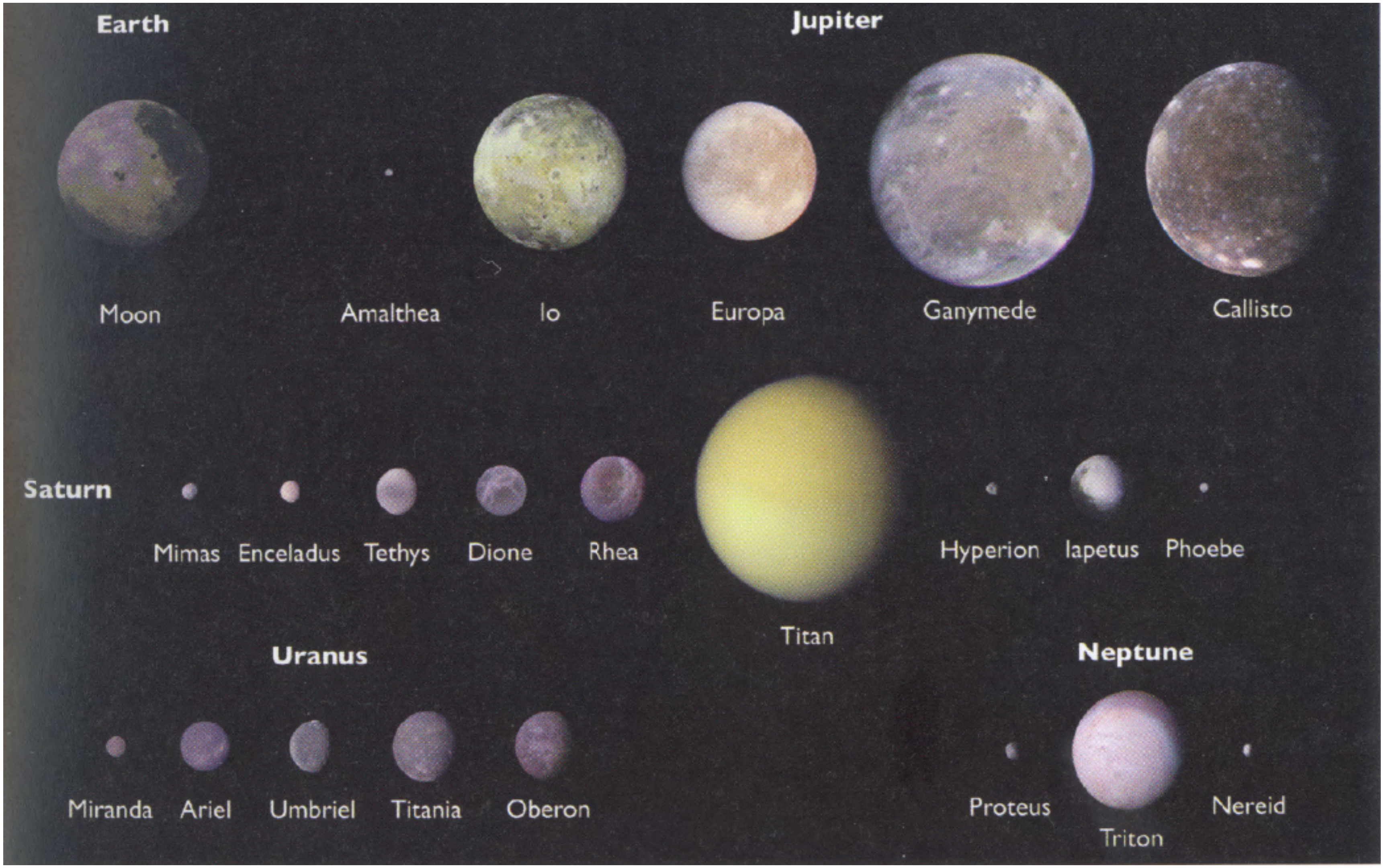
Moons in the solar system



Jupiter’s Galilean moons

Figure 5.73

- Io, Europa, Ganymede and Callisto

Jupiter's Galilean satellites

4 largest ; discovered by Galileo

- Io is innermost ; very few craters

Q: What does this suggest about its geological history ?

It has many active volcanos ; we see them erupting in real time. It is the most geologically active body in the solar system.

— Most of its interior is molten ! —

Heating caused by tidal effects from Jupiter and Europa, whose orbital period is exactly twice that of Io's.

Q. How would this help ?

Body tides on the Earth have amplitude ~ 2 cm.

Body tides on Io are as much as 100 <u>meters</u> !

Colorful regions on Io caused by sulfur compounds.

Black-looking lava is likely molten silicates

S is fairly abundant on Earth but much is tied up in FeS in core

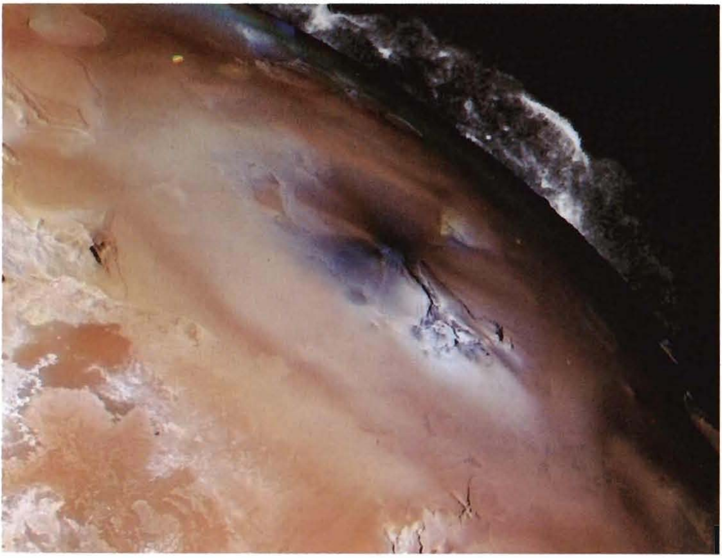


Figure 22. Pele was the first active volcanic event discovered on Io, and it is also the largest yet found. The immense but tenuous plume of dust rises some 300 km above the satellite (the plume's contrast has been enhanced above the satellite's limb). It created a set of concentric yellow and brown rings on the surface roughly the size of Alaska (up to 1,400 km across). The source of Pele's outpourings is the hill-and-valley complex at its center. Ironically, although the volcano was erupting vigorously when Voyager 1 acquired the images used in this mosaic, it had become inactive four months later when Voyager 2 passed by.

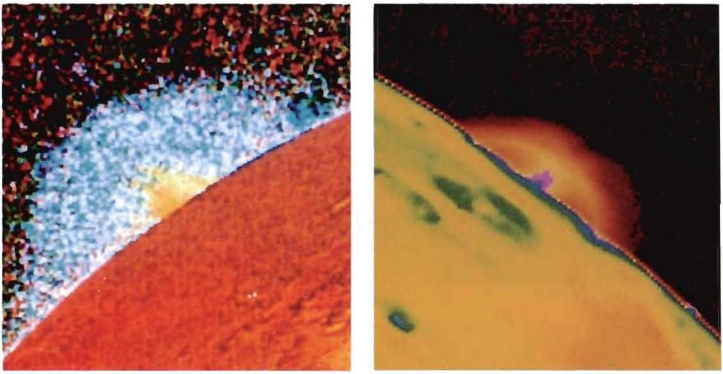


Figure 23. All of Io's volcanoes are not alike. Compare the enormous plume of Pele (Figure 22) with those of Prometheus (left) and Loki (right), shown here in false color at the same scale. These are only 300 and 400 km across, respectively, and represent a smaller, cooler, and longer-lived class of eruptions.

So
fal
las
an
po
I
fea
lik
flu
Pe
thi
de
so
va
I
of
int
by
pri
pro
pro
me
ma
low
Ea
rea
the
un
dee
ma
Sh
wit
the
C
ob
ra
est
yea
an
the
tha
vo
pro
pro
vo
co

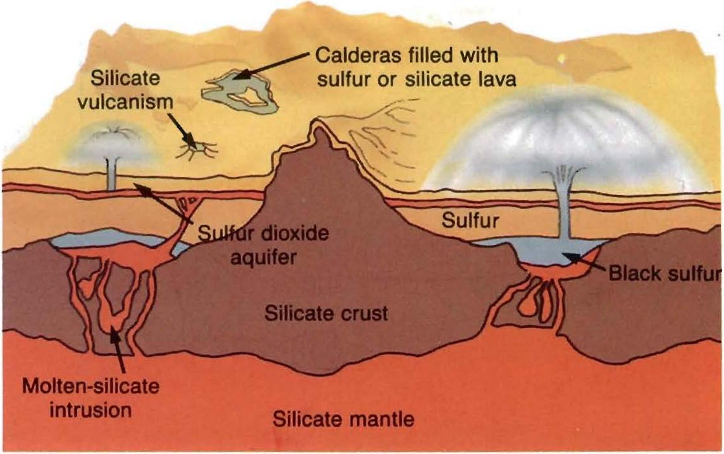


Figure 28. A schematic depiction (not to scale) of most of the major phenomena found on Io. As described in the text, at least three distinct types of active volcanism appear to be reworking the satellite's surface and outer layers of crust.

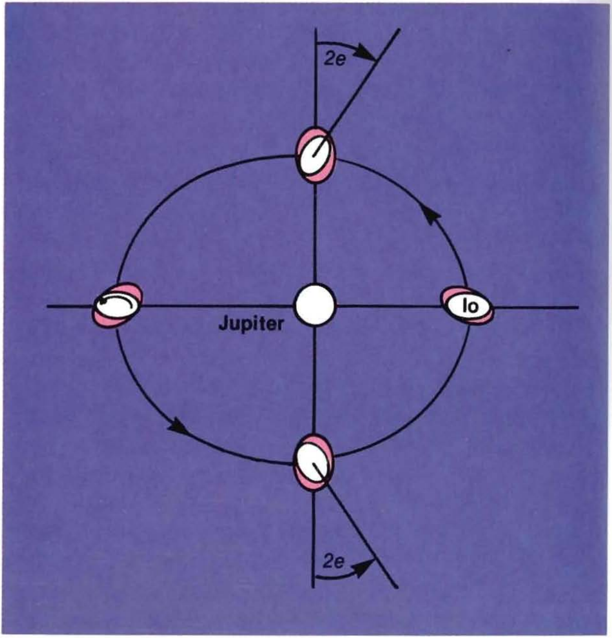
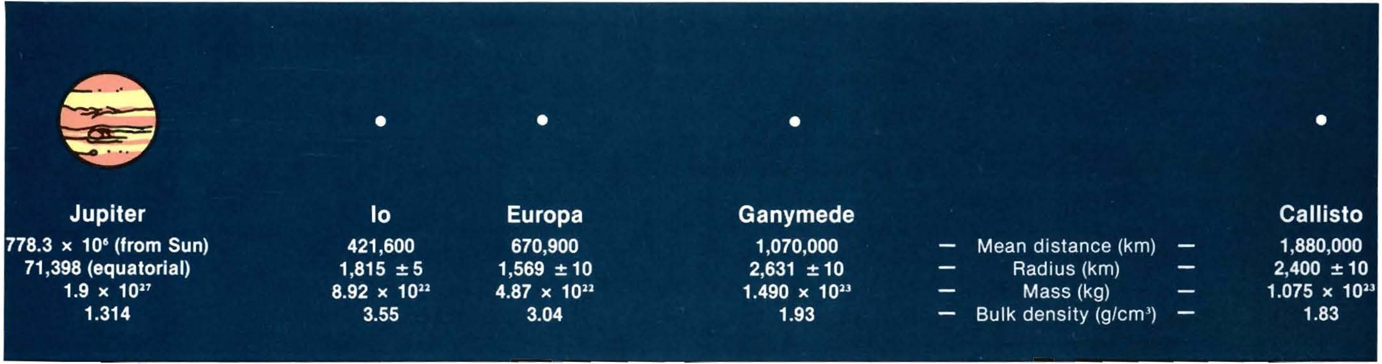


Figure 29. Io's dynamic activity stems from an orbital resonance with nearby Europa that forces Io into a slightly eccentric orbit. Ordinarily, Jupiter's strong gravity would keep one hemisphere of the satellite facing the planet at all times. But the forced eccentricity makes Io move at different velocities along its orbit, and the side facing Jupiter nods back and forth slightly as seen from the planet. Tidal forces develop inside the satellite that generate heat through friction, and much of the interior remains partially molten as a result.

Io, Europa and Ganymede are locked together by tidal forces into a 1:2:4 orbital resonance

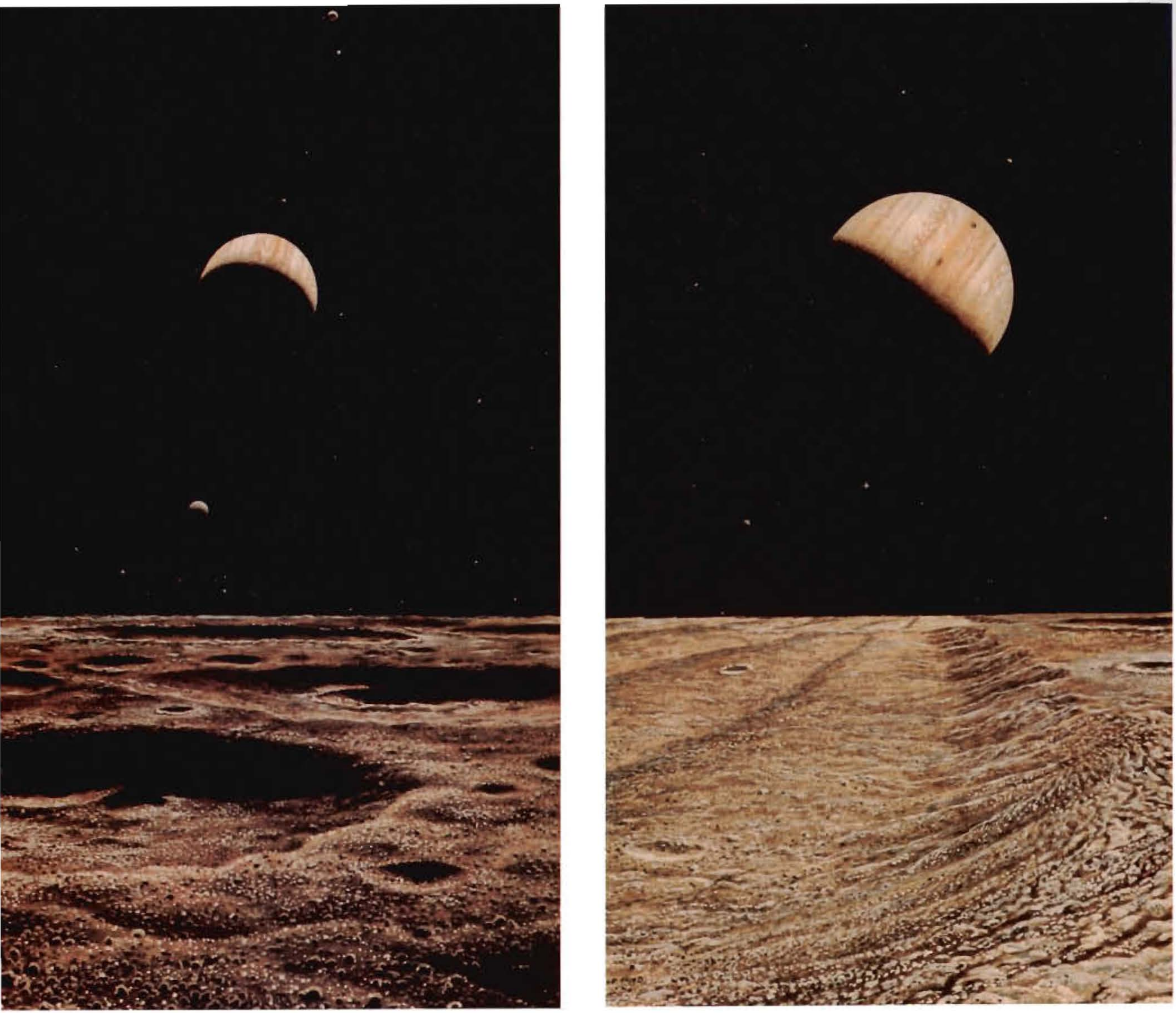
ie Europa's period is twice Io's
Ganymede's is twice Europa's

→ In a few hundred million years, Callisto will be locked in too, with a period twice Ganymede's

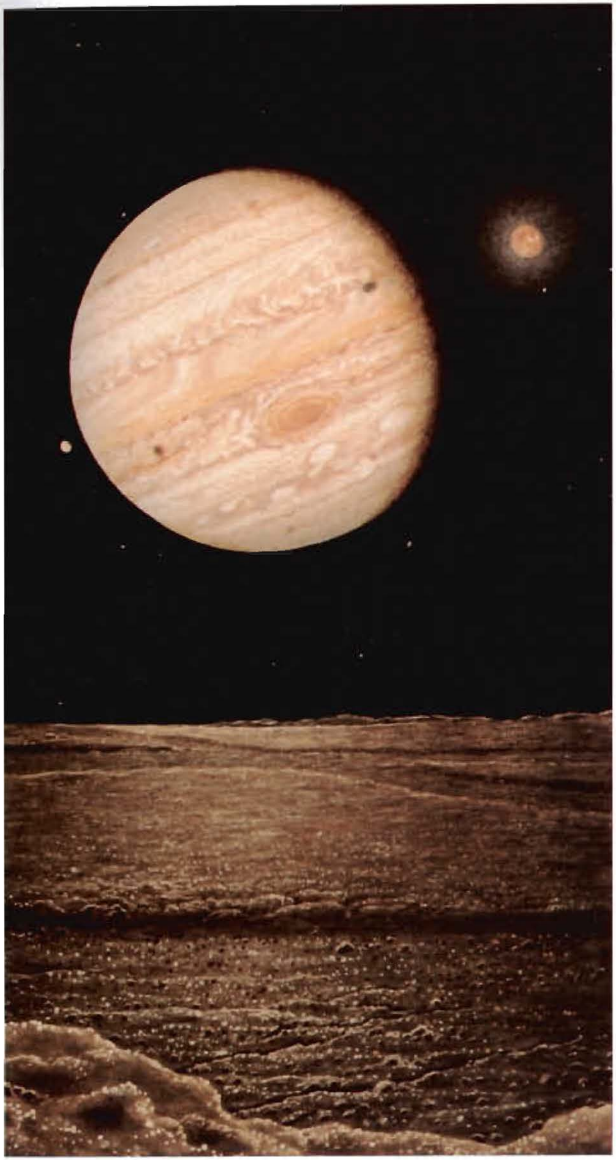


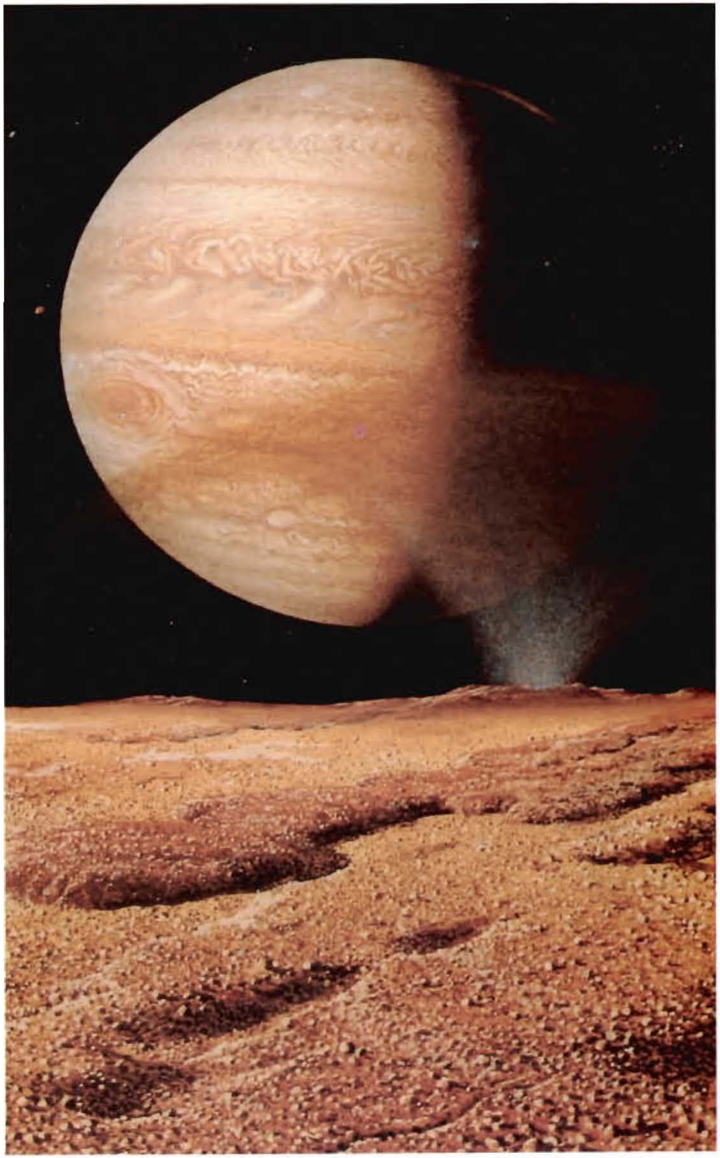
	Jupiter	Io	Europa	Ganymede	Callisto
Mean distance (km)	778.3×10^6 (from Sun)	421,600	670,900	1,070,000	1,880,000
Radius (km)	71,398 (equatorial)	1,815 ± 5	1,569 ± 10	2,631 ± 10	2,400 ± 10
Mass (kg)	1.9×10^{27}	8.92×10^{22}	4.87×10^{22}	1.490×10^{23}	1.075×10^{23}
Bulk density (g/cm³)	1.314	3.55	3.04	1.93	1.83

Figure 1. Jupiter and the distances (but not sizes) of its Galilean satellites are shown to scale. The Galilean satellites are planet-size worlds. Two are roughly the size of Earth's Moon, while Ganymede is bigger than Mercury and the largest satellite in the solar system.



ure 3. What vistas await would-be travelers to the Galilean satellites? Artist Don Davis has rendered these landscapes based on Voyager results. From left to





right are the surfaces of Callisto, Ganymede, Europa, and Io. Each scene shows Jupiter at its correct relative size.

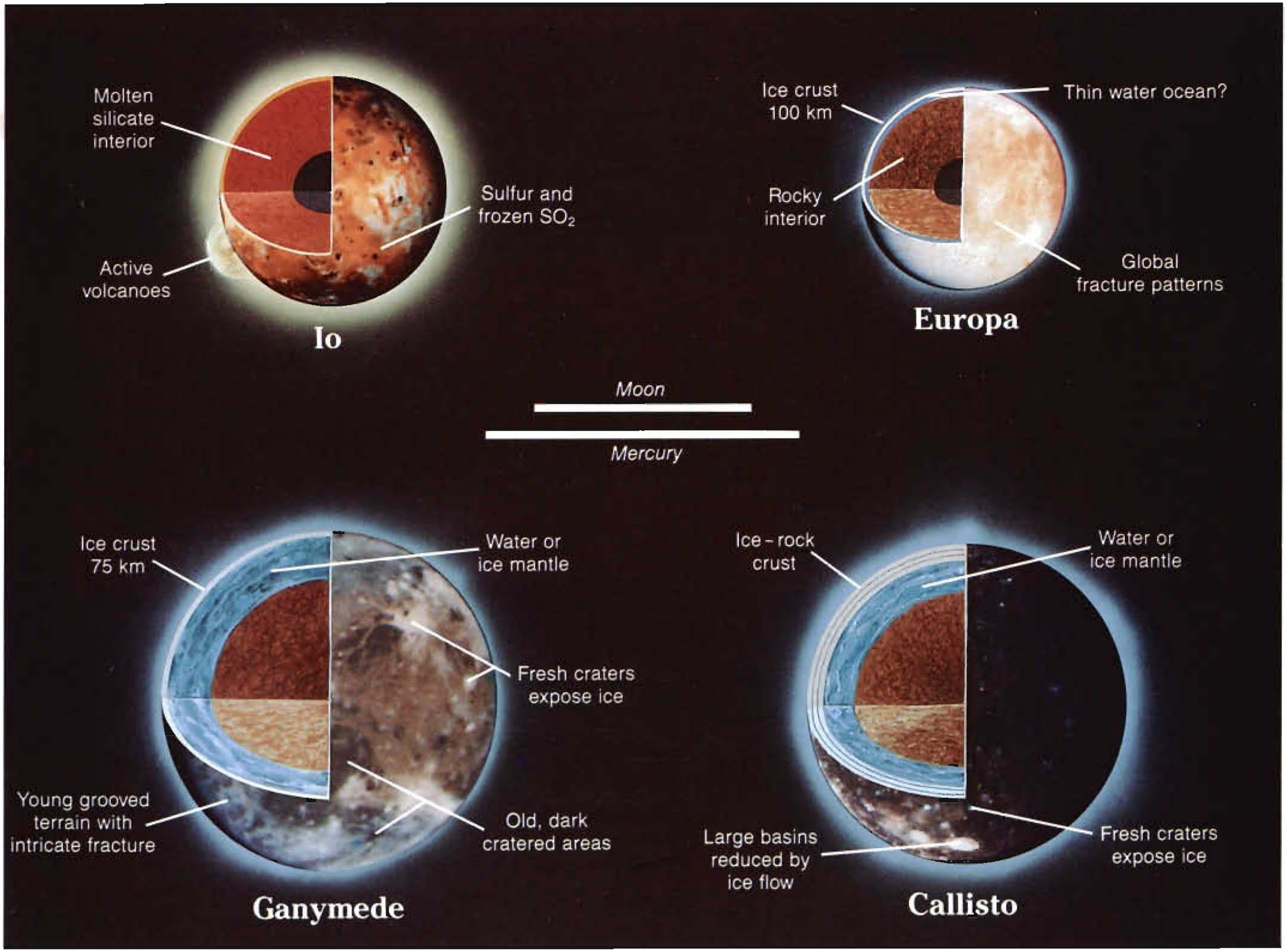


Figure 4. These schematic illustrations portray each satellite's interior as presently understood. Earlier models, based primarily on telescopic observation, were generally confirmed in light of the Voyager findings, though it had been thought that Io's interior was solid and that Callisto's density was somewhat lower. Horizontal scale bars indicate diameters of the Moon and Mercury.

Ring systems

Jupiter, Saturn, Uranus, Neptune have rings

Very flat disks; not solid
- stability argument
- can see through rings

Saturn - bright, made up of icy moonlets
a few meters across, 20,000 km wide
<2 km thick

Uranus - narrow, dark (carbon-contaminated rock?)

smaller particles ~20 cm

Neptune - similar to Uranus

Jupiter - faint ring of <u>dust</u>

~3 microns diameter

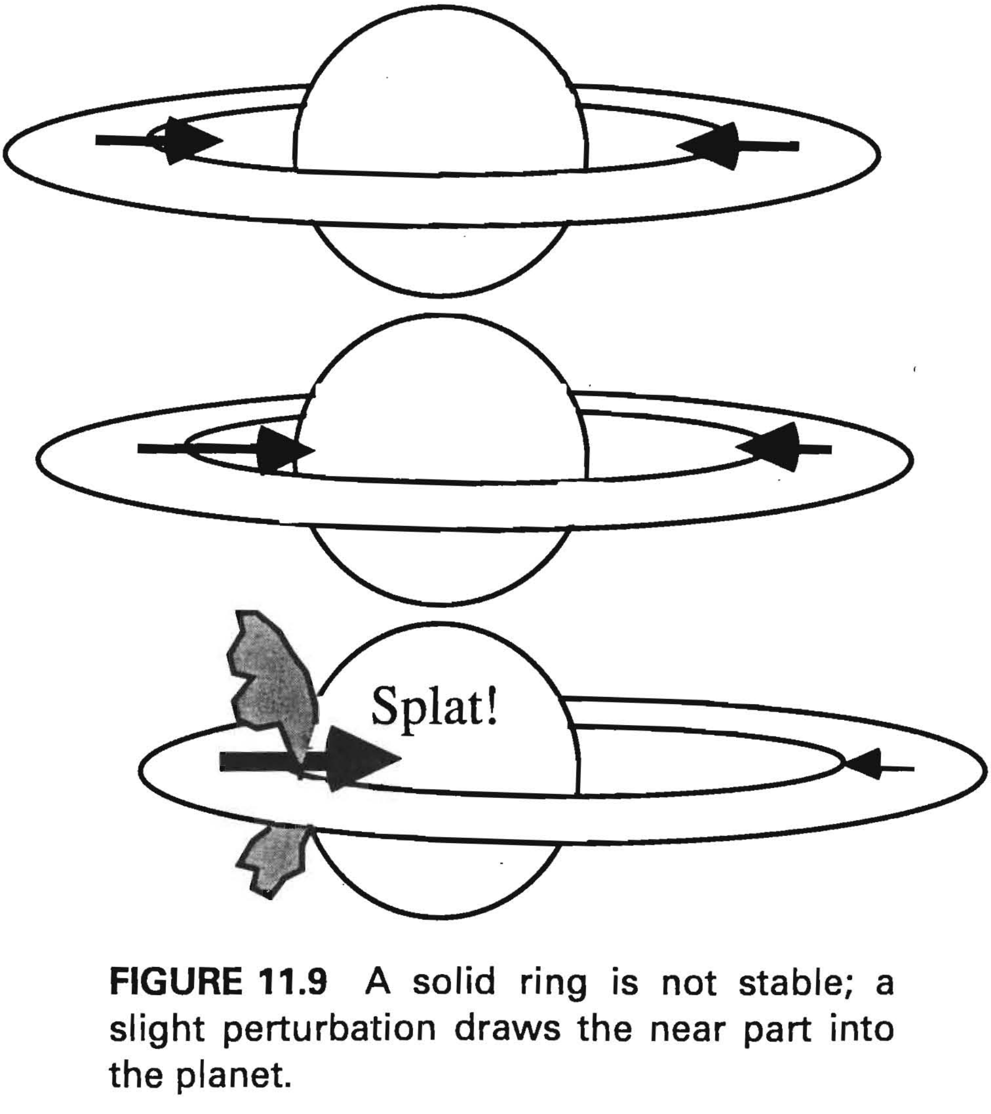


FIGURE 11.9 A solid ring is not stable; a slight perturbation draws the near part into the planet.

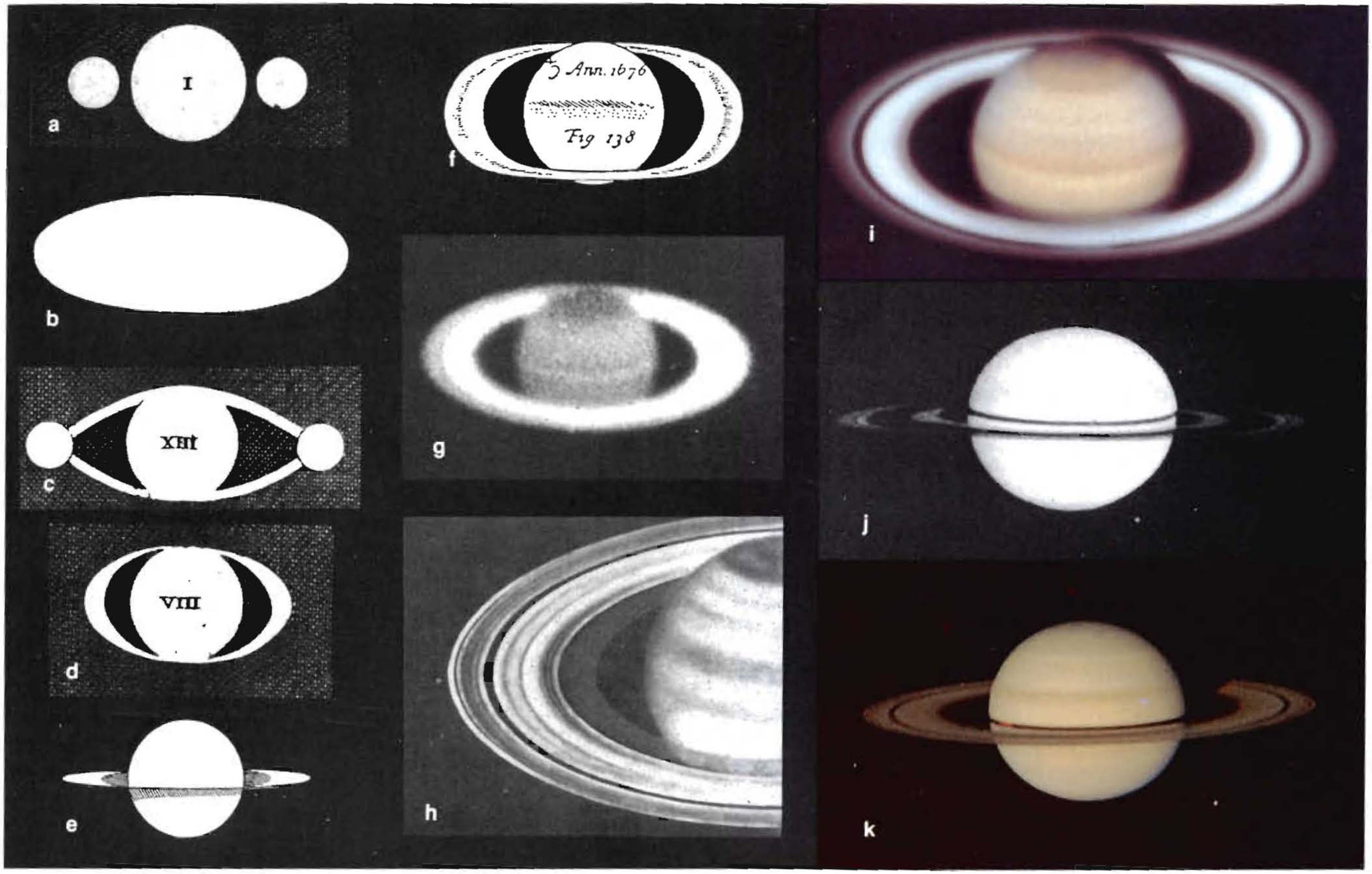


Figure 1. Our view of Saturn's rings has improved remarkably during the past 3½ centuries: *a*, a drawing by Galileo (1610); *b*, a sketch by Gassendi (1634); *c*, Fontana's view (1646); *d*, a drawing by Riccioli (1648); *e*, Huygens' sketch (1655); *f*, Cassini's drawing (1676), showing his division; *g*, first photograph of the rings by Common (1883); *h*, Lyot's diagram (1943); *i*, S. Larson's photograph (1974); *j*, Pioneer 11's (1979) view of scattered light through the rings; *k*, Voyager 1's (1980) contrast-enhanced image of back-scattered light.

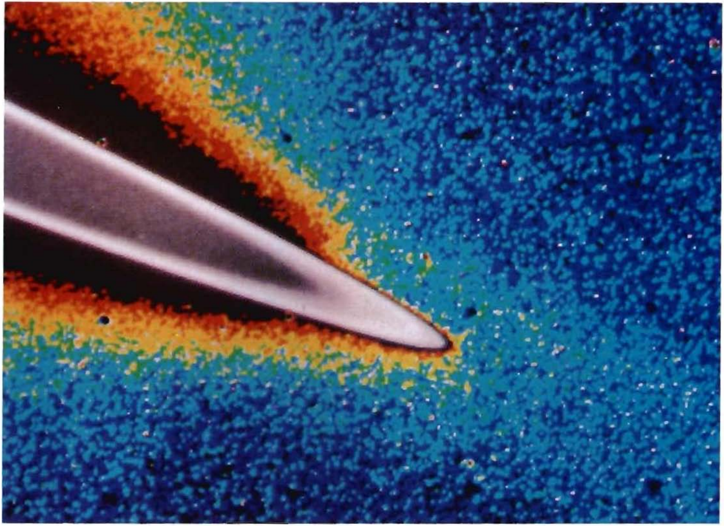


Figure 9. One arm of Jupiter's ring system, as seen by Voyager 2 when in the planet's shadow and color-coded according to brightness. The main ring (the nearly uniform white strip) is the brightest; the halo (outlined in red-yellow) begins at the main ring's inner edge and extends vertically above and below the ring. The gossamer ring (blue-green band) extends outward from the main ring. The mottled background is image noise.

Planets and moons are held together by gravity, not molecular forces such as hold us together

If a moon gets too close to a planet, different parts feel different forces (ie tidal forces) and it is pulled apart

Jupiter's moon Io is almost this close

Tidal forces may also prevent a moon forming close to a planet in the first place

Q Can you think of any other way of studying rings around a giant planet apart from taking images of them ?

Hint : what if they didnt reflect light ?

A If a planet's orbit takes it close to the line of sight to a bright star, we can monitor the brightness of the star as the planet moves in front.

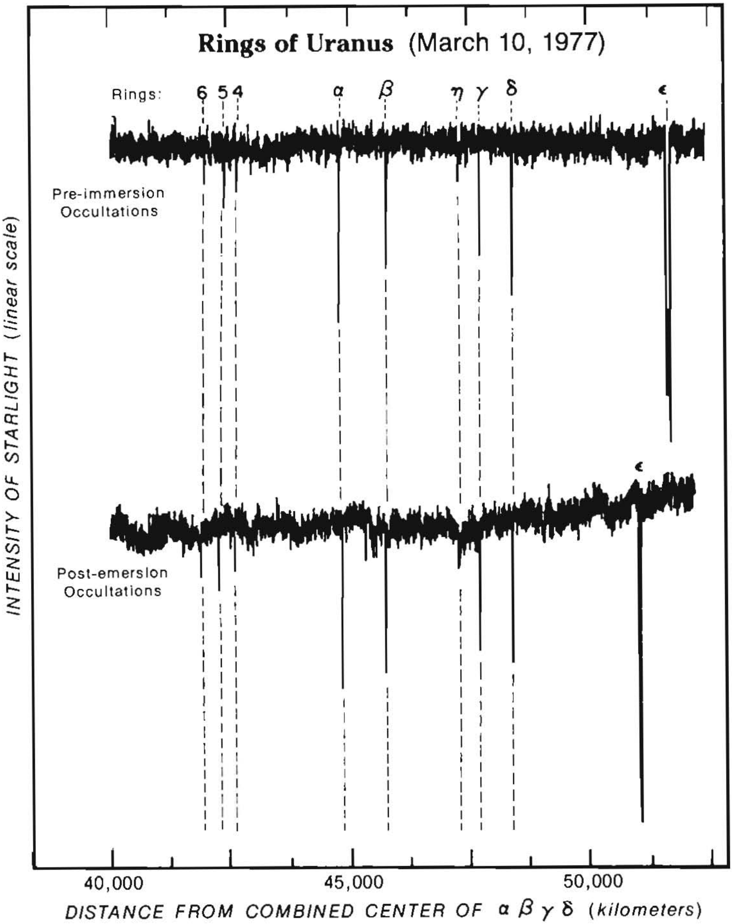
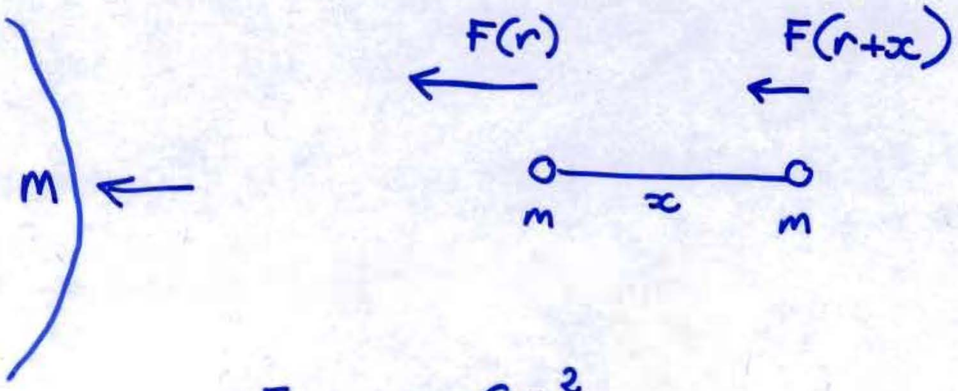


Figure 10. Light from the star SAO 158687 was recorded before (top) and after (bottom) its occultation by Uranus' disk in 1977. Dips in the tracing are due to each of the nine Uranian rings (labeled individually); apparent fluctuations in the star's brightness are caused by system "noise." Note that the starlight is diminished at nearly the same distances on either side of the planet, implying the rings are nearly circular. Most rings obscure the star very well and rather abruptly, so they must be quite opaque and have well-defined edges. But to have these properties, small satellites must exist nearby to prevent the rings from spreading. Ring ε is the most eccentric and shows different widths on the two sides of the planet.

The Roche limit

attractive force holding 2 masses m together:



$$F_{att} = \frac{G m^2}{x^2}$$

$$\text{Tidal force} = F(r+x) - F(r)$$

$$= \frac{dF}{dr} \cdot x$$

$F(r)$ due to mass M $= \dfrac{G m M}{r^2}$

So $\dfrac{dF}{dr} = -\dfrac{2 G M m}{r^3}$

So Tidal force $= -\dfrac{2 G M m x}{r^3}$

The Roche limit is where $F_{att} = F_{tidal}$

$$\frac{2 G m M x}{r^3} = \frac{G m^2}{x^2}$$

$$\frac{2M}{r^3} = \frac{m}{x^3} \qquad (*)$$

mass of particles $= 2m$

volume occupied $\sim x^3$

So $\rho_{moon} \simeq \frac{2m}{x^3}$

Substituting in $(*)$, $\rho_{moon} \simeq \frac{4M}{r^3}$

or Roche limit at $r \simeq \left(\frac{4M}{\rho_{moon}}\right)^{1/3}$

If density of moon $\simeq$ density of planet

$$\rho_{planet} = \frac{M}{\frac{4}{3}\pi R_{planet}^3}$$

$r \simeq \sqrt[3]{16}\, R_{planet}$ or $2.5\, R_{planet}$

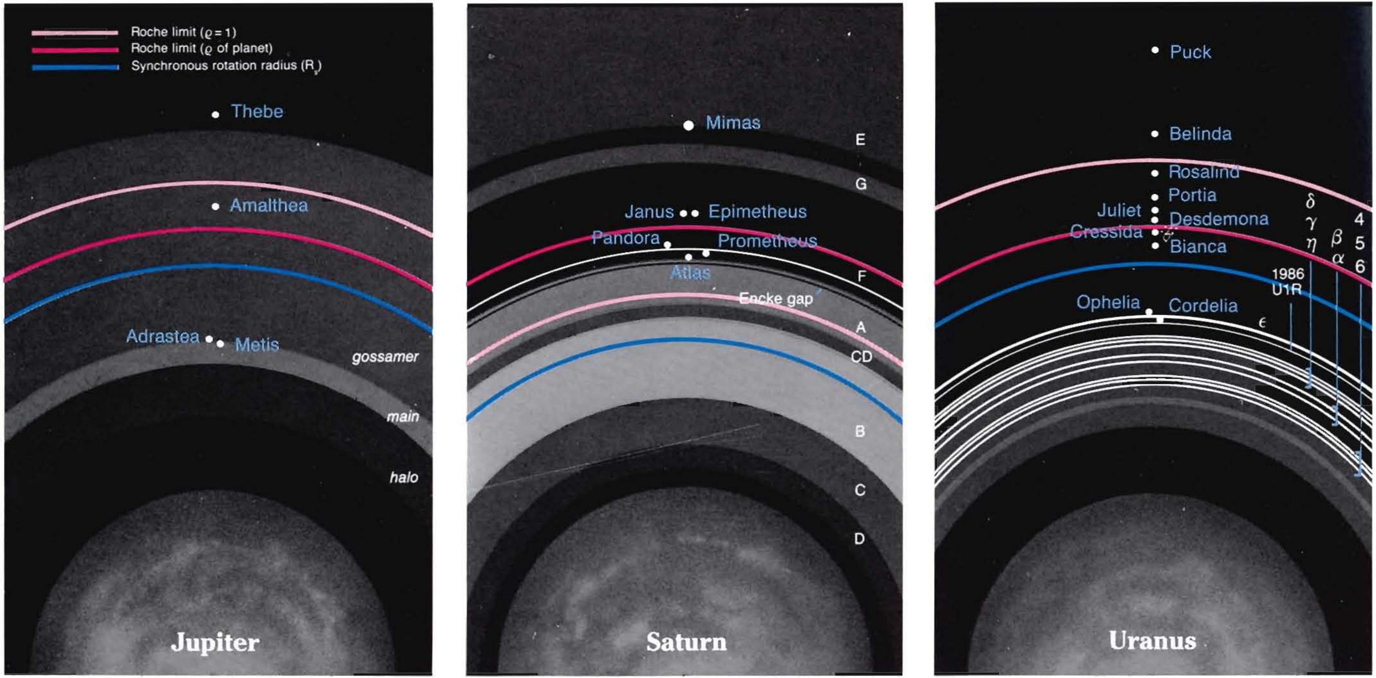


Figure 7. The known planetary ring systems are compared by making the planets' radii all the same size. Illustrated here are the distribution of ring material, nearby satellite locations, the synchronous-orbit radius R_s, and the Roche distances for satellites having either the density of 1 g/cm^3 (that of water) or the density of the planet.

Q Saturn's rings also show 'spokes' that appear to rotate with the rings. Why can this not be so?

A The rings are not solid bodies but collections of particles that orbit according to Kepler's laws So outer rings orbit more slowly than inner ones.

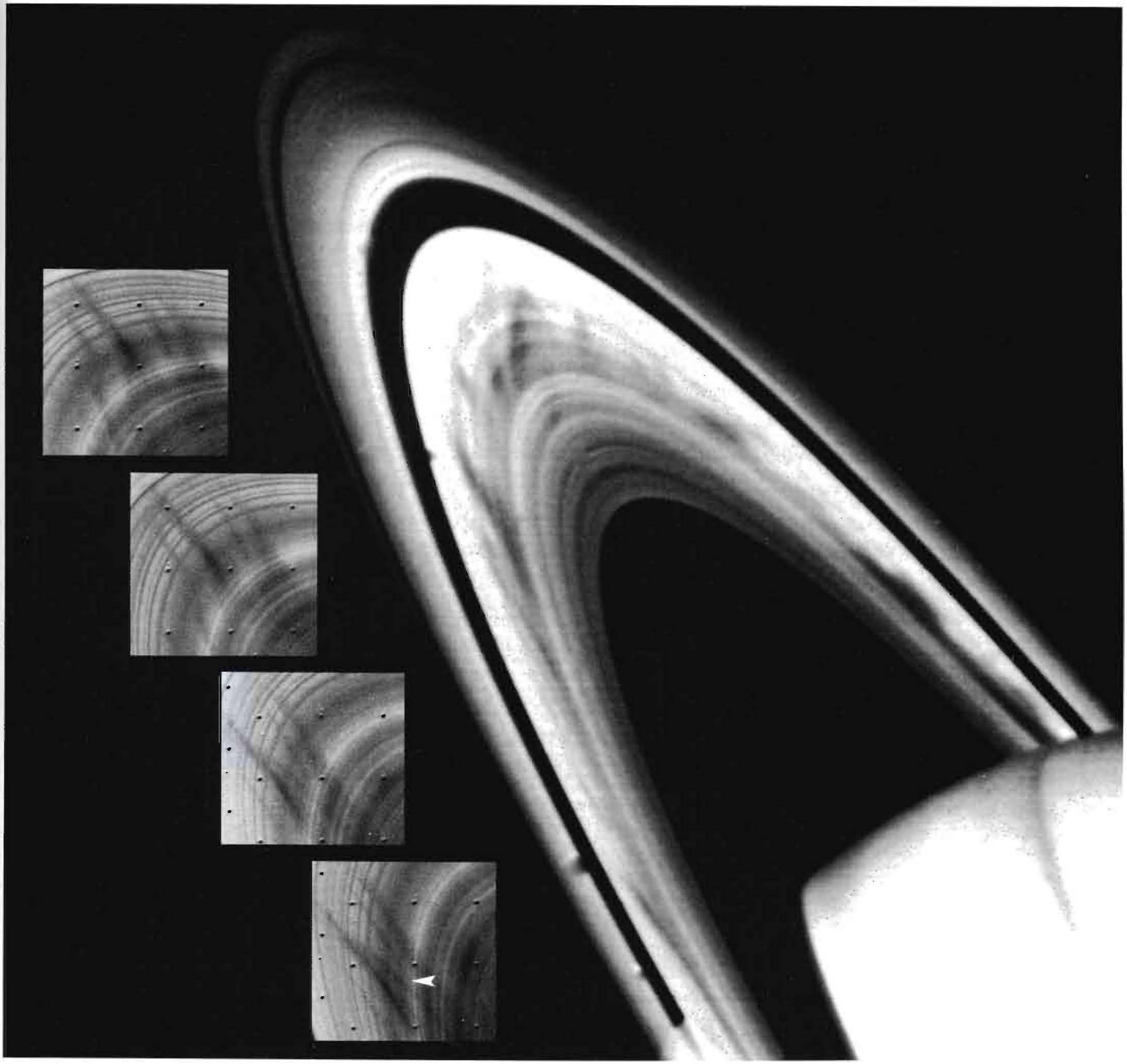


Figure 25. The dark, shadowy fingers known as "spokes" in Saturn's B ring occur sporadically in time, with a preference toward the morning ansa. Depending on illumination and viewing geometry, their brightness changes relative to their surroundings (for example, seen here in back-scattered light they appear dark); this indicates that spoke regions are areas of enhanced dustiness. The insets show the swift formation of a new, radially aligned spoke (arrow in last panel) among a number of already-existing ones in the center of the B ring over a span of 35 minutes. (The regularly spaced black dots are reference marks used for geometric calibration of the imaging system.)

It is thought that the spokes may be small charged dust particles that levitate off larger ring objects & rotate according to Saturn's magnetic field

Other features of ring systems :
gaps such as Cassini division in Saturn rings.

Moons clear out regions via resonances & spiral density waves

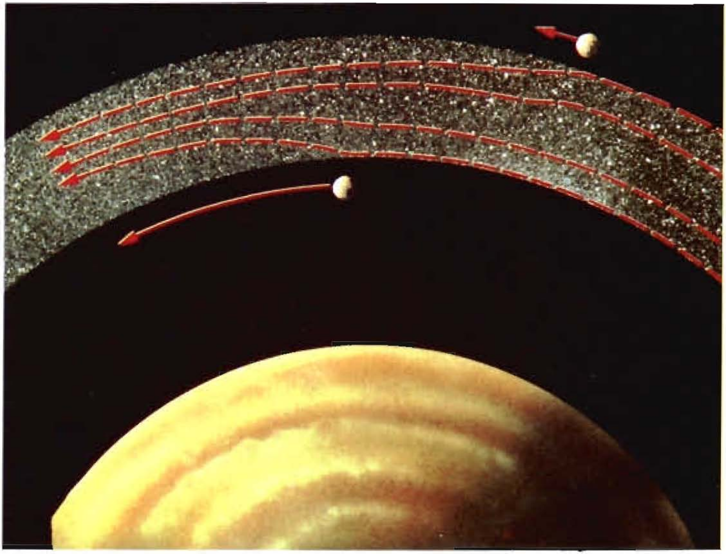


Figure 6. The Goldreich-Tremaine model for constraining narrow rings employs "shepherd satellites" that force a group of particles to travel along narrow paths. Moving slower than the ring inside it, the outer satellite attracts particles going by. This force is slightly greater after particles have passed the satellite, because in slipping past it their paths have been pulled somewhat closer to the shepherding object (not shown). This extra force causes them to lose energy and "fall" closer to the planet, as shown by the red dashed lines. Conversely, the faster-moving inner satellite adds energy to nearby particles and kicks them onto higher orbits. Together, these forces herd the particles into a narrow ring. The same process can explain how an embedded satellite could cause a ring system to spread apart.