The Forces that Sculpt Saturn's Rings….

CHARM telecon 8-31-2010

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Saturn's rings are a truly alien environment, consisting of many small bodies in orbit around the planet.

Artist's conception of the rings

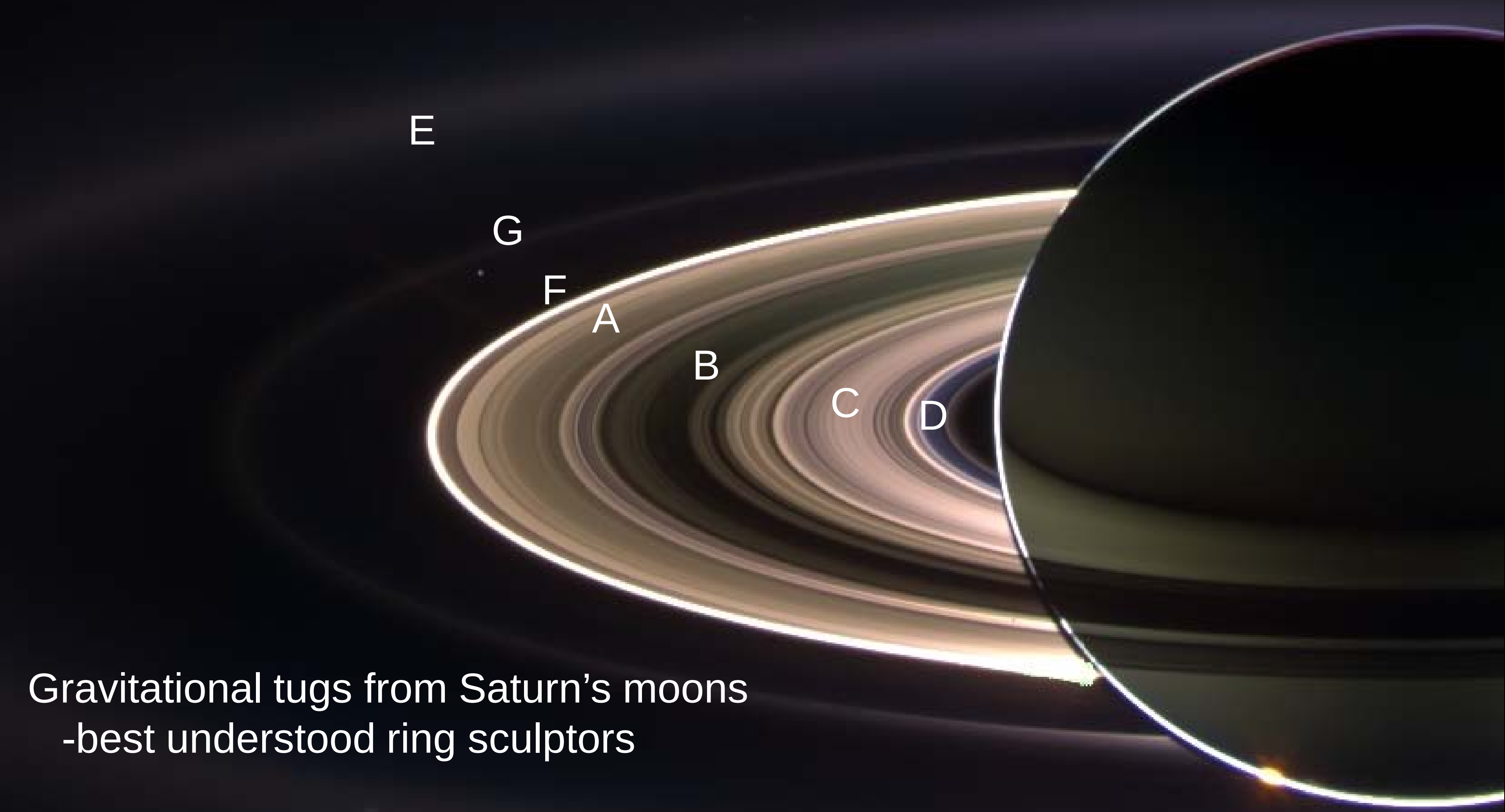
These particles aren't distributed randomly in space, but instead form complex structures.

How do so many ring particles get so organized?

Under the right conditions, the interactions between ring particles alone can produce coherent structures (such as the so-called self-gravity wakes in the A ring).

Also, outside forces can push ring particles around and sculpt the rings in various ways.

Overview of the rings and their sculptors



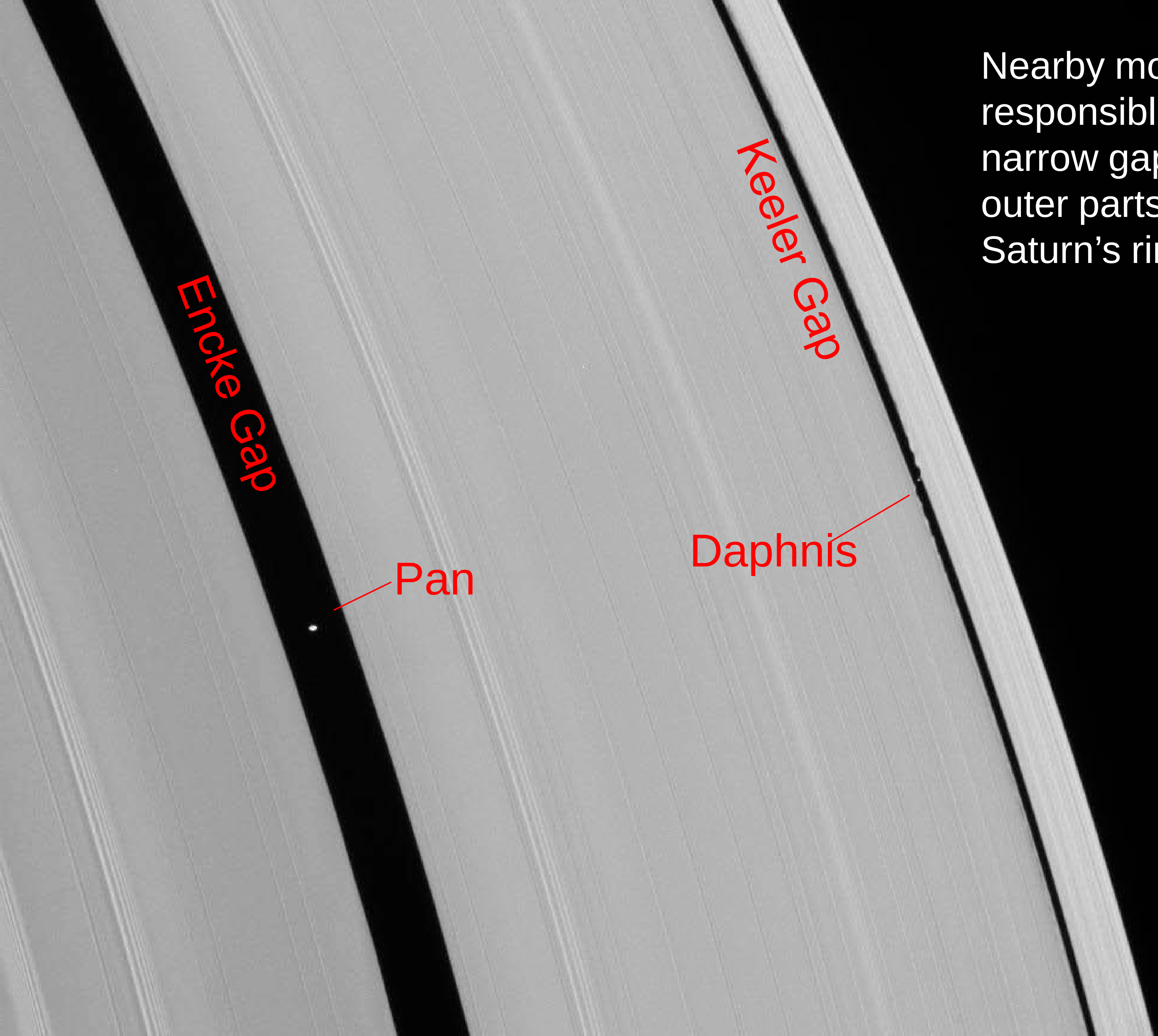
Gravitational tugs from Saturn’s moons
- best understood ring sculptors

Other things that could be sculpting the rings
- Gravity of Saturn’s massive rings?
- Saturn’s magnetosphere?
- Sunlight?

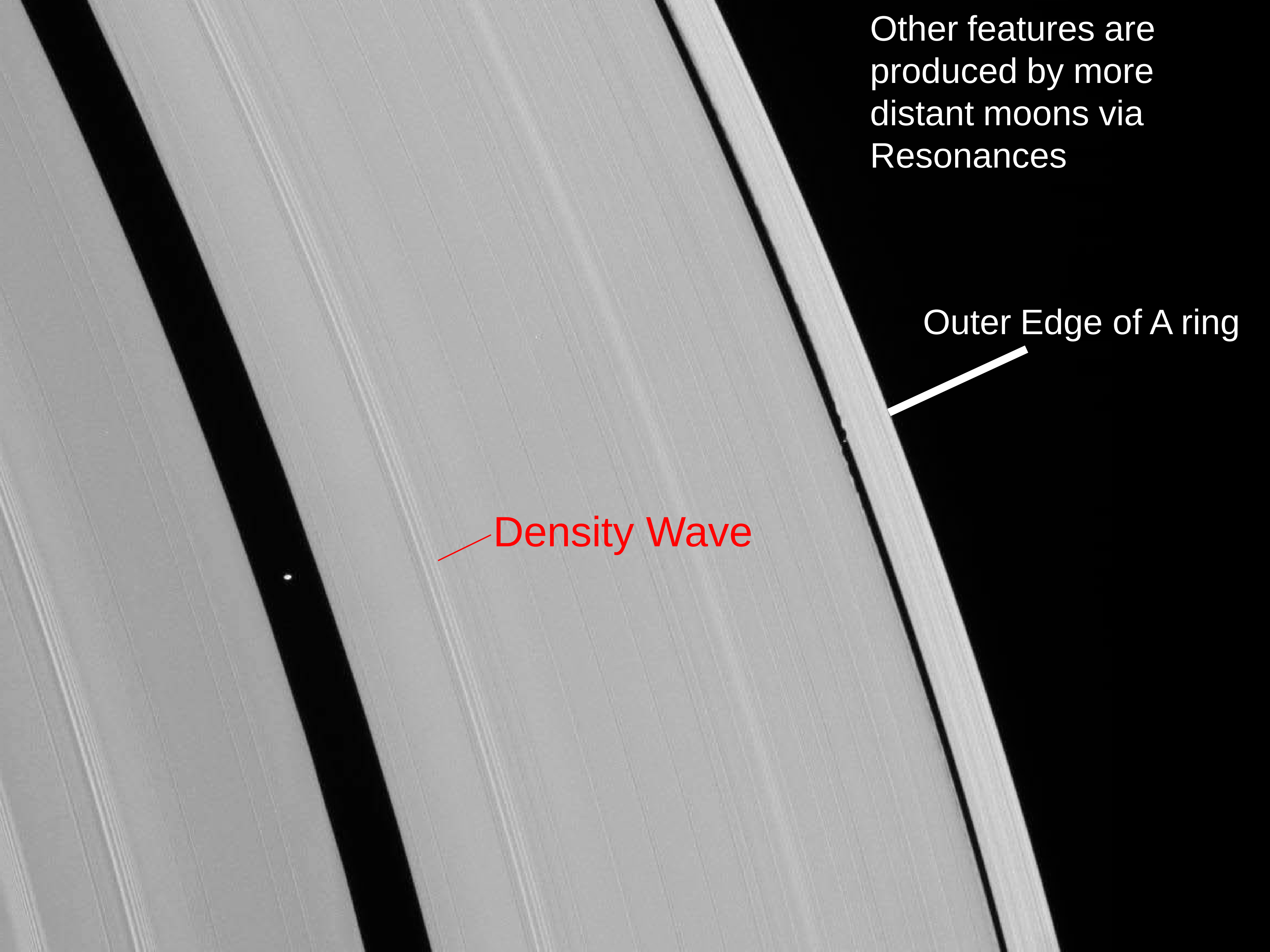
The gravitational tugs from Saturn’s moons are responsible for a wide variety of structures in Saturn’s rings:

- Sharp edges
- Density variations
- Vertical Warps
- Arcs

The moons’ effects are most important when the moons are near the rings or at various resonances…

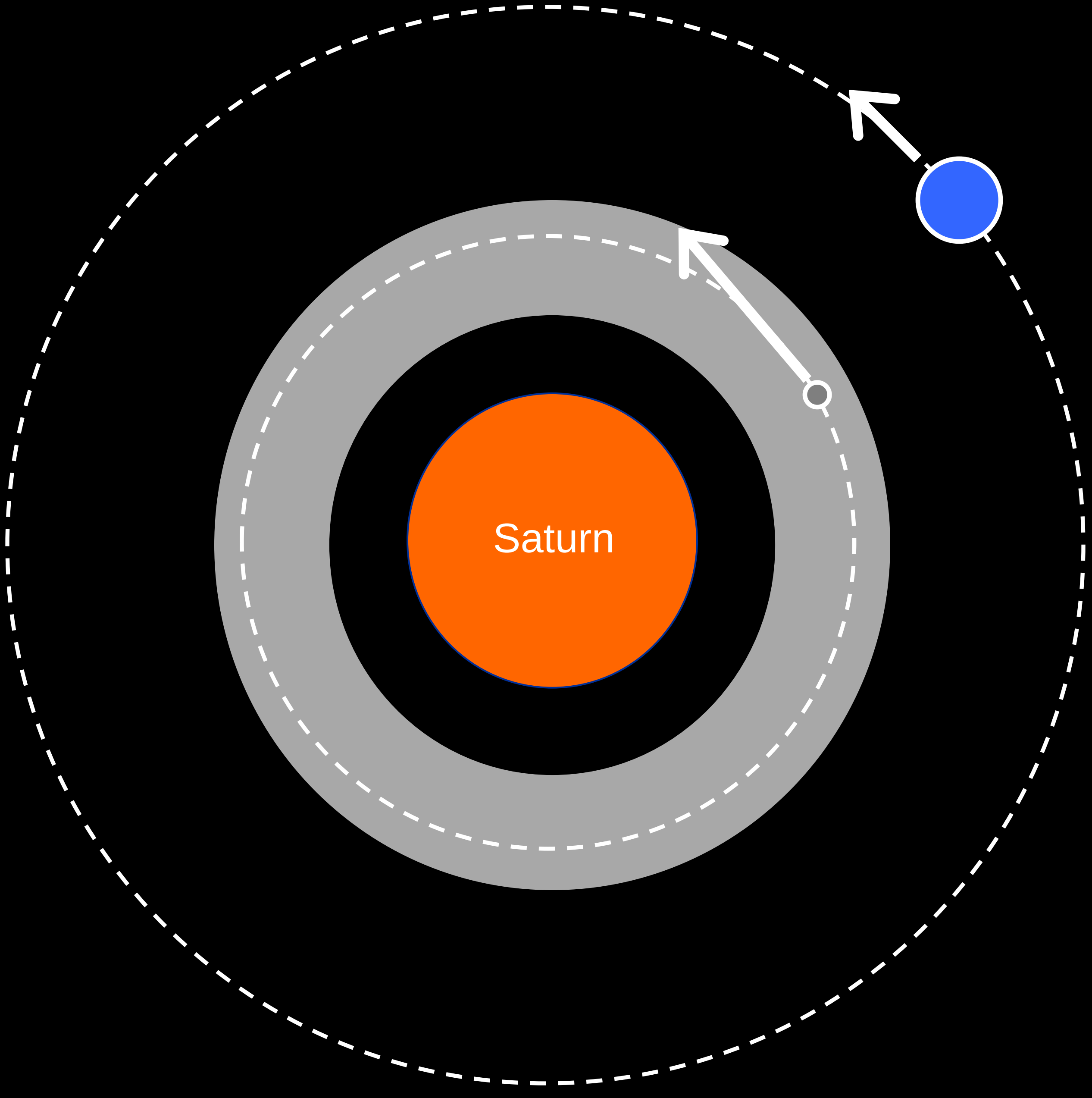


Nearby moons are responsible for two narrow gaps in the outer parts of Saturn’s rings…


Other features are produced by more distant moons via Resonances
Outer Edge of A ring
Density Wave

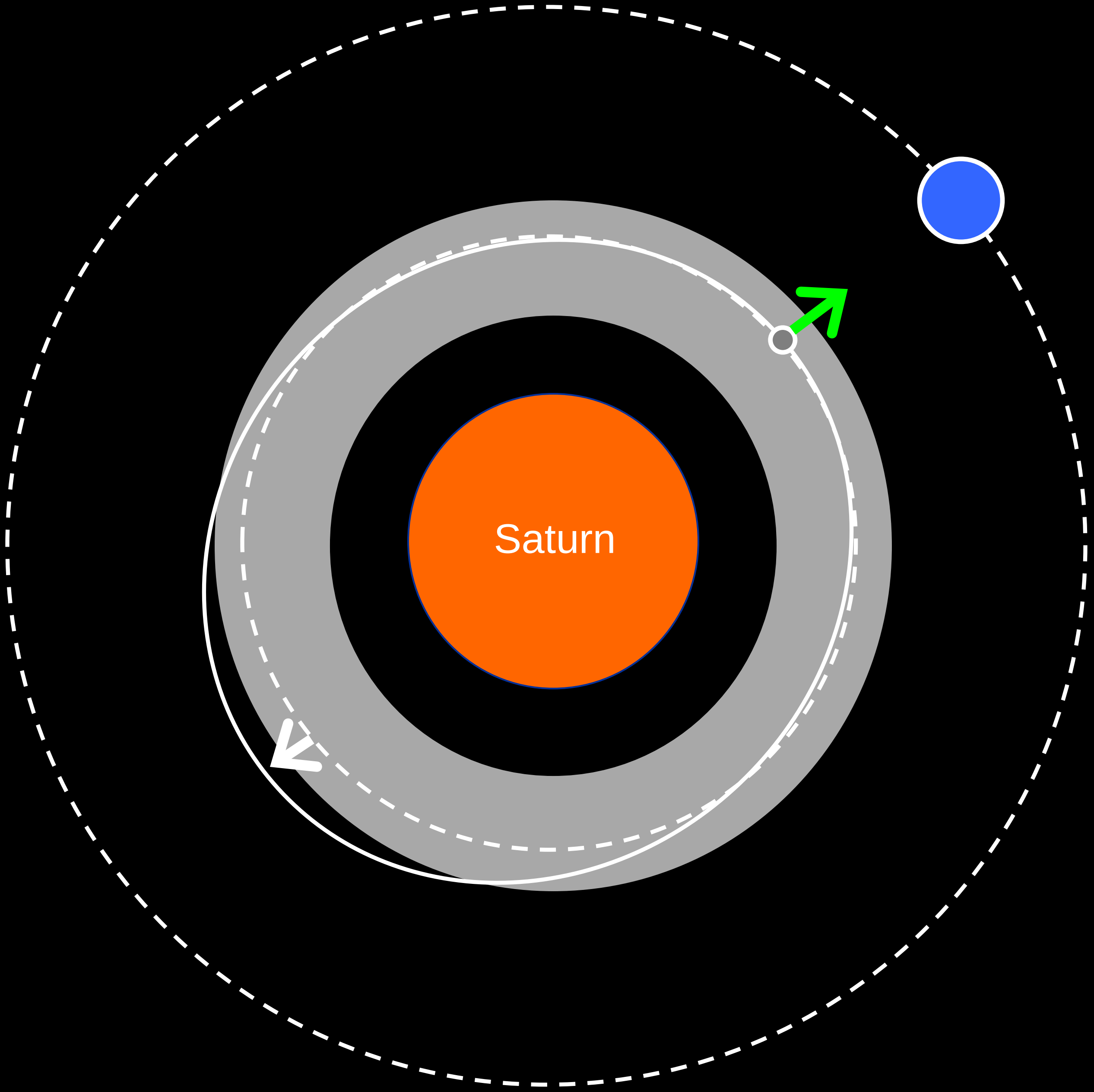
How do resonances work?

Particles in the rings travel faster than the moons, simply because they are closer to the planet.



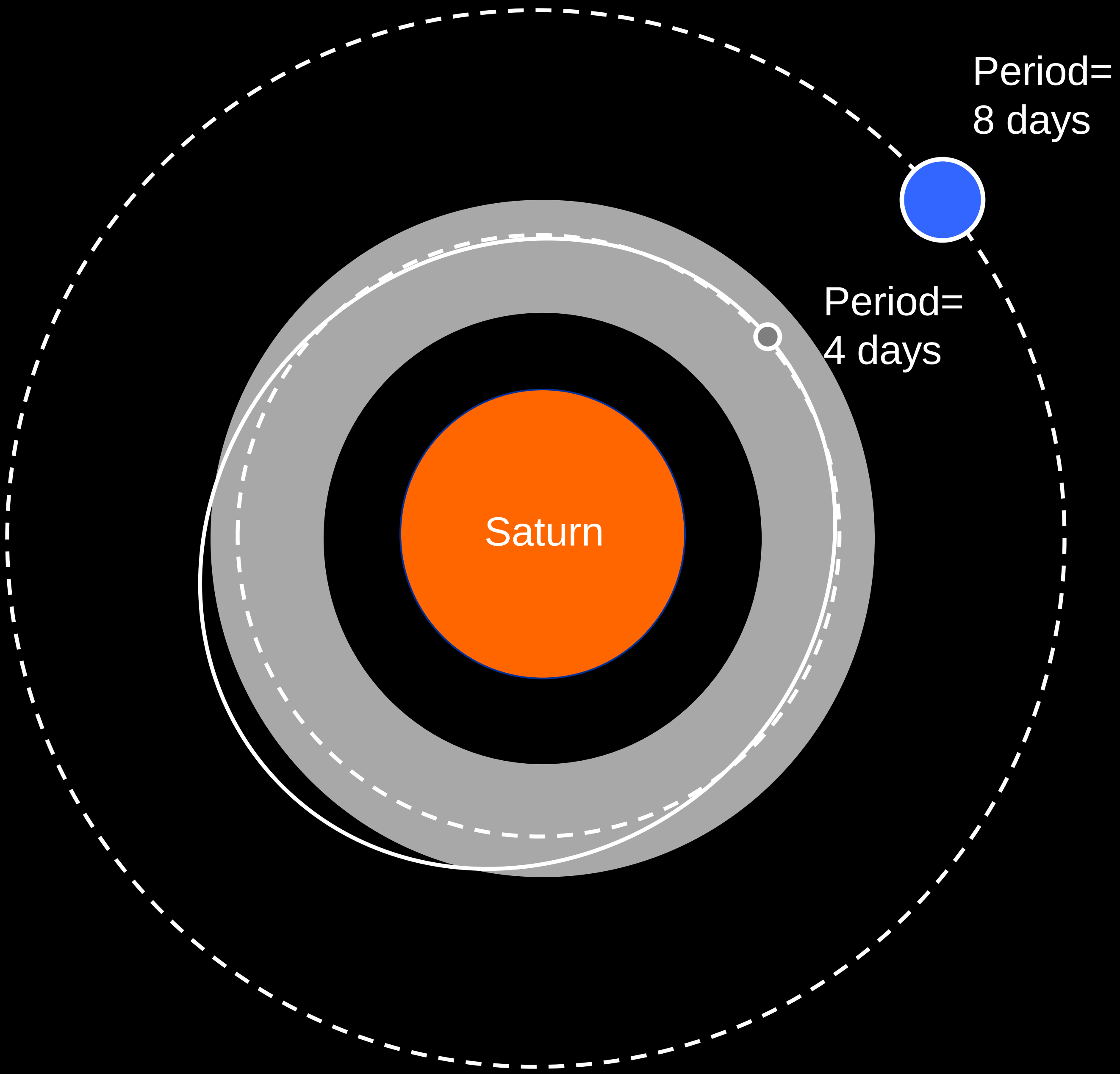
When the particle passes the moon, it feels a little extra tug from the moon's gravity which changes its orbit slightly (exaggerated here).

In most cases, the particle is tugged in different directions each time it passes the moon, so on average these tugs don't do much….

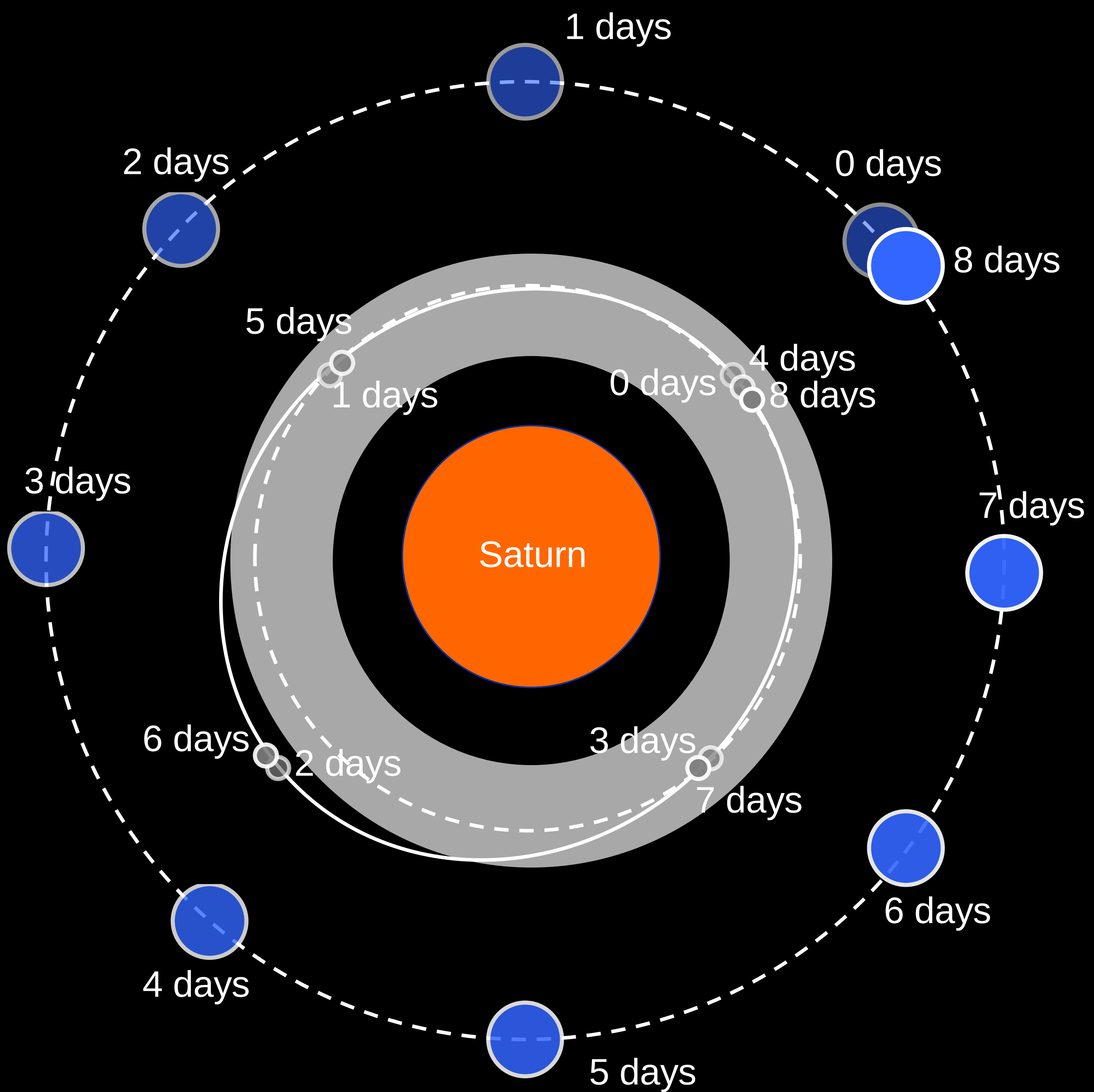


However, if the particle's orbital period is a whole number ratio times the moon's orbital period, the perturbations to the particle's orbit can grow and become significant.

For example, say the particle's orbital period was ½ the moon's orbital period….



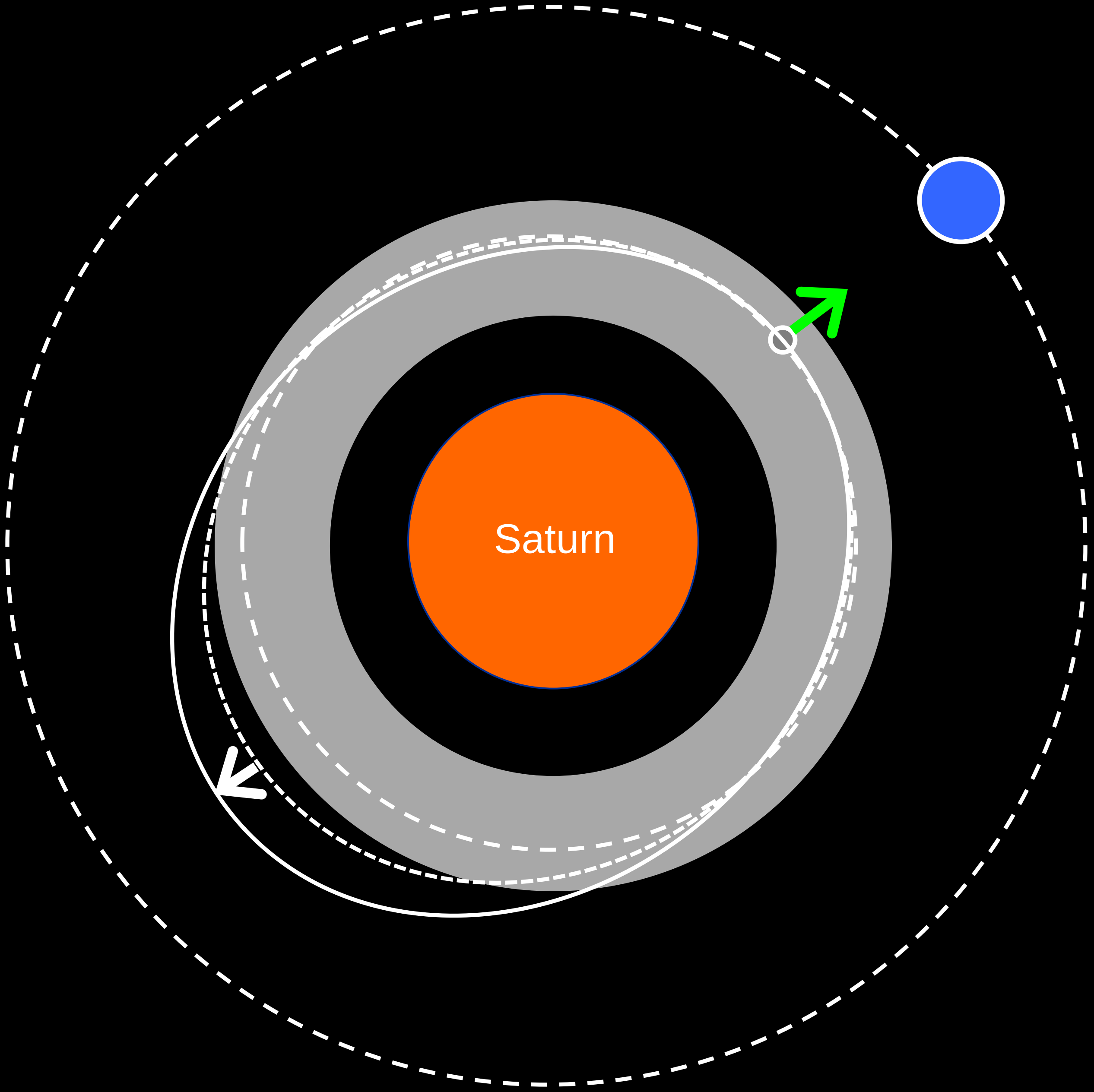
In this case, the particle again passes the moon when both the moon and the particle are in the same configuration as they were during the first encounter



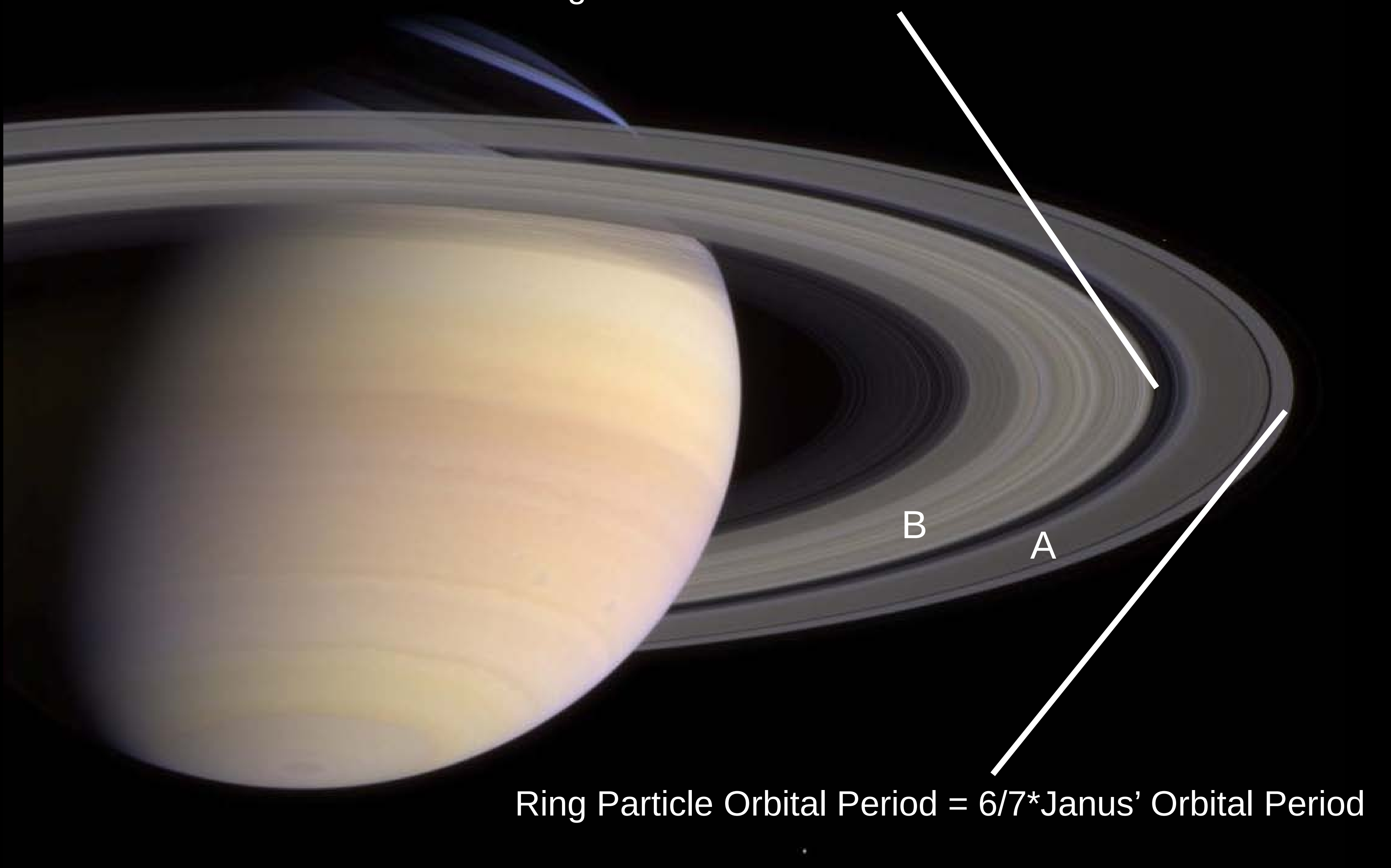
Thus the orbit of the particle will be distorted in the same way as it was during the previous encounter.

These small perturbations can then build up and push the particle orbits around significantly.

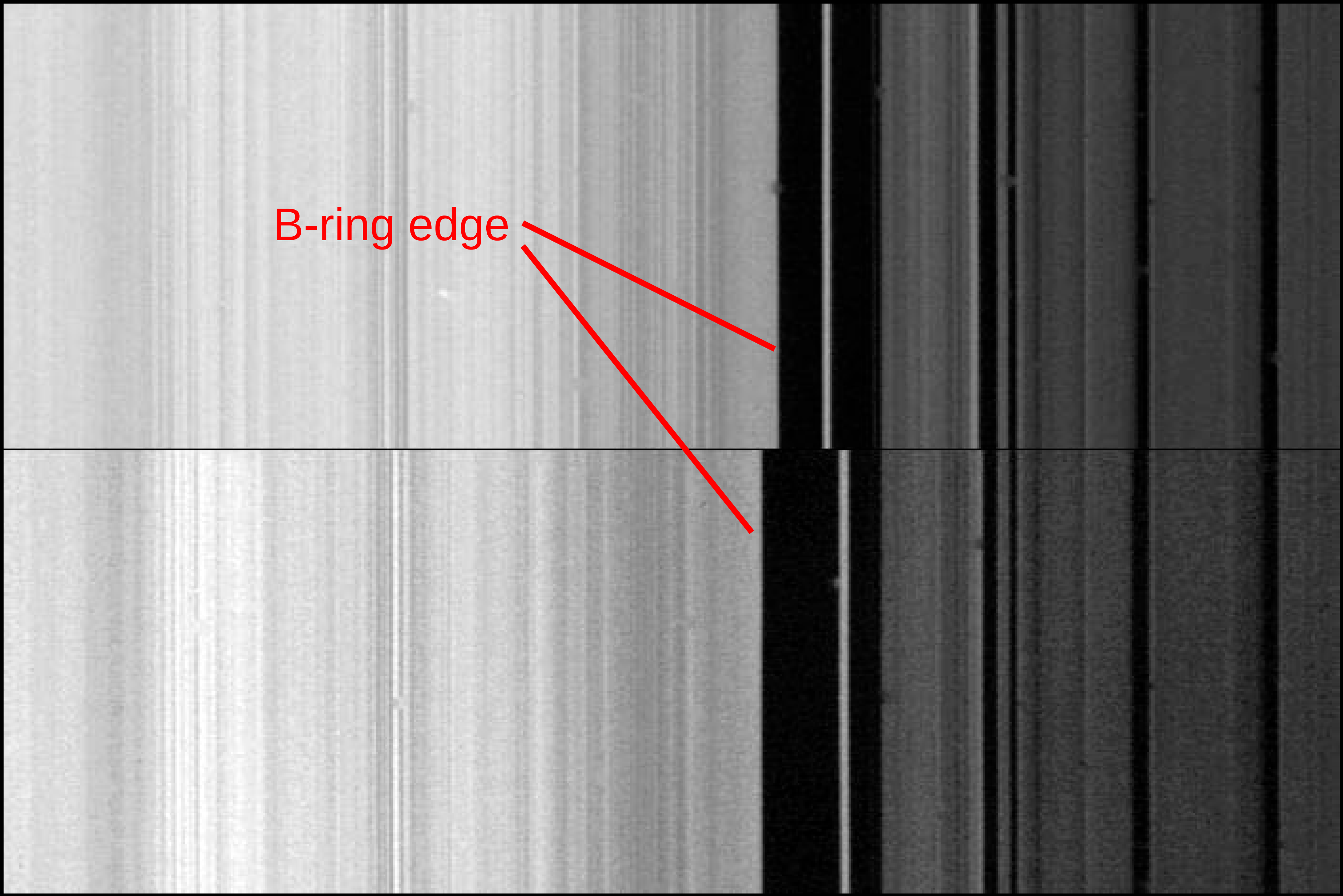
Resonances are locations where these phenomena can occur.



The outer edges of the A and B rings both occur at strong resonances

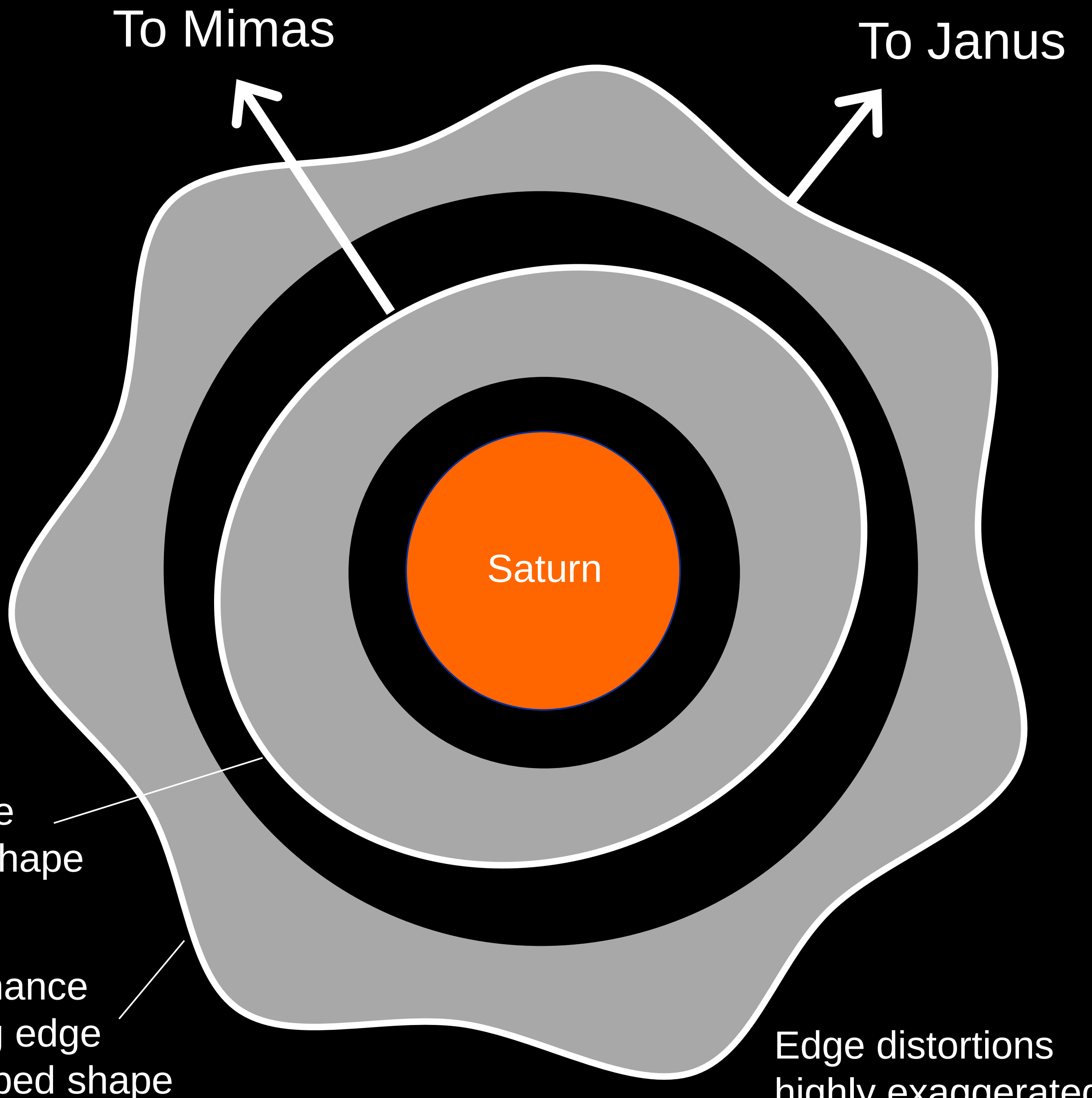


The perturbations from the moons cause the edges to move in and out…



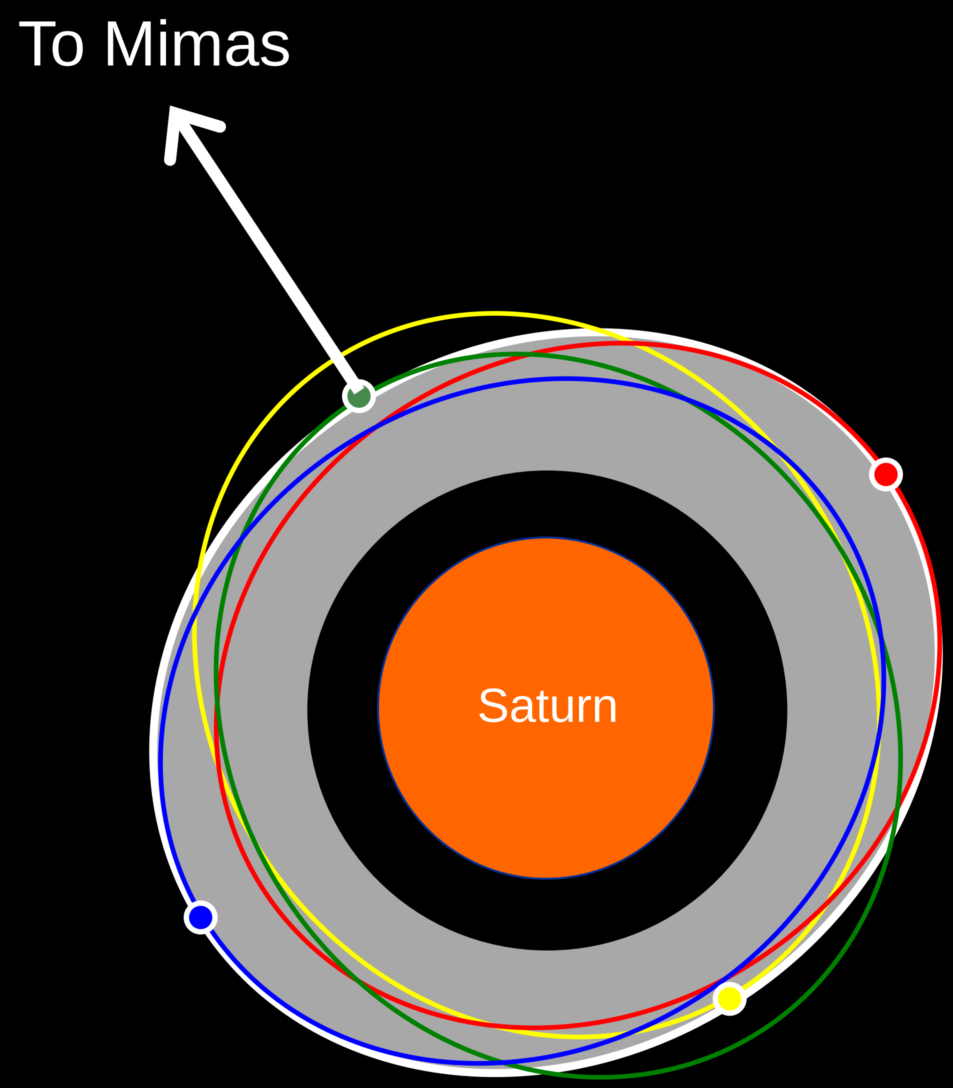
Ideally, the perturbed edges should have a shape set by the orbital period ratio and should maintain a fixed orientation relative to the perturbing moon

In reality things are more complicated



Note that while the edges have more than one lobes, individual particles on the edge are following simple elliptical paths.

The perturbations from the moon synchronize these radial motions to produce the two-lobed patterns.



Edge distortions highly exaggerated

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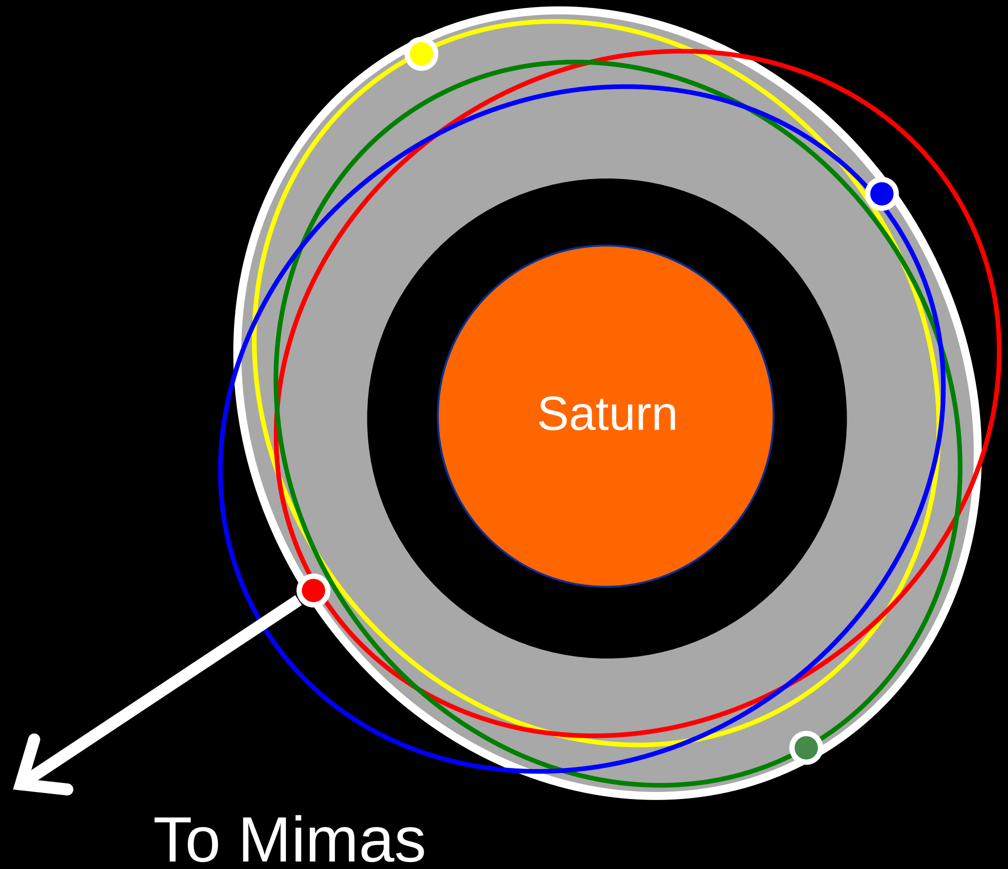
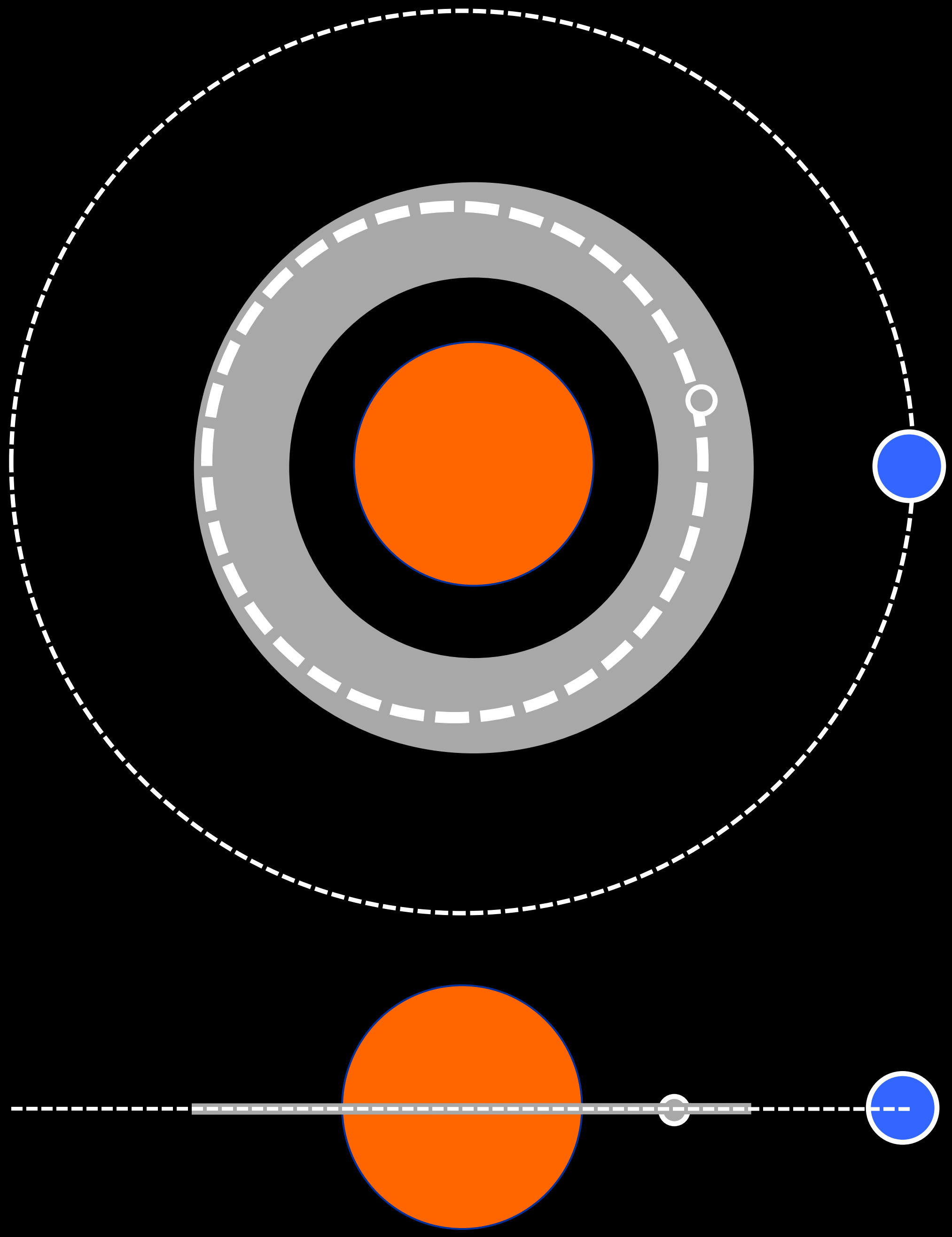


Edge distortions highly exaggerated

These perturbed edges occur at a particular type of resonance known as a Lindblad Resonance.

These resonances occur where the in-and-out motion of the ring particle is a whole number ratio times the moon’s orbital period.

Besides producing sharp edges, these radial perturbatons can produce variations in the local surface density known as density waves.

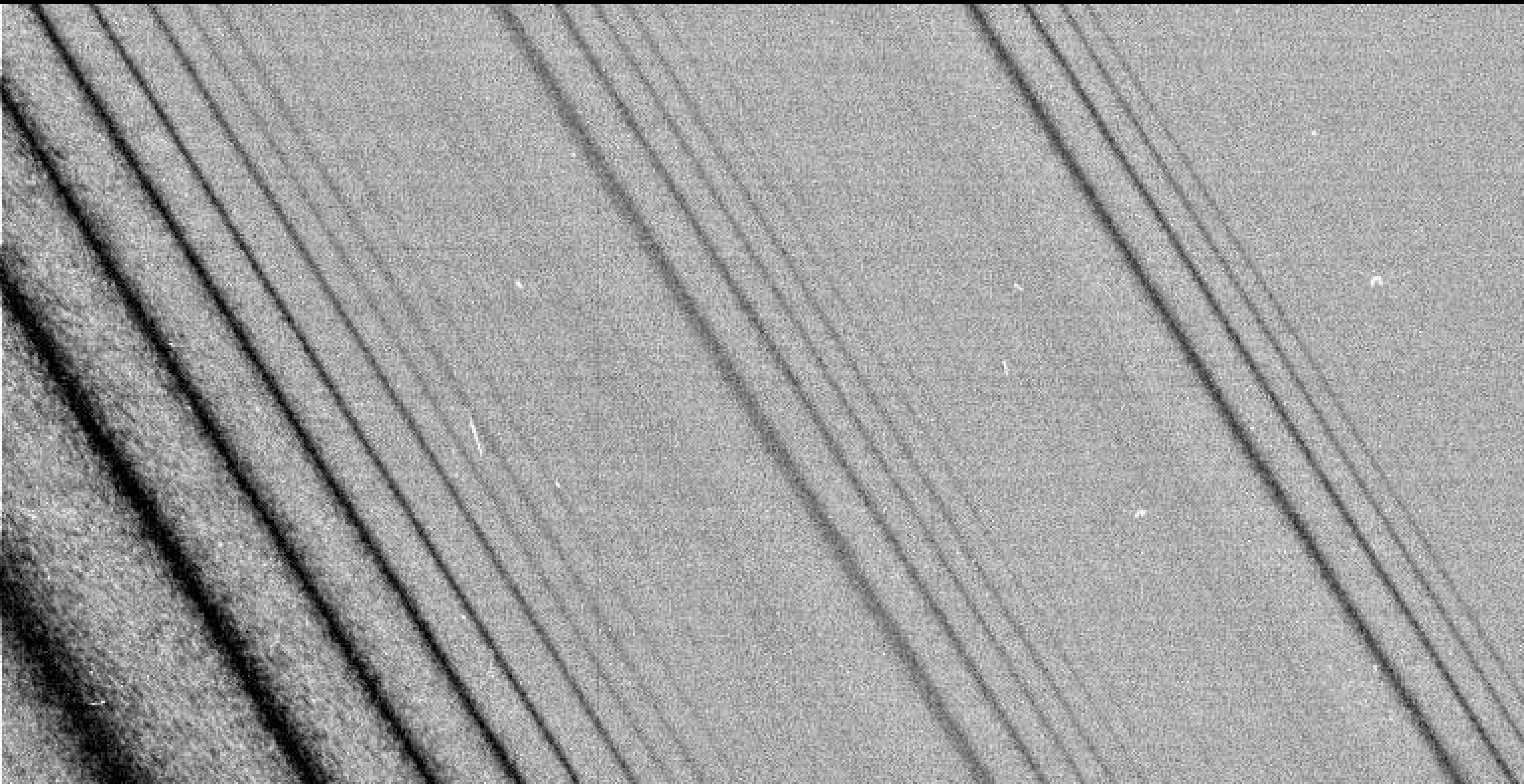


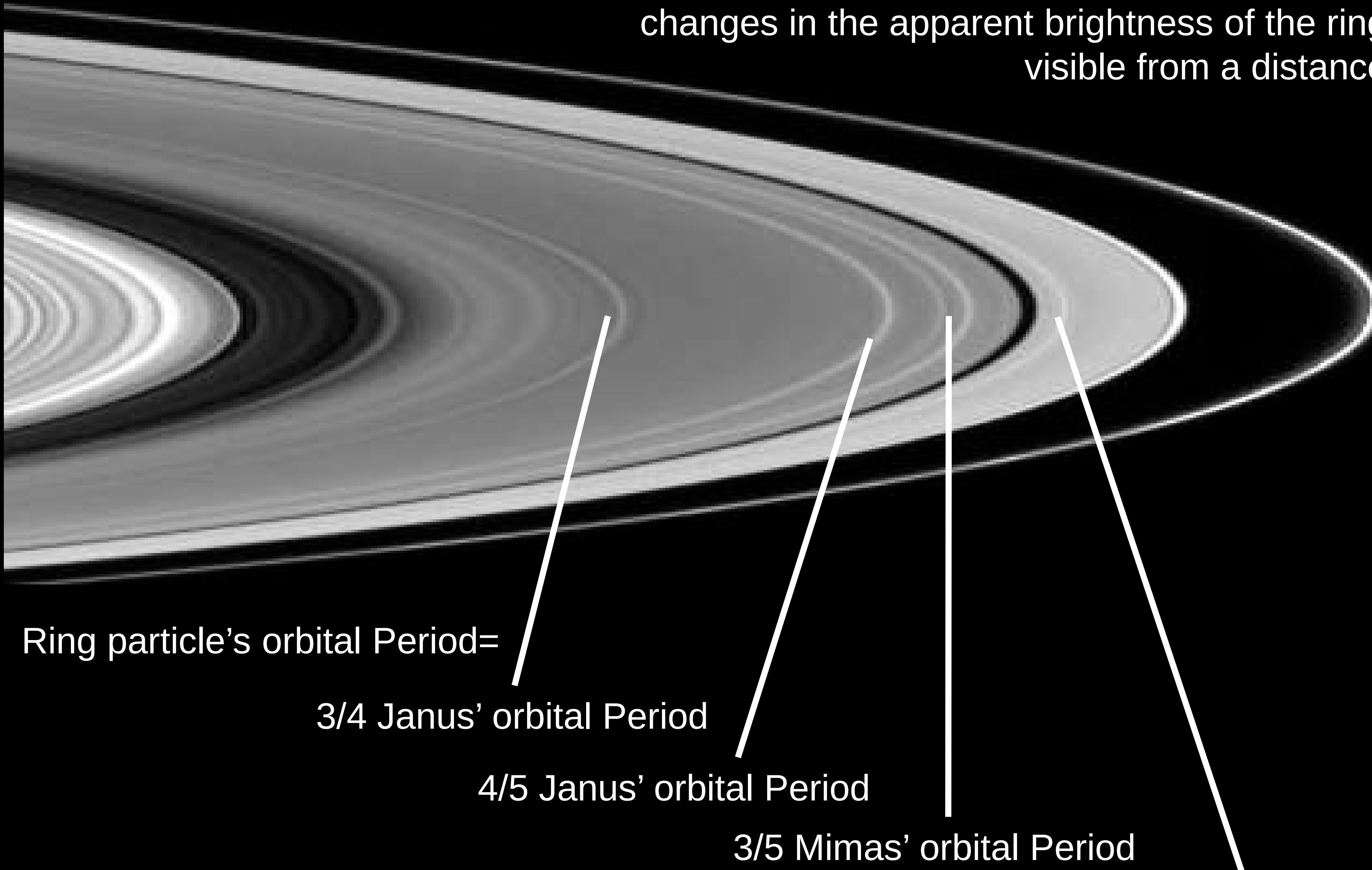
Different resonances produce different waves…

Ring Particle
Orbital Period=
5/6 Janus'
Orbital Period

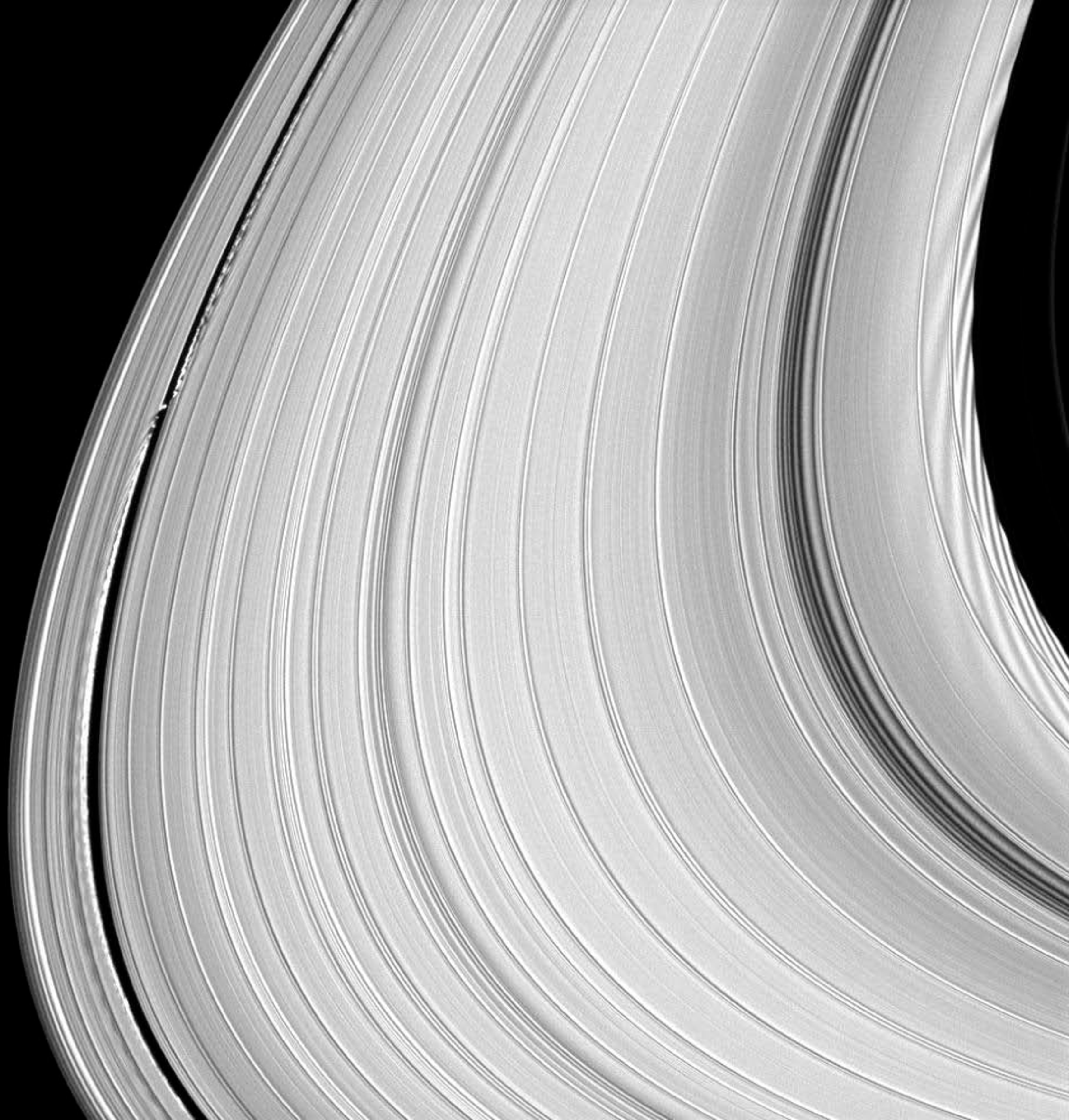
Ring Particle
Orbital Period=
12/13 Pandora's
Orbital Period

Ring Particle
Orbital Period=
18/19 Prometheus'
Orbital Period



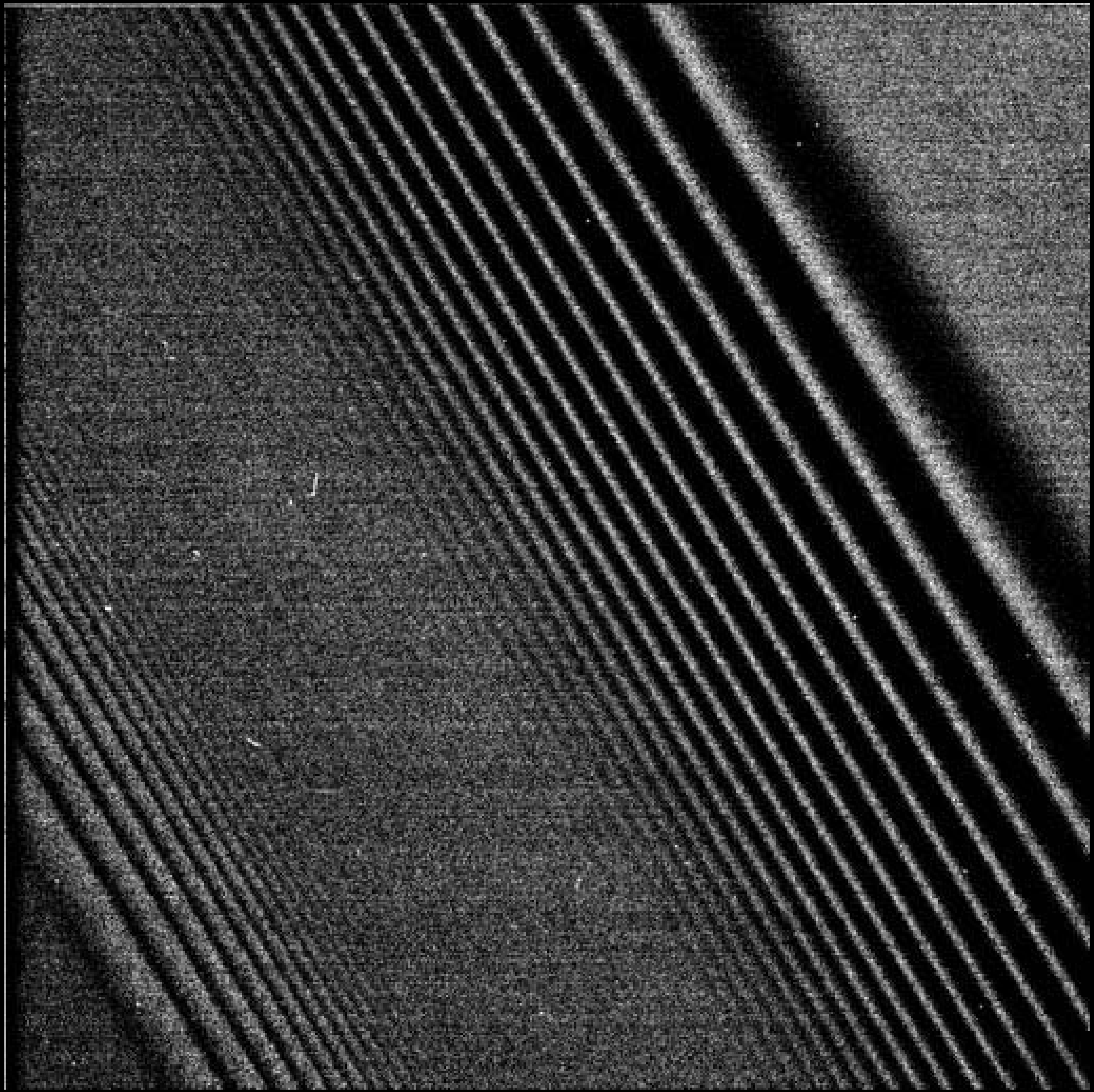

These localized disturbances can even lead to changes in the apparent brightness of the ring visible from a distance
Ring particle’s orbital Period=
3/4 Janus’ orbital Period
4/5 Janus’ orbital Period
3/5 Mimas’ orbital Period
5/6 Janus’ orbital Period

Many of the "grooves" seen here are due to density waves generated at resonances with various moons



However, not all moon-related disturbances are density waves produced by Lindblad Resonances.

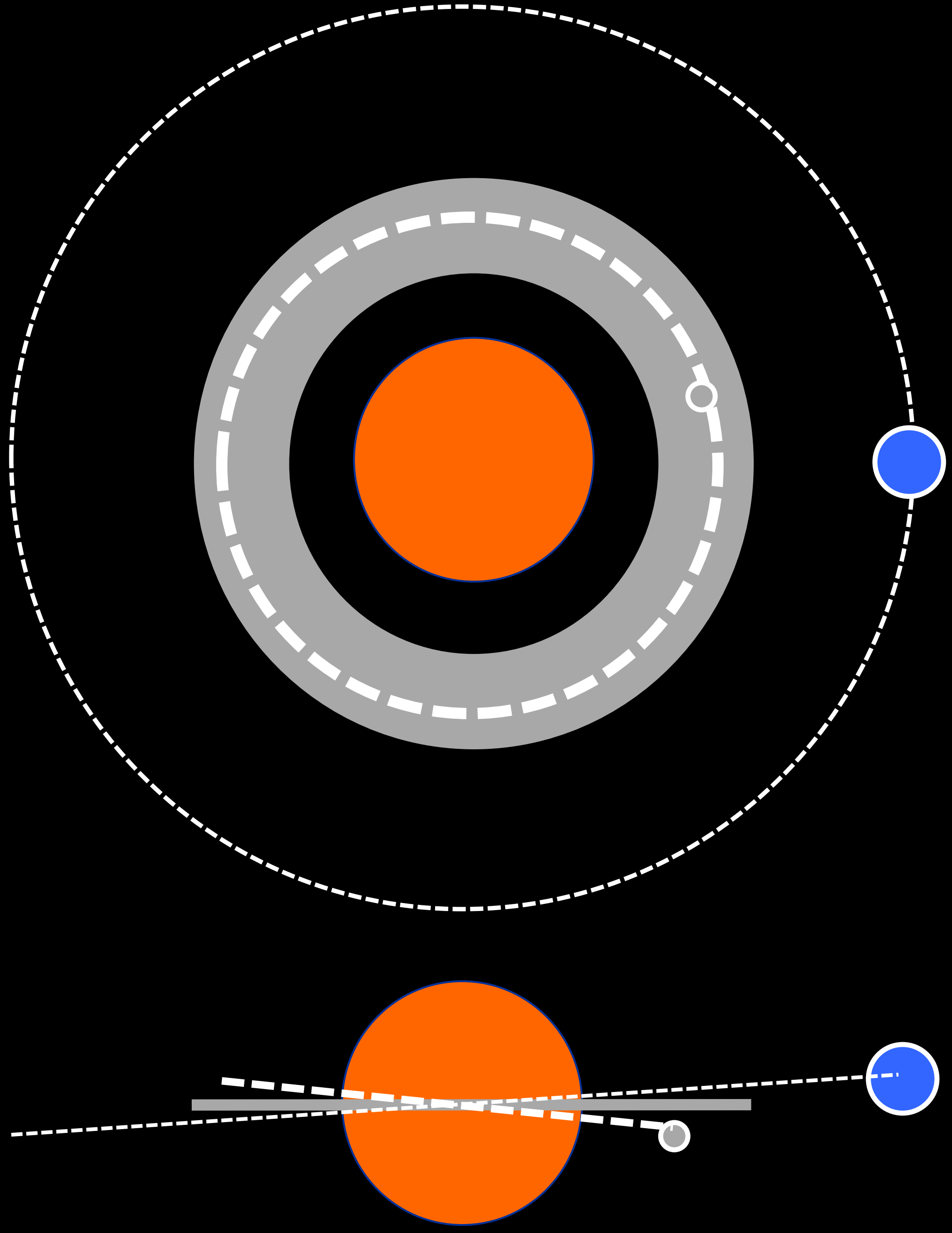
Other features, like the wave seen here are produced by other types of resonances

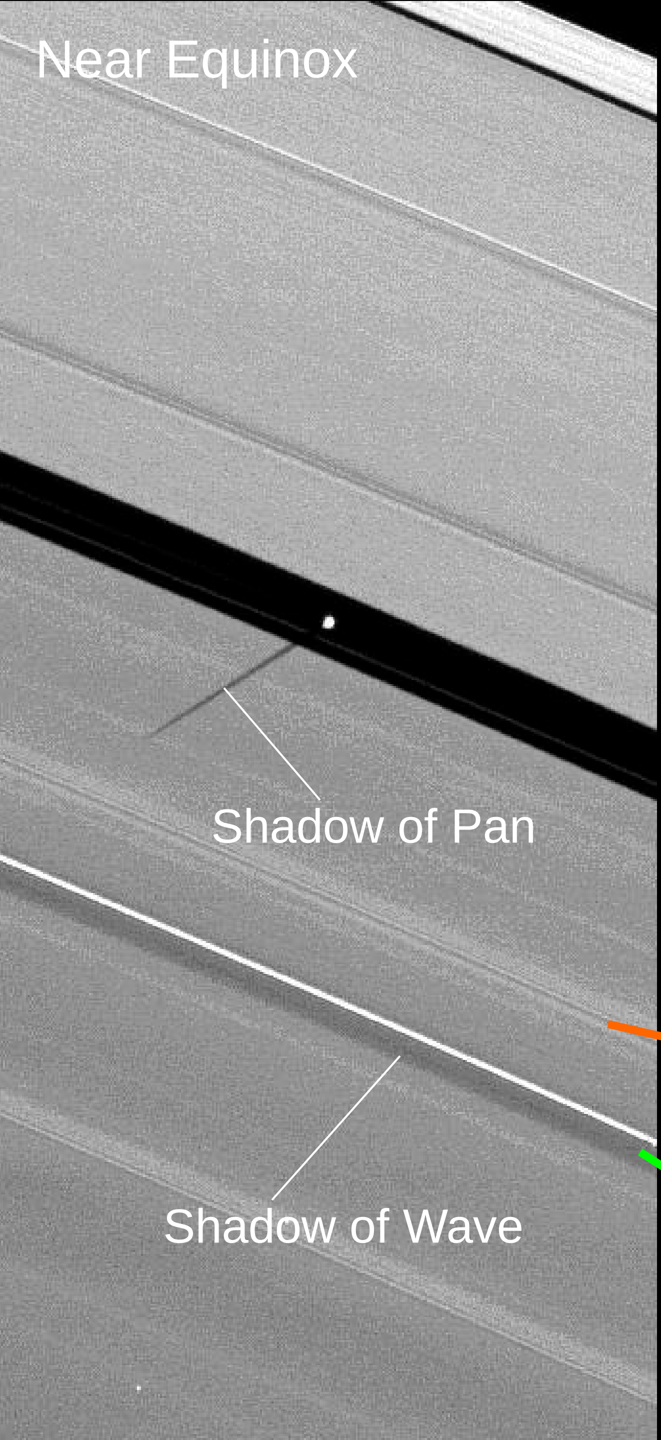


Other types of resonances arise if the moon is not on a perfectly circular orbit in the same plane as the rings.

For example, if the orbit of the moon is inclined, the moon's gravity can pull ring particles up and down.

When the period of the particle's vertical motion is a whole number ratio of the moon's orbital period, there can be a Vertical Resonance.



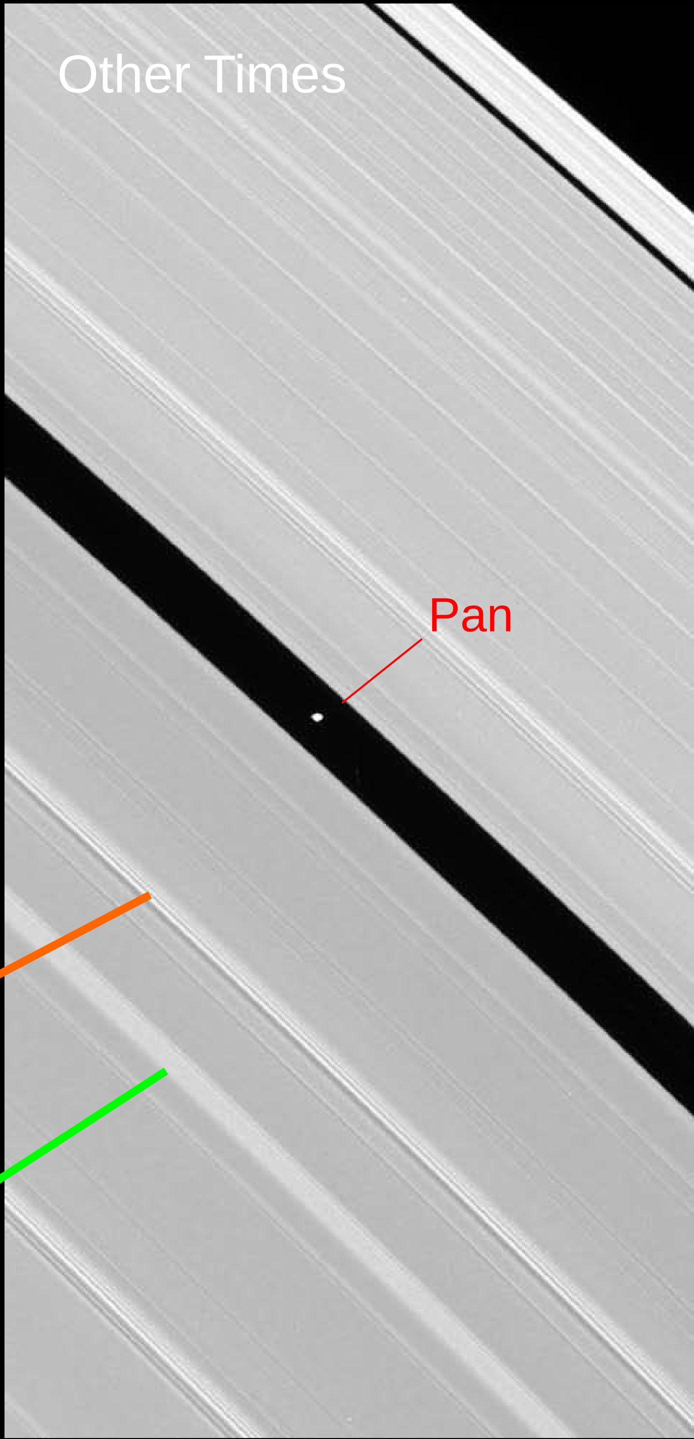


Due to Saturn's flattened shape, vertical resonances do not occur at exactly the same places as Lindblad resonances.

The vertical resonance produces warps in the rings that behave differently from density waves. For example, they can cast shadows!

Mimas 5:3
Density Wave

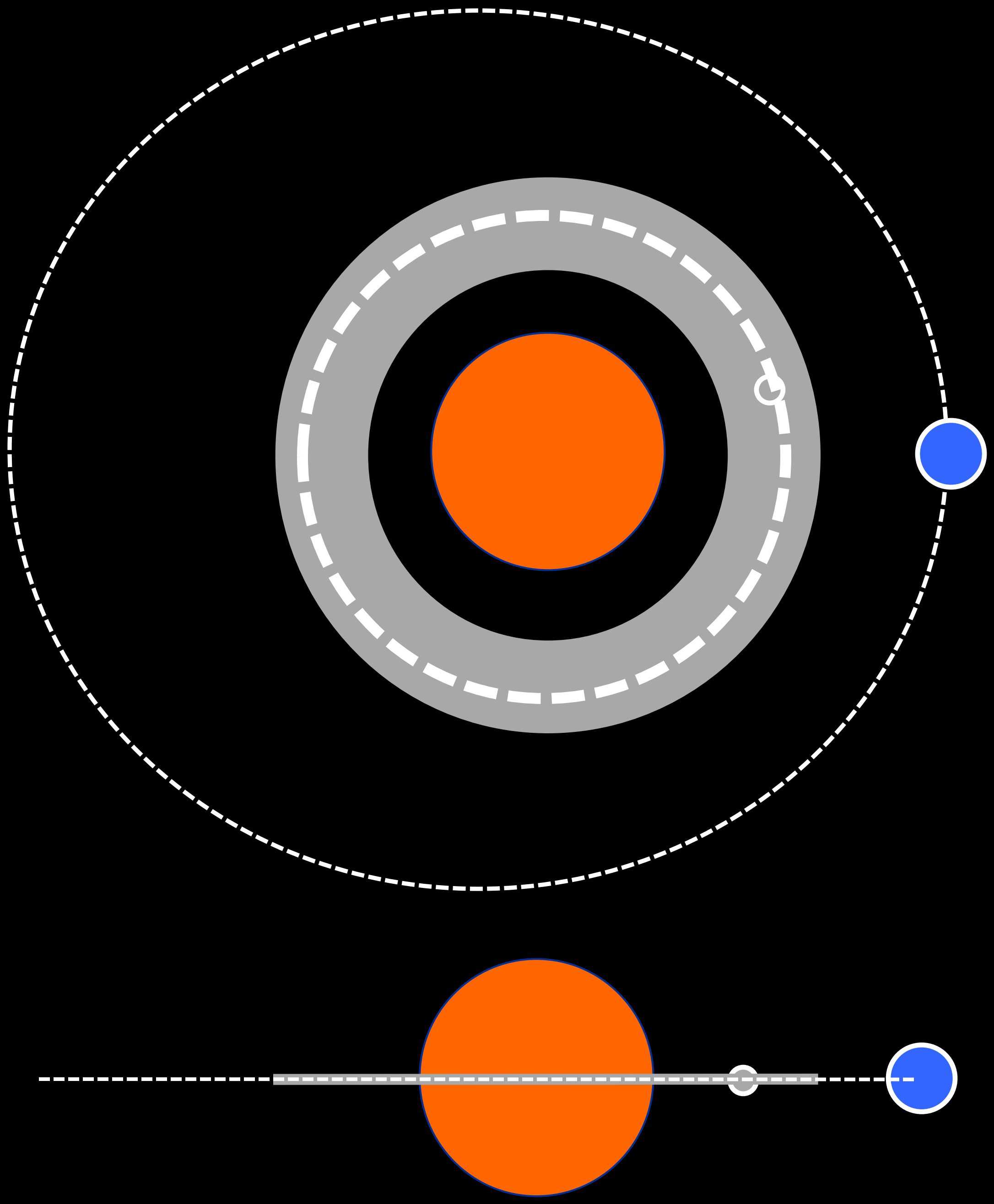
Mimas 5:3
Bending Wave



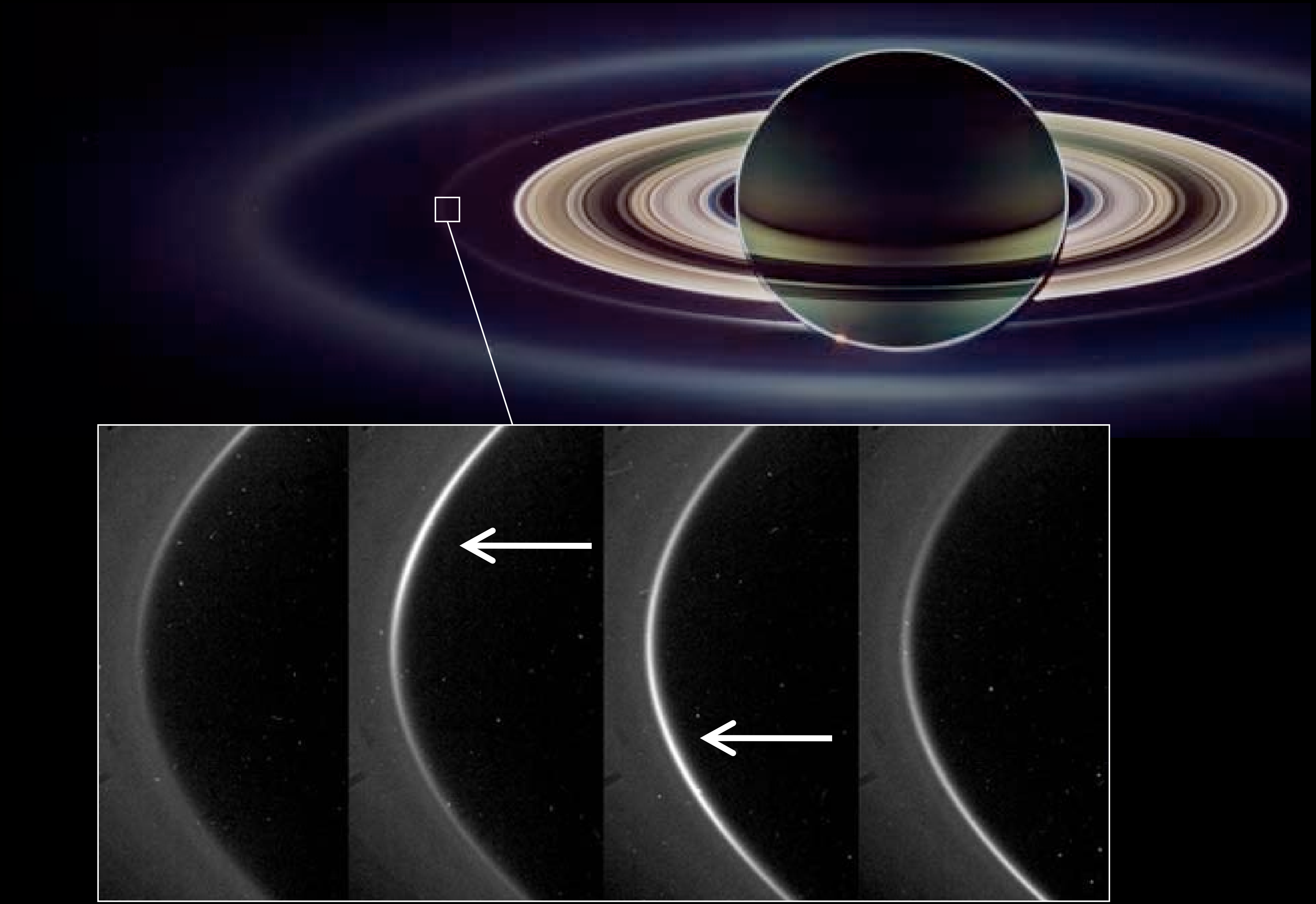
If the moon is on an elliptical orbit, it can tug the particles back and forth in a way that it could not do if it were on a circular orbit.

At places where the particle's orbital period equals a whole number ratio times the period of radial motion for the moon, there is a Co-Rotation Resonance.

These resonances can confine material in longitude, producing arcs.

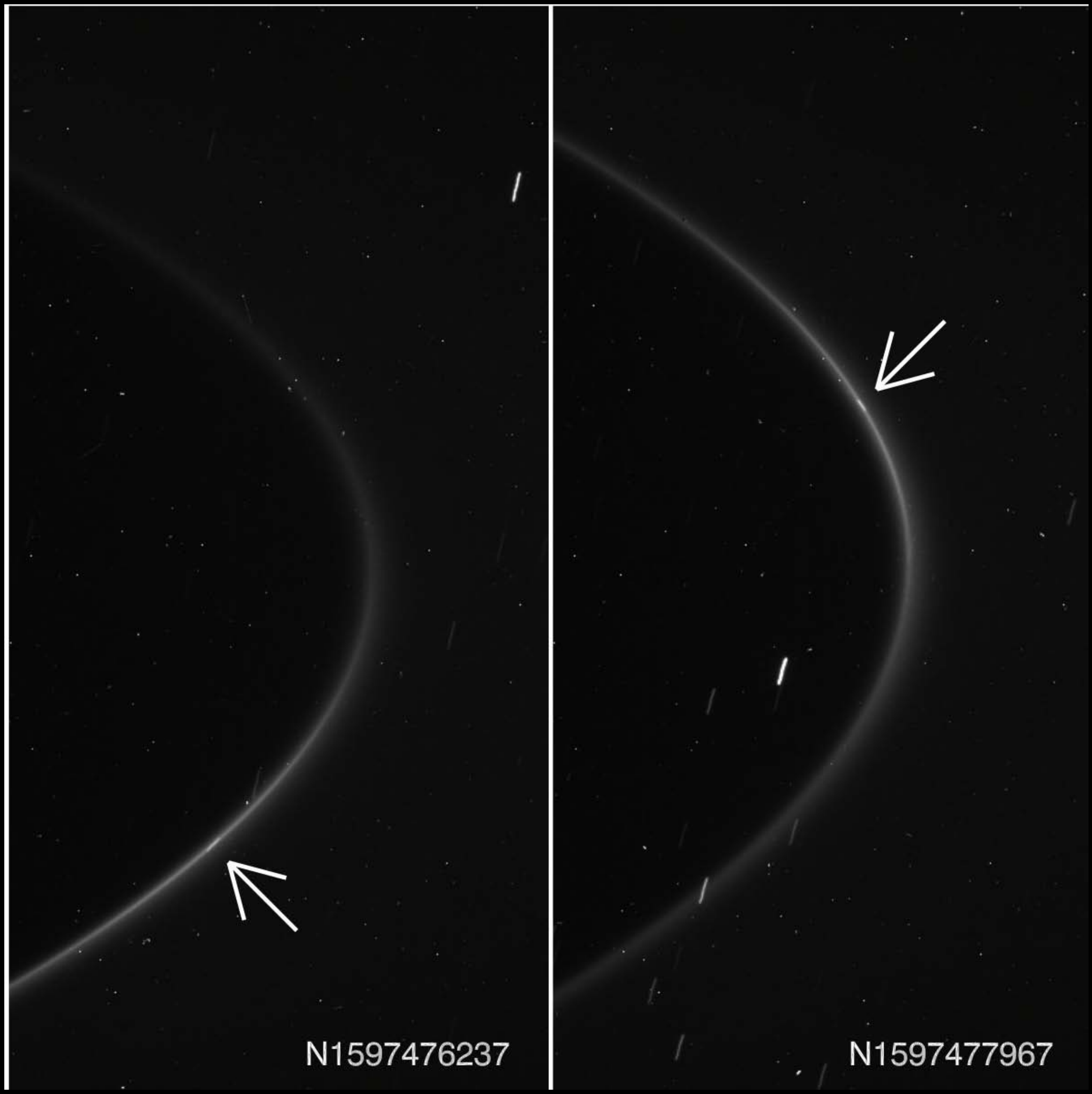


The G ring contains a bright arc of material trapped by the 7:6 Corotation Resonance with Mimas:

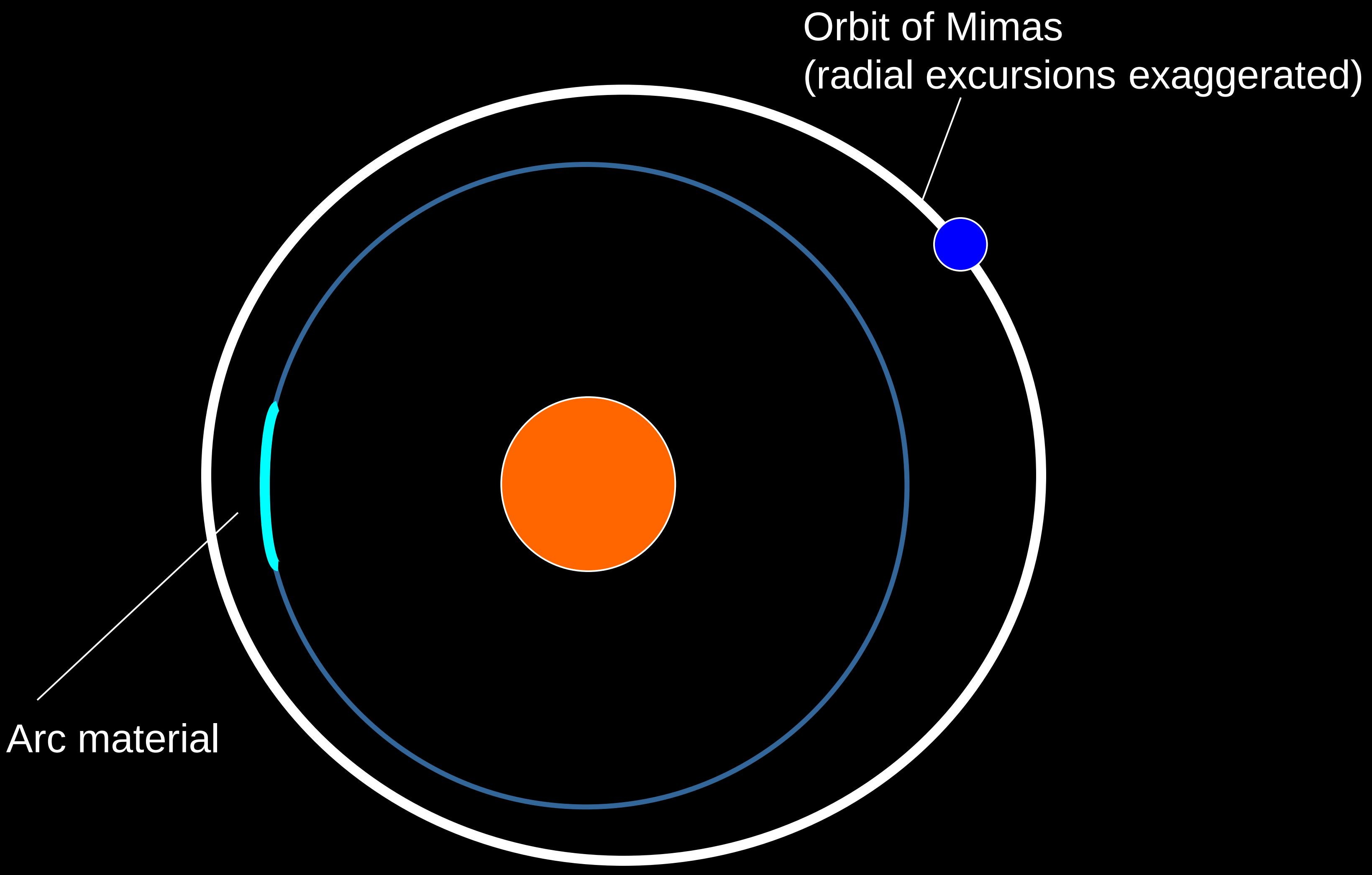


Images designed to study this arc in detail revealed a small bright feature in the center of the arc.

This was the moon Aegaeon, which is less than 1 km across, and would have been hard to find without the arc to tell us where to look!

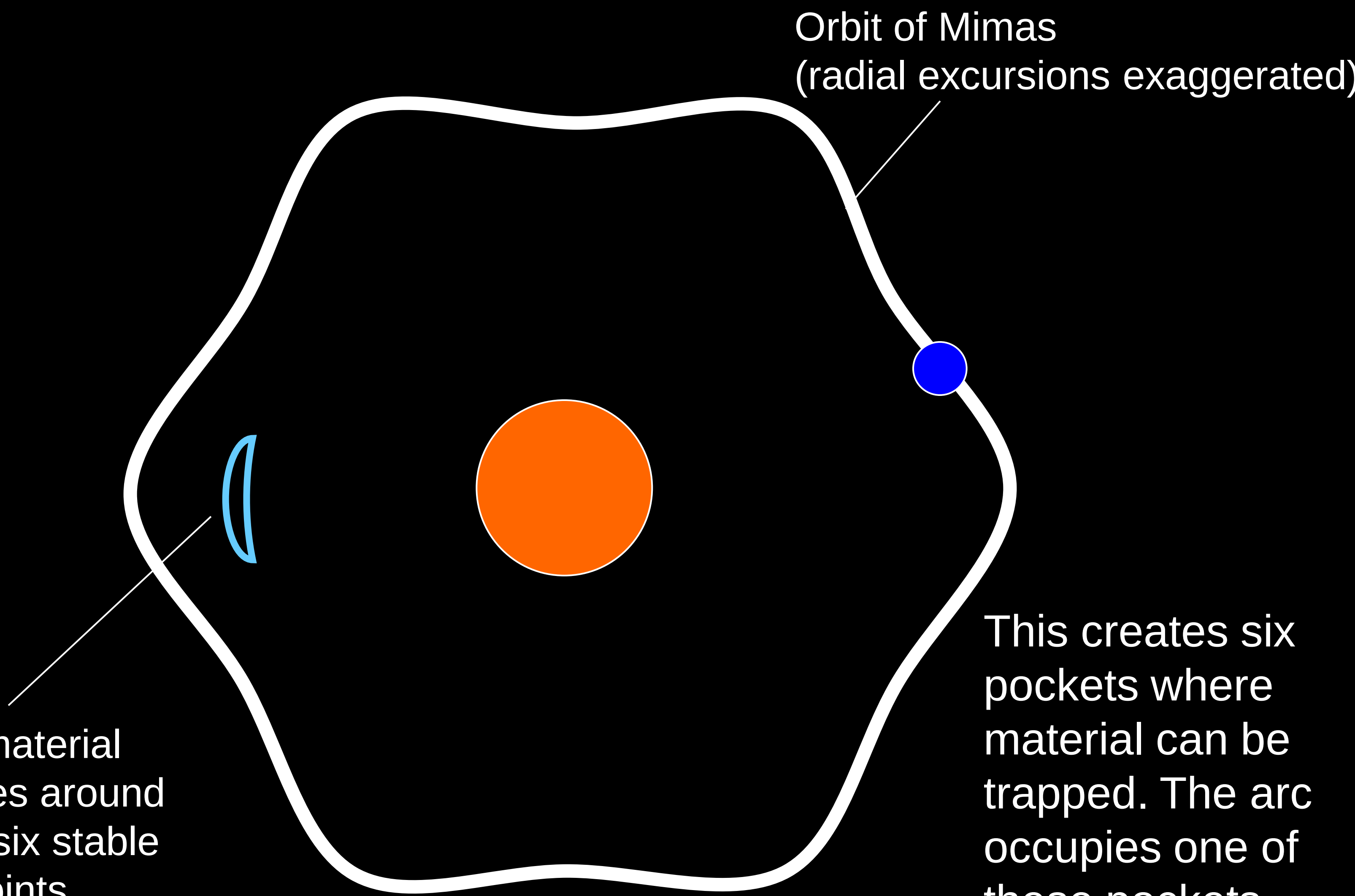


How does a corotation resonance confine an arc?



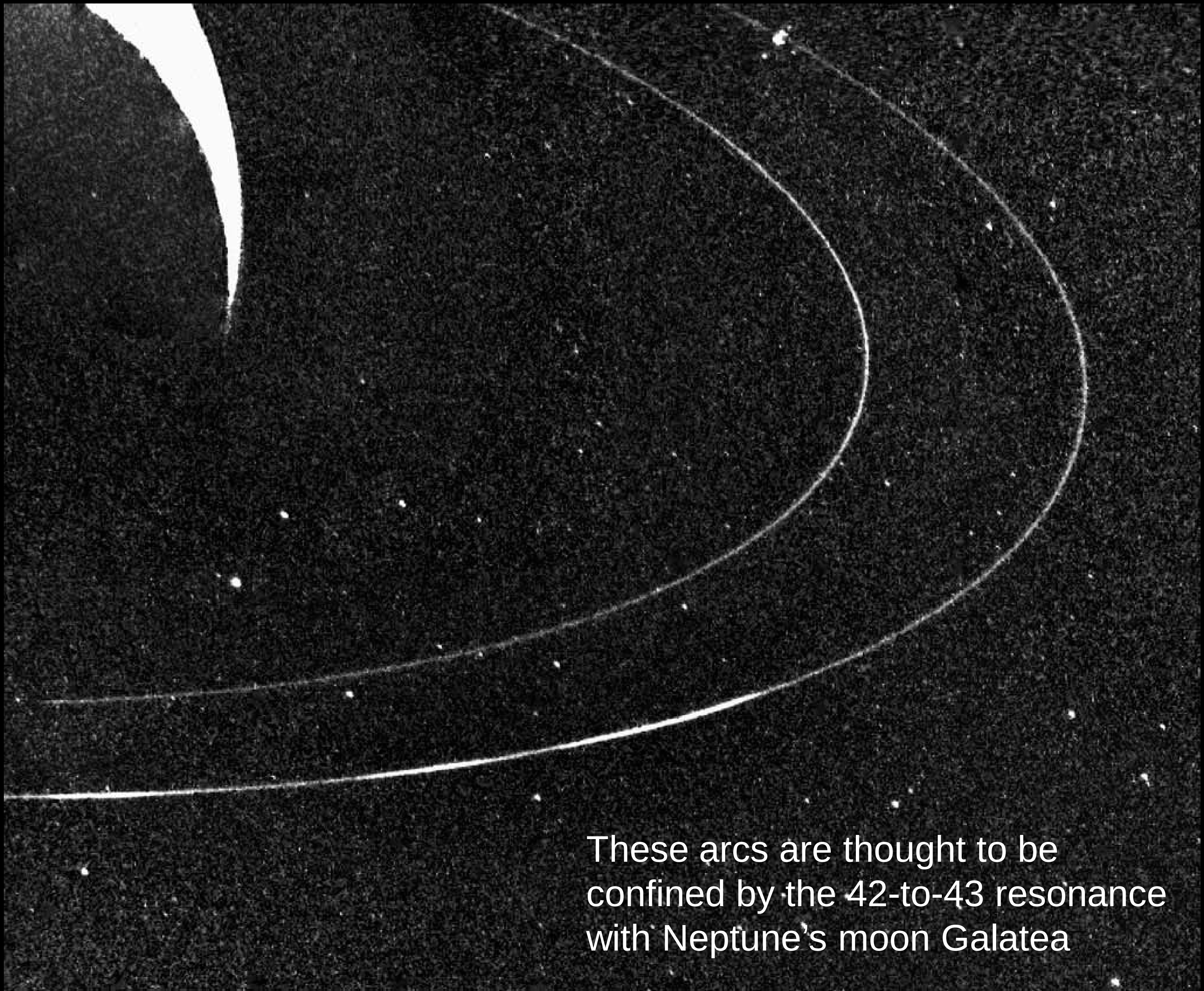
How does a corotation resonance confine an arc?

From the arc’s perspective, Mimas moves in a six-lobed orbit:

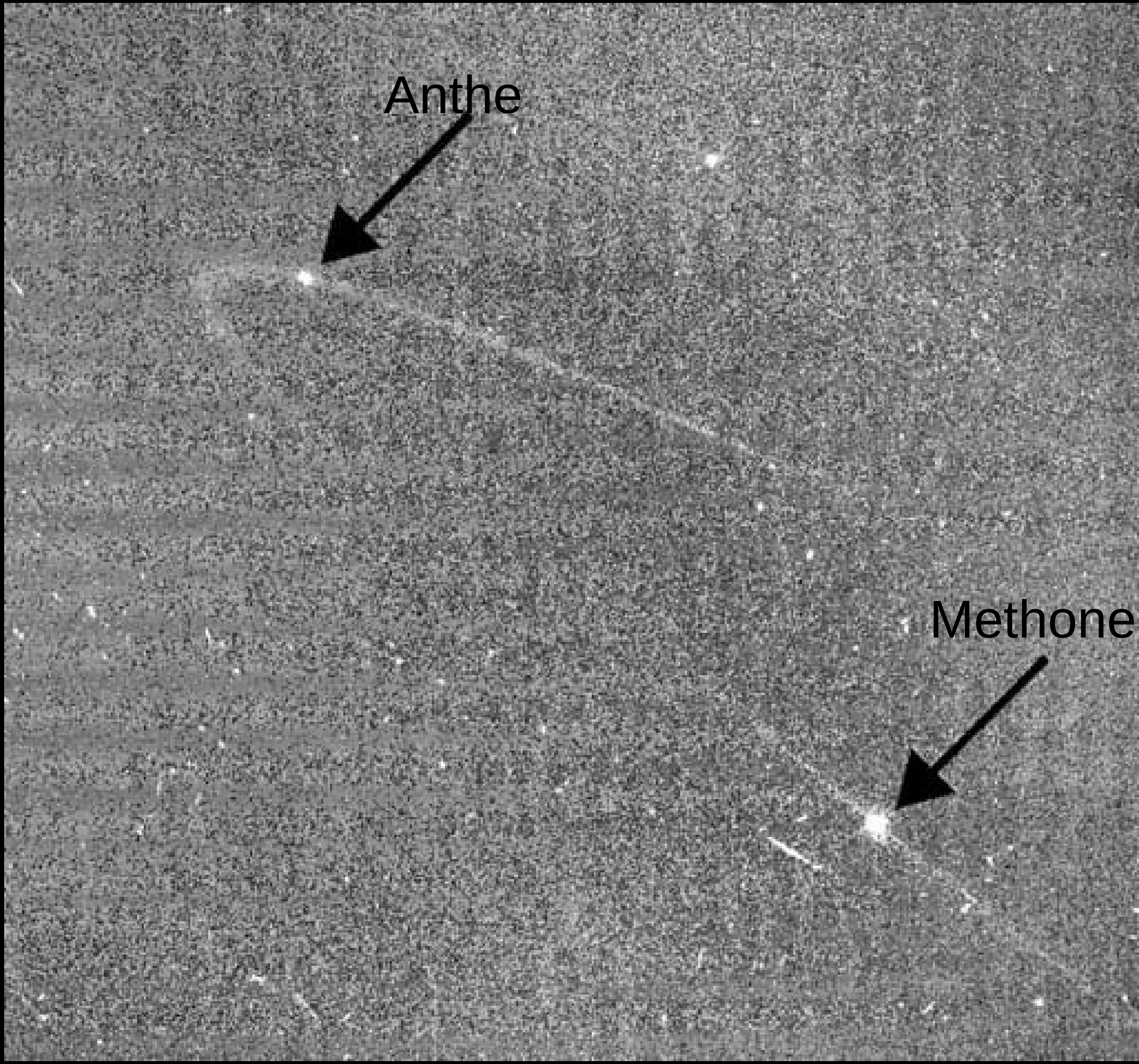


This creates six pockets where material can be trapped. The arc occupies one of these pockets

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



These tiny moons of Saturn and their associated ring arcs are also confined by co-rotation resonances with Mimas.



There are numerous structures in Saturn’s rings whose locations are not consistent with the resonances of any known moon.

The orientations and shapes of these features provide clues to what forces might be acting on the rings at these locations.

Thus far, structures have been found that could be generated by:

--Sunlight

--Electromagnetic forces from Saturn’s magnetosphere

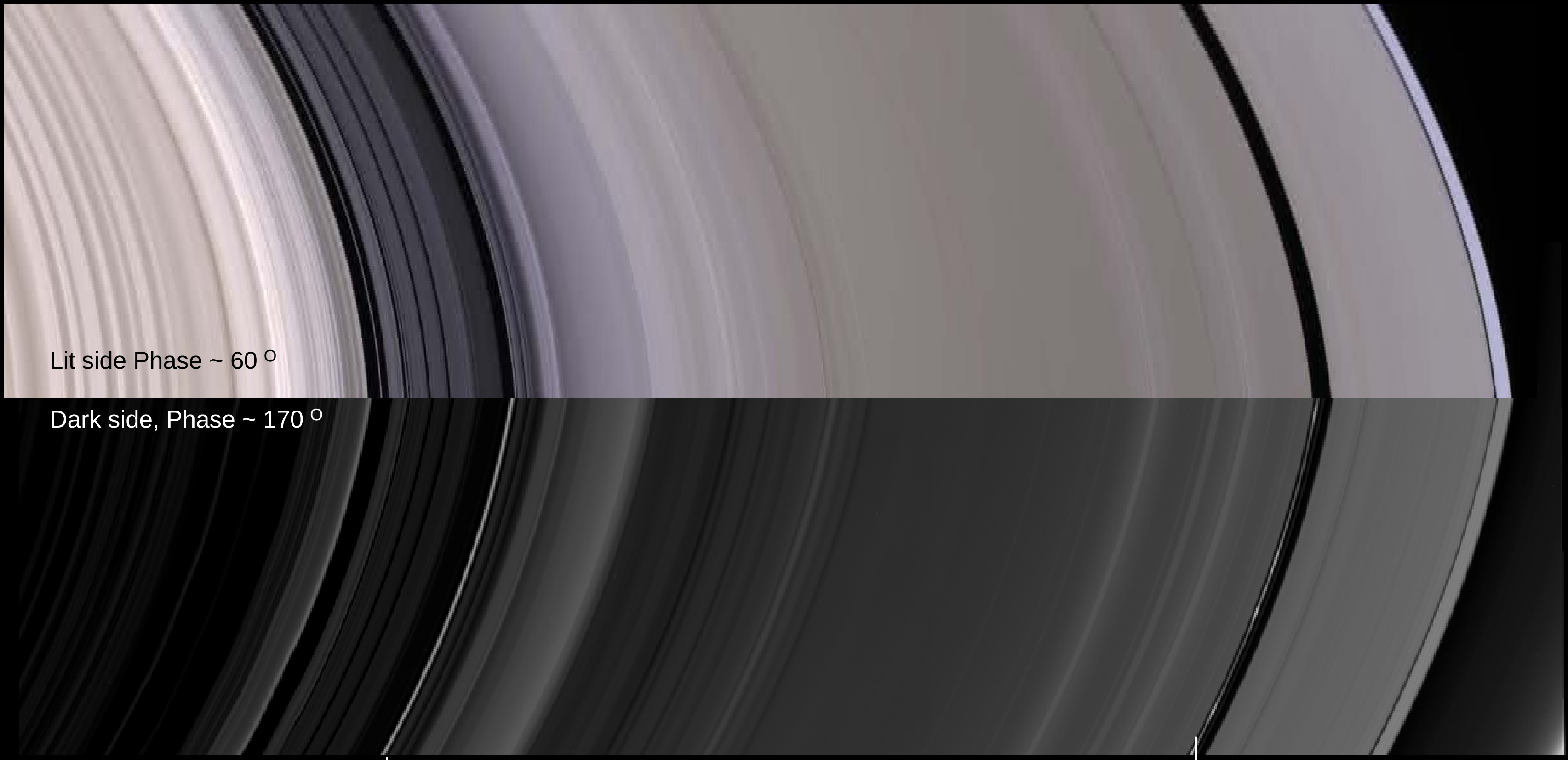
--Gravitational forces from other massive rings

The interpretation of some of these features is still very much a work in progress, and could change as more data are analyzed.

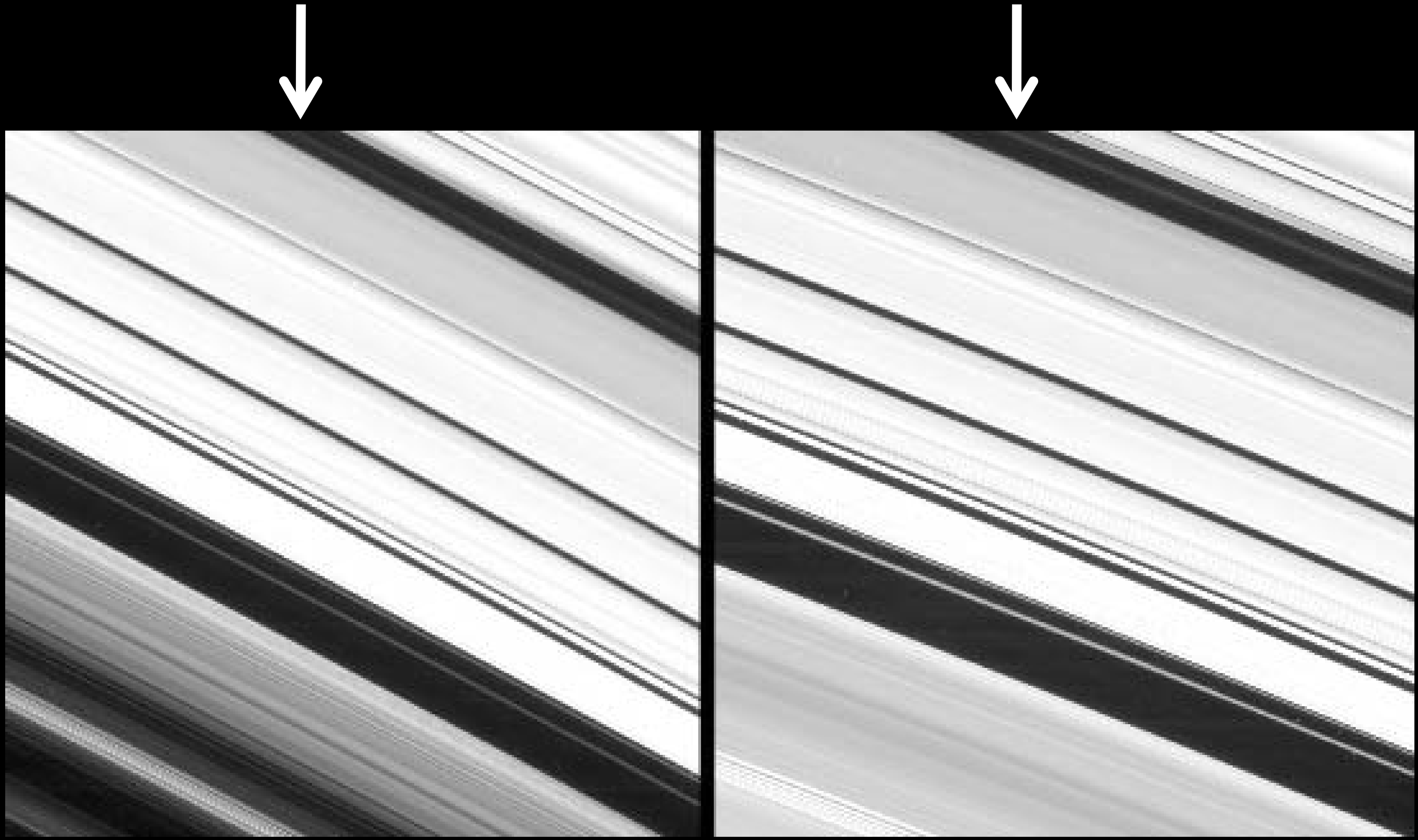
Several of these features are found in dusty rings, composed mostly of small particles less than 0.1 cm across

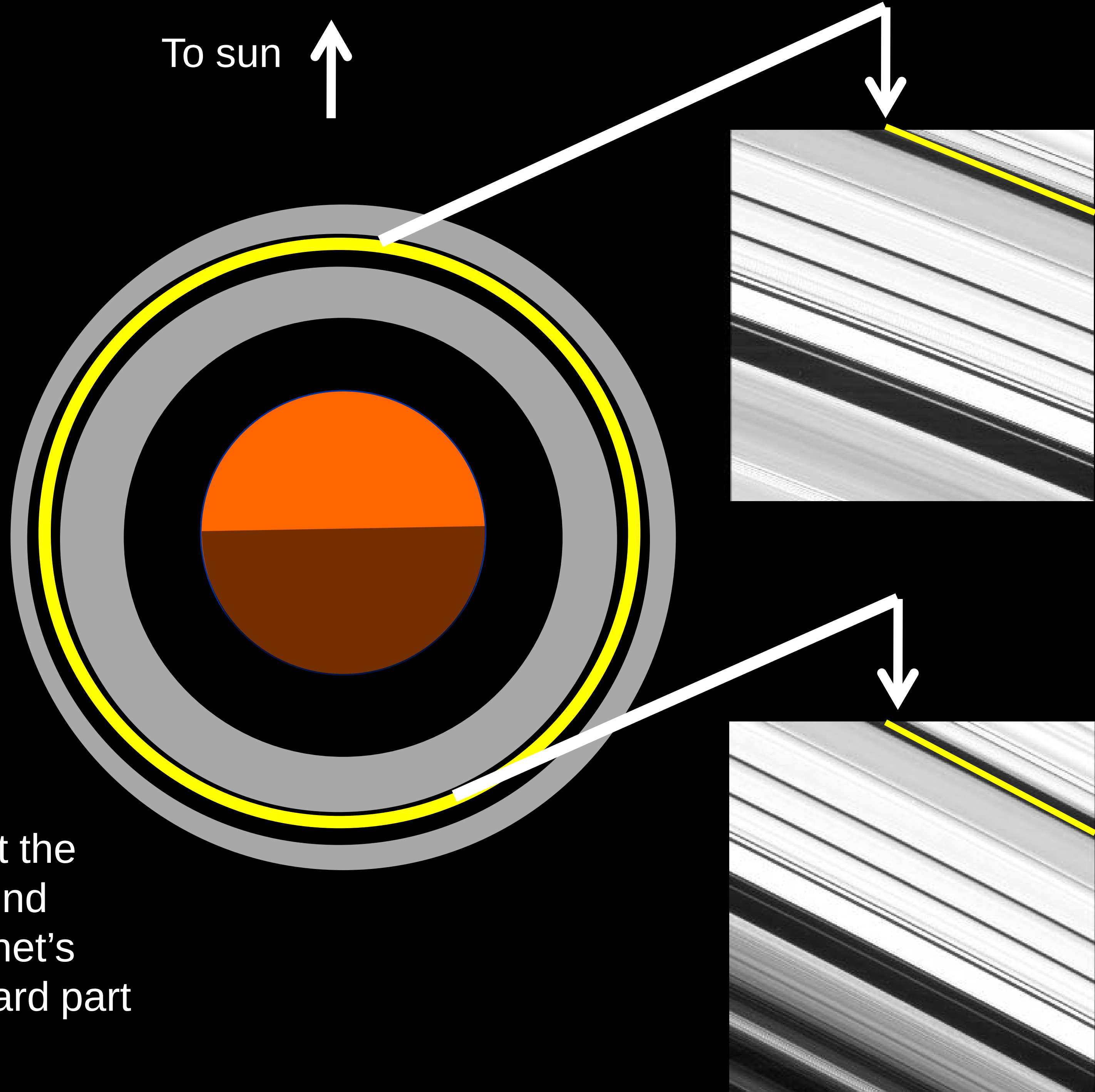
Such small particles are especially sensitive to non-gravitational forces.

Some dusty rings seem to be perturbed by sunlight.



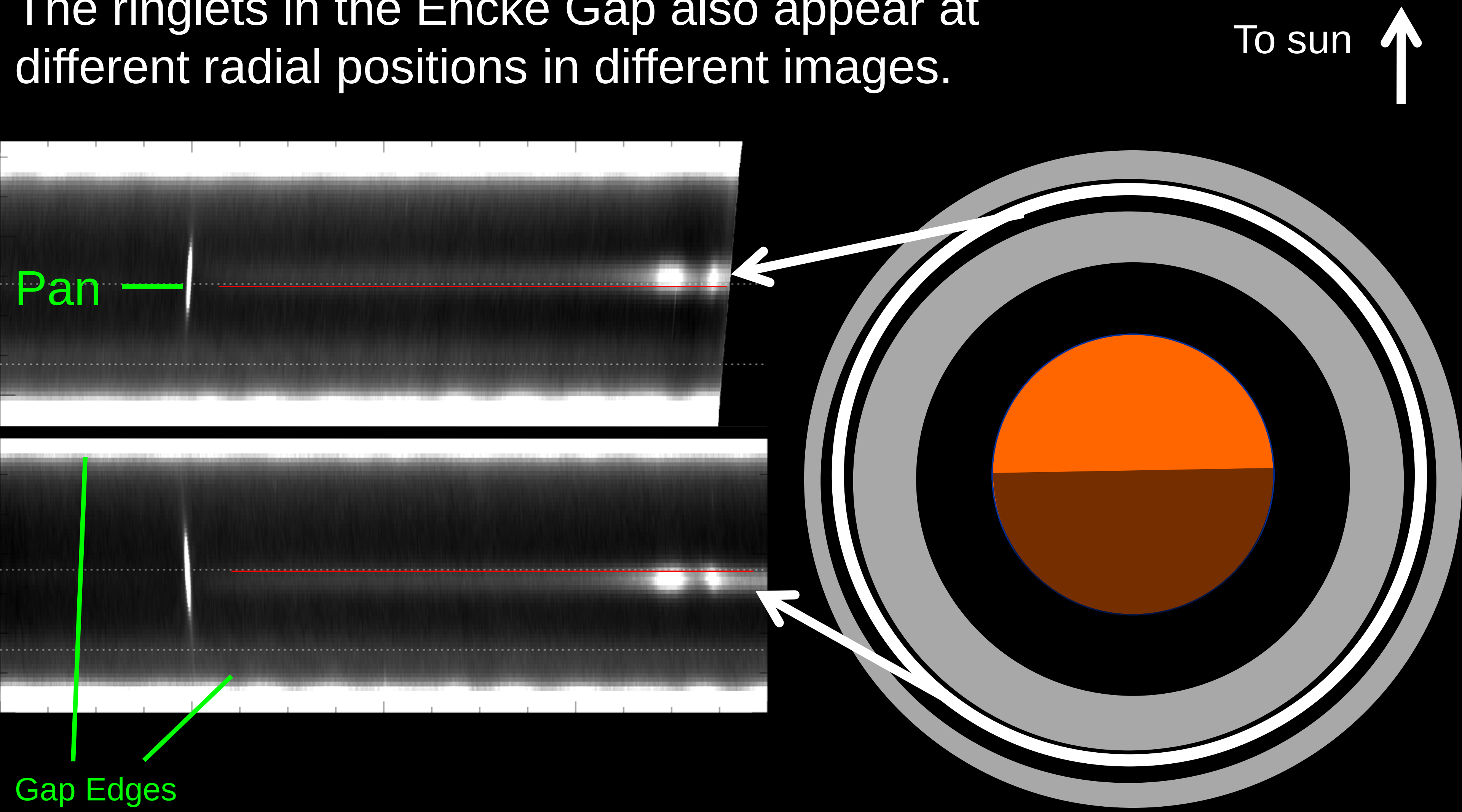
The “charming” ringlet in the Cassini Division is clearly not circular, as it appears at different distances from the edges of the gap it occupies in different images





Comparing multiple images, we find that the ringlet is always found further from the planet's center on the sunward part of the rings…

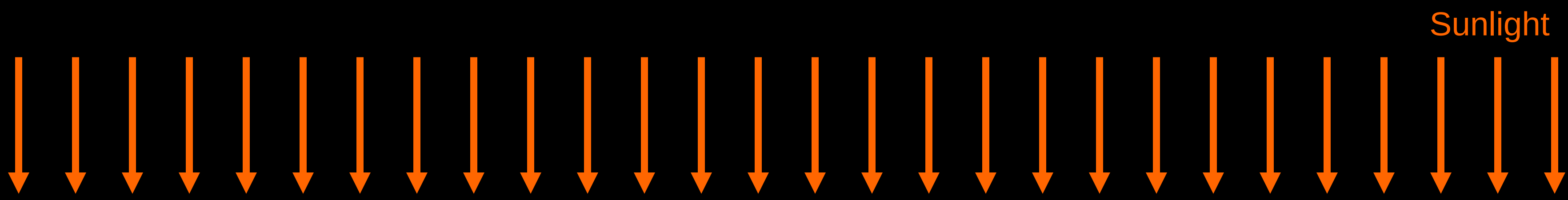
The ringlets in the Encke Gap also appear at different radial positions in different images.



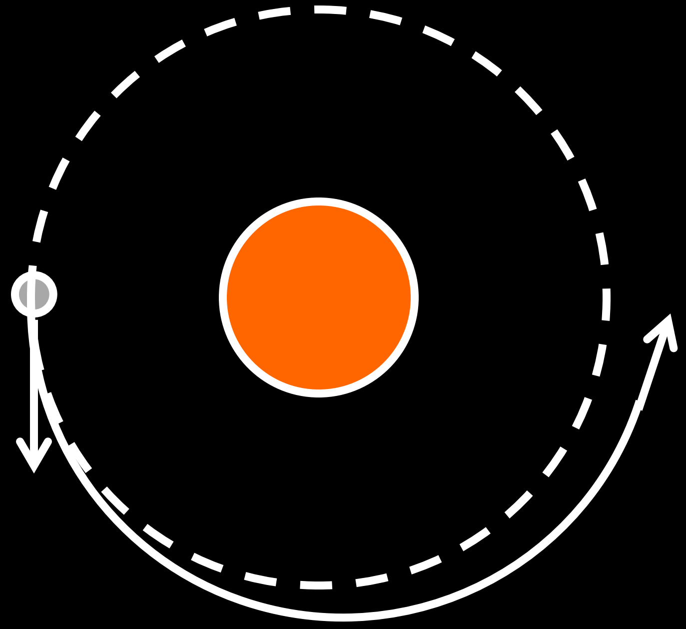
Again, the position of the ringlets depend on whether the ring is observed on the sunward or shadow-ward side of the rings.

Possible Mechanism: Solar Radiation Pressure

Counter-intuitively, solar radiation pressure can push particles towards the Sun



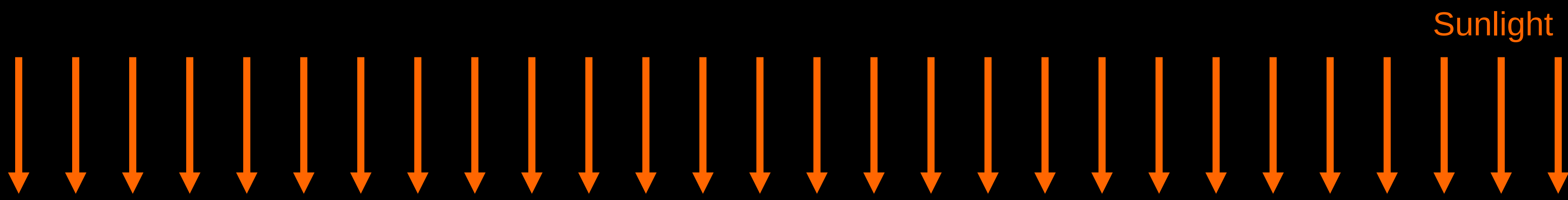
Imagine a particle starts out on a circular orbit, heading away from the Sun, then the Sunlight pushes it ahead, causing it to move faster.



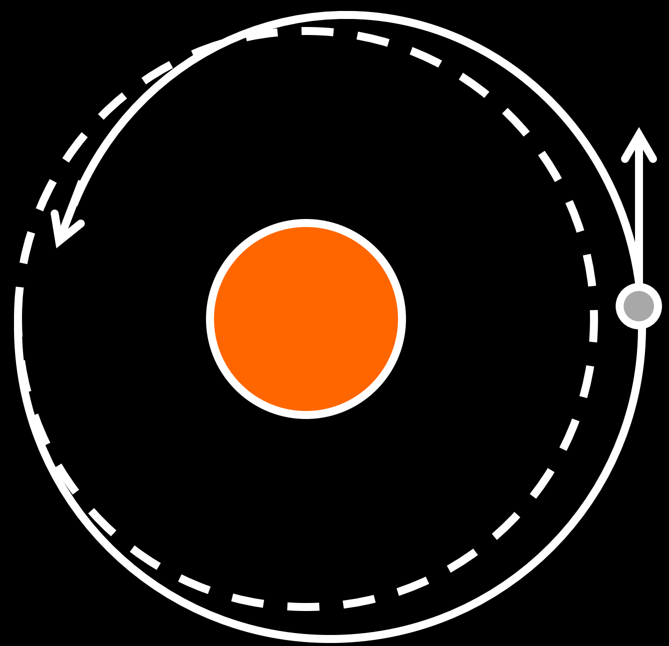
Due to this extra nudge, the particle gets thrown a bit farther from the planet.

Possible Mechanism: Solar Radiation Pressure

Counter-intuitively, solar radiation pressure can push particles towards the Sun



On the other side of the planet, the particle heads into the Sunlight, so the solar radiation pressure slows it down, causing the particle to fall closer to planet again.



The particle’s orbit becomes elliptical instead of circular.

Possible Mechanism: Solar Radiation Pressure

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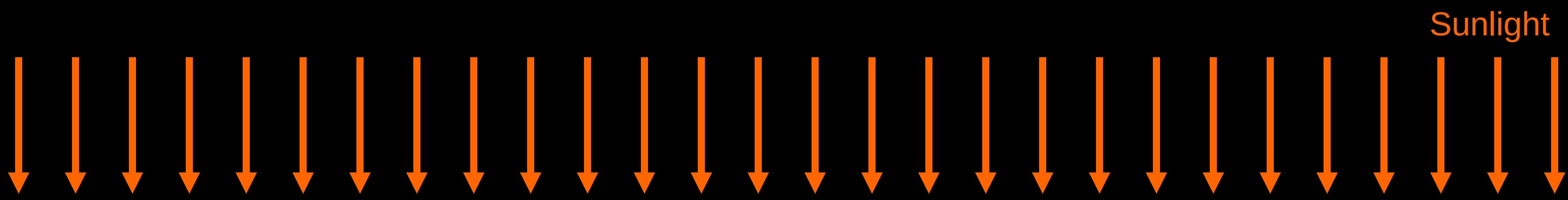
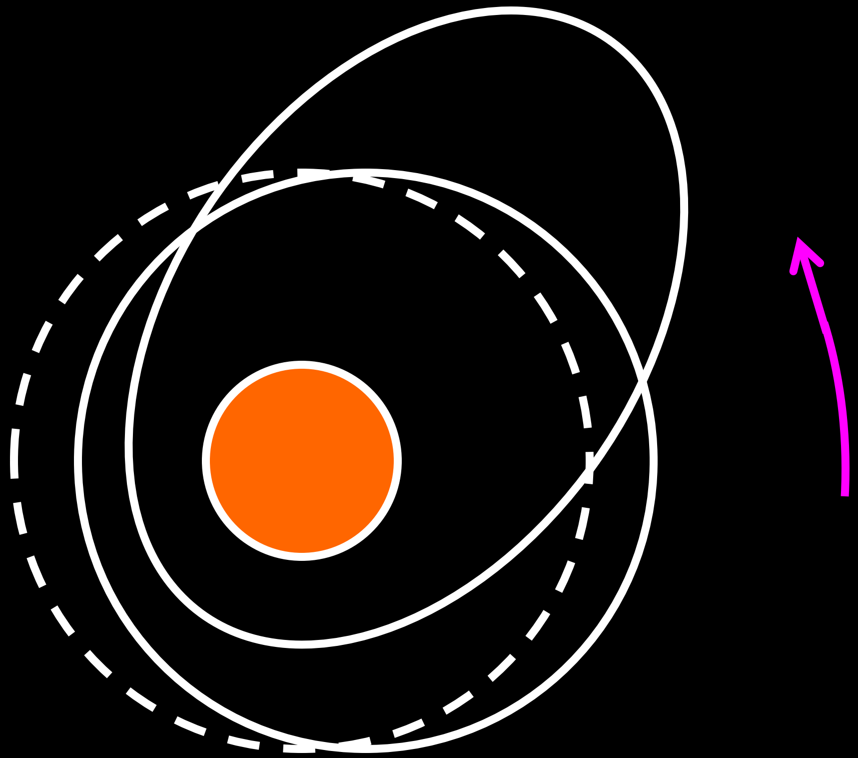


Elliptical orbits drift around the planet under the influence of Saturn's gravity.

As they drift, the sunlight continues to cause the orbit to stretch out.



Possible Mechanism: Solar Radiation Pressure

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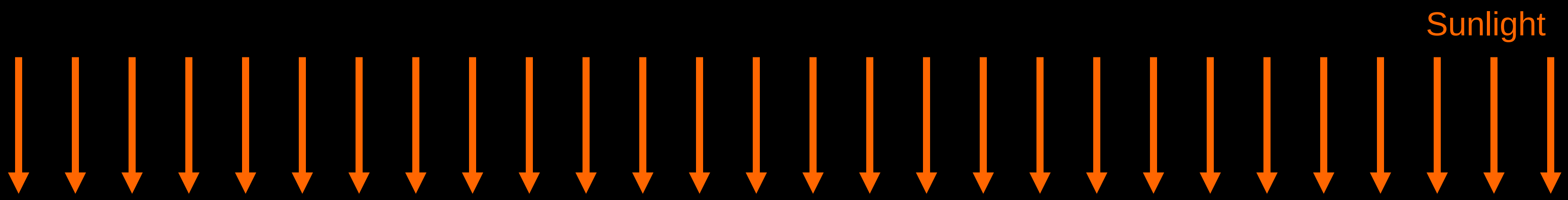
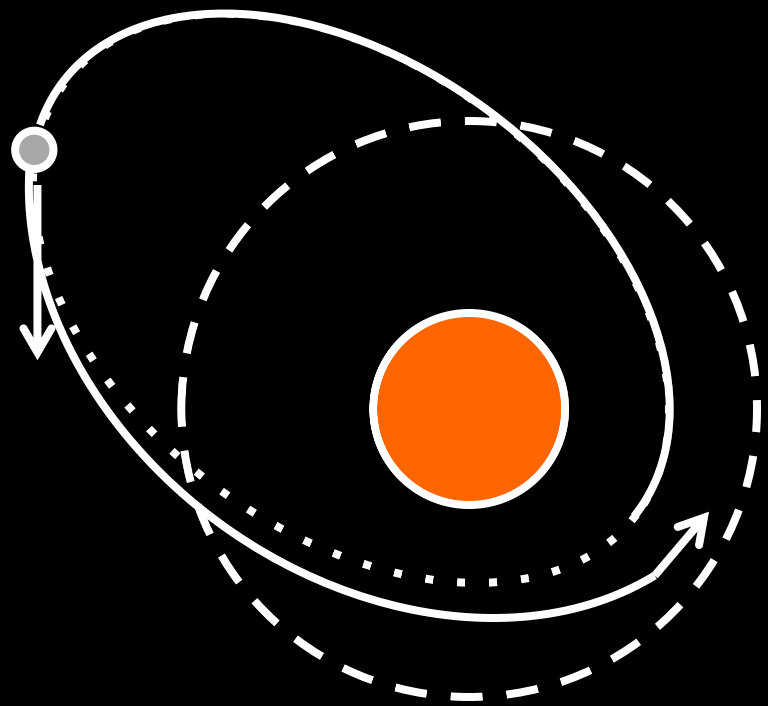
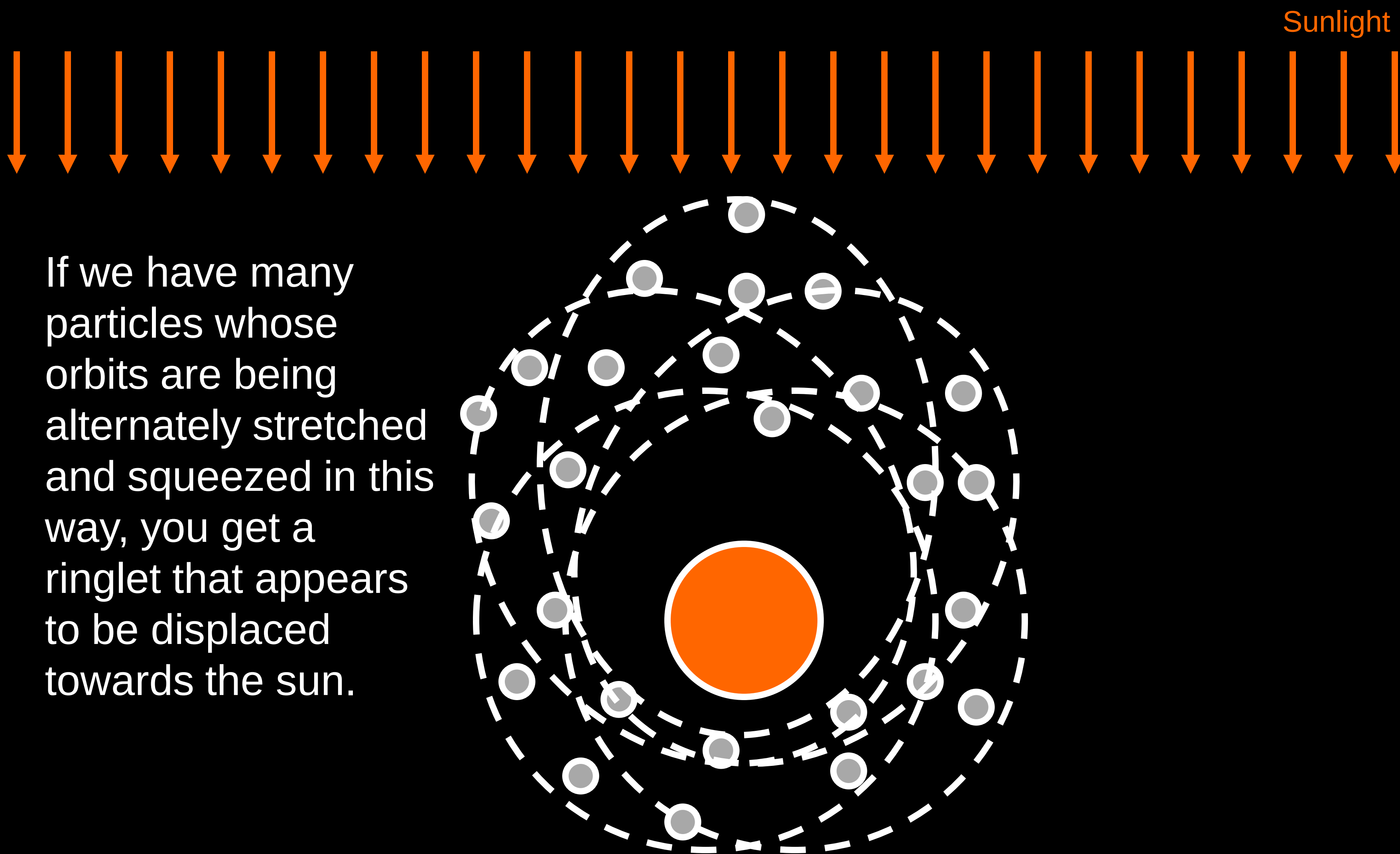


Once the orbit drifts far enough around the planet, the nudges from the sun make the orbit more circular.



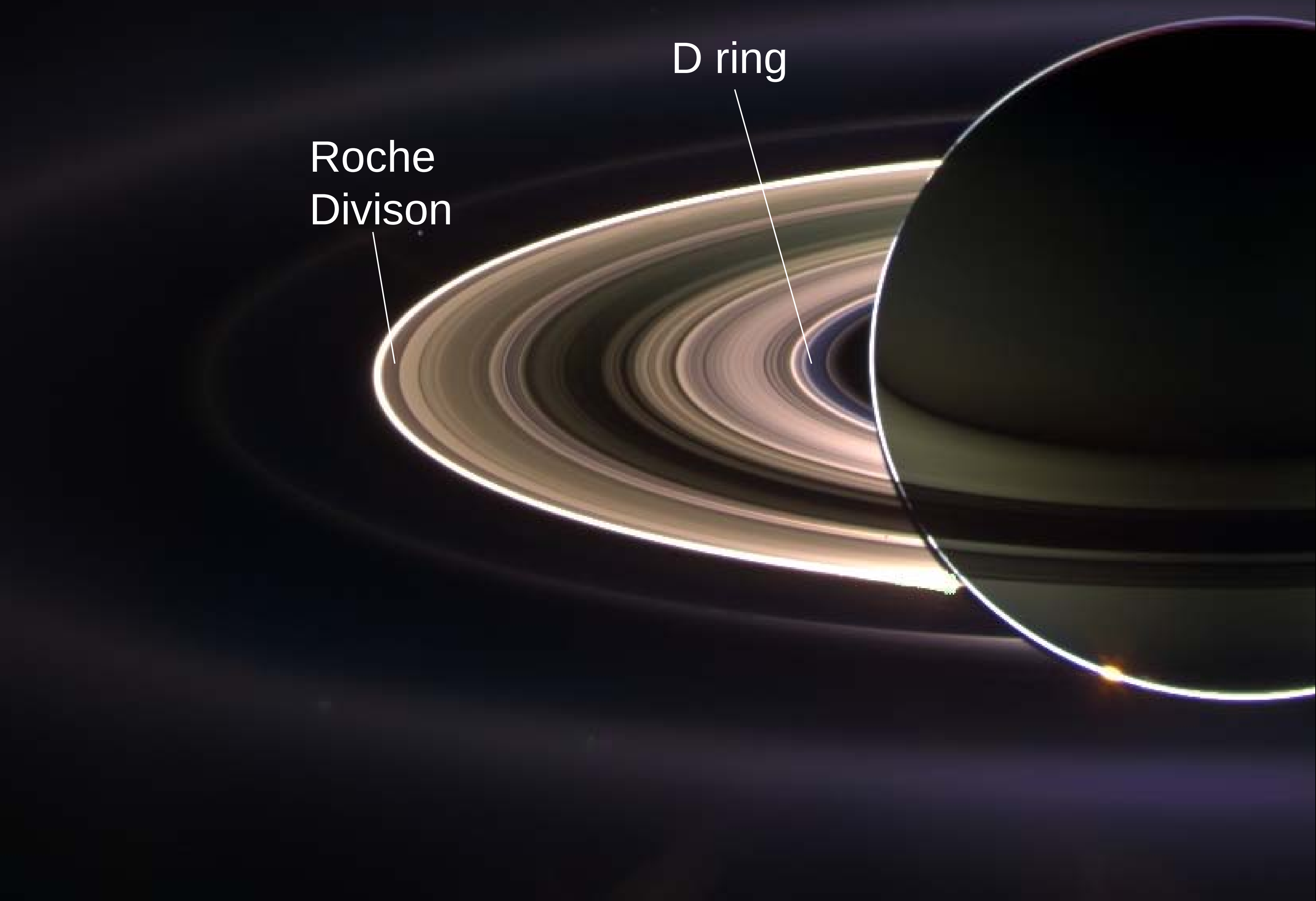
Possible Mechanism: Solar Radiation Pressure

Counter-intuitively, solar radiation pressure can push particles towards the Sun

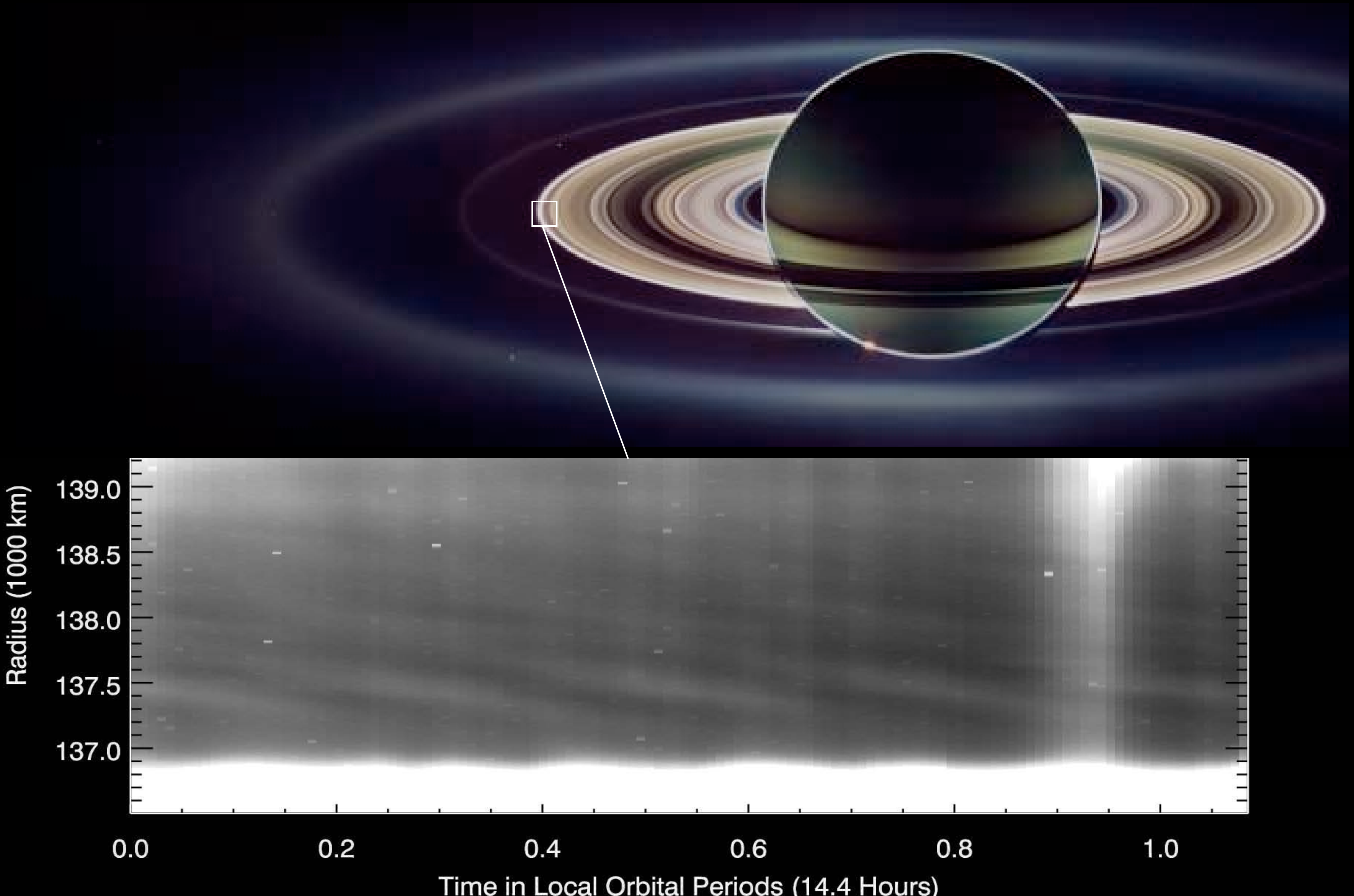


If we have many particles whose orbits are being alternately stretched and squeezed in this way, you get a ringlet that appears to be displaced towards the sun.

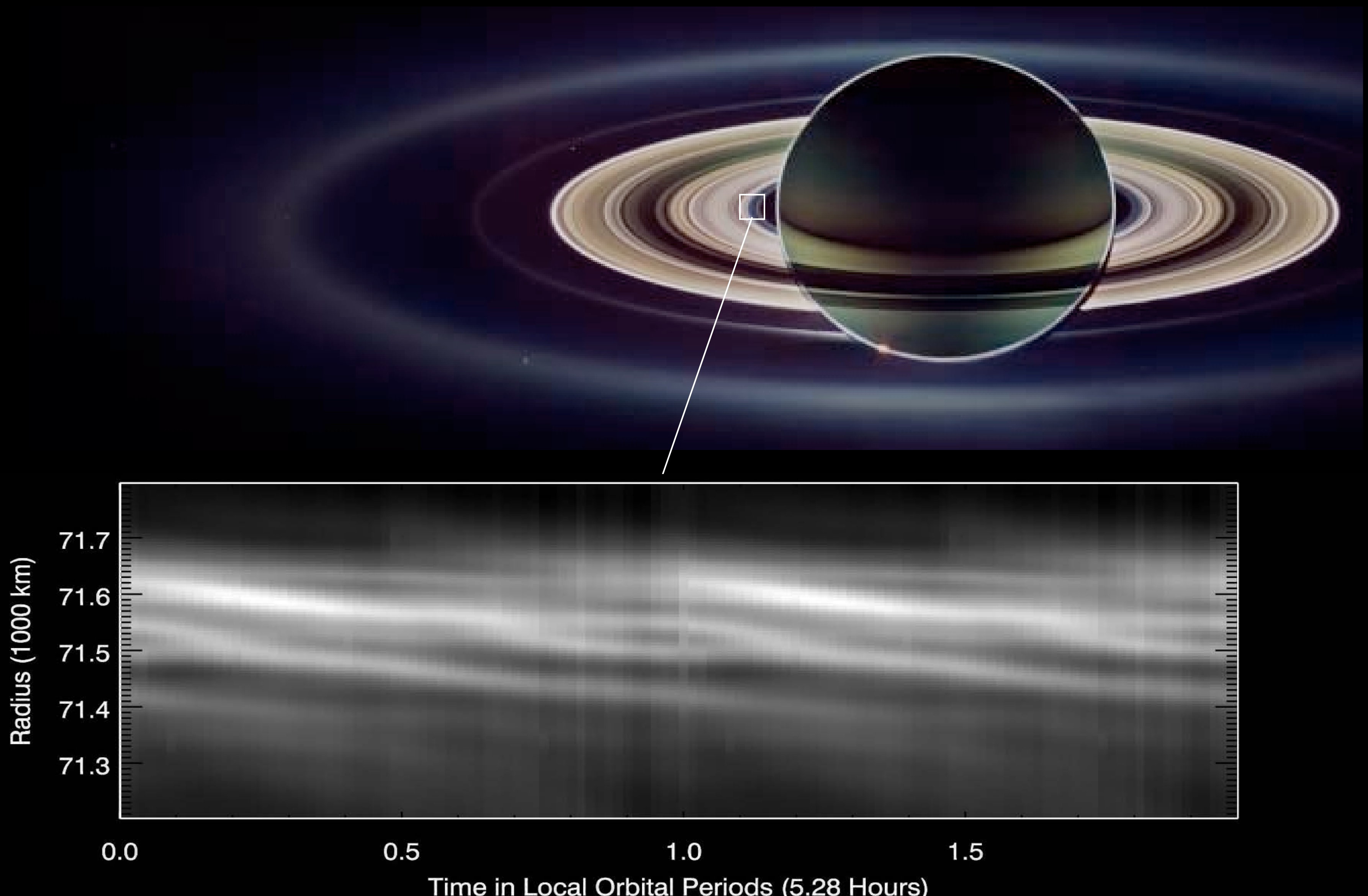
Other asymmetric structures in dusty rings…



In the Roche Division, we see curious periodic structures

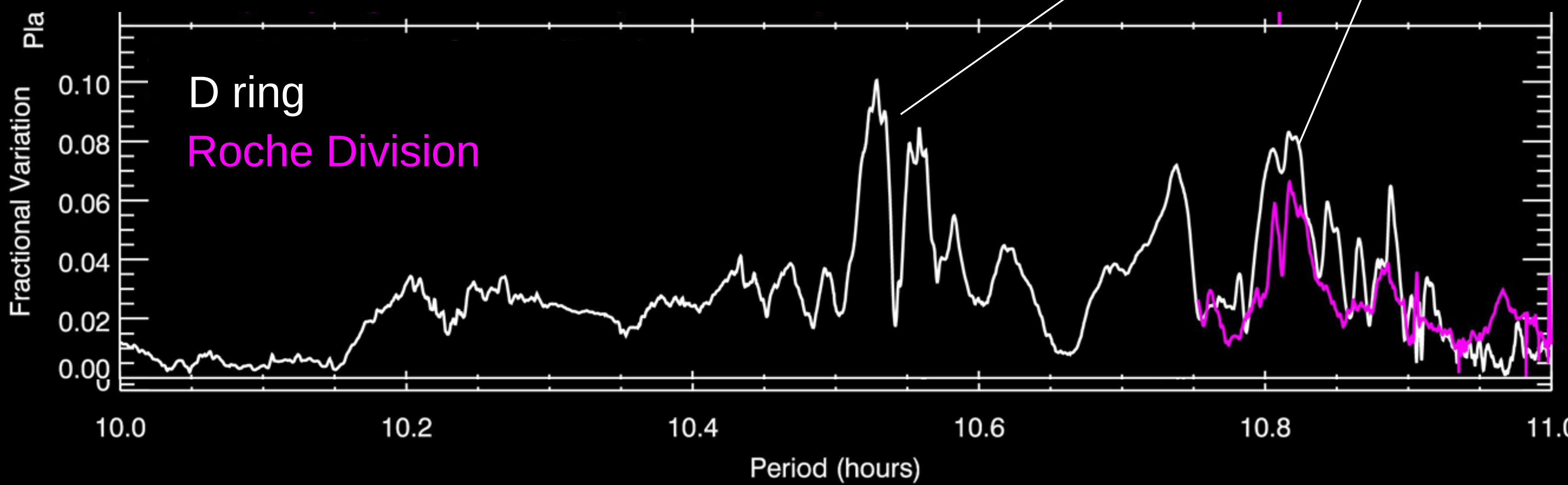


Similar structures are visible in the D ring



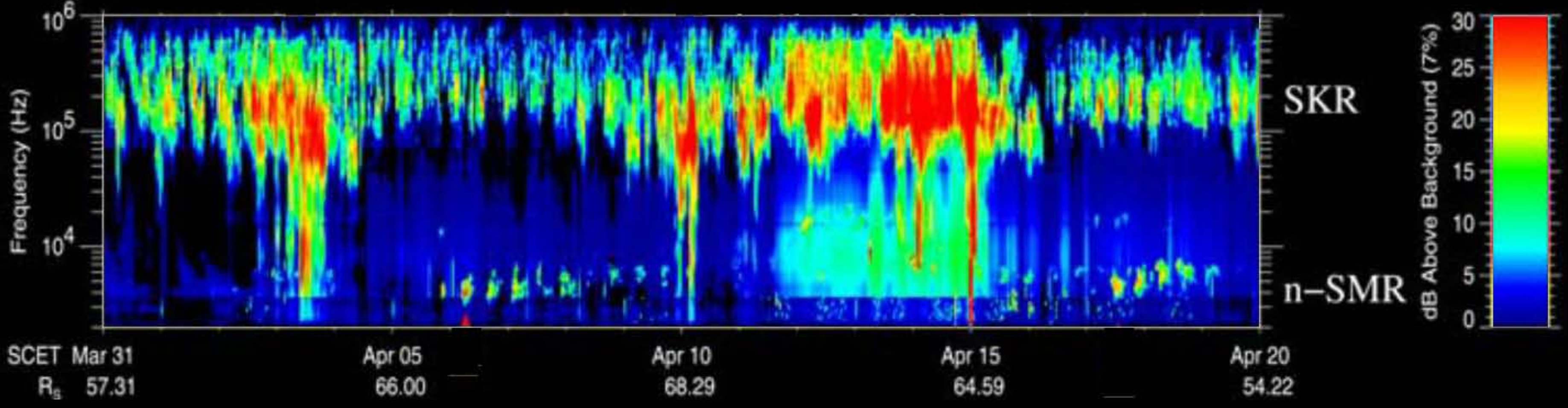
By comparing images of these patterns taken at different times, we can estimate how fast they move around the planet.

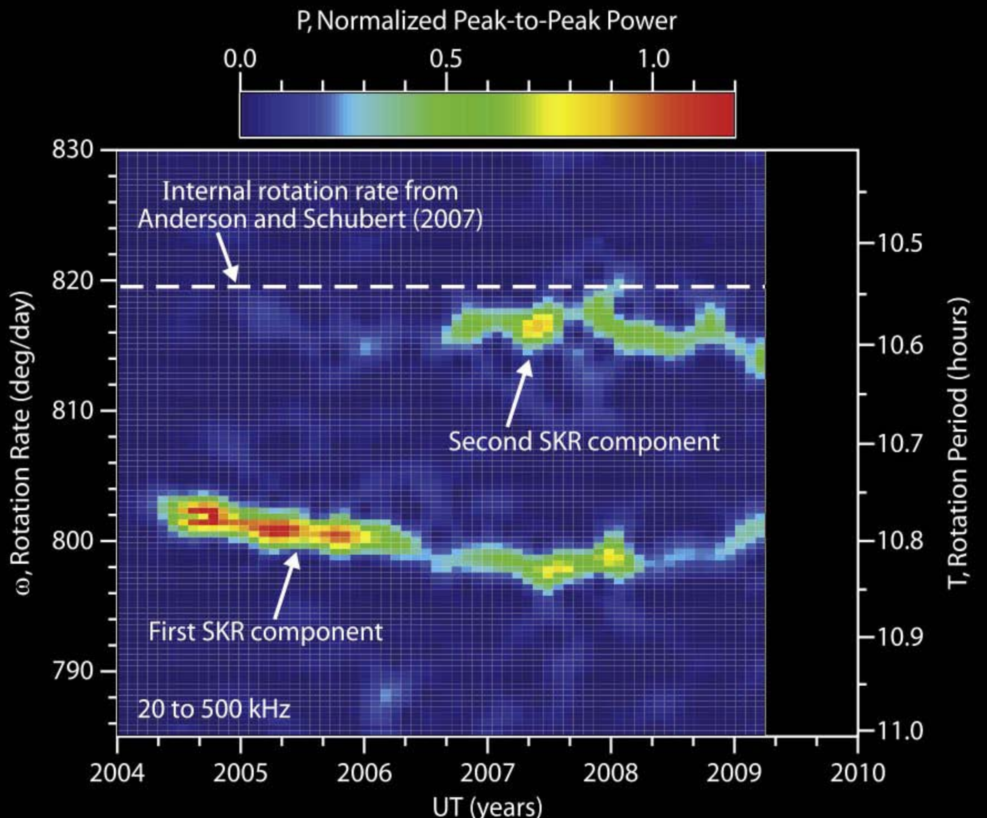
The most intense patterns have periods of about 10.55 and 10.8 hours



These periods are close to the rotation period of Saturn and to the period of certain radio emissions from Saturn's magnetosphere.

From Laurn et al. 2007

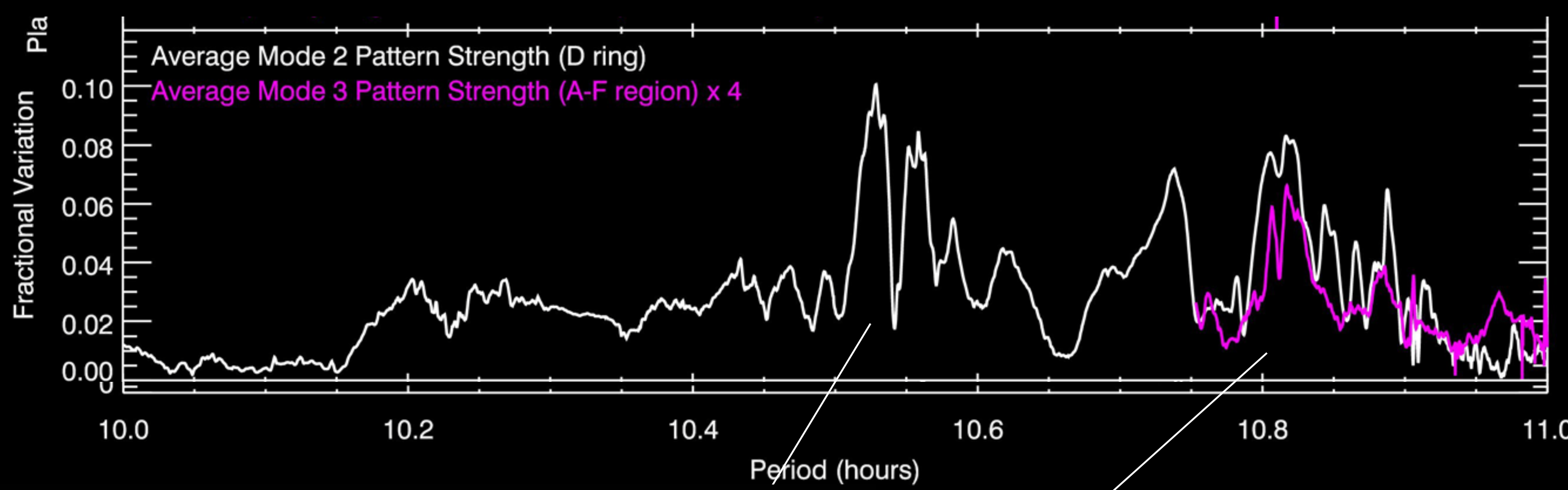


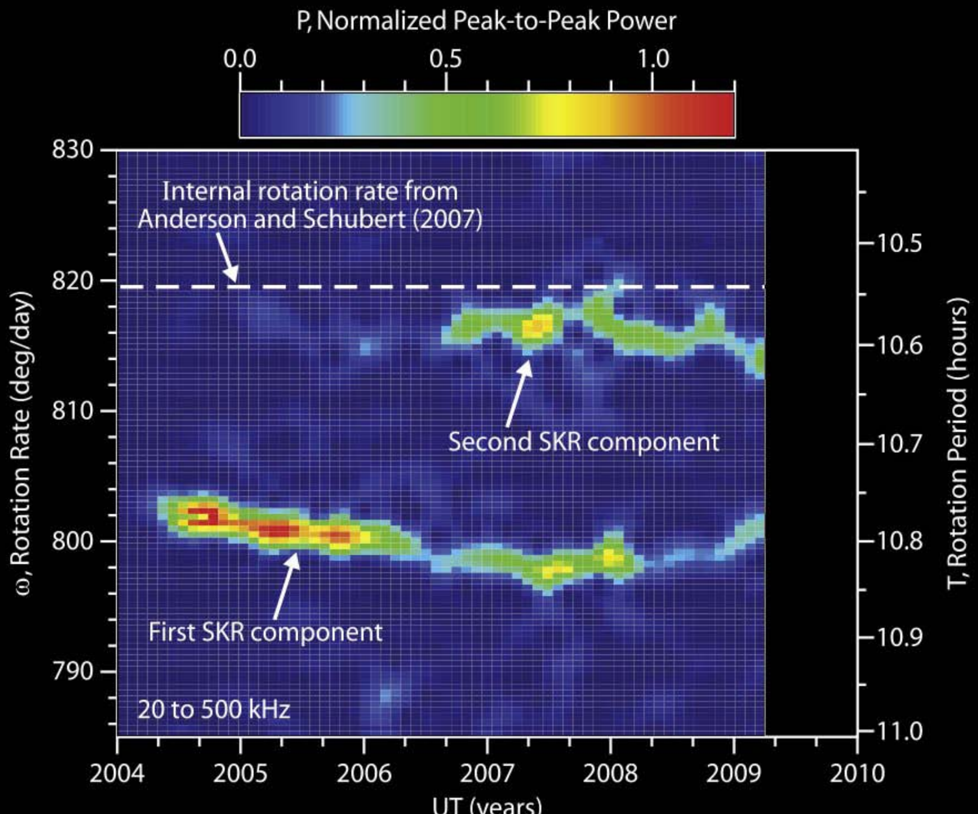


From Gurnett et al. 2009

Saturn emits periodic radio signal, which are measured by the RPWS instrument onboard Cassini.

Recently, it was found that there were two distinct periods in these signals.



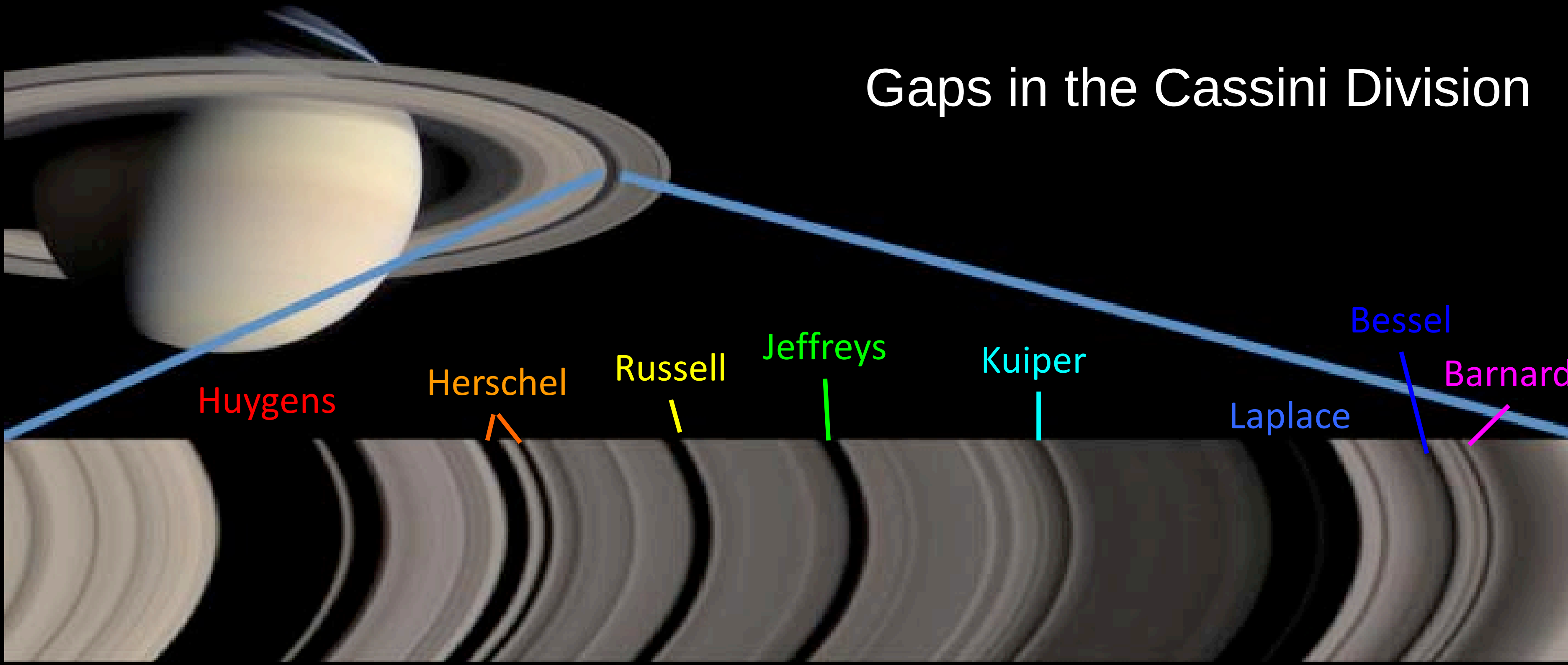


From Gurnett et al. 2009

The periods of the radio emissions match the periods of the strongest patterns in the dusty rings.

Whatever is producing these radio signals seems to also be perturbing the rings…

Gaps in the Cassini Division



The Cassini Division between the A and B rings contains a series of eight gaps.

Thus far, no one has found a small moon in any of these gaps, so they are probably not made like the gaps in the outer A ring.

Strong resonances with moons are only found in a couple of these gaps

The shapes of the other gaps' edges reveal patterns that might be produced by a resonances with the motion of structures found the outer edge of the B ring.

Questions?