A new perspective on Saturn's Rings….

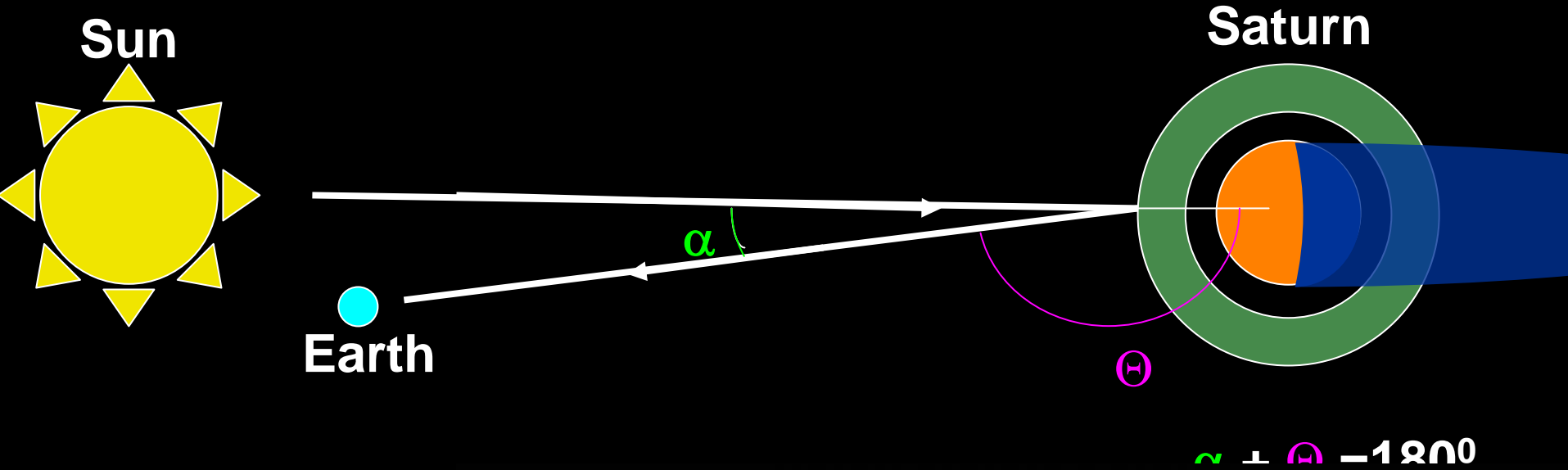Matt Hedman
Cassini ISS team
Cassini VIMS team

….and recent results on the faint rings.

From earth, we always observe the rings in back-scattered light. This means small phase angles (α) or large scattering angles (Θ)

Sun

Saturn

α

Θ

$\alpha + \Theta = 180^0$

This geometry yields pictures that look like this (from HST).
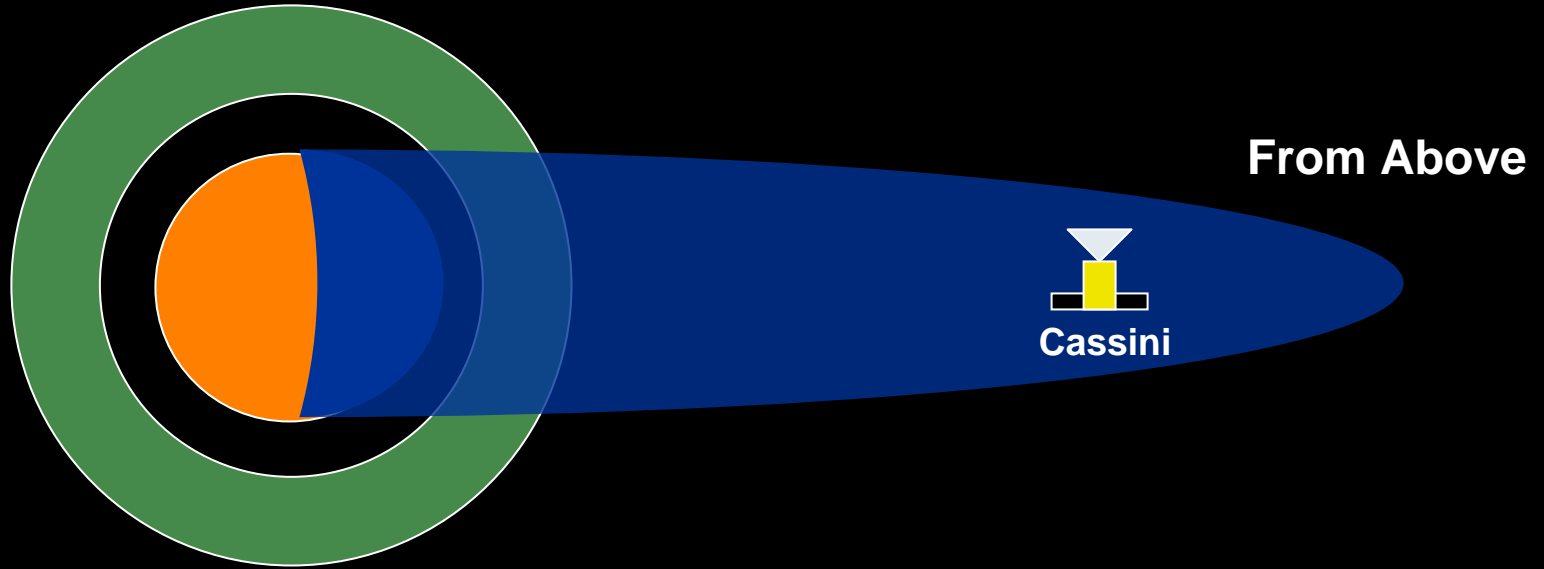
Note lack of visible shadows

A and B rings bright

Cassini not only can look at Saturn close up, but can also look at the Saturn and the rings from a much wider range of phase angles and elevations…..
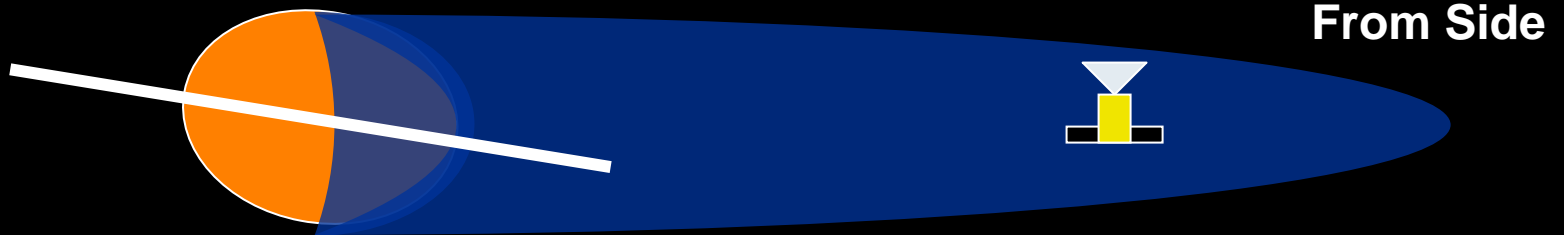

Image from phase angle ~70^0

On September 15, Cassini obtained a unique view of rings From within Saturn's shadow (very high phase)
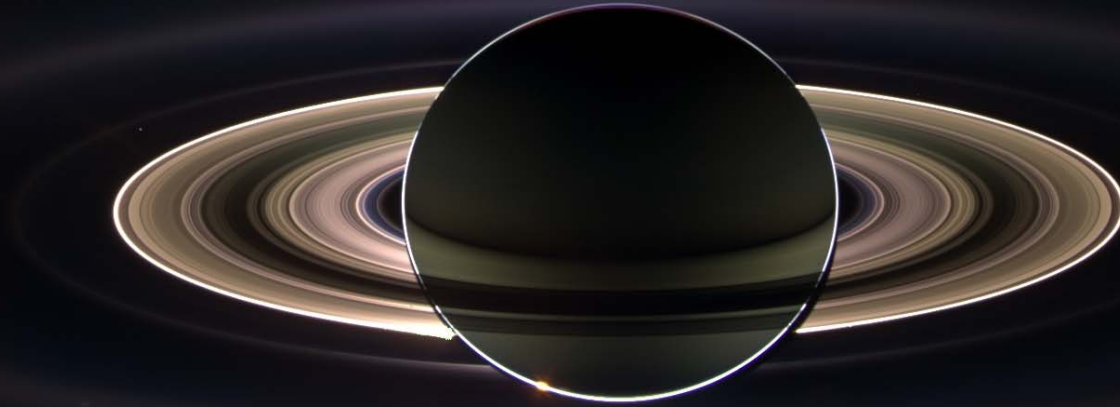

Not to Scale

From Above

Cassini

To Sun

From Side

The spacecraft was near apoapse (~2,000,000 km from Saturn) at this time and spent over 12 hours in the shadow, enabling it to take many pictures....

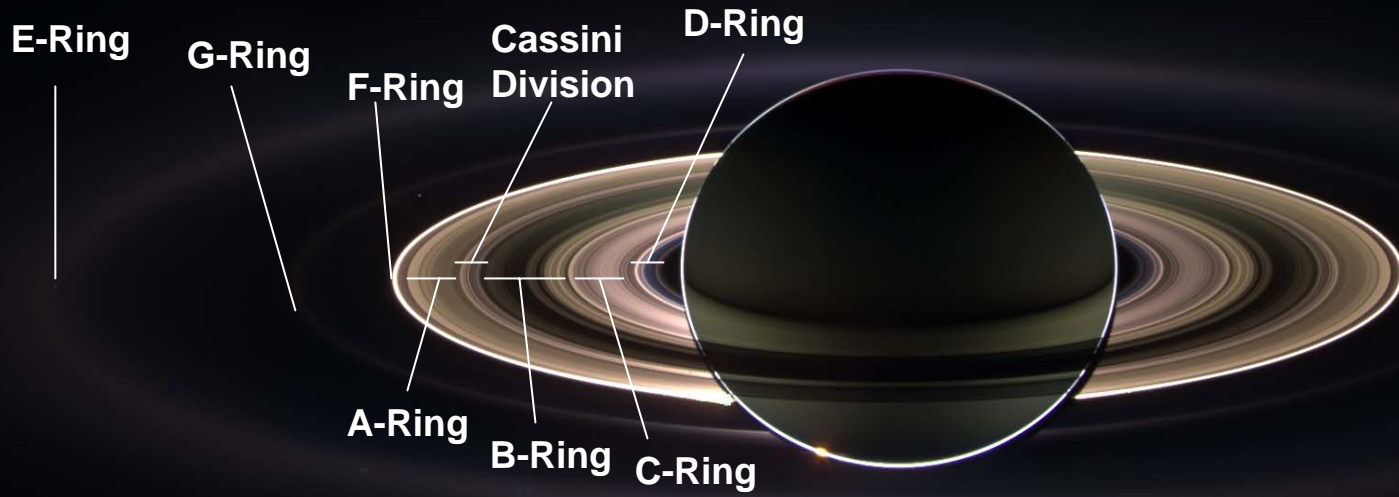# The pictures returned from this time were spectacular.

Mosaic produced from a mosaic of WAC images, approximate natural color based on data from Cassini UV, CLR and IR filters.
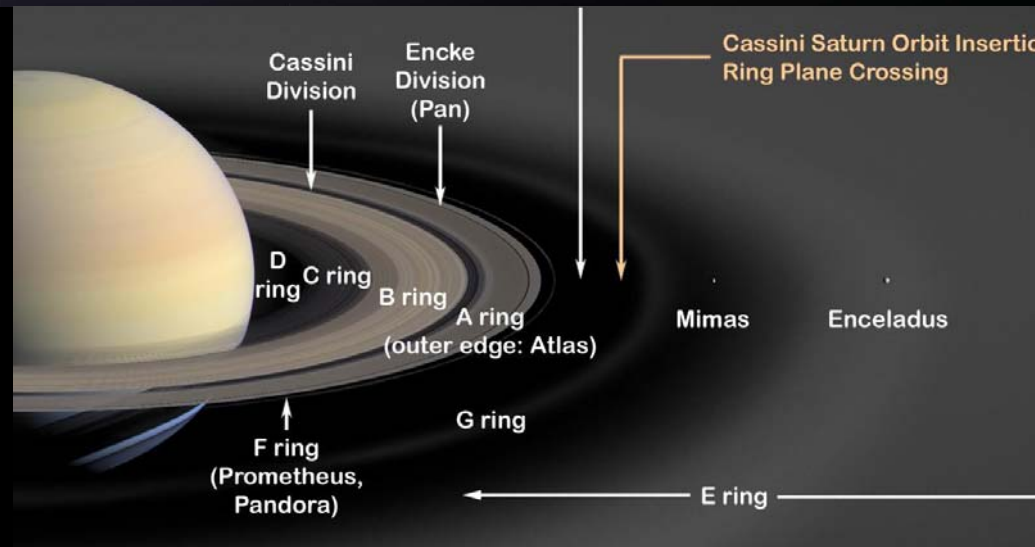
The entire image has a common stretch.

You are here

# For the first time, we can see all the rings clearly in a single image!

E-Ring, G-Ring, F-Ring, Cassini Division, D-Ring, A-Ring, B-Ring, C-Ring

There is a lot going on in this image, so let's take a closer look....

Cassini Division, Encke Division (Pan), Cassini Saturn Orbit Insertion Ring Plane Crossing, D ring, C ring, B ring, A ring (outer edge: Atlas), Mimas, Enceladus, F ring (Prometheus, Pandora), G ring, E ring

No need for these artist's renditions anymore.

Why are all the rings about the same brightness?

Big particles (much larger than wavelength of light) are brightest at low phase….

Larger α (Smaller Θ) ⟶

Low-Phase   **High-Phase**
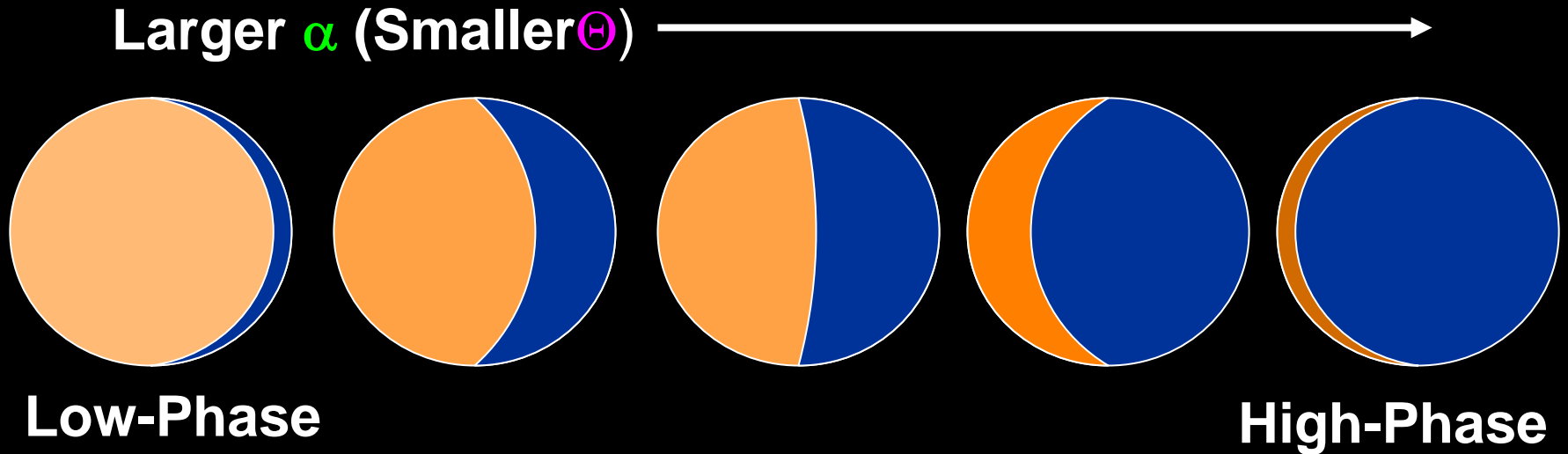
Not only is more of the visible surface illuminated, but solid surfaces are actually brighter at lower phase angles

The A, B and C rings, as well as the Cassini Division, are mostly composed of such large particles.

Why are all the rings the same brightness?

Light also diffracts around particles. The amount of light diffracted is comparable to the amount scattered or absorbed by the surface.

However, the diffracted radiation is largely confined to a cone with opening angle of λ/d (in radians)

λ = wavelength of light, d = particle diameter

For visible light $\lambda \sim$ 500 nm and particles ~1 cm across, the opening angle is smaller than 0.01^0 and is not observable in even these high-phase images.

To obtain a cone ~1^0 wide, need particles 10-100 microns across.

Small particles will therefore appear exceptionally bright in this geometry.
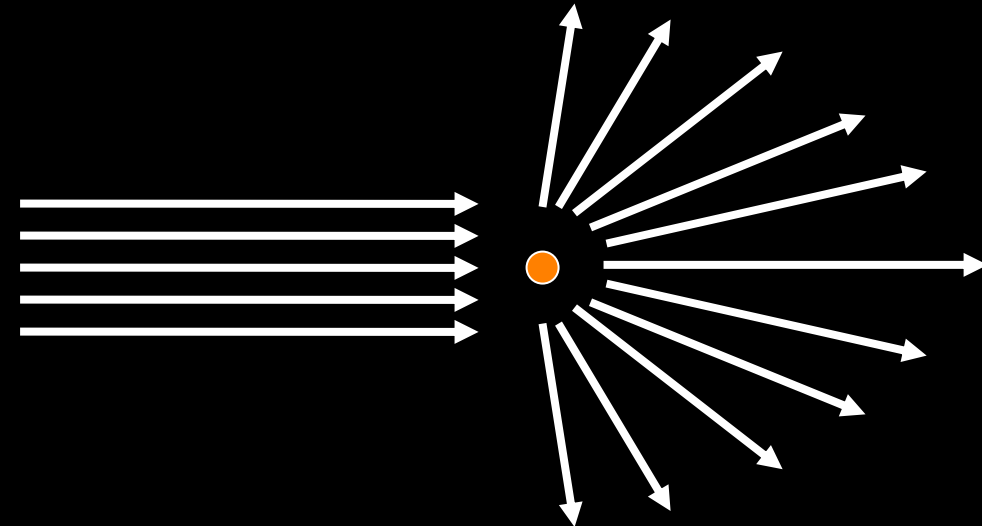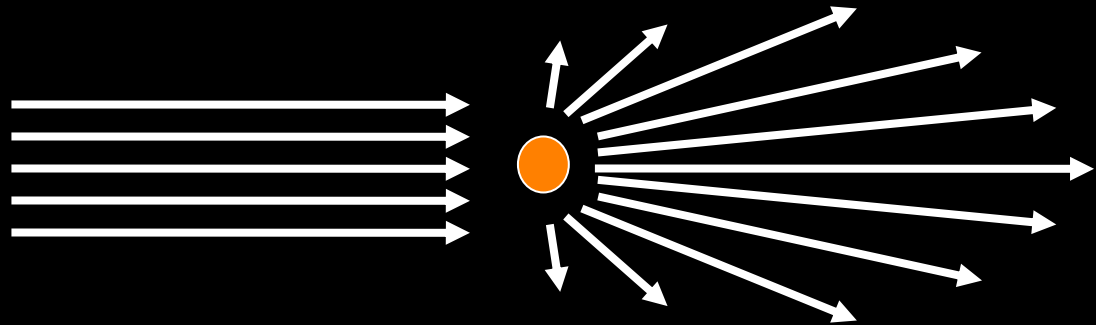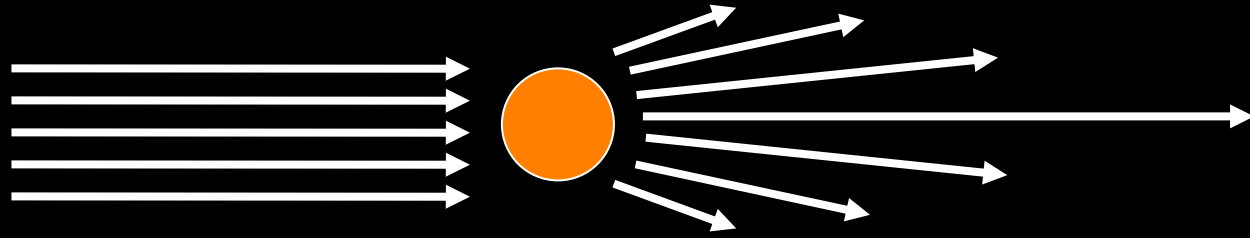
The "faint" rings like the D, E, F and G rings are mostly made of small dust particles and therefore appear bright in this geometry.

D-Ring

F-Ring

E-Ring

G-Ring
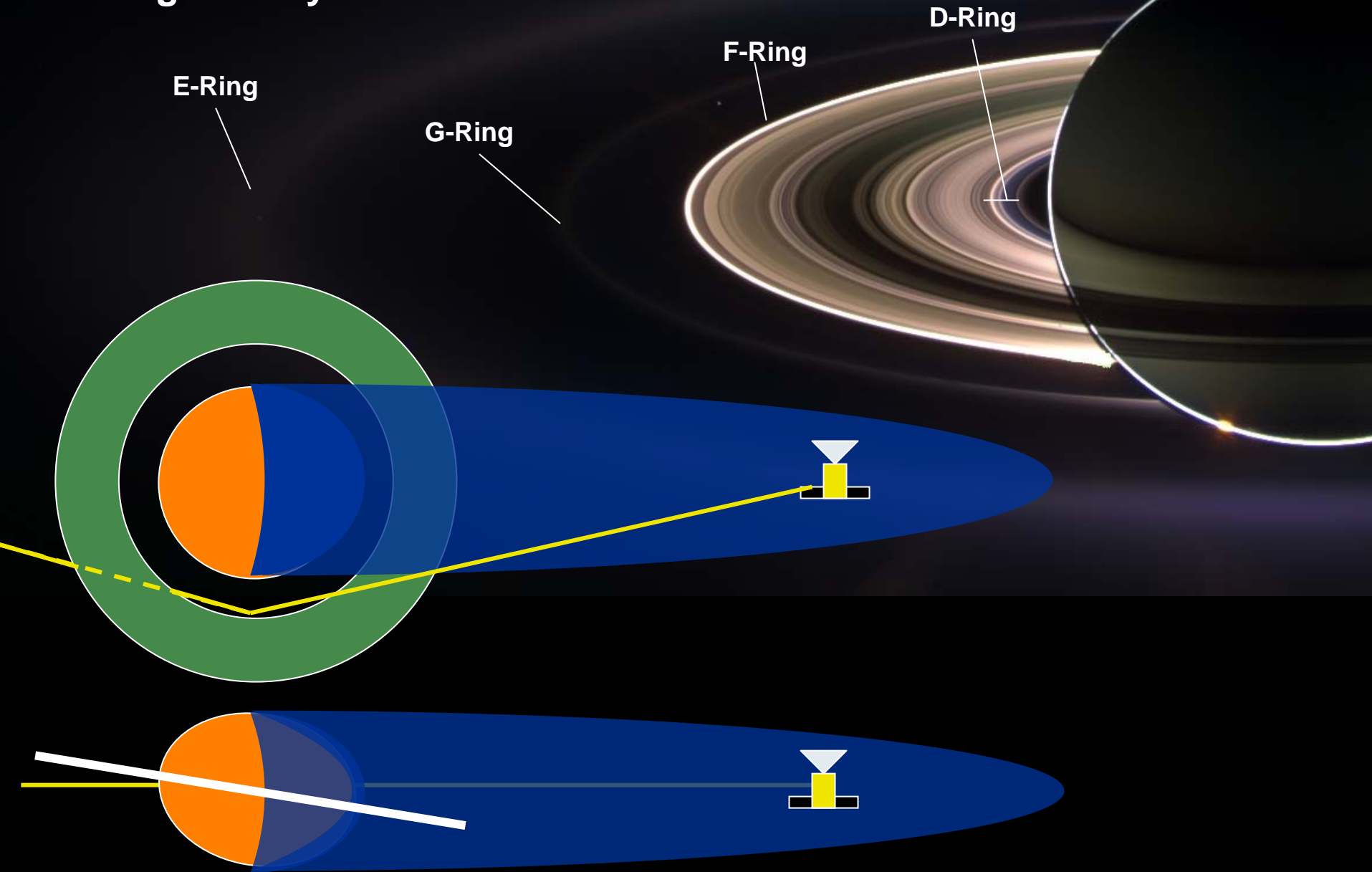
The A, B and C rings are mostly composed of bigger particles are therefore are rather dark in this geometry
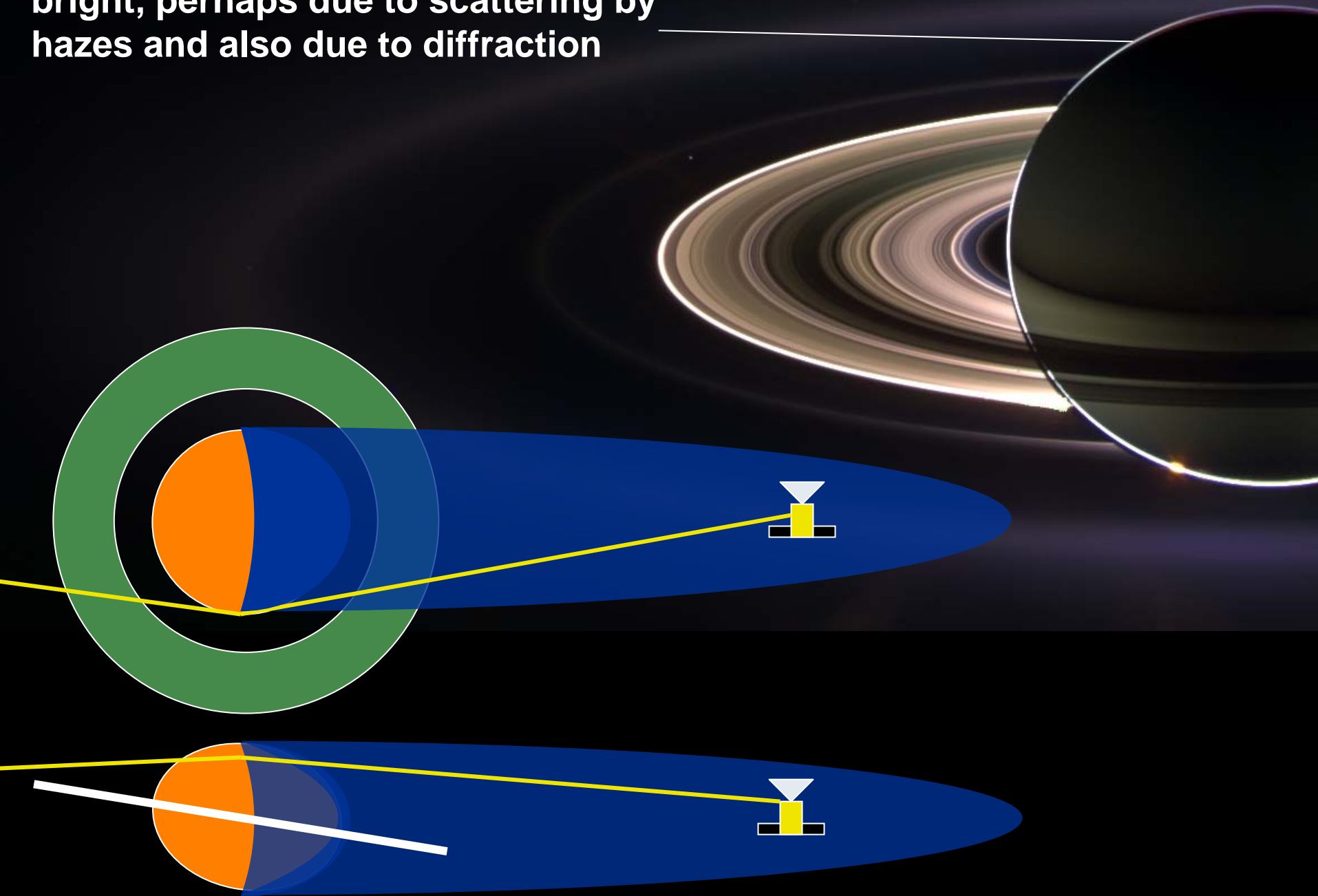
The outer B ring is exceptionally dark because little light can pass through it.

A-Ring

B-Ring
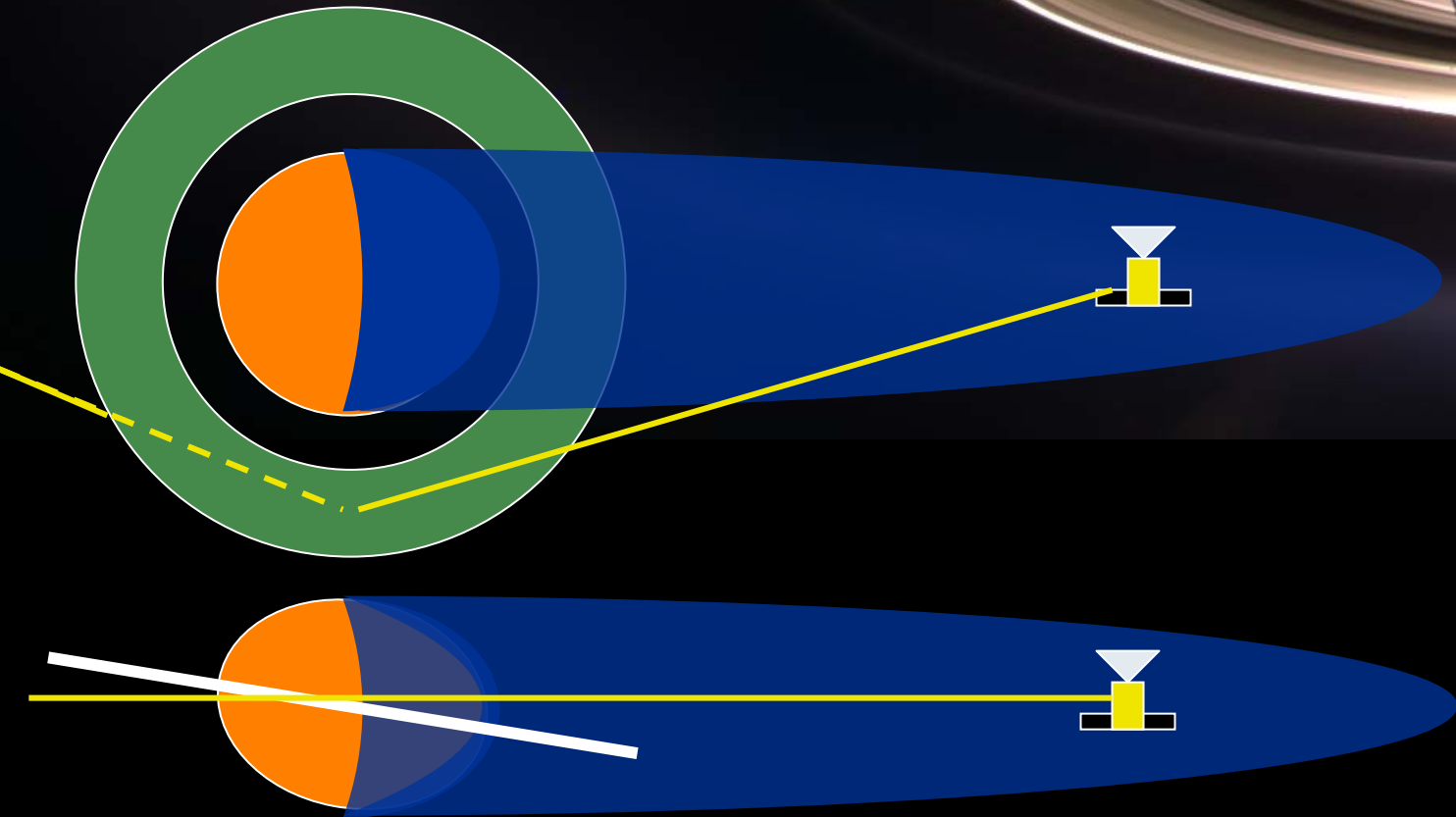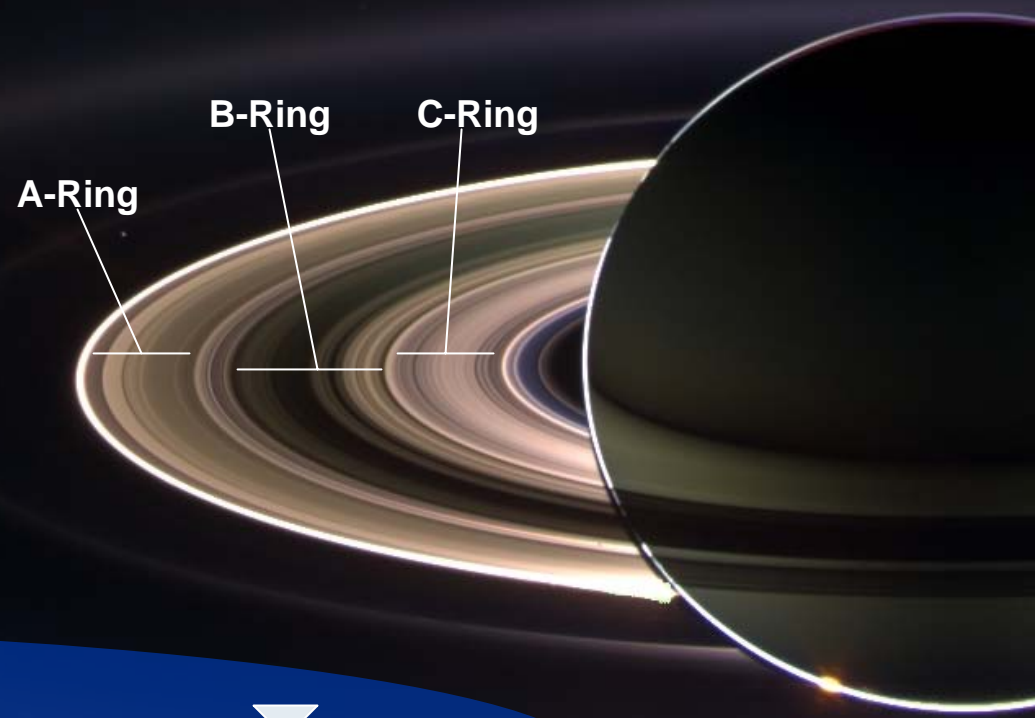
C-Ring

On the far side of the A, B and C rings we see a faint green glow, this is due to light reflected from the lit side of the planet bouncing off the ring to the spacecraft.
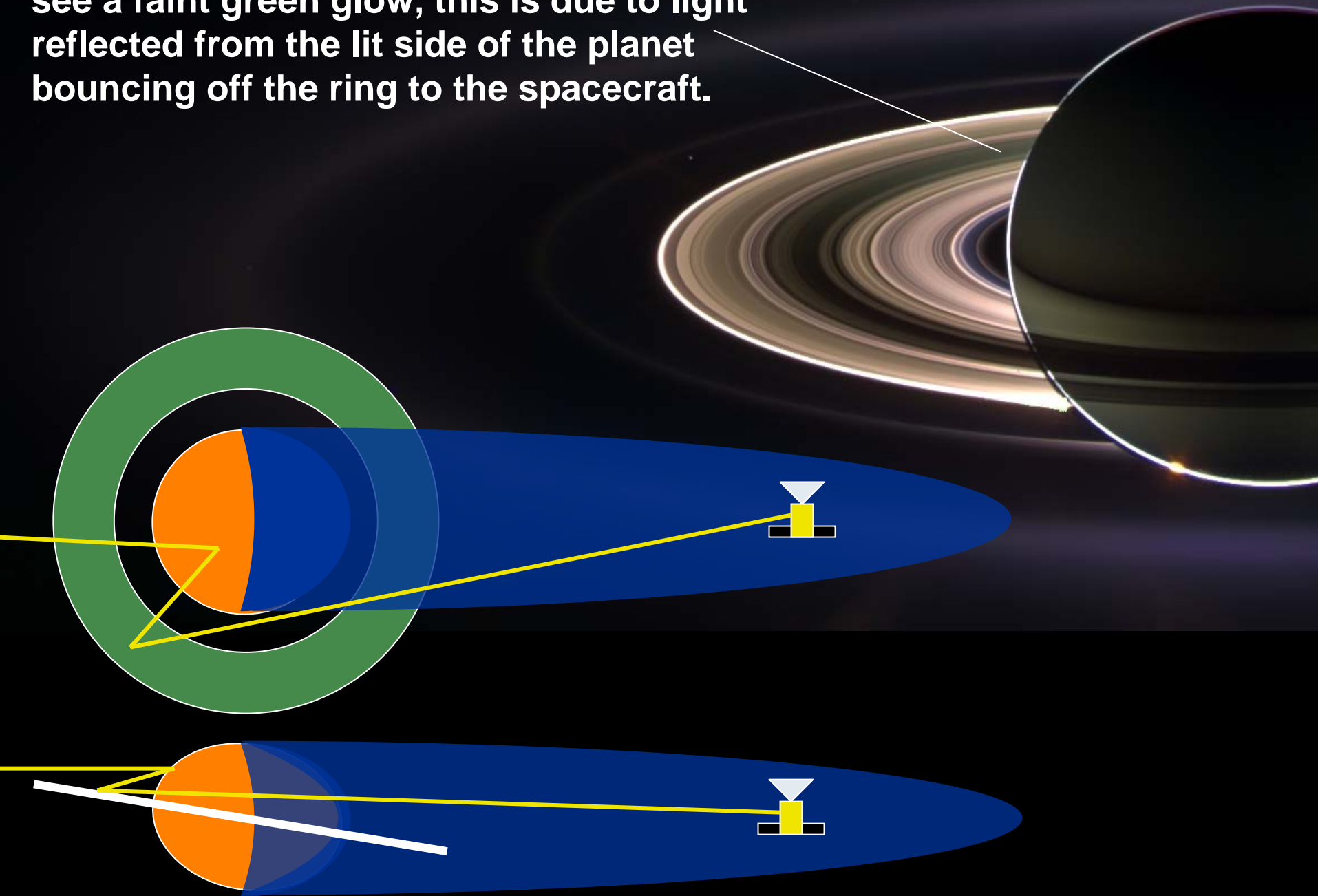
The limb of the planet also appears bright, perhaps due to scattering by hazes and also due to diffraction

The dark side of the planet is not completely dark in the northern hemisphere. This is due to light scattered and transmitted through the rings
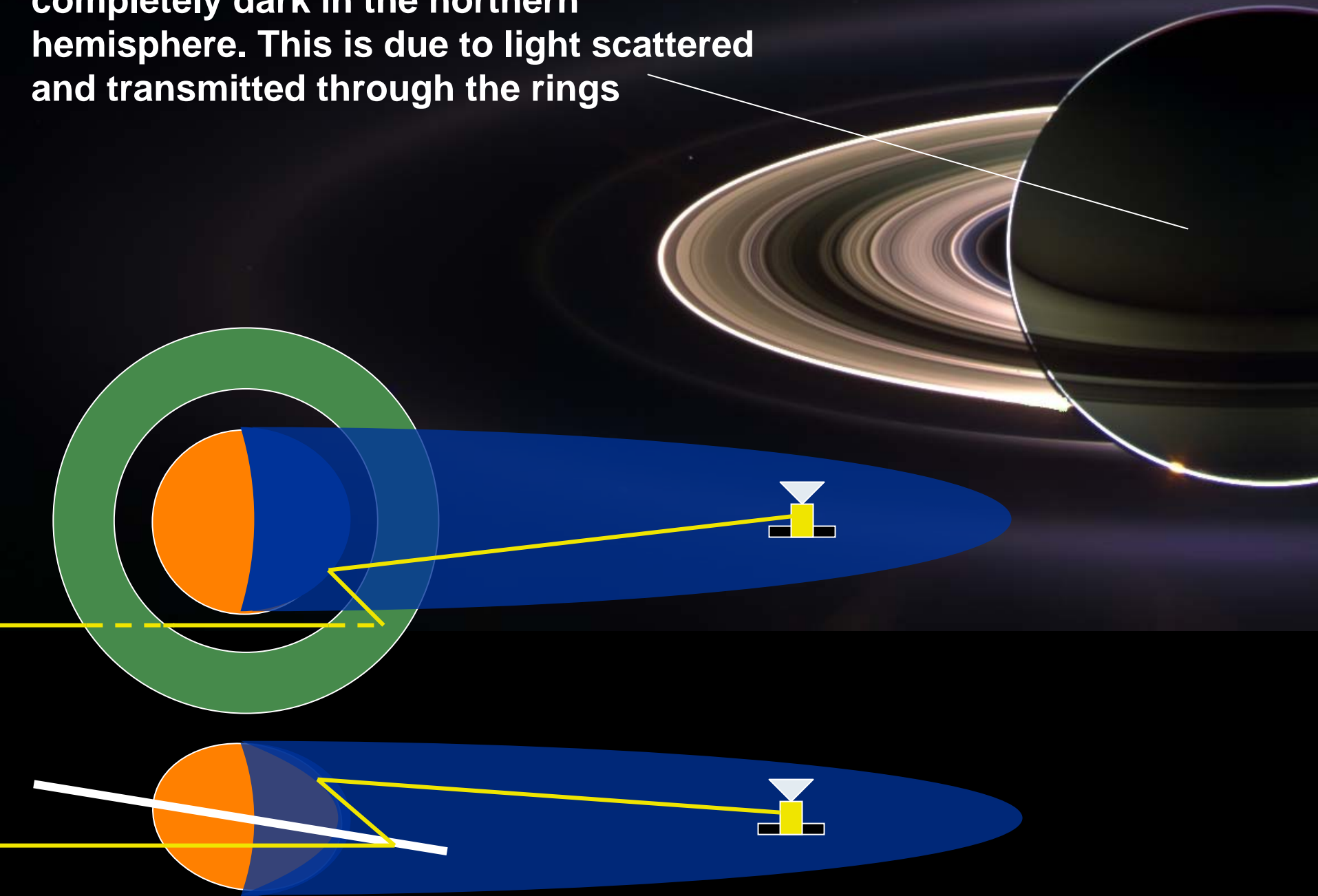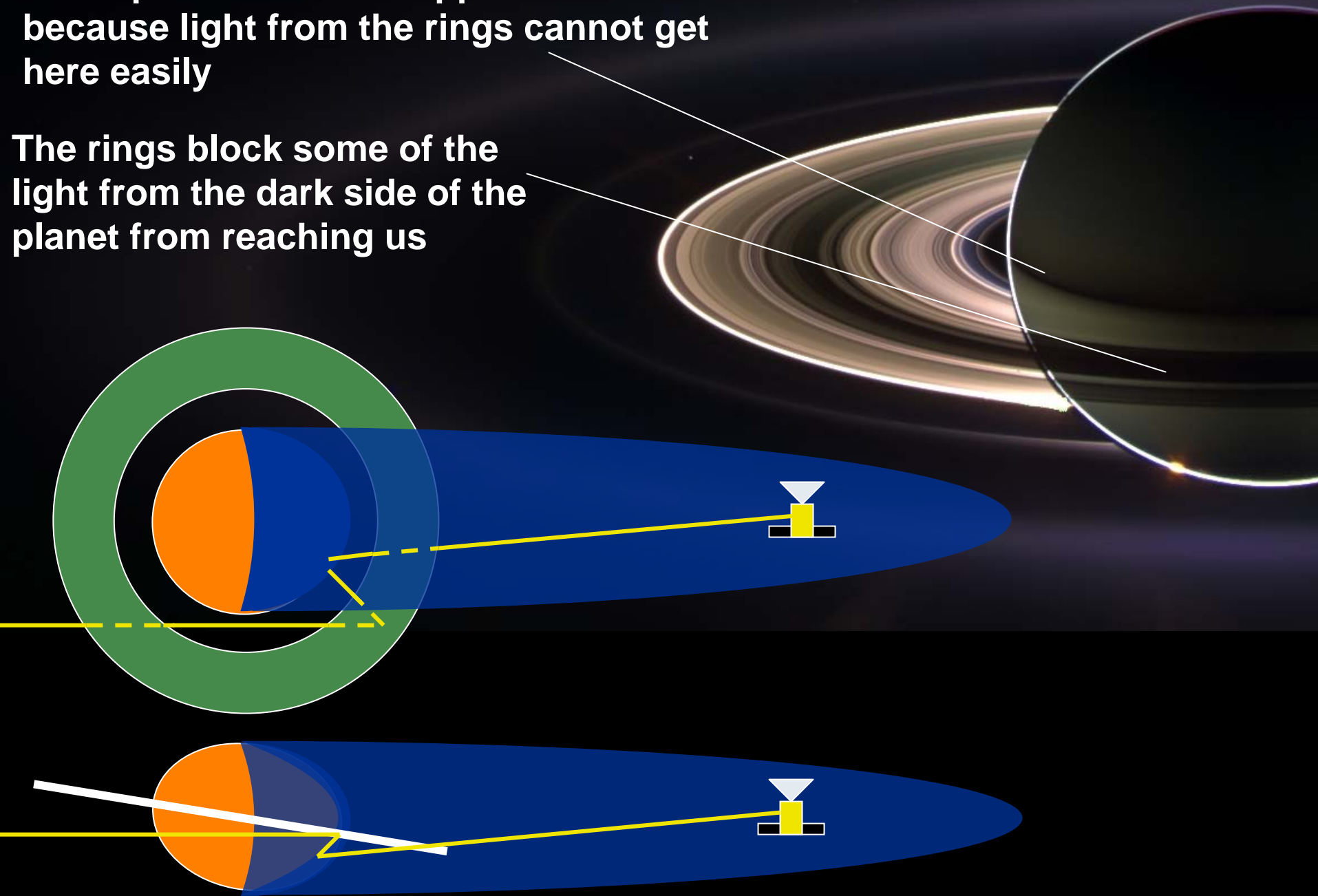
The dark side of the planet is not completely dark in the southern hemisphere. This is due to light reflected off the rings
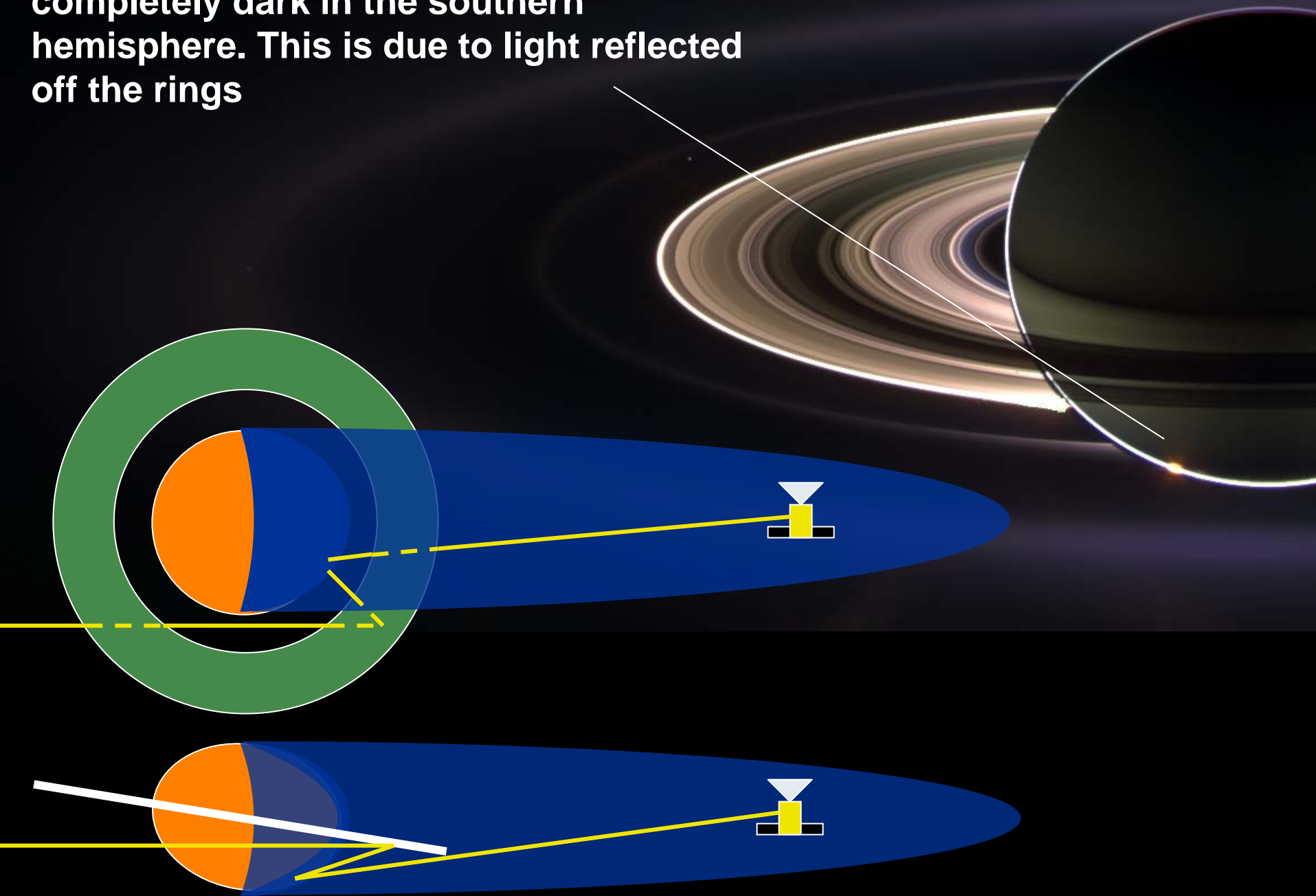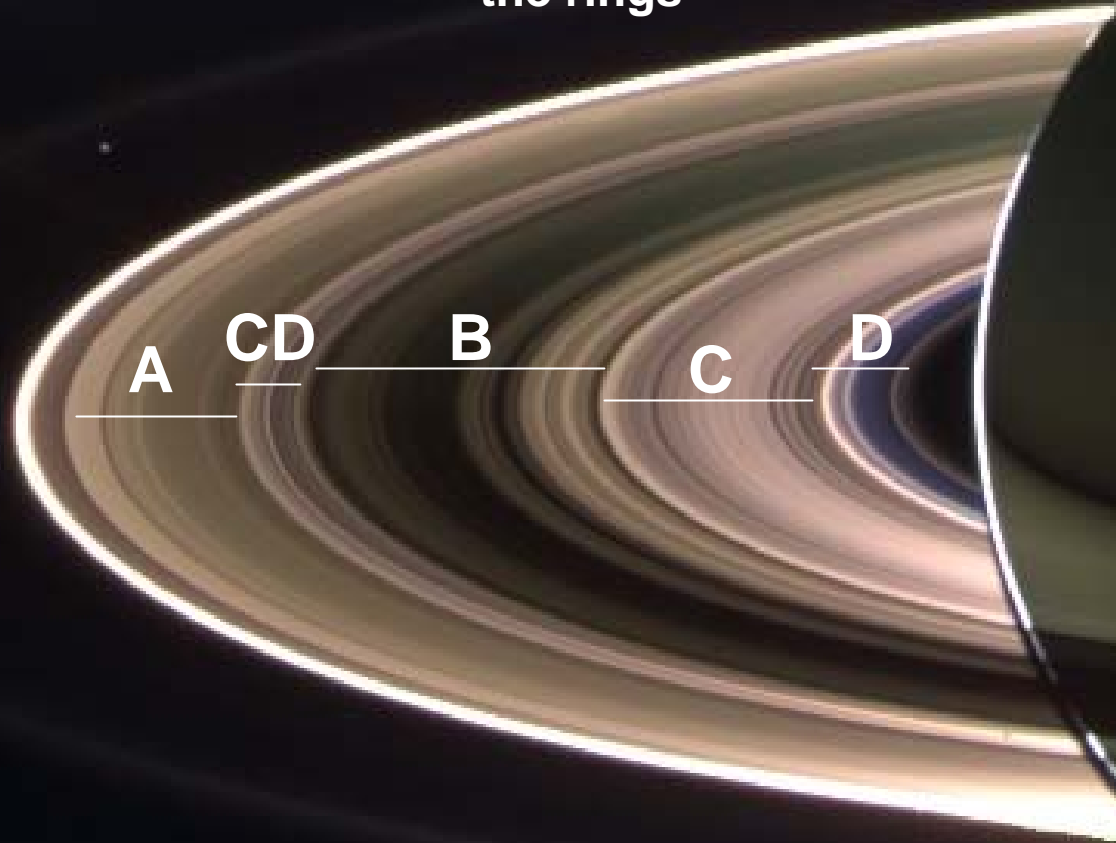
The equator of Saturn appears dark because light from the rings cannot get here easily
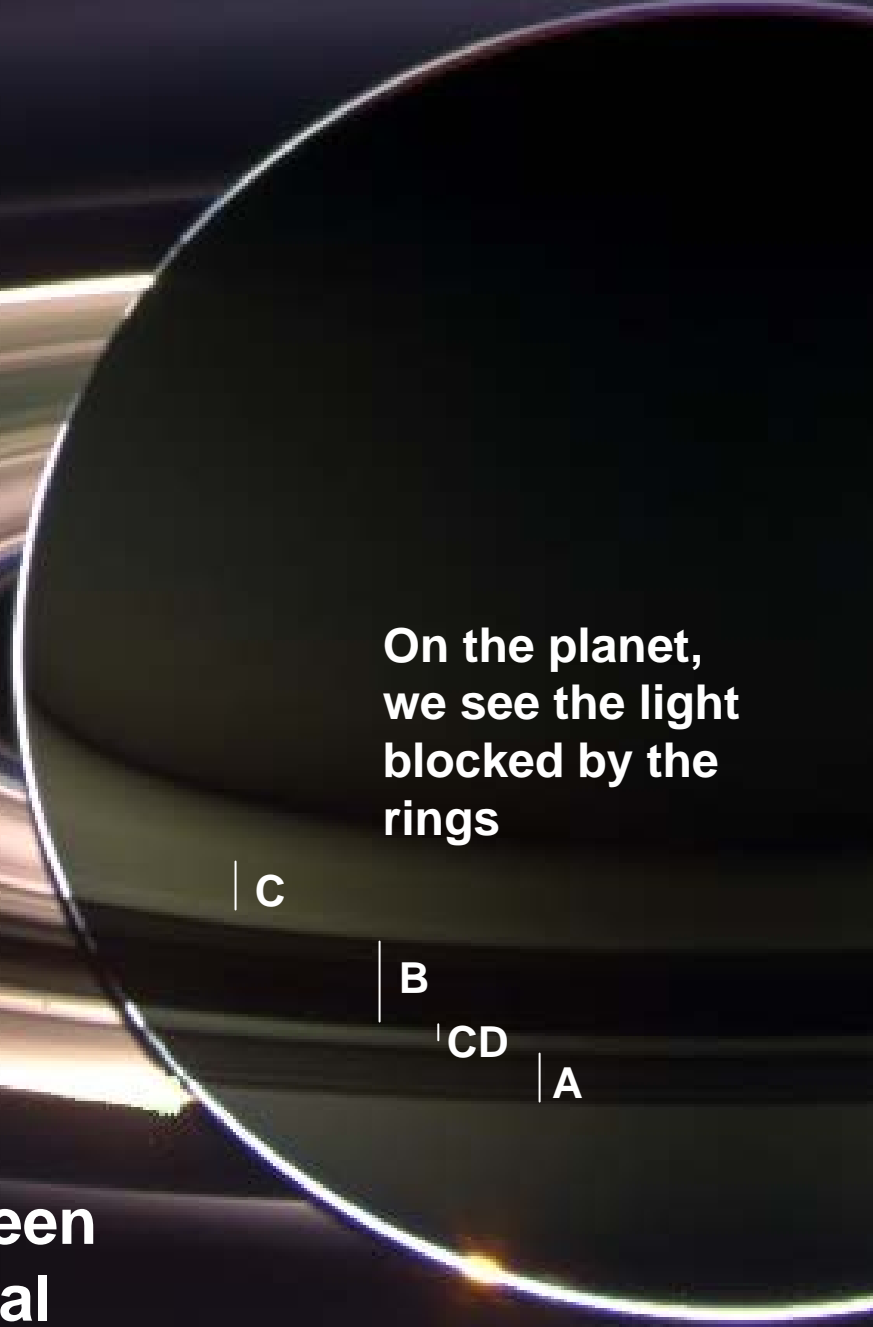
The rings block some of the light from the dark side of the planet from reaching us

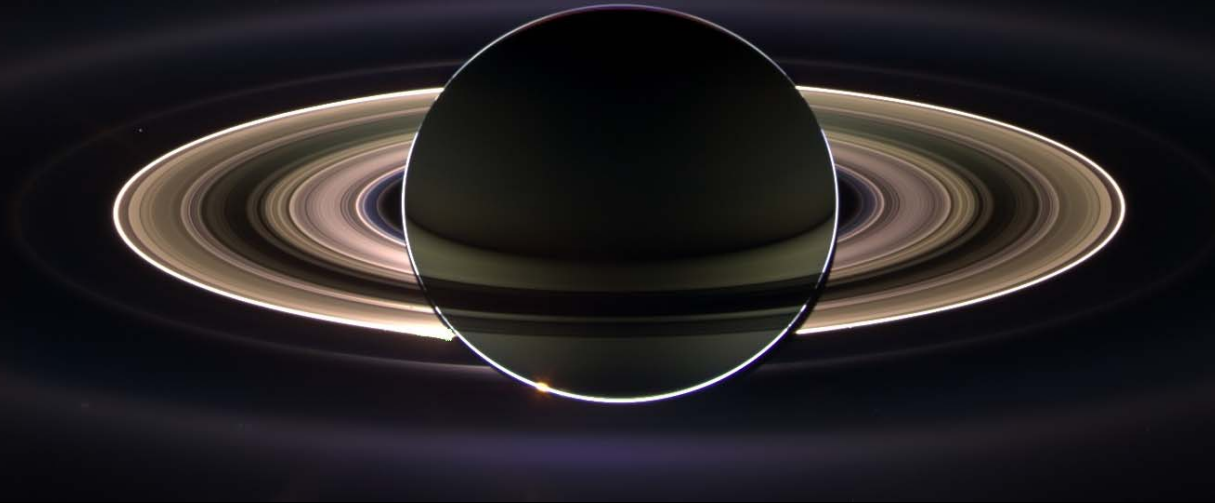Out here, we see the light scattered by the rings

A CD B C D

On the planet, we see the light blocked by the rings

C

B

CD

A

The non-trivial relationship between brightness and amount of material leads to strange images….

**Beyond being pretty, these images contain some important information about the rings**

1. Interesting brightness and color variations.
2. Unexpected new structures in the E ring
3. New rings!

All the rings get brighter closer to the sun because the scattering angles are smaller here. The steepness of the brightening should constrain the grain sizes in these rings

Rough position of sun behind Saturn
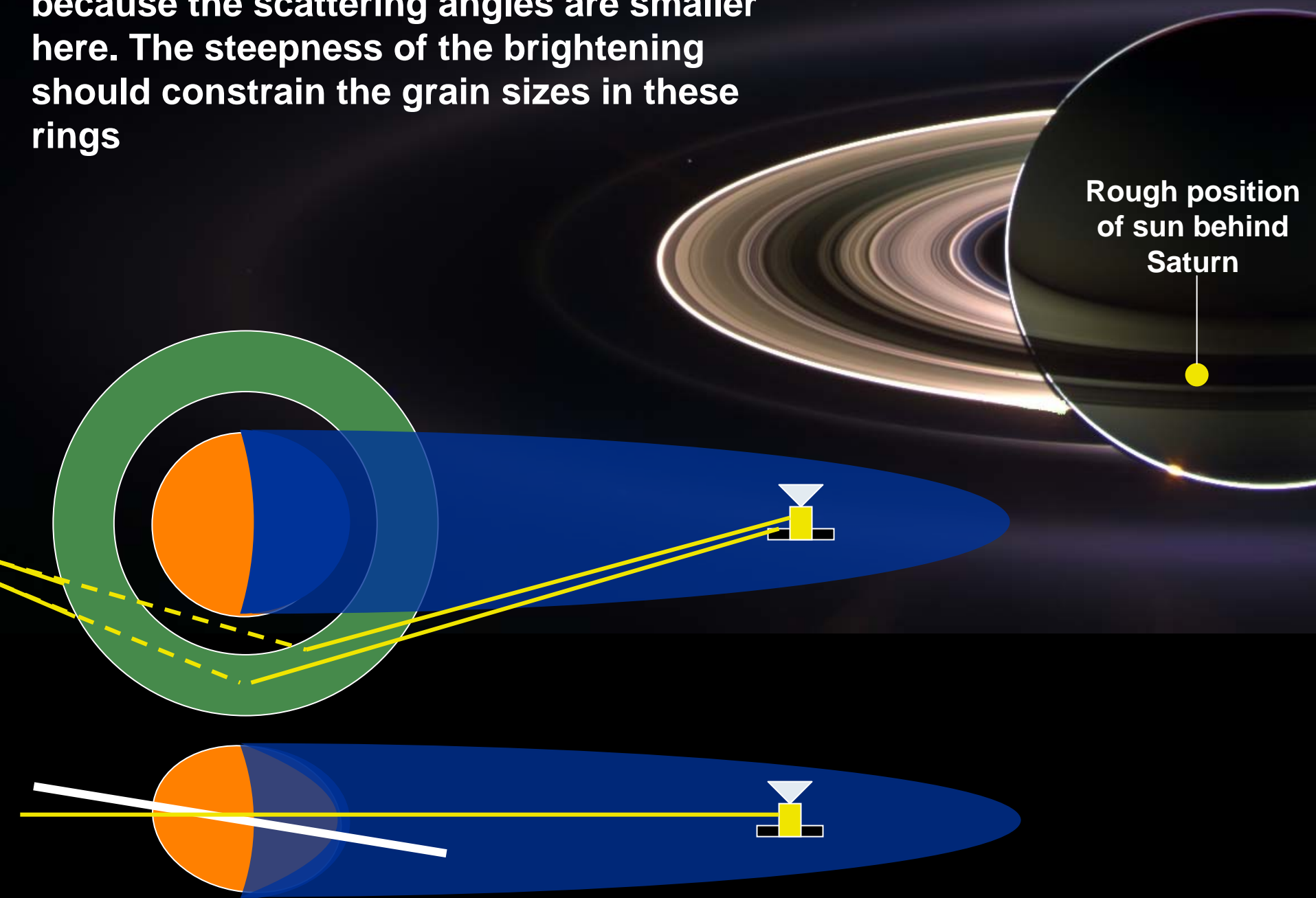
Color variations
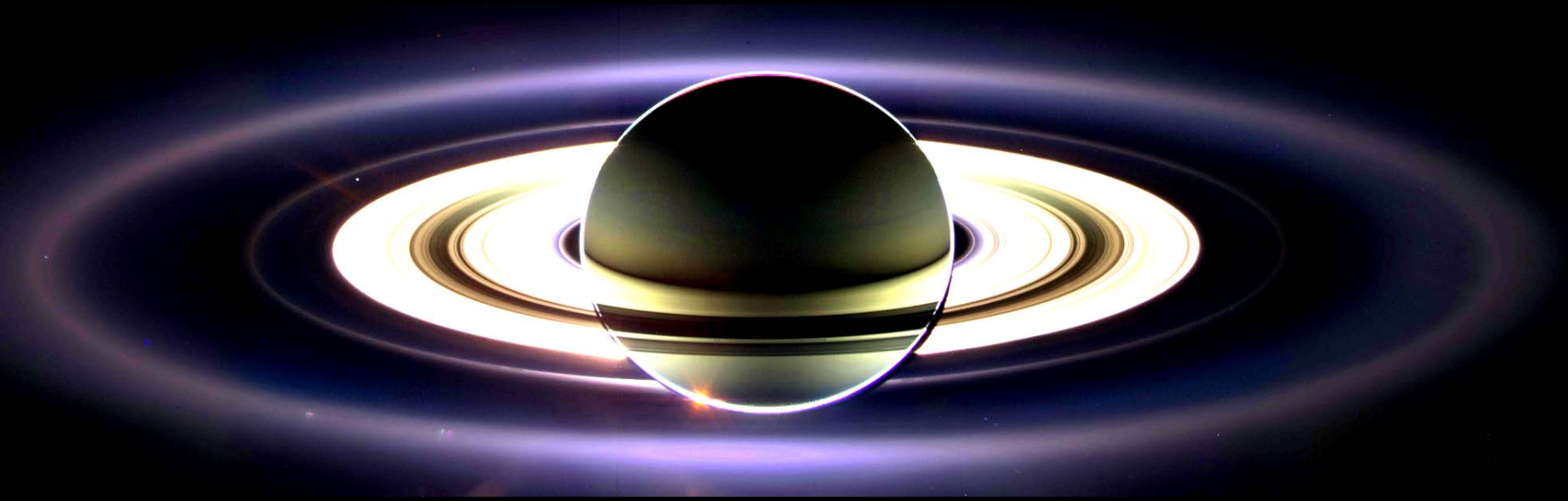
Note E ring becomes bluer closer to the planet. This
Is because the width of the diffraction lobe goes like λ/d,
so the same-size particles have narrower forward-
scattering cones in UV than in the IR. The rings therefore
become bluer at higher phase.

Color variations between rings seen in IR

Dusty rings probably appear blue because they contain particles 1-100 microns across

Main rings probably appear red because they are primarily composed of big particles

F-ring appears white because it is saturated. Red feature outside F ring an artifact.
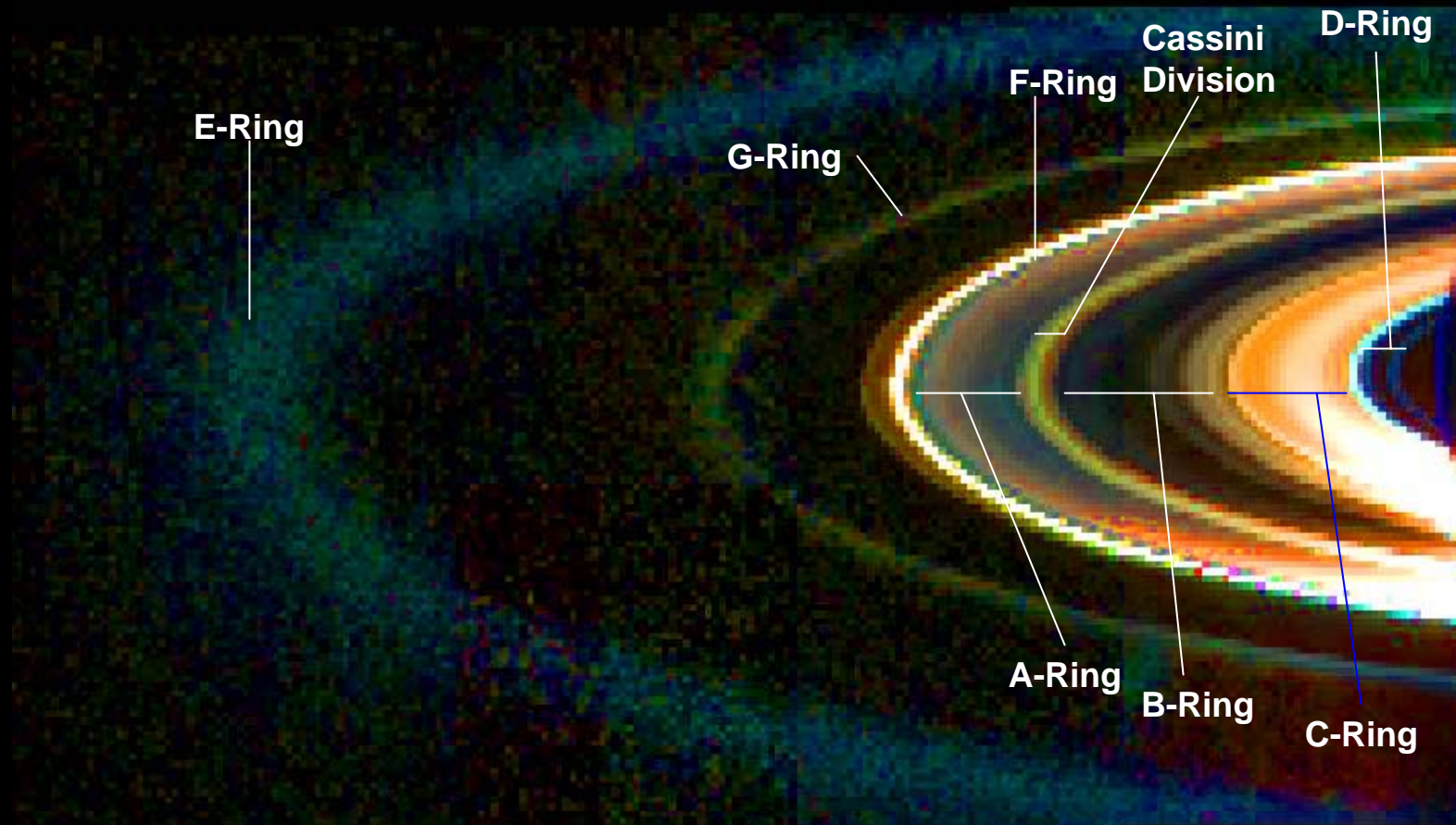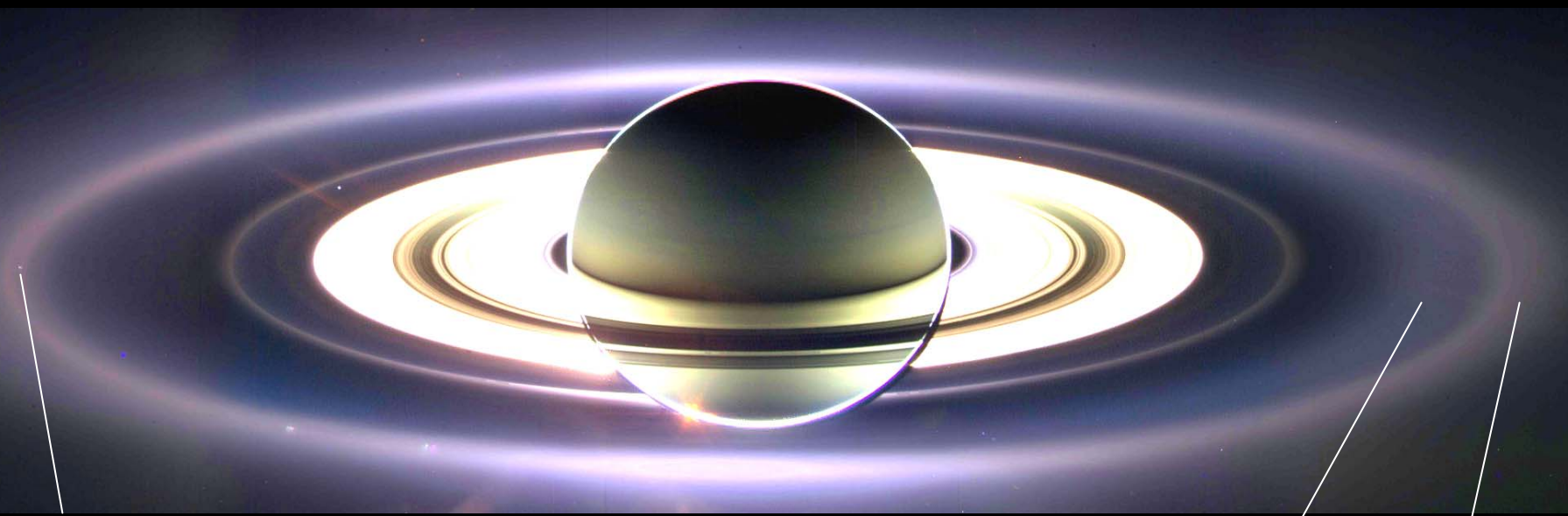

Image based on VIMS data: Red=3600 nm, Green=1750 nm, Blue=1000 nm

New Pictures showing Enceladus sculpting or disrupting the E ring
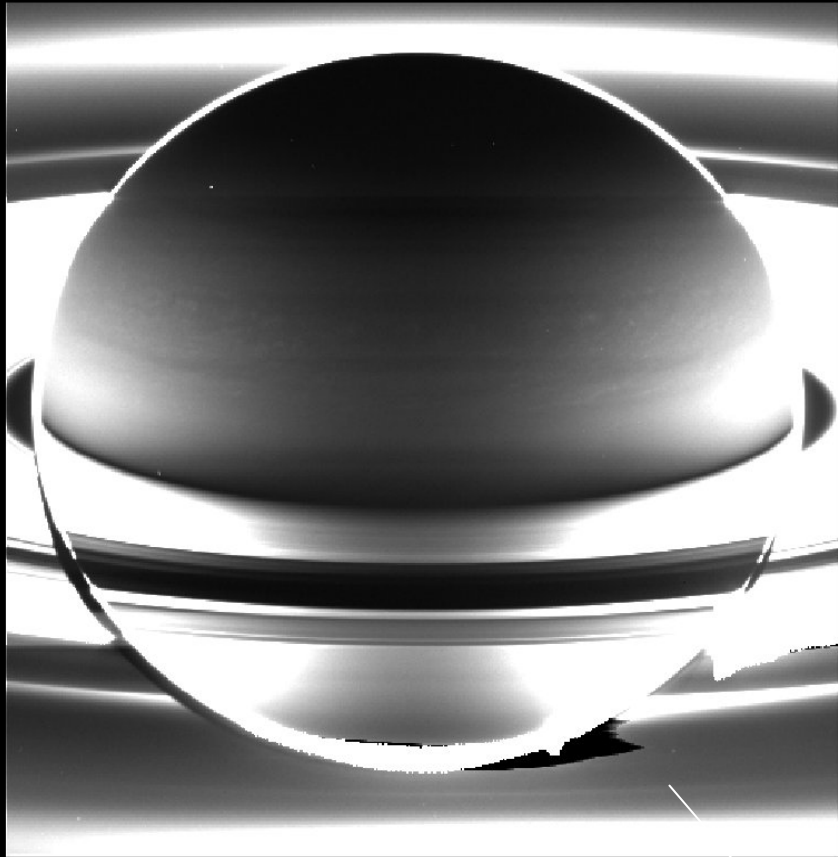
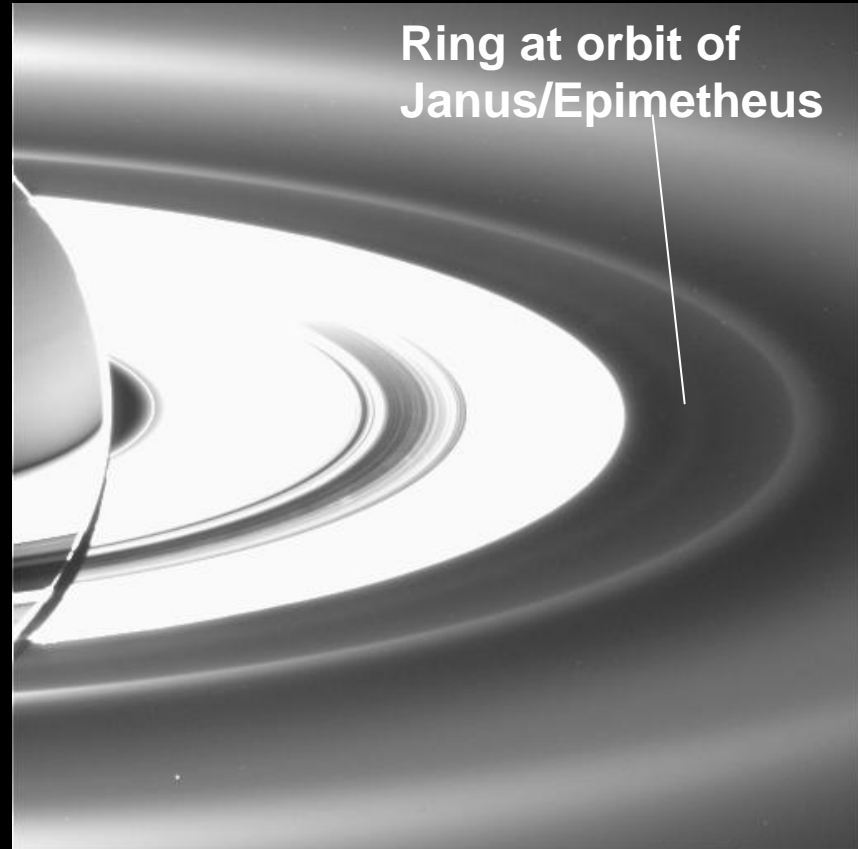# Strange asymmetry in the E-ring

**Red Core
with Bluer
wings**

**Blue and red
rings separate?**

**There seems to be an asymmetry between morning
and evening that may reflect interaction of the E ring
particles with solar radiation and the magnetosphere…..**

Two new rings discovered in these images, both associated with small moons

Ring at orbit of Janus/Epimetheus

Ring at orbit of Pallene

Rings likely produced by particles kicked off of little moons by micrometeoroid impacts….

New insights into the dynamics of the G and D rings

Why do we want to look at small particles/dust?

Collisions in dusty rings are rare, making some aspects of their dynamics simpler.

Small particles have shorter time constants….

Energetic particles in Saturn's magnetosphere destroy particles 1 micron across in ~1000 years.

Non-gravitational forces like plasma drag can alter the orbits of particles 1 micron across in ~100,000 years.

Dusty rings appear to be very dynamic and change on time scales as short as a few years!

Dusty rings are also found at other planets….

What is the source of the G ring?
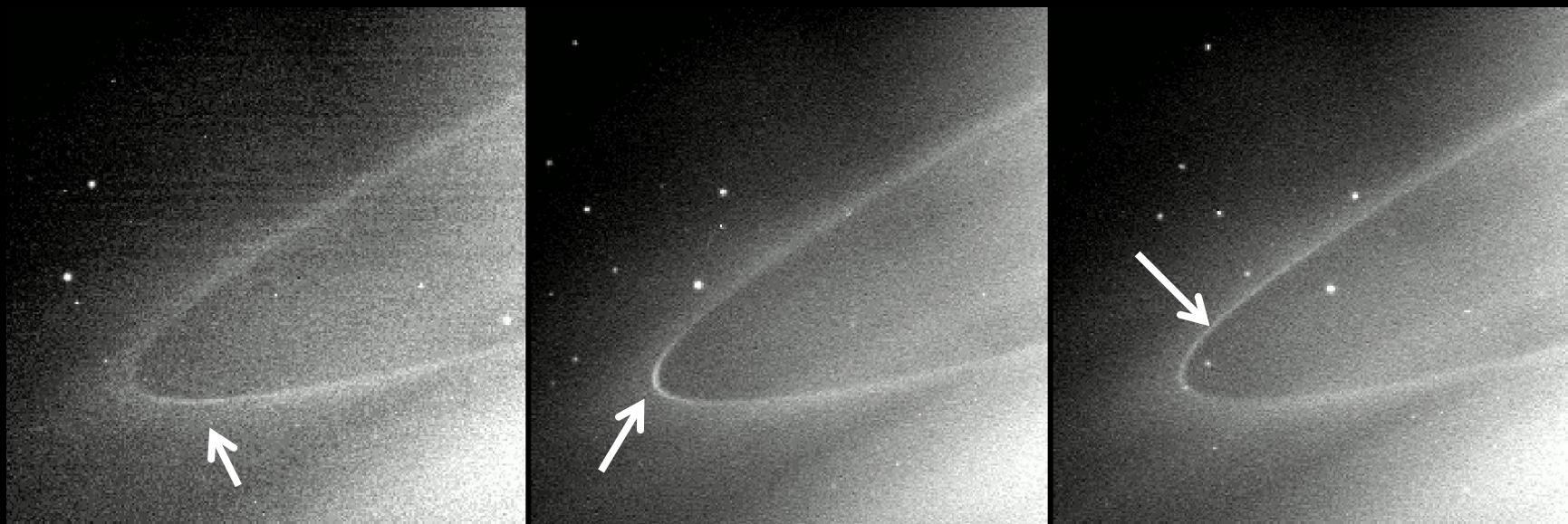
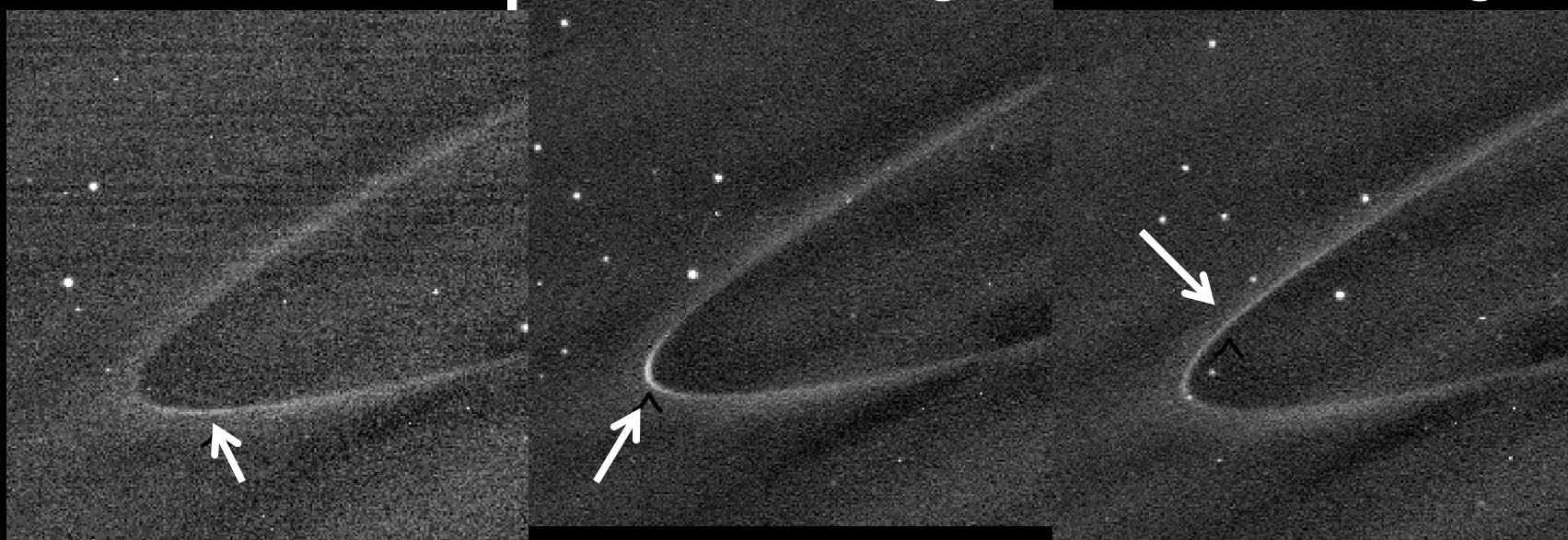**Typical appearance of the G ring**
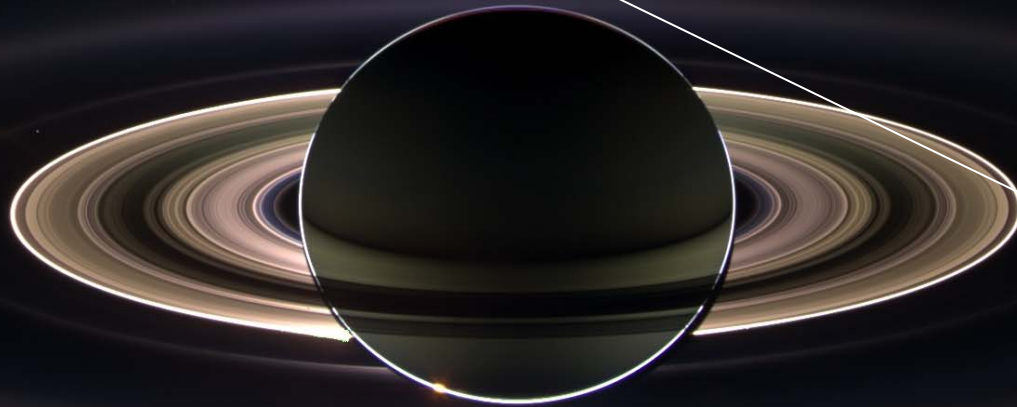
G - Ring Dynamics:

Sometimes, we see a bright, narrow arc on the inner edge of the G ring

The Arc in Motion (see also animation on ciclops.org)

Raw Images (Rev 8 REGAURORA)

High-Passed Filtered Images

Fitting the Arc's Orbit with observations to date

Over the first two years of the Cassini mission, we have observed the arc ~15 times. Fitting these data, we find the arc's orbital period is 0.80813 days (semi-major axis = 167,496 km)

Mimas' period is 0.94242 days so $(P_{mimas}/P_{arc})=(7/6)-0.0005$

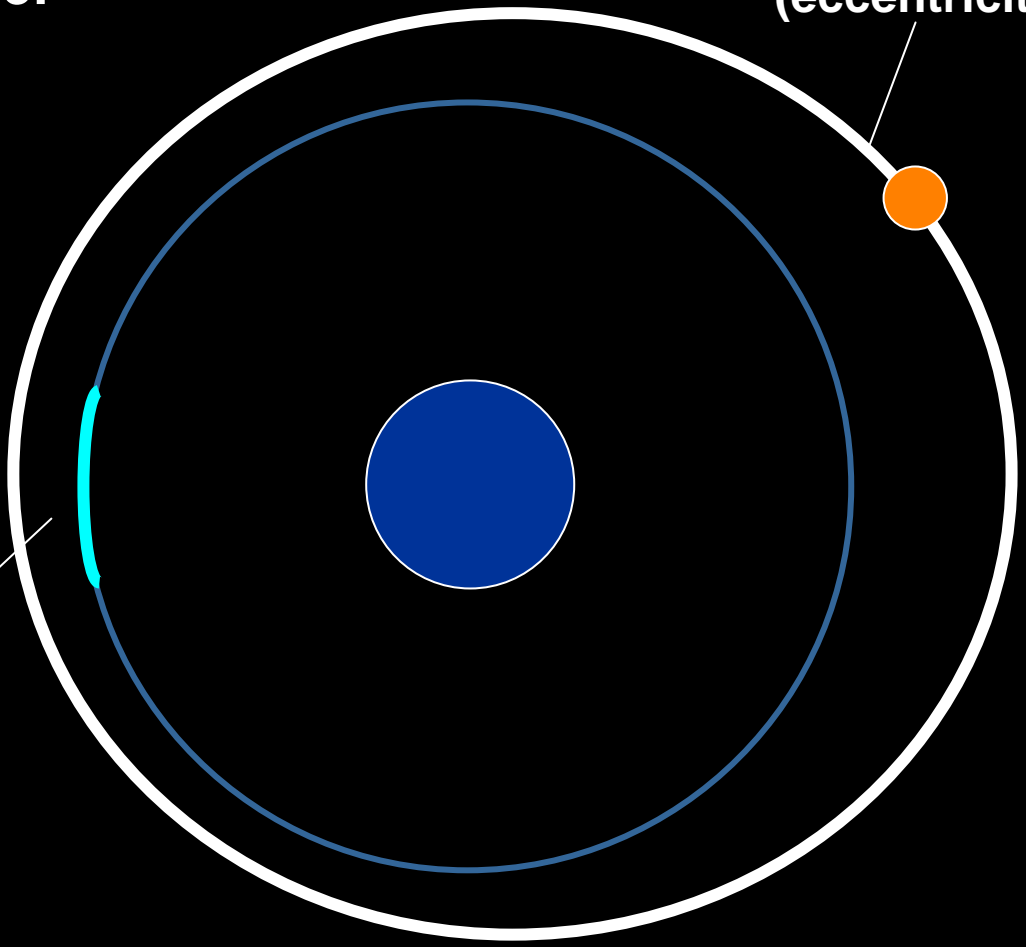We think the arc is being confined by a resonance with Mimas….

How can a resonance confine an arc?

$$6\lambda_{arc} - 7\lambda_{Mimas} + \varpi_{Mimas} = \pi$$
$$6(\lambda_{arc} - \lambda_{Mimas}) + (\varpi_{Mimas} - \lambda_{Mimas}) = \pi$$

In an inertial frame:
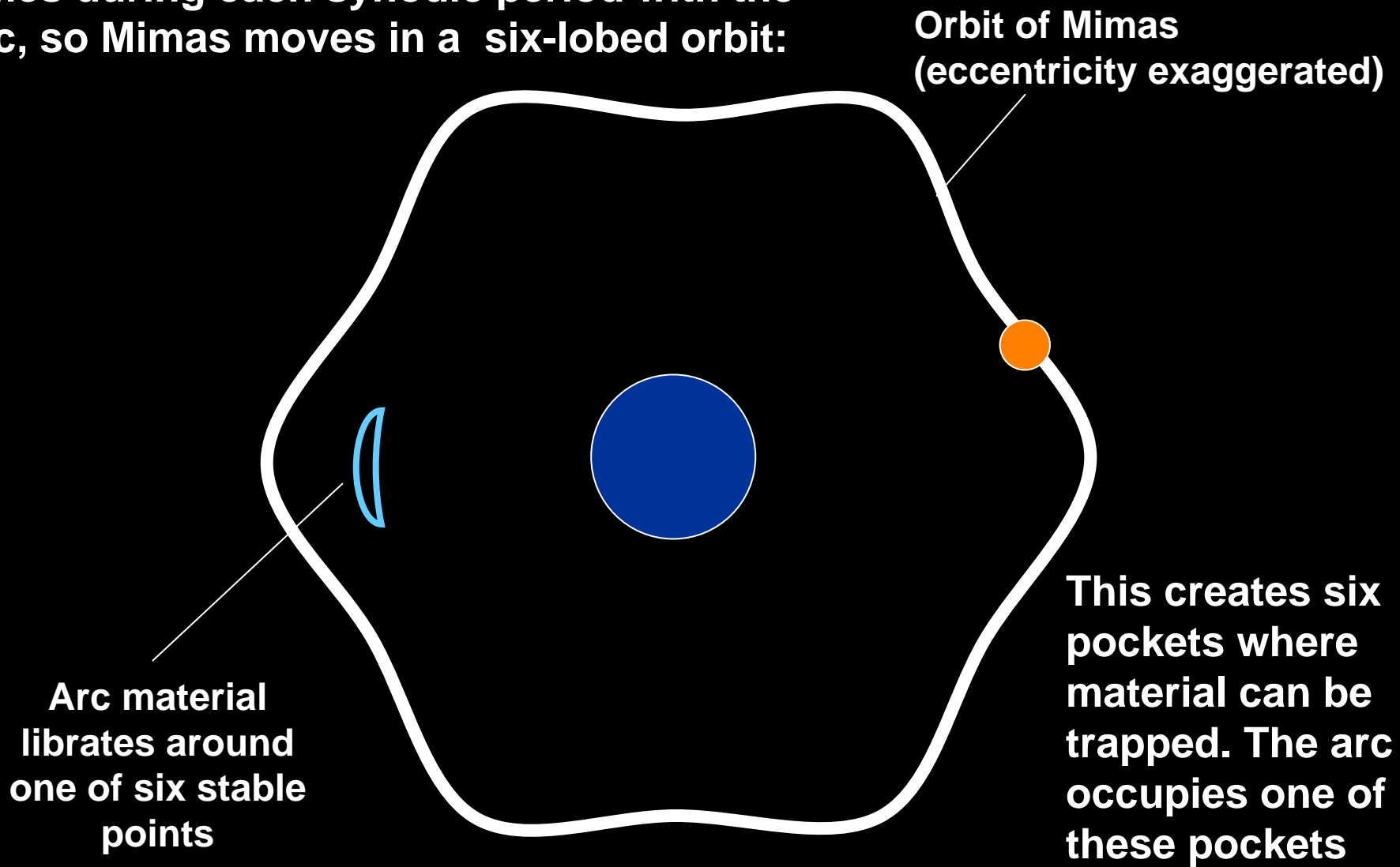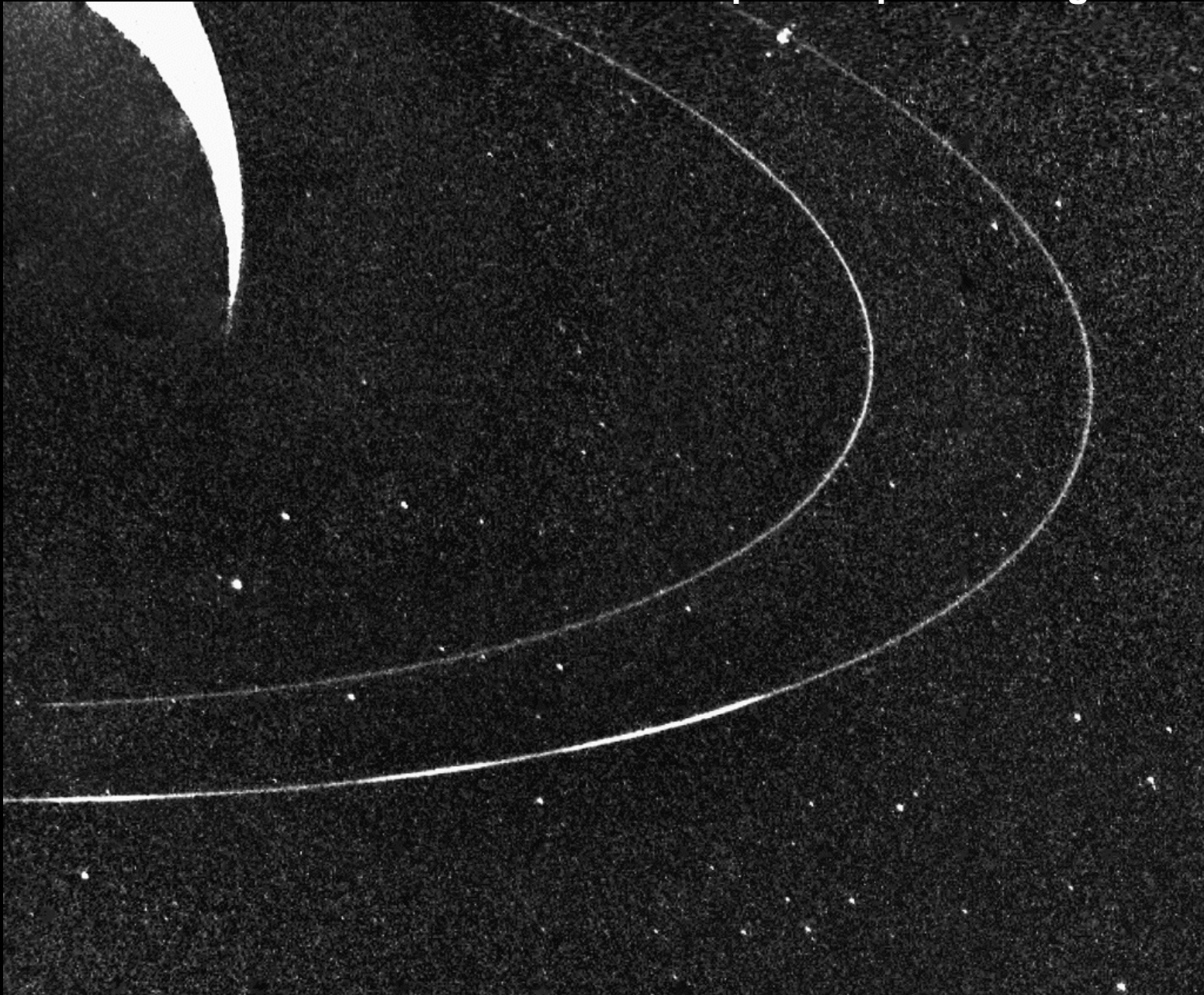
**Orbit of Mimas
(eccentricity exaggerated)**

Arc material

The 7:6 resonance Geometry

$$6\lambda_{arc} - 7\lambda_{Mimas} + \varpi_{Mimas} = \pi$$
$$6(\lambda_{} - \lambda_{}) + (\varpi_{} - \lambda_{}) = \pi$$

In the frame of the arc's mean motion, Mimas moves in and out due to its eccentricity six times during each synodic period with the arc, so Mimas moves in a six-lobed orbit:

Orbit of Mimas
(eccentricity exaggerated)

This creates six pockets where material can be trapped. The arc occupies one of these pockets

Arc material librates around one of six stable points

This same mechanism has been used to explain Neptune's ring arcs….

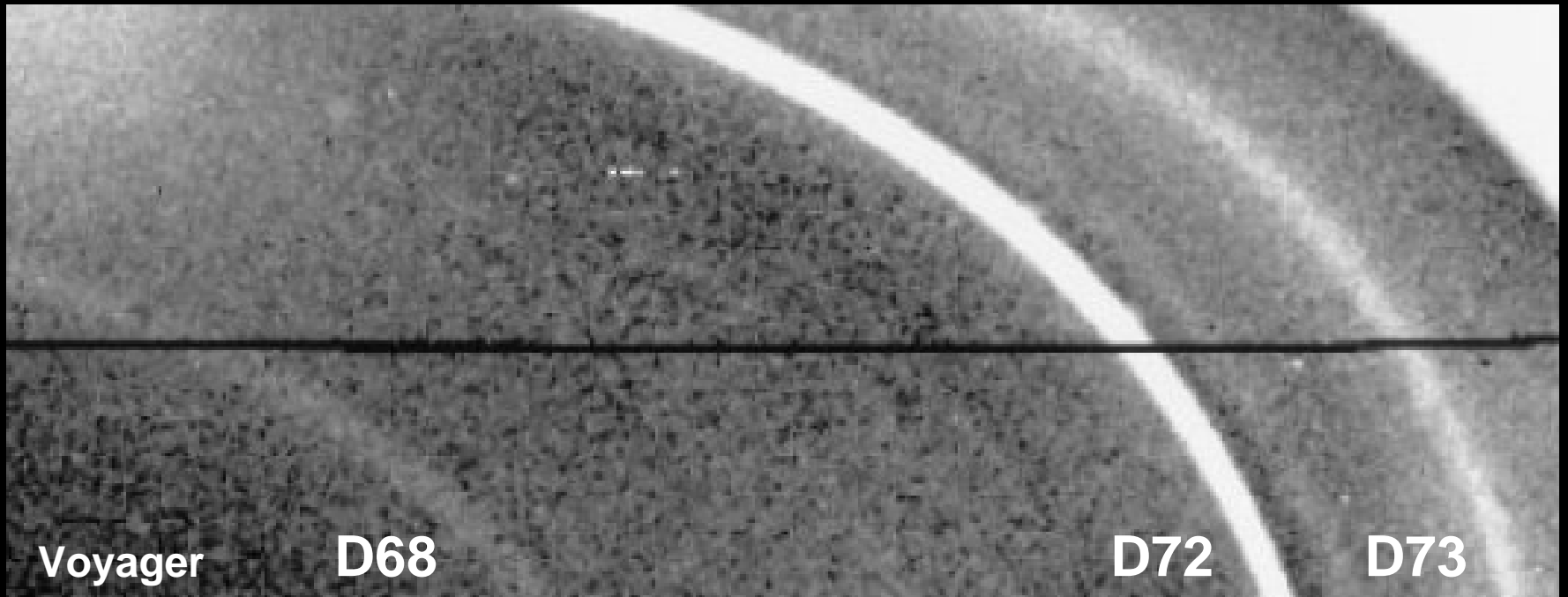# What about the rest of the G ring?

Perhaps the rest of the G-ring is produced by material leaking out of the arc under the influence of non-gravitational forces?
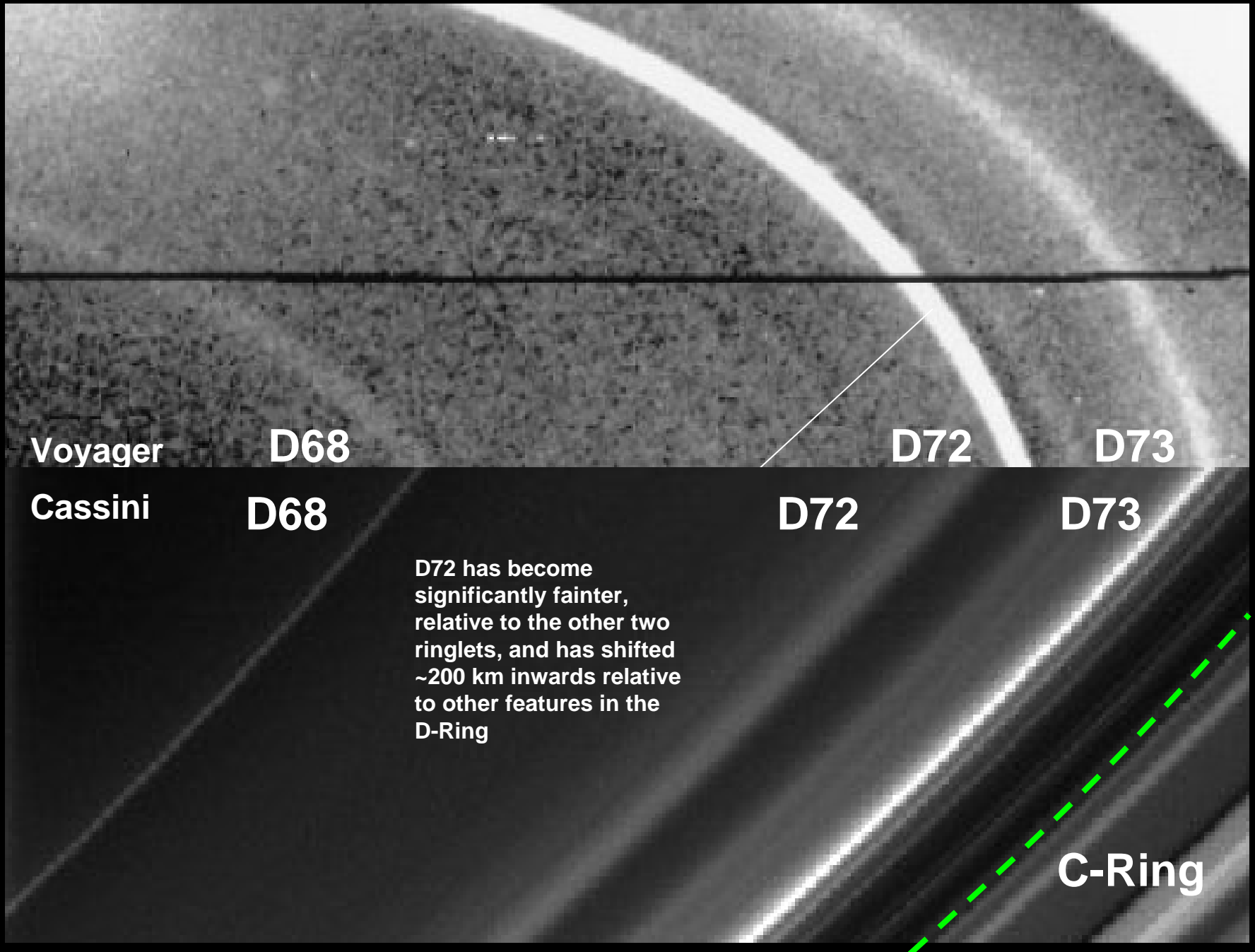
D-ring

The D-Ring, as observed by Voyager

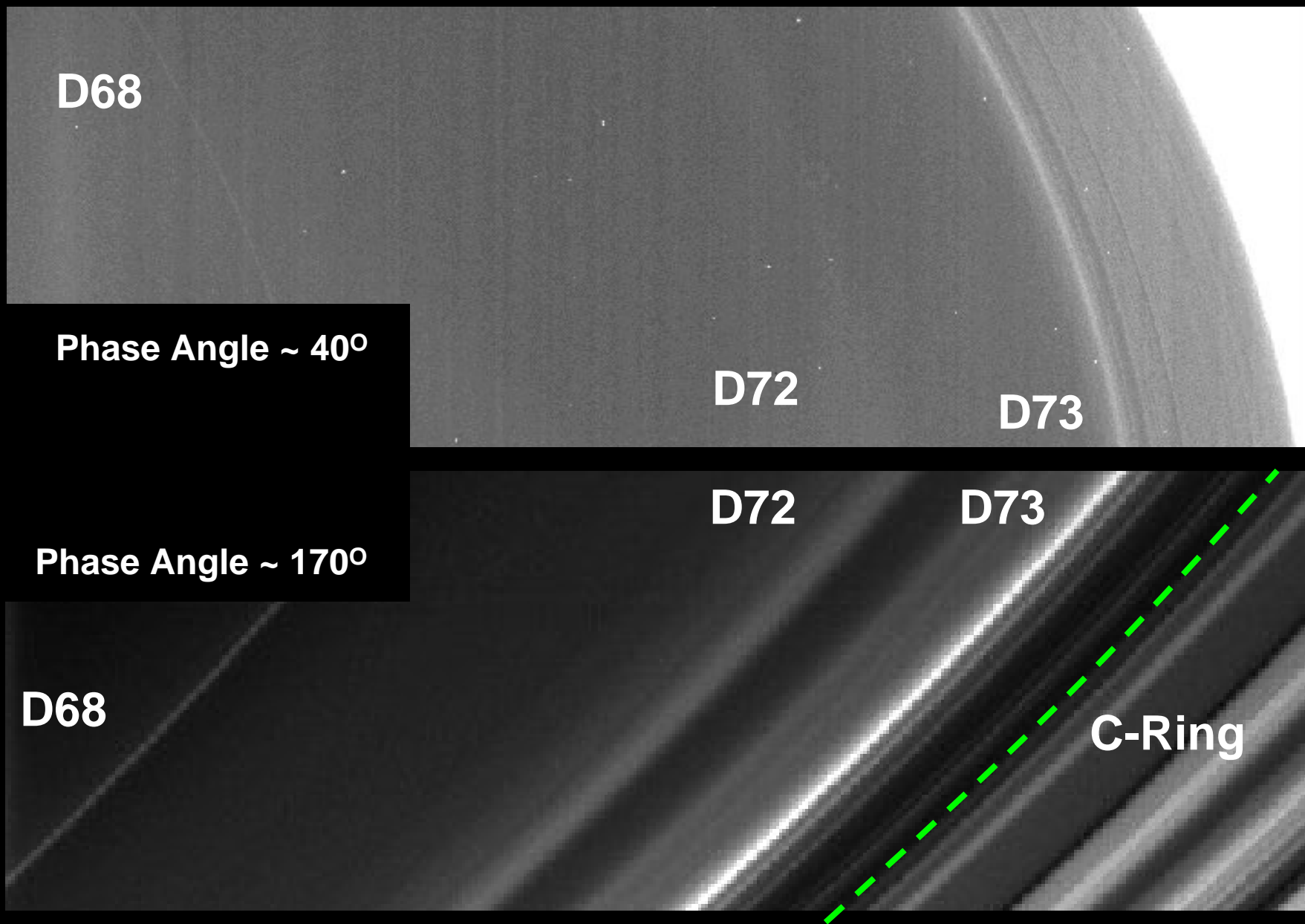Voyager   D68   D72   D73

The D-Ring has changed dramatically in the last 25 years

Voyager D68 D72 D73

Cassini D68 D72 D73

D72 has become significantly fainter, relative to the other two ringlets, and has shifted ~200 km inwards relative to other features in the D-Ring

C-Ring

The Two Faces of the D-ring

D68

Phase Angle ~ 40°
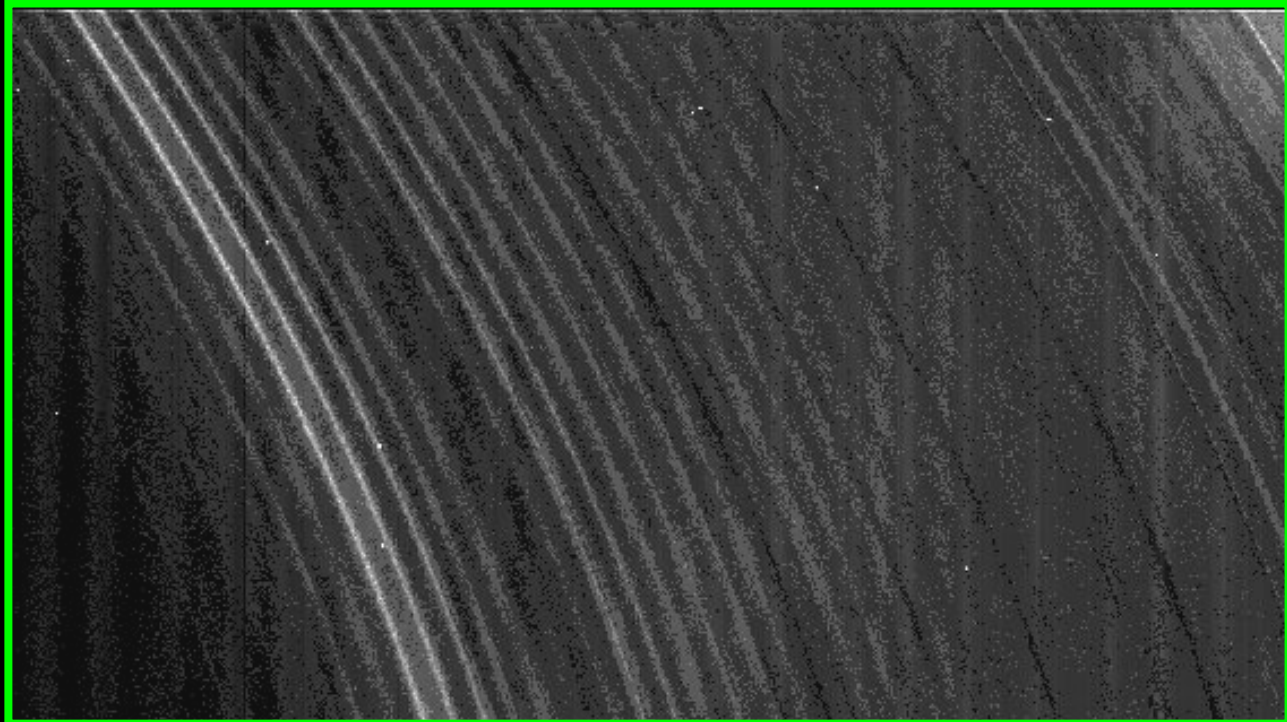
D72

D73

Phase Angle ~ 170°

D72

D73

D68

C-Ring
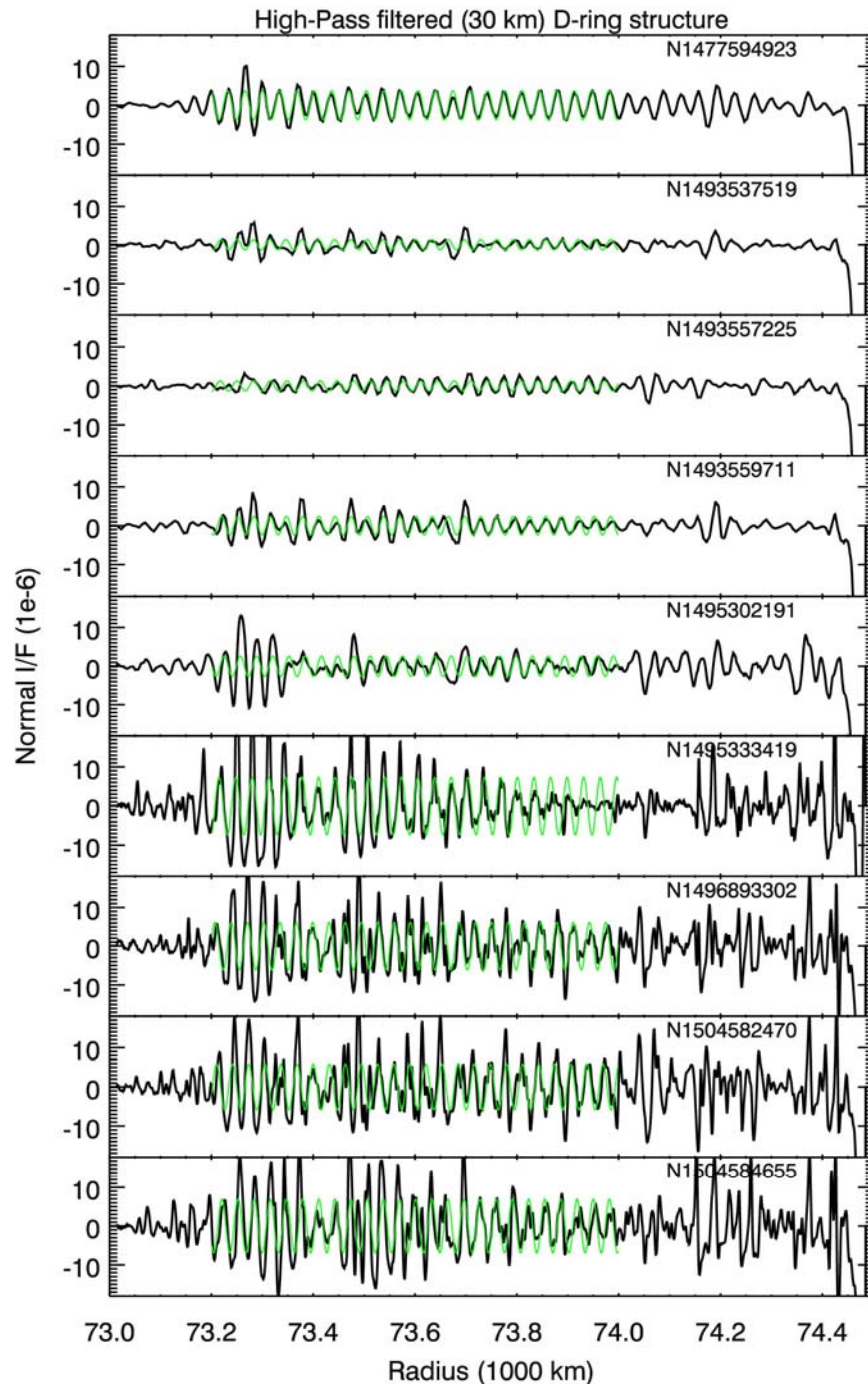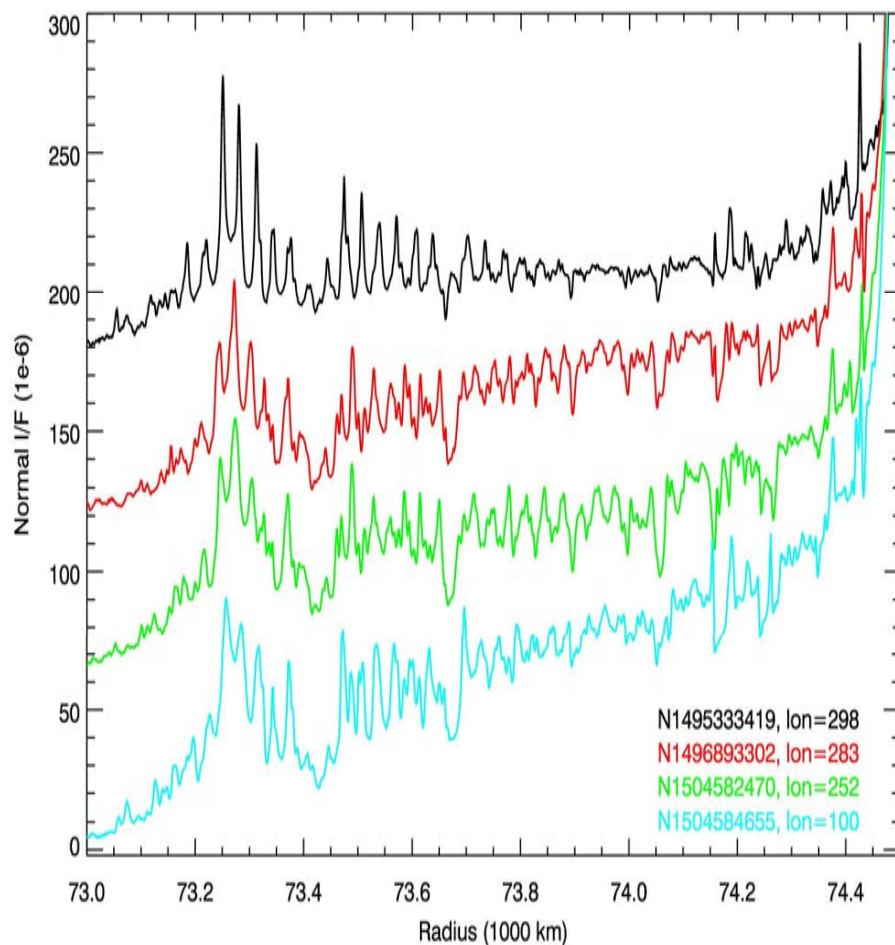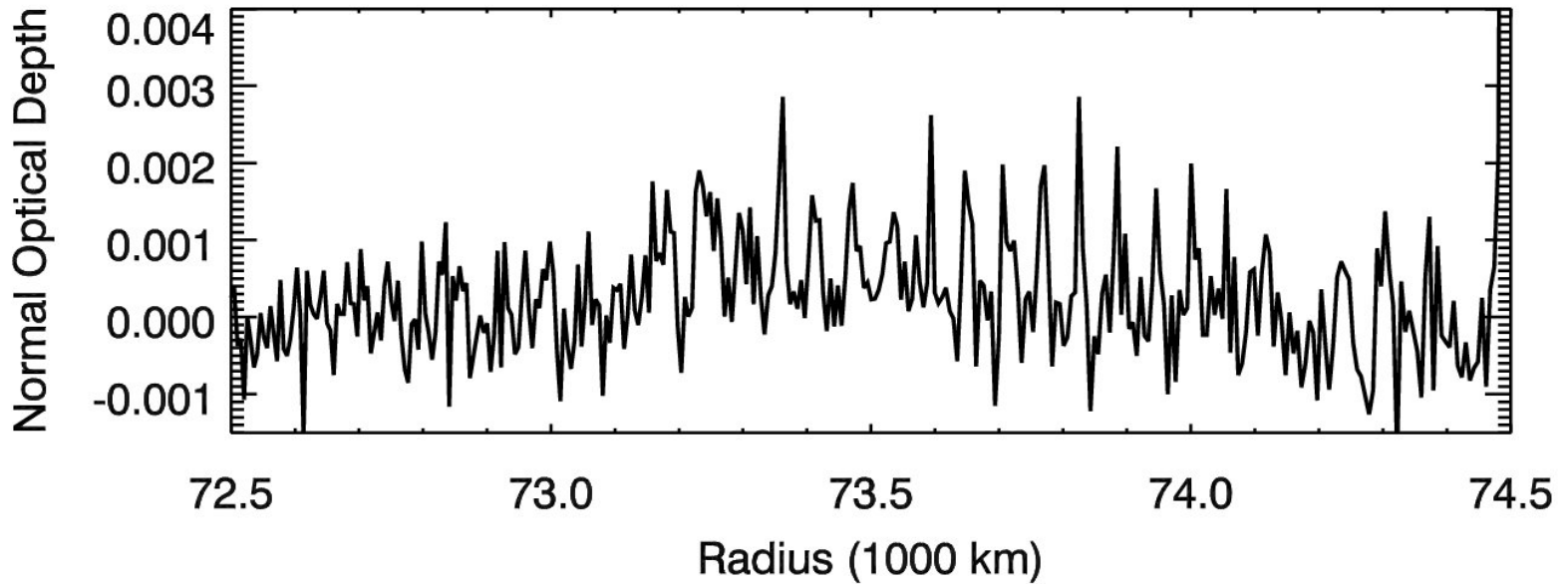
High Resolution views of Outer D-Ring

D68　　　　　　　　　D72　　　　D73

This periodic structure is found in all images with sufficient resolution, with a wavelength of 30-34 km
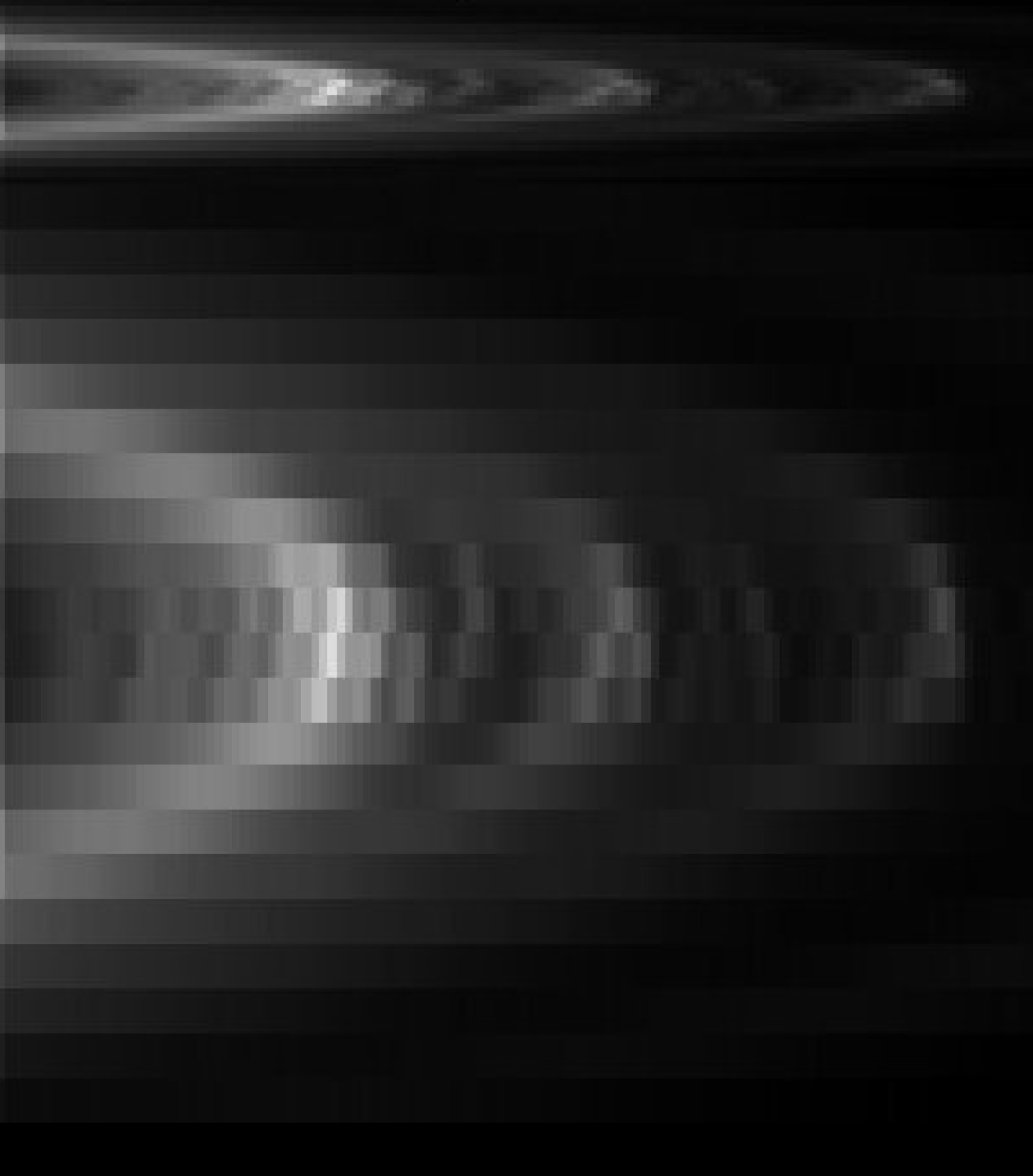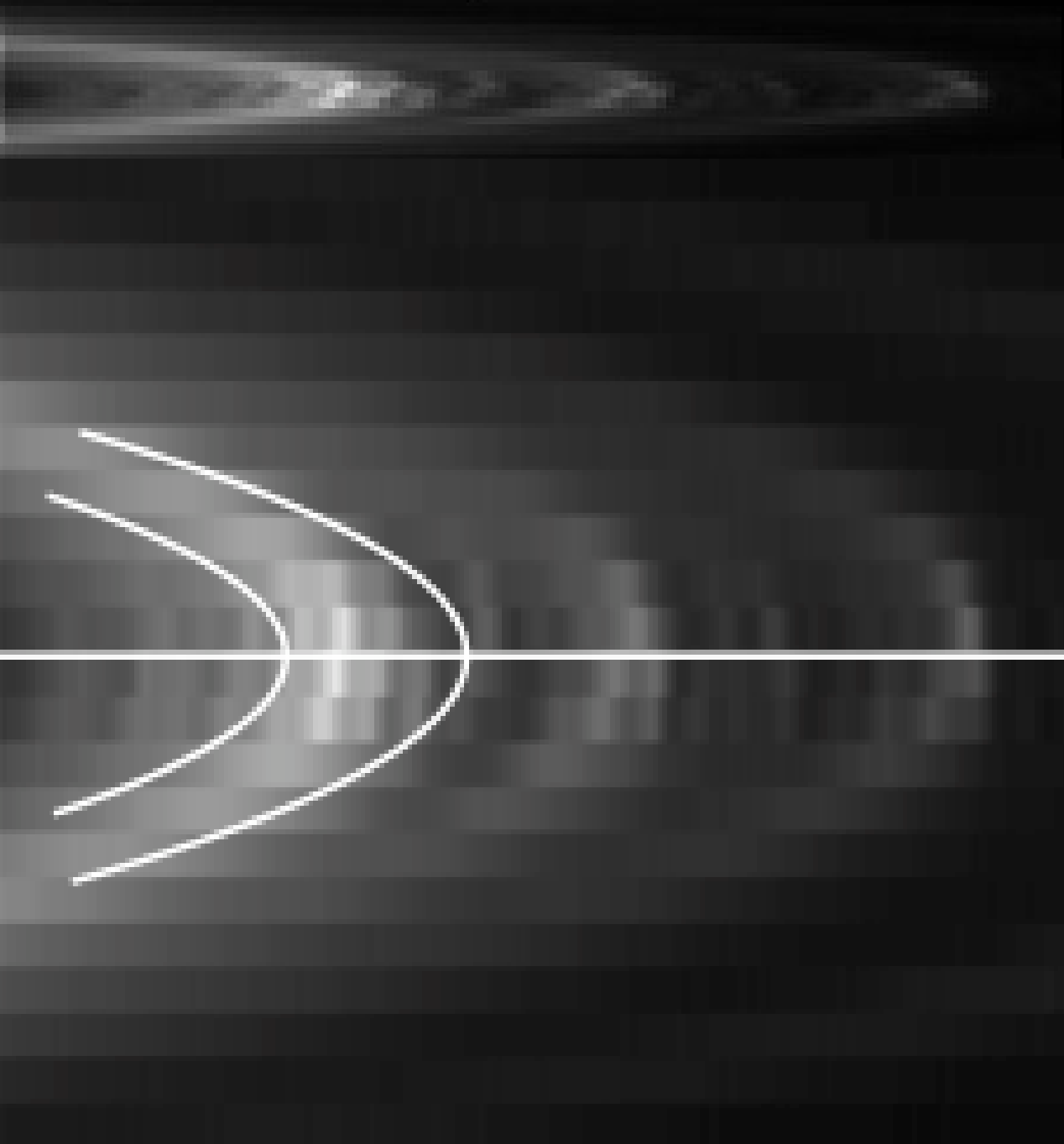

High-Pass filtered (30 km) D-ring structure

In 1995, the D ring occulted a star. This occultation was observed by HST, and showed a periodic variation with a typical wavelength of ~60 km….
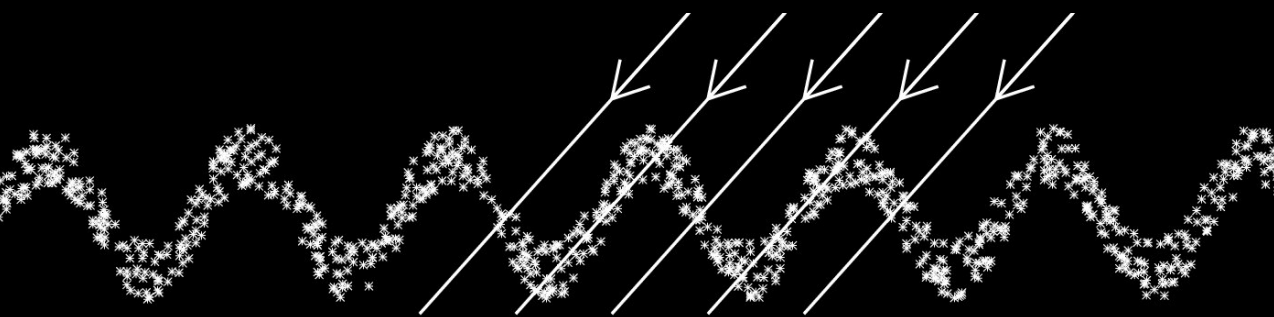

Data from A. Bosh

Images of the outer D ring at high phase with a low opening angle show unusual structures
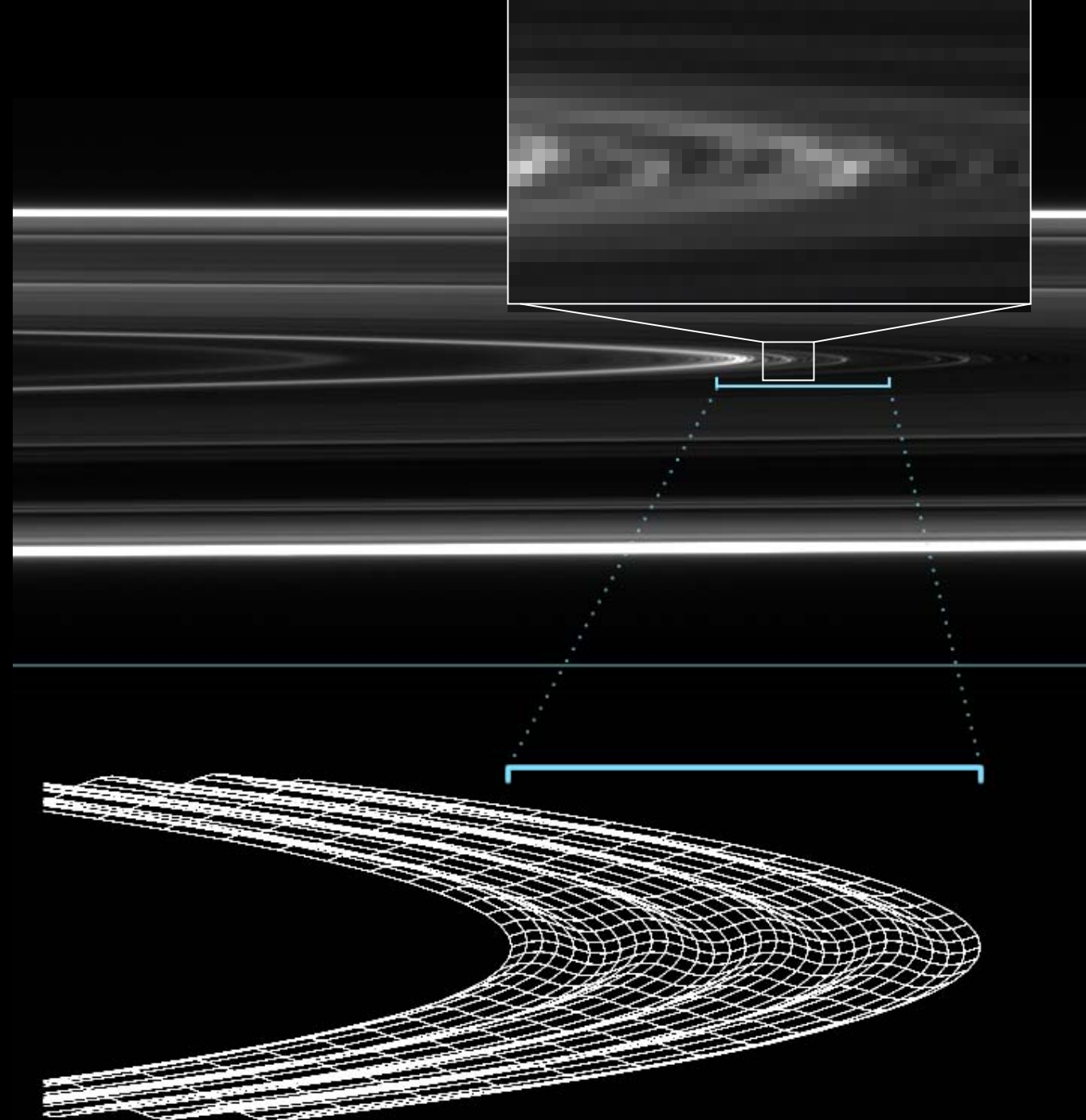
Images of the outer D ring at high phase with a low opening angle show unusual structures

"Contrast Reversals" across the ansa can be most easily explained in terms of vertical corrugations

Vertical corrugations produce brightness variations because of differences in the amount of material along the line of sight.
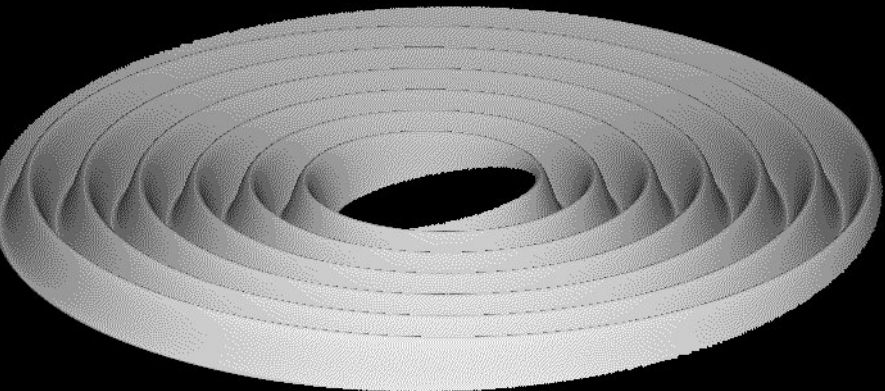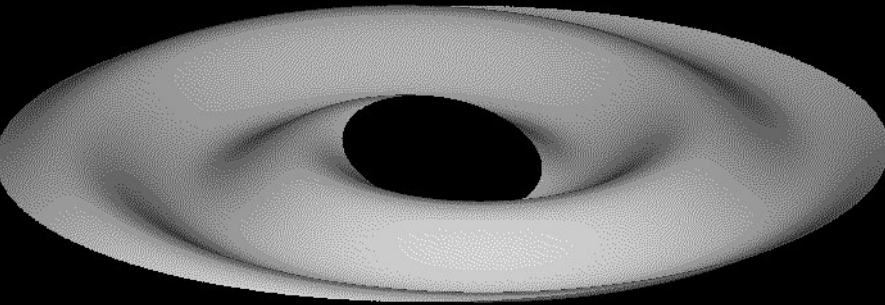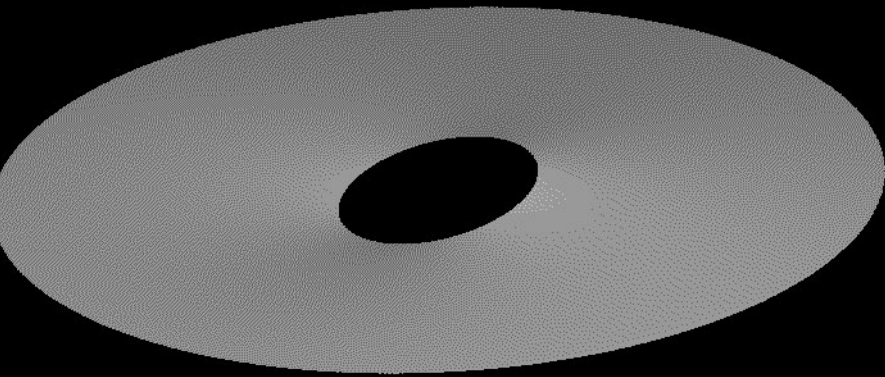
Vertical corrugations naturally explain contrast reversals like we observe.

Similar features found in Jovian Main Ring….

Credit
        M. Showalter

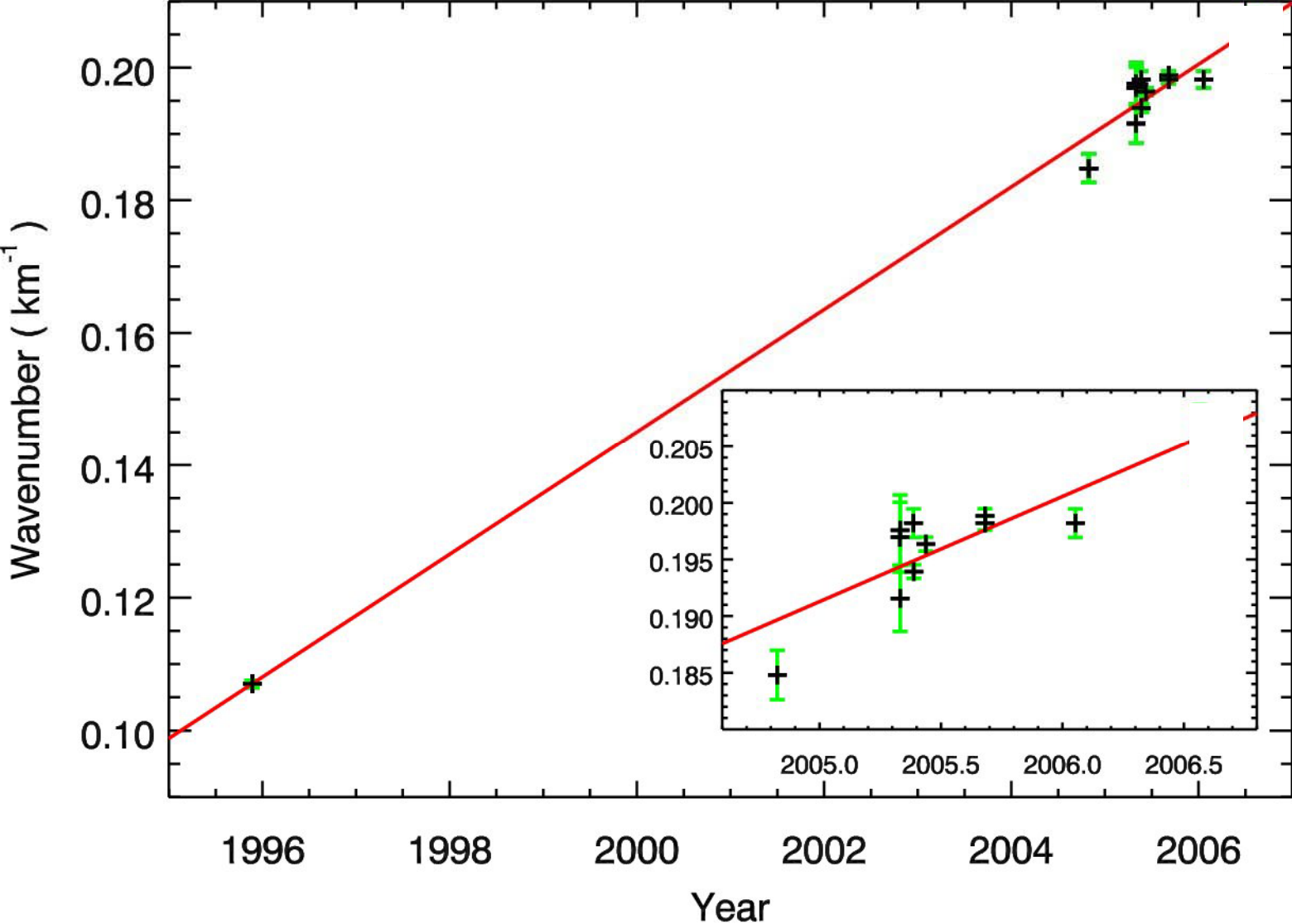# A possible explanation for the time-variable vertical structure.

–

Say that at some time in the past, the outer D ring became inclined relative to Saturn's equator plane. Due to Saturn's oblateness, the nodes of the particle orbits (where the orbit crosses Saturn's equator plane) will begin to regress.

The rate of nodal regression depends on the orbit's semi-major axis, so the inclined sheet will begin to twist up, forming an increasingly tight spiral.

Eventually, we obtain a vertically corrugated ring, where the wavelength of the corrugation steadily decreases over time.

This model predicts radial wavenumber $k=2\pi/\lambda$ should increase linearly over time, and we can indeed fit a linear trend to the Cassini and HST data….

This model predicts radial wavenumber k=2π/λ should increase linearly over time, and we can indeed fit a linear trend to the Cassini and HST data….

New data points confirm this trend!
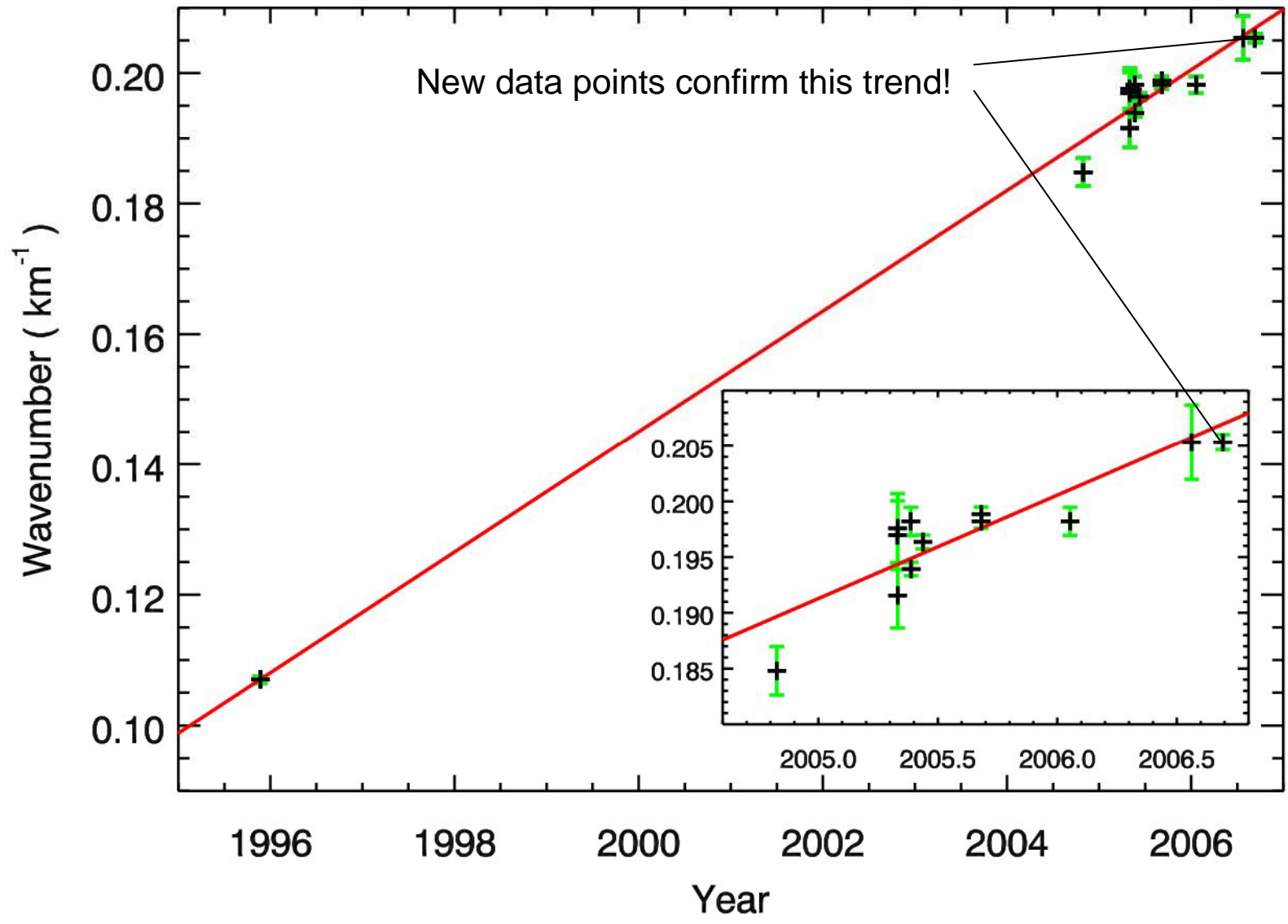
The observed data indicates that dk/dt = 2.5 *10^{-5} km $^{-1}$ /day

The predicted winding rate due to differential precession of the nodes is

$$\frac{dk}{dt} = \left| \frac{d(n - \nu)}{da} \right| \approx 2.4 * 10^{-5} / km / day$$

We can therefore attribute this change over time as the result of differential nodal regression of an initially inclined ring

Note winding rate is very sensitive to high order gravity harmonics like J_{14}

Extrapolating the observed trend back in time, we find k=0 in the spring of 1984.
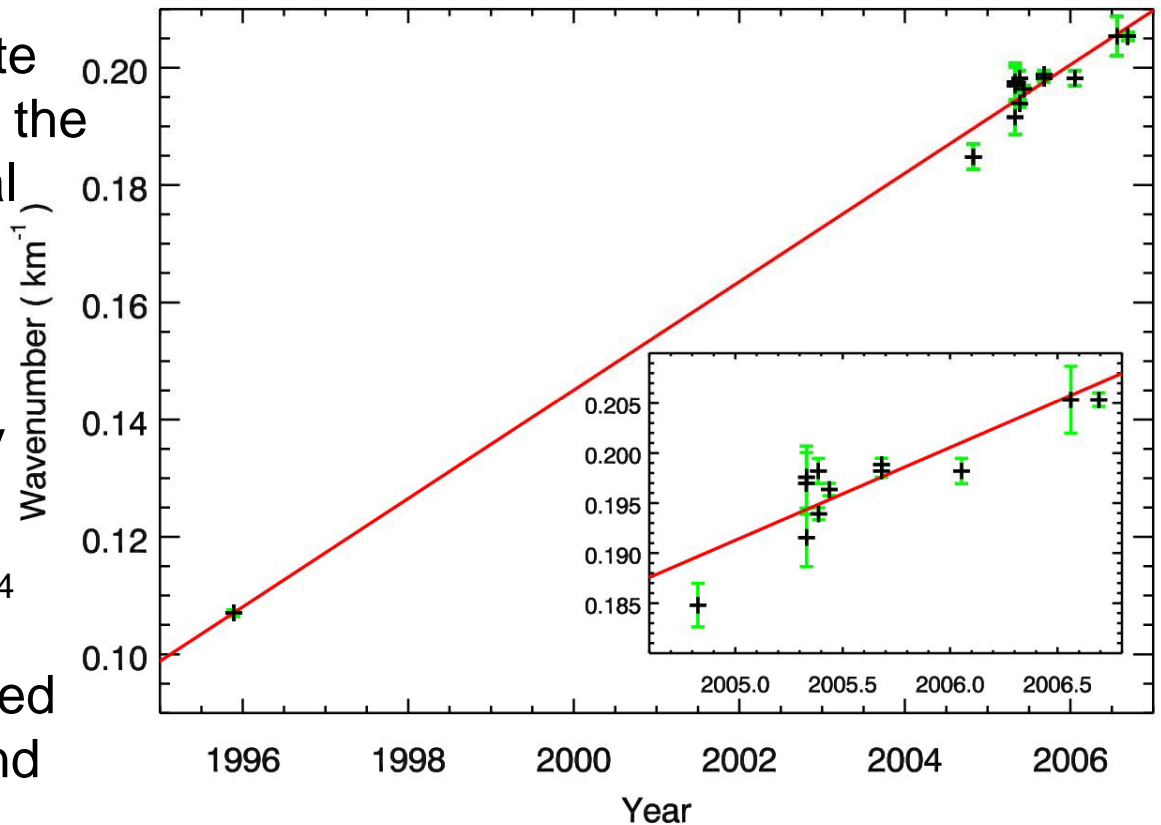
What happened to the D ring in 1984?

An ice-rich body a few meters across would have sufficient momentum to produce the observed inclinations….

Questions?