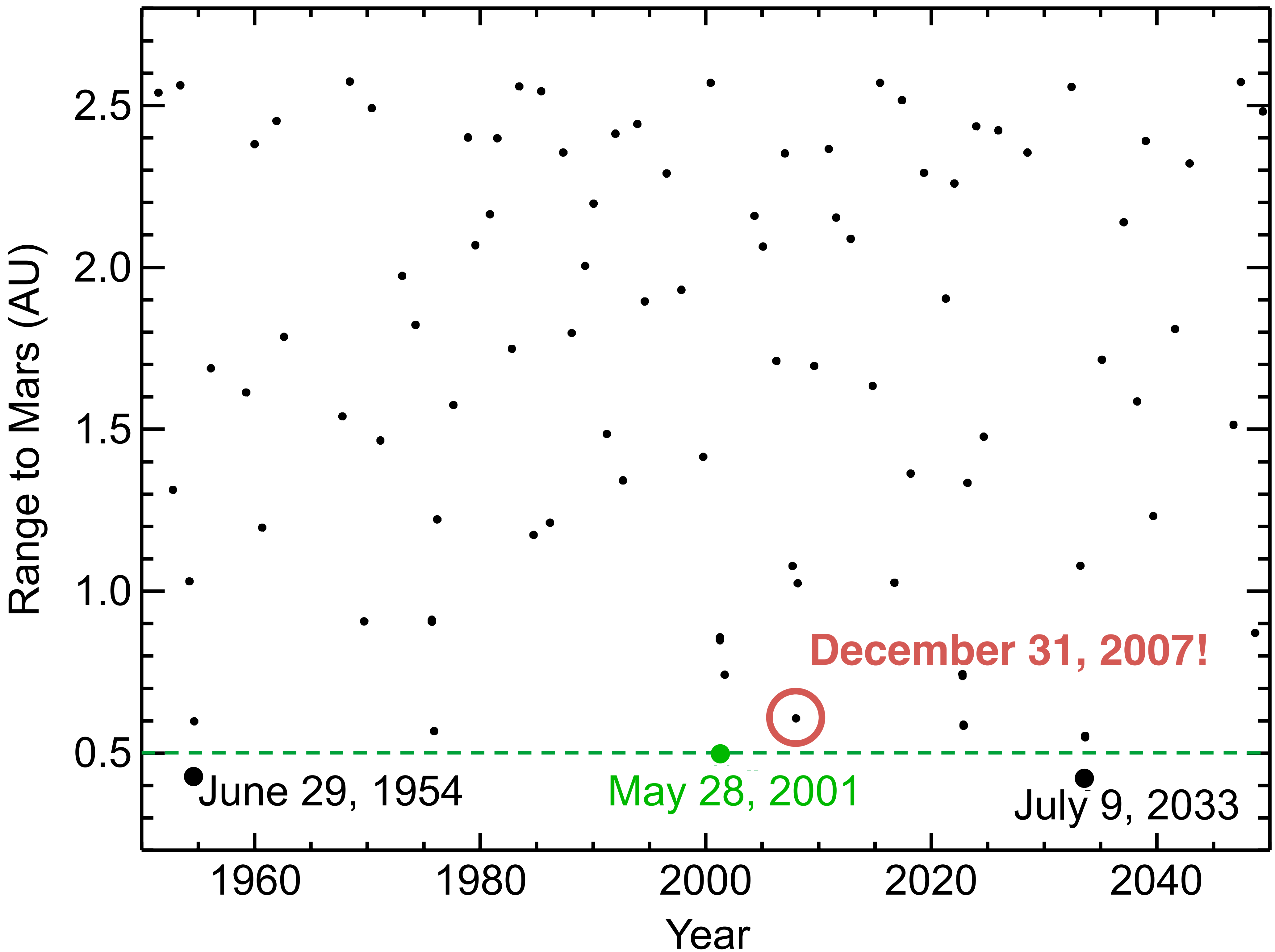
Synthetic Moons Added



Conclusions from HST Campaign in 2001

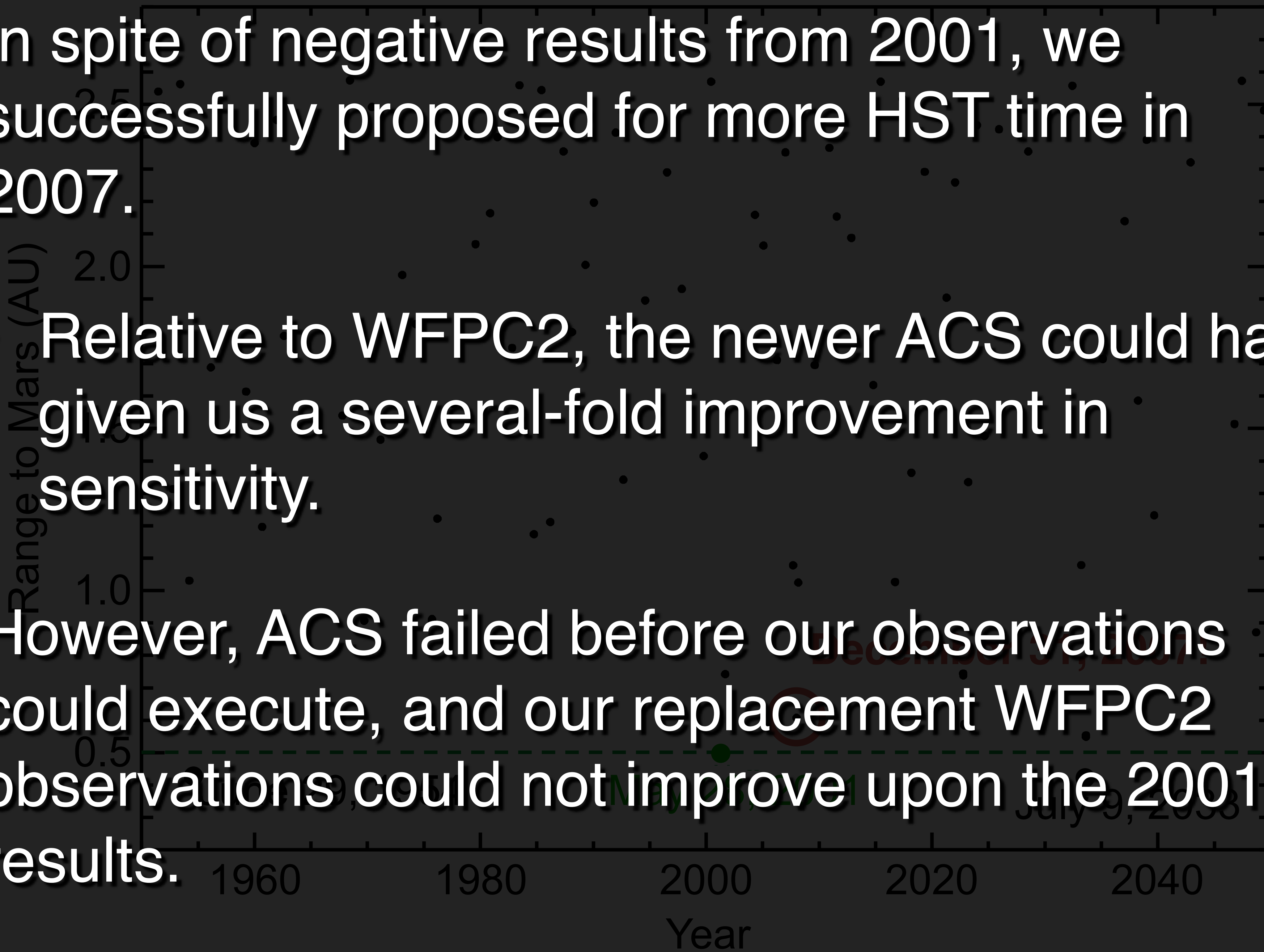
- No evidence for faint rings in the orbits of Phobos or Deimos.
  - Optical depth limits are ~ 10^{-7} for a Phobos ring and ~ $4{\times}10^{-7}$ for a Deimos ring.
  - Still consistent with, but at the low end, of dynamical predictions.
  - 300× improvement over limit set using Viking Orbiter.
- No unseen moons were detected.
  - 100–200 m limits were not quite as good as with Viking.
  - Coverage was 40–80% complete, depending on semimajor axis.

Sad Tales of Lost Opportunities (1)

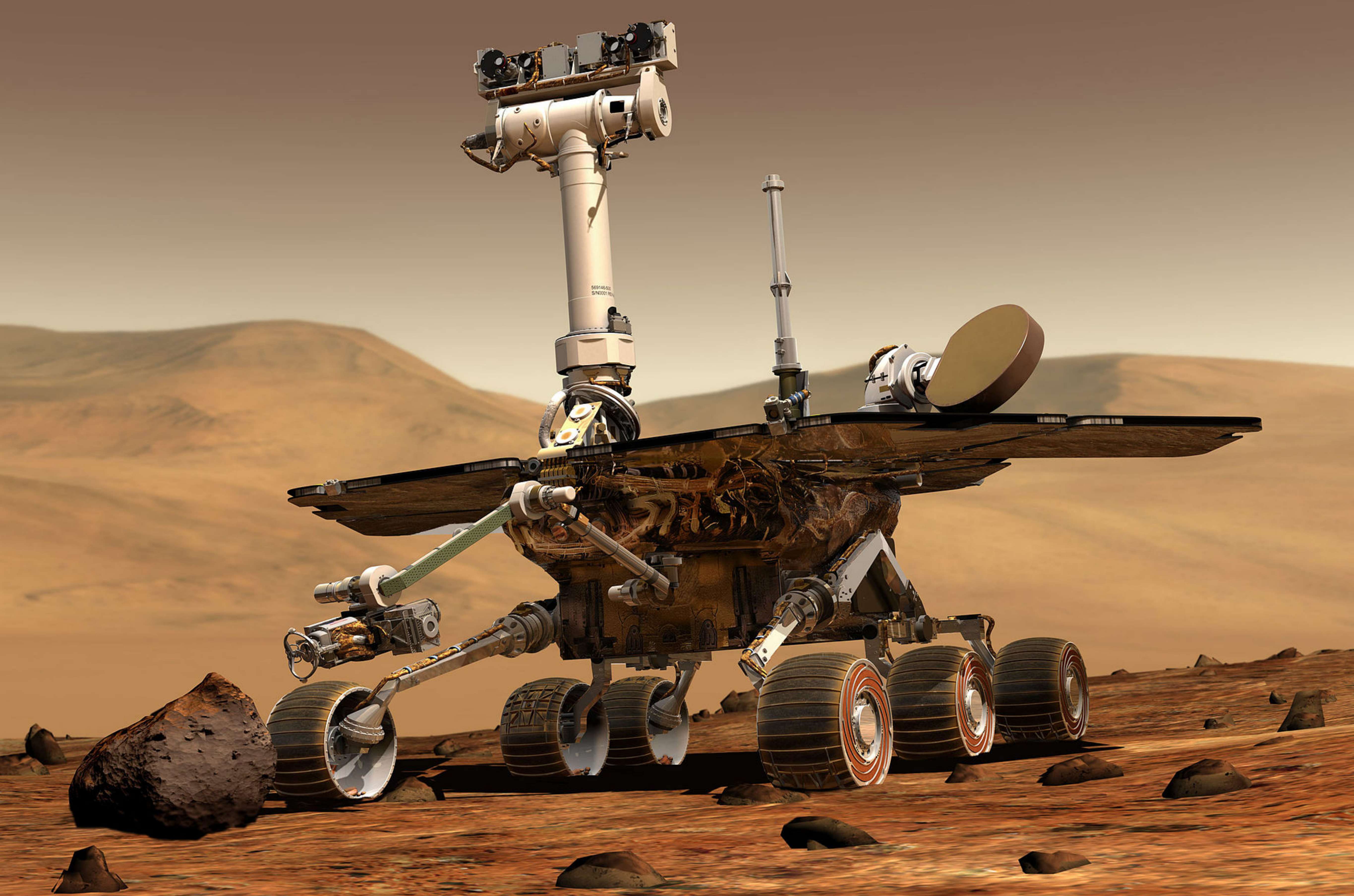


Sad Tales of Lost Opportunities (1)

- In spite of negative results from 2001, we successfully proposed for more HST time in 2007.
  - Relative to WFPC2, the newer ACS could have given us a several-fold improvement in sensitivity.
- However, ACS failed before our observations could execute, and our replacement WFPC2 observations could not improve upon the 2001 results.



Sad Tales of Lost Opportunities (2)



Sad Tales of Lost Opportunities (2)

- In late 2007, Jim Bell (PI of the MER cameras) and I initiated plans to search for the rings from below.
- During the Martian summer, the solar panels would charge up the batteries to operate for a short while after sunset.
- The wide-angle camera was ideal to study the shadow of Mars crossing a diffuse ring.
- However, a global dust storm arrived before we could execute our plans.

Sad Tales of Lost Opportunities (3)

- On October 19, 2014, Mars passed through the tail of new comet Siding Spring.
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- However, HST orientation contraints ensured that any such puff of smoke would be obliterated by the overexposed planet.
- All Ground-based observations were also deemed infeasible.

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- On July 4, 1998, Japan launched the Nozomi (Planet-B) spacecraft toward Mars.
    - It carried a dust counter, capable of the first in situ detections of Martian ring dust.
- However, due to a series of unfortunate malfunctions, it never went into orbit around Mars.

Where do we go from here?

- There really must be some dust out there, right?
- In situ observations using an orbiting dust detector are probably our best remaining hope.
- A few opportunities for remote observations remain:
  - Pursue the “looking up” option with MSL?
  - JWST may provide greater sensitivity.
    - Note that optimal observing times with JWST will be different from my pre-calculated list of Earth-based opportunities.