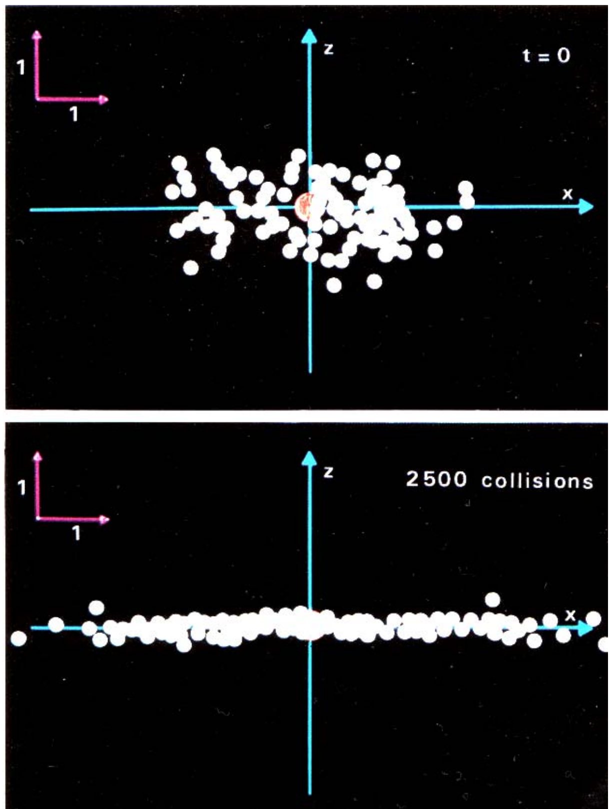
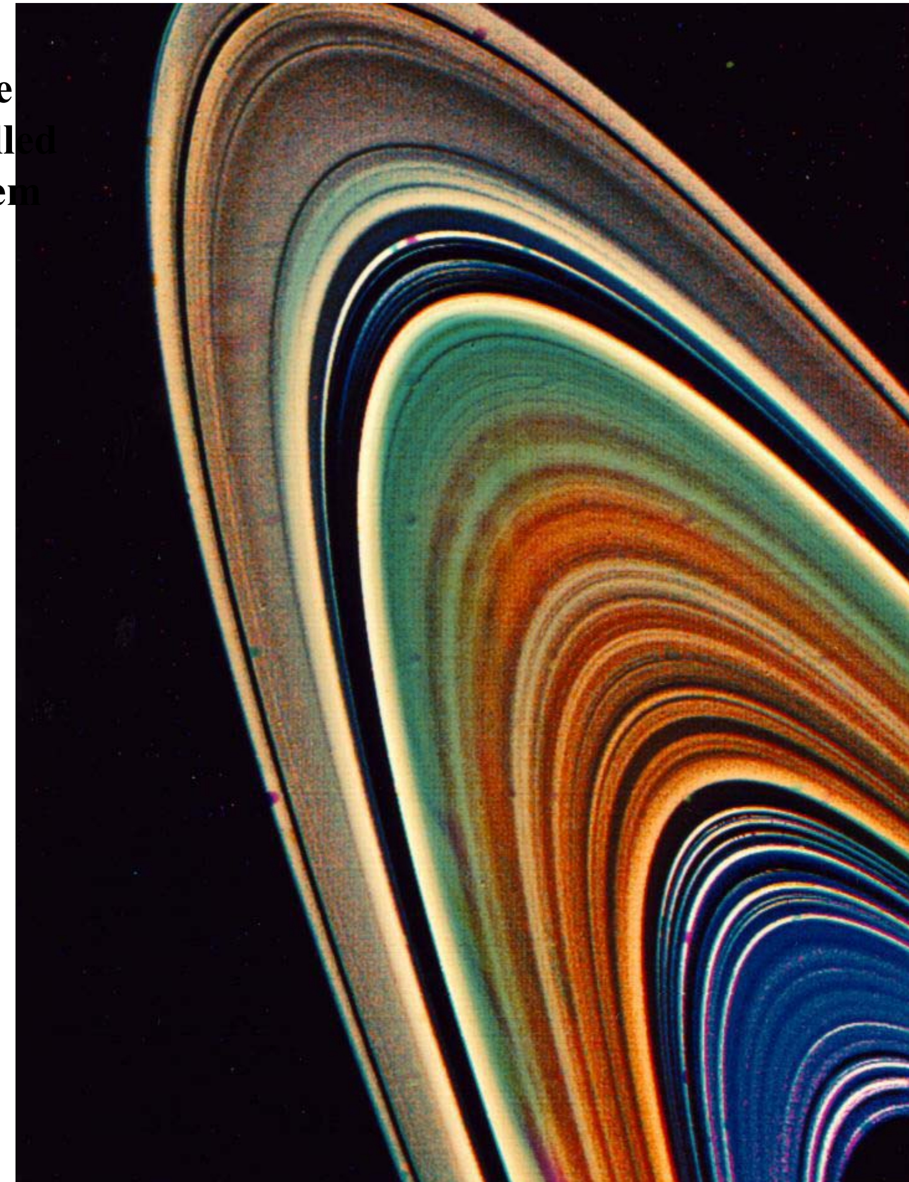
PHYSICAL MECHANISMS in SATURN'S RINGS

BELOW: colour differences between the different rings, strongly exaggerated- these differences indicate differences of chemical composition- which have apparently remained segregated over a very long time.

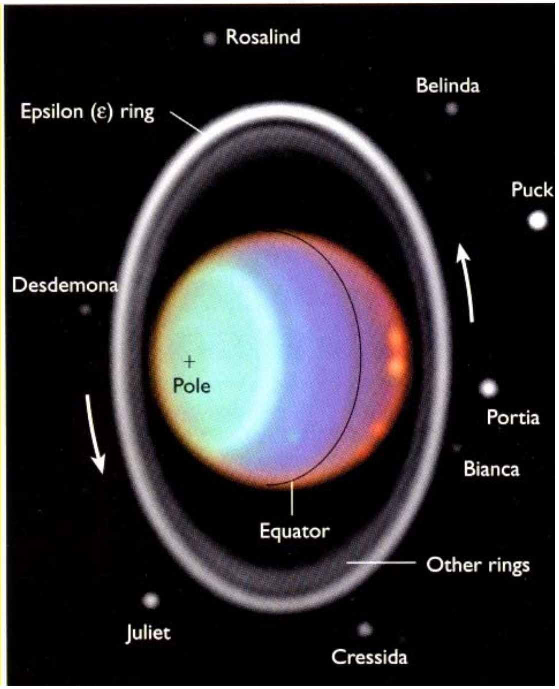
The rings exist because any large body which is close enough to Saturn (inside the Roche limit) will be pulled apart by tidal forces. Collisions then rapidly pull them into the plane of their net angular momentum. This explains their existence but not their fine structure.



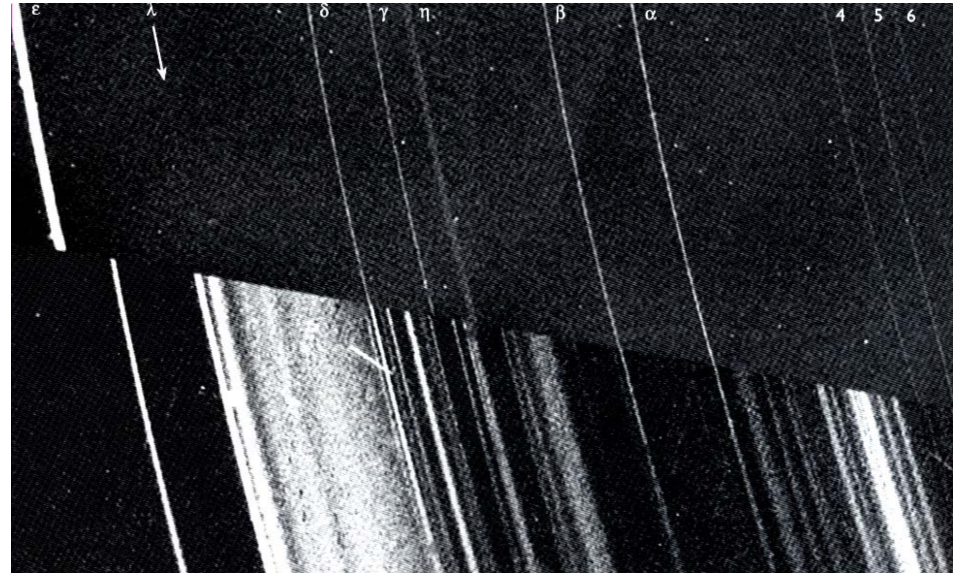
Simulation of orbiting particles in time



Other PLANETARY RINGS



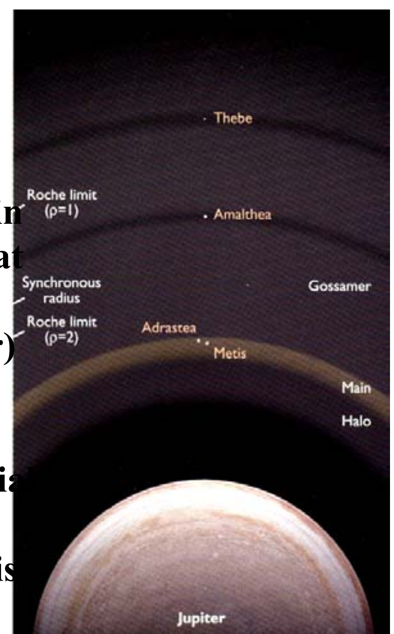
Hubble photo of Uranus rings



ABOVE: Rings of Uranus in (a) scattered (b) transmitted light

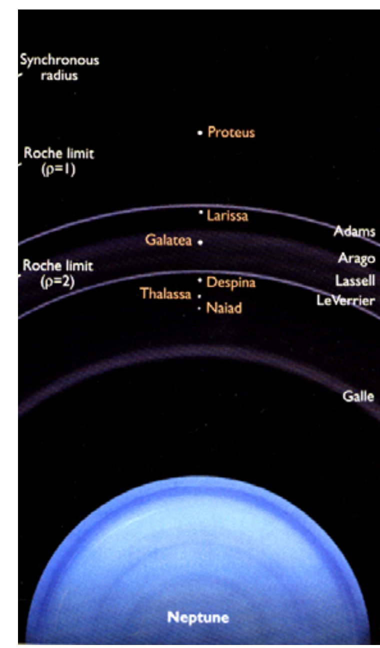
We now know that all the giant planets possess ring systems. They are all aligned in their planetary equatorial planes- since that of Uranus is tilted at 98° from the solar system plane (defined by the sun's equator) we can see its rings side-on. The rings of Uranus are more extensive than those of Jupiter or Neptune, but all are insubstanti relative to those of Saturn. The role of satellites in shepherding these other rings is Clear, just as with Saturn's rings.

Rings of Jupiter



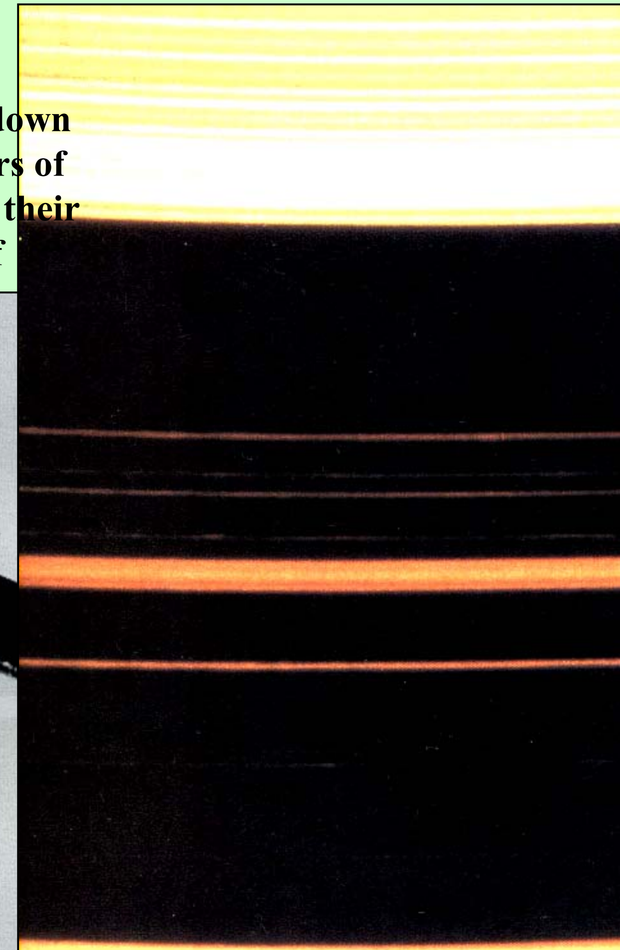
Rings of Uranus

Rings of Neptune

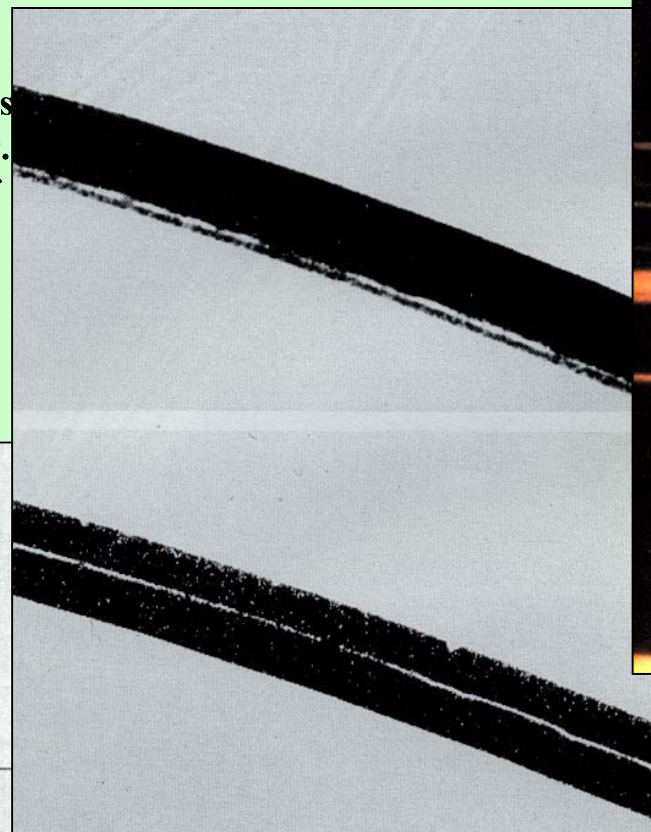


CLOSE-UP of the RING GAPS

The detailed structure in the rings is quite fantastic. Here we see structure down to scales much less than 1 km- and yet one sees filaments in which vast numbers of ring particles appear to follow identical orbits in a coherent way- even though their mutual gravitational interactions are quite negligible compared to the effect of Saturn's moons. This structure is most easily discerned in the gaps, where we also see that the orbits of these filaments or the gap edges, aren't always circular. Even more amazing is that the orbits of the filaments and ringlets vary in time, & yet they maintain their coherence.

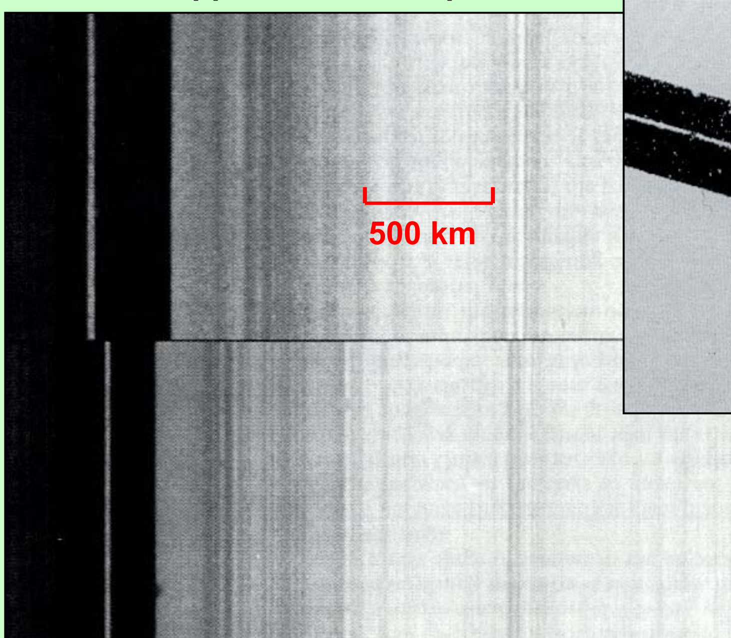


ABOVE: close-up of Encke gap, showing v fine ringlet structure



LEFT: Voyager photos of Encke gap on opposite sides of planet

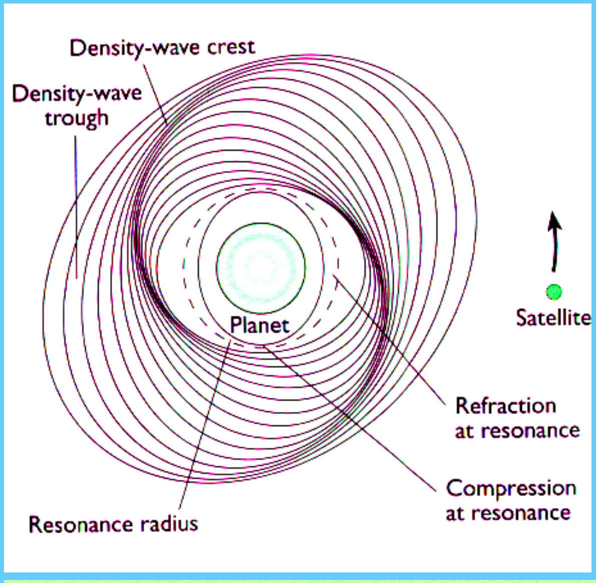
Voyager photos of inner edge of Cassini division, on opposite sides of planet



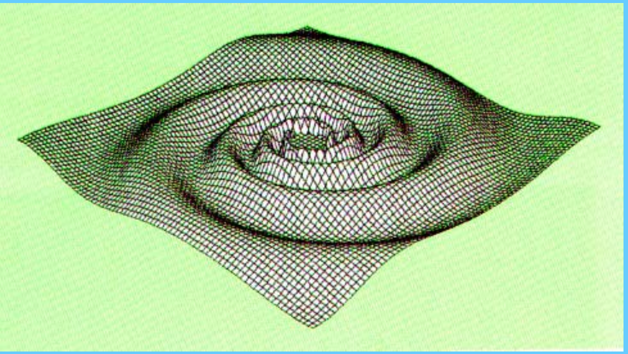
The smallest structures one sees in these ringlets and filamen perhaps 50-100 m (in occultation photos taken through the rin This is not much larger than the size of the largest objects in th rings, which is believed to be roughly 10 m.

WAVES in SATURN'S RINGS

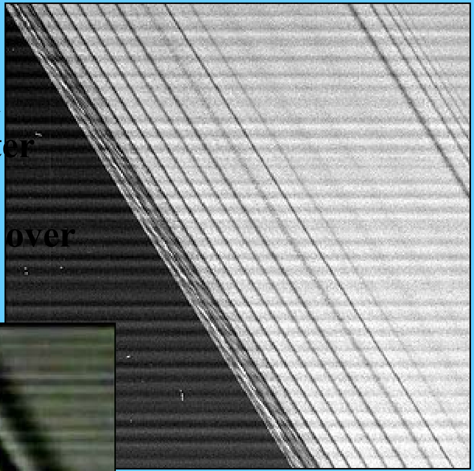
One of the best understood phenomena in the rings is the presence of density waves, and also of spiral distortions of the rings. These are not like density waves in condensed matter or gases, caused by interactions- they are caused by perturbations from satellites which push the ring particles into slightly elliptical orbits, causing "bunching" of the particles- over time the weak excess gravity from these bunches produces waves (similar waves exist in galaxies). Collisions inside these bunches also prevent the elliptical orbits from closing- this can clear gaps in the rings at or near any resonance with a satellite, because the particles then lose energy and angular momentum and move inwards.

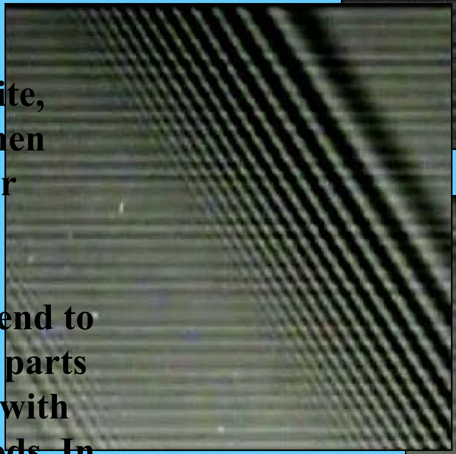


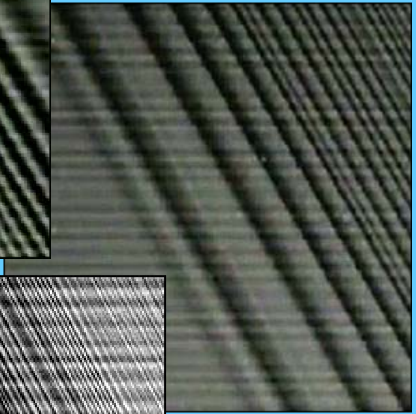
Different satellites tend to start waves at different parts of the rings, coinciding with different resonant periods. In some cases waves can be seen propagating in and out from the same region.

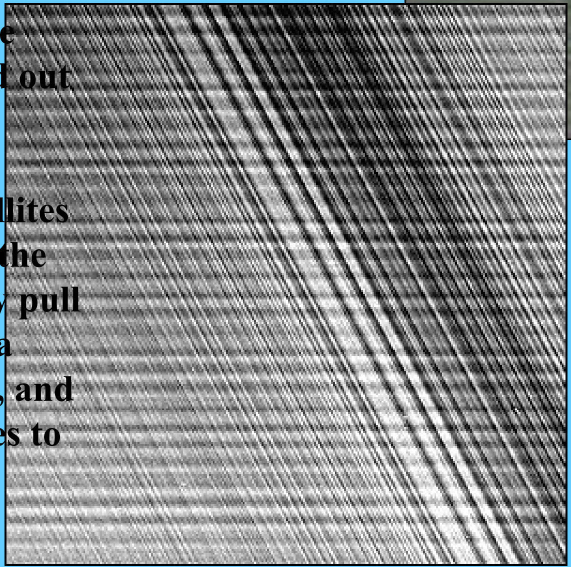


The Saturnian satellites are not all exactly in the same plane- thus they pull the rings away from a completely flat plane, and cause distortion waves to propagate (see left).





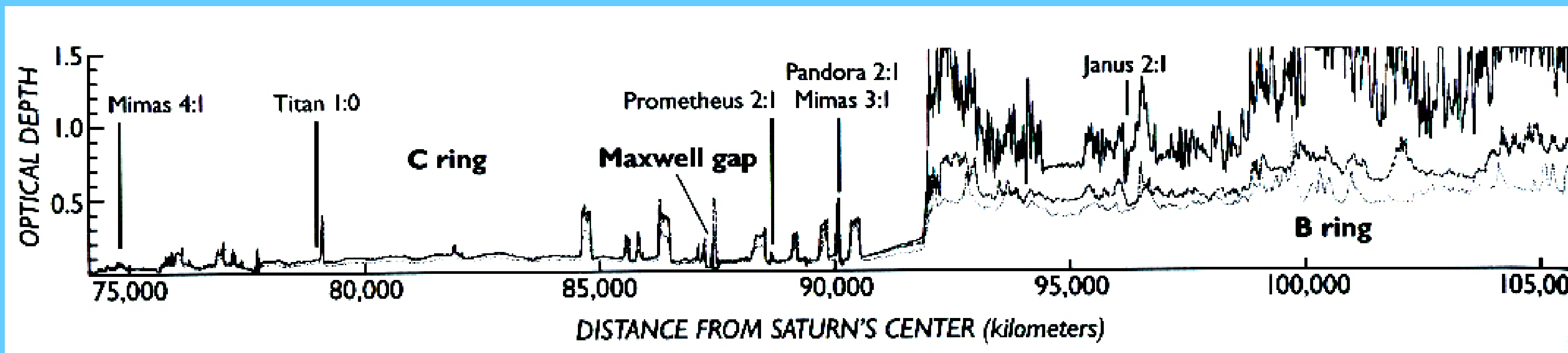




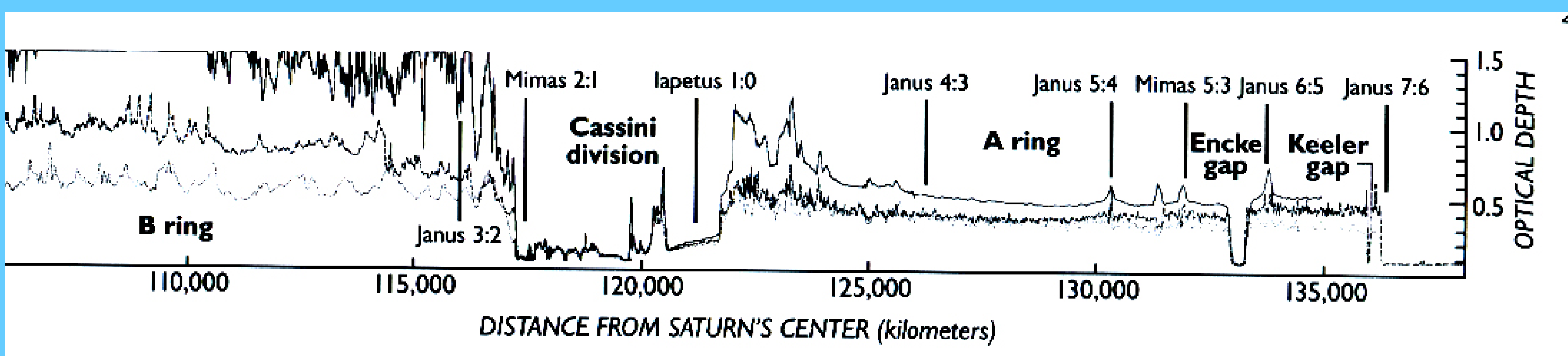
High resolution Voyager 2 photos of waves in rings. These photos are less than 1000 km across.

RESONANT INTERACTION with SATELLITES

A map of the optical density of the rings (defined by how much light gets through them) reveals much. Thi below for different wavelengths. If one converts the distances to orbital periods one immediately notices th gaps and excess concentrations of ring particles (ie, ringlets) often correspond to fractions of the periods o satellites- a sure sign of resonant interactions with these (via gravitational forces).



We see that the bulk of the ring particles are contained in the B ring- you can amuse yourself by matching features on these maps with those in the photos. The most important resonant interactions are with the satellite Mimas, and the moonlets Janus, Epimetheus, Pandora, and Prometheus- all of these are not far outside the rings, and the moonlets have orbits only a few thousand km larger than the outer edge of ring A. Satellites further out only have an obvious effect if they are large (like Tethys, Dione, Rhea, and Iapetus- and of course the massive Titan). For details see the next slide.



KEY DATA on SATURNIAN SYSTEM

This is but a small part of what we know about the Saturnian system- a few facts about the most important moons, plus the innermost moonlets (there are at least 50 other moons & moonlets now known).

Satellites of Saturn

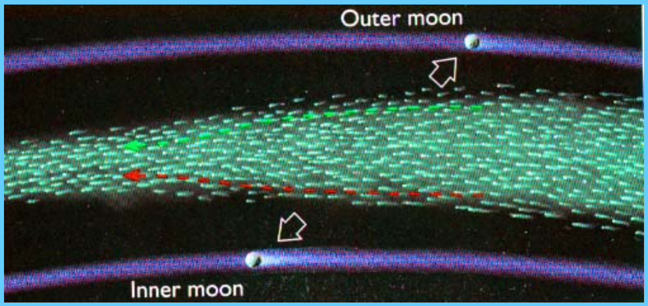
Name	*Discoverer(s)*	*Year of discovery*	*Magnitude (V_0)*	*Mean distance from Saturn's center (km)*	*Sidereal period (days)*	*Orbital inclination (°)*	*Orbital eccentricity*	*Radius (km)*	*Mass (g)*	*Mean density (g/cm^3)*
Pan	M. Showalter	1990	(19)	133,583	0.575	(0)	(0.0)	(10)	?	?
Atlas	R. Terrile	1980	18.0	137,640	0.602	(0)	0.003	18 × 14	?	?
Prometheus	S. Collins and others	1980	15.8	139,350	0.613	(0)	0.002	74 × 34	1.4×10^{20}	0.27
Pandora	S. Collins and others	1980	16.5	141,700	0.629	(0)	0.004	55 × 31	1.3×10^{20}	0.42
Epimetheus	R. Walker and others	1966	15.7	151,422	0.695	0.34	0.009	69 × 53	5.5×10^{20}	0.63
Janus	A. Dollfus	1966	14.5	151,472	0.695	0.14	0.007	99 × 76	2.0×10^{21}	0.65
Mimas	W. Herschel	1789	12.9	185,520	0.942	1.53	0.020	199	3.7×10^{22}	1.12
Enceladus	W. Herschel	1789	11.7	238,020	1.370	0.02	0.004	249	6.5×10^{22}	1.00
Tethys	G. Cassini	1684	10.2	294,660	1.888	1.09	0.000	529	6.1×10^{23}	0.98
Telesto	B. Smith and others	1980	18.5	294,660	1.888	(0)	(0)	15 × 8	?	?
Calypso	D. Pascu and others	1980	18.7	294,660	1.888	(0)	(0)	15 × 8	?	?
Dione	G. Cassini	1684	10.4	377,400	2.737	0.02	0.00	560	1.1×10^{24}	1.49
Helene	P. Laques, J. Lecacheux	1980	18.4	377,400	2.737	0.2	0.01	16	?	?
Rhea	G. Cassini	1672	9.7	527,040	4.518	0.35	0.00	764	2.3×10^{24}	1.24
Titan	C. Huygens	1655	8.3	1,221,850	15.945	0.33	0.03	2,575	1.34×10^{26}	1.88
Hyperion	W. Bond	1848	14.2	1,481,100	21.277	0.43	0.10	185 × 113	?	?
Iapetus	G. Cassini	1671	10.2–11.9	3,561,300	79.330	7.52	0.03	720	1.6×10^{24}	1.0
Phoebe	W. Pickering	1898	16.4	12,952,000	550.48	175.3	0.16	115 × 105	?	?

To this one can add data deduced from optical density & spectral mmts of the rings. We see that the rings came from a body which had a mass exceeding 3.6 x 10^{25} g, and had a diameter of perhaps 2,800-3,000 km (our moon has a mass of 7.35 x 10^{25} g, and a diameter of 3476 km).

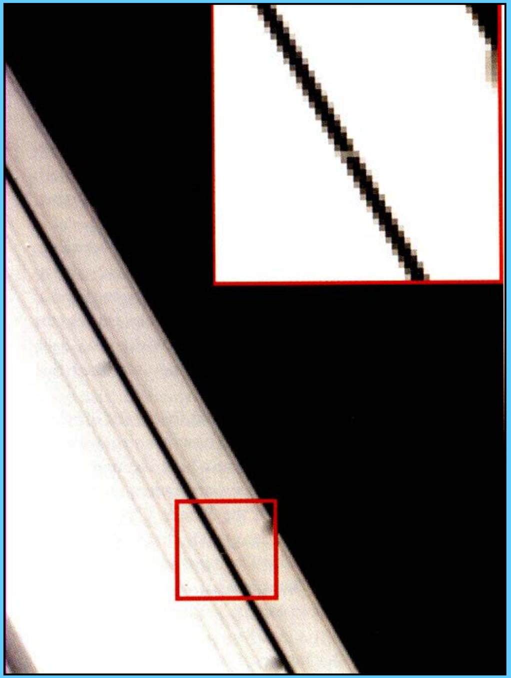
Rings of Saturn

Name	*Distance from Saturn's center (R_S)*	*(km)*	*Radial width (km)*	*Thickness (km)*	*Optical depth*	*Total mass (g)*	*Albedo*
D	1.11–1.24	66,000–73,150	7,150	?	(0.01)	?	?
C	1.24–1.52	74,500–92,000	17,500	?	0.05–0.35	1.1×10^{24}	0.12–0.30
Maxwell gap	1.45	87,500	270				
B	1.52–1.95	92,000–117,500	25,500	0.1–1	0.8–2.5	2.8×10^{25}	0.5–0.6
Cassini division	1.95–2.02	117,500–122,200	4,700	?	0.05–0.15	5.7×10^{23}	0.2–0.4
A	2.02–2.27	122,200–136,800	14,600	0.1–1	0.4–0.5	6.2×10^{24}	0.4–0.6
Encke gap[13]	2.214	133,570	325				
Keeler gap	2.263	136,530	35				
F	2.324	140,210	30–500	?	0.01–1	?	0.6
G	2.72–2.85	164,000–172,000	8,000	100–1,000	10^{-6}	10^{20}	?
E	(3–8)	(180,000–480,000)	(300,000)	15,000	10^{-5}	?	?

The ROLE of SHEPHERD SATELLITES



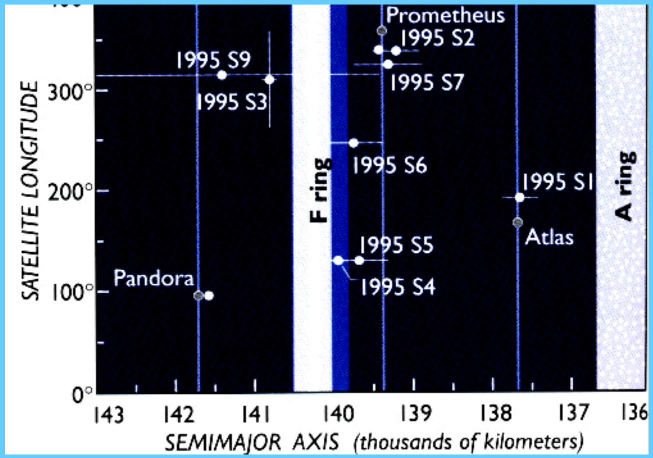
Focussing of ring particles by pair of moons in a ring system



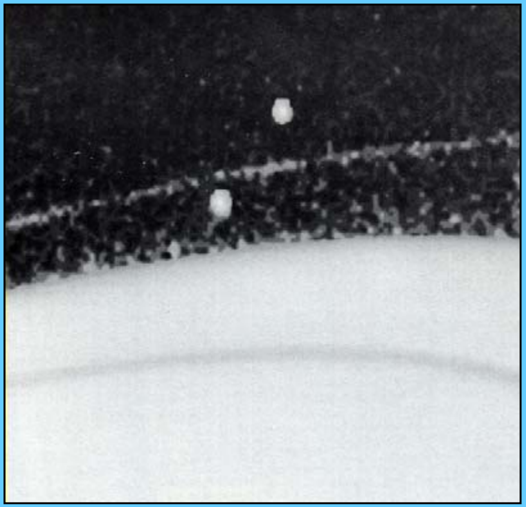
Discovery of the ring-moon Pan (diameter 20 km) in the Encke gap

The existence of fine filamentary ringlets led to the development of another theoretical idea- that PAIRS of moonlets could together create filamentary structures, as well as waves in these filaments (below right). Paradoxically, the effect of one or more satellites can be to *confine* the rings, instead of spreading them- the effect of creating elliptical orbits, followed by waves & collisions, is to focus a previously broad ring into a narrow one, and to create gaps and edges in the ring structure. The abrupt outer edge of the rings is caused by the tiny moonlets just outside it.

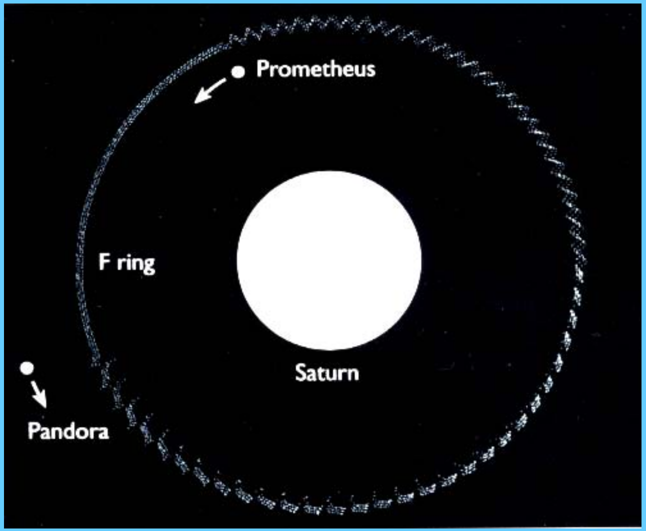
In the same way a clump or tiny moonlet inside the ring system itself can create a gap. The hypothesis that this caused the 500-km wide Encke Gap led to a search of 30,000 photos, & the discovery of the moonlet Pan.



Positions of the shepherd moonlets



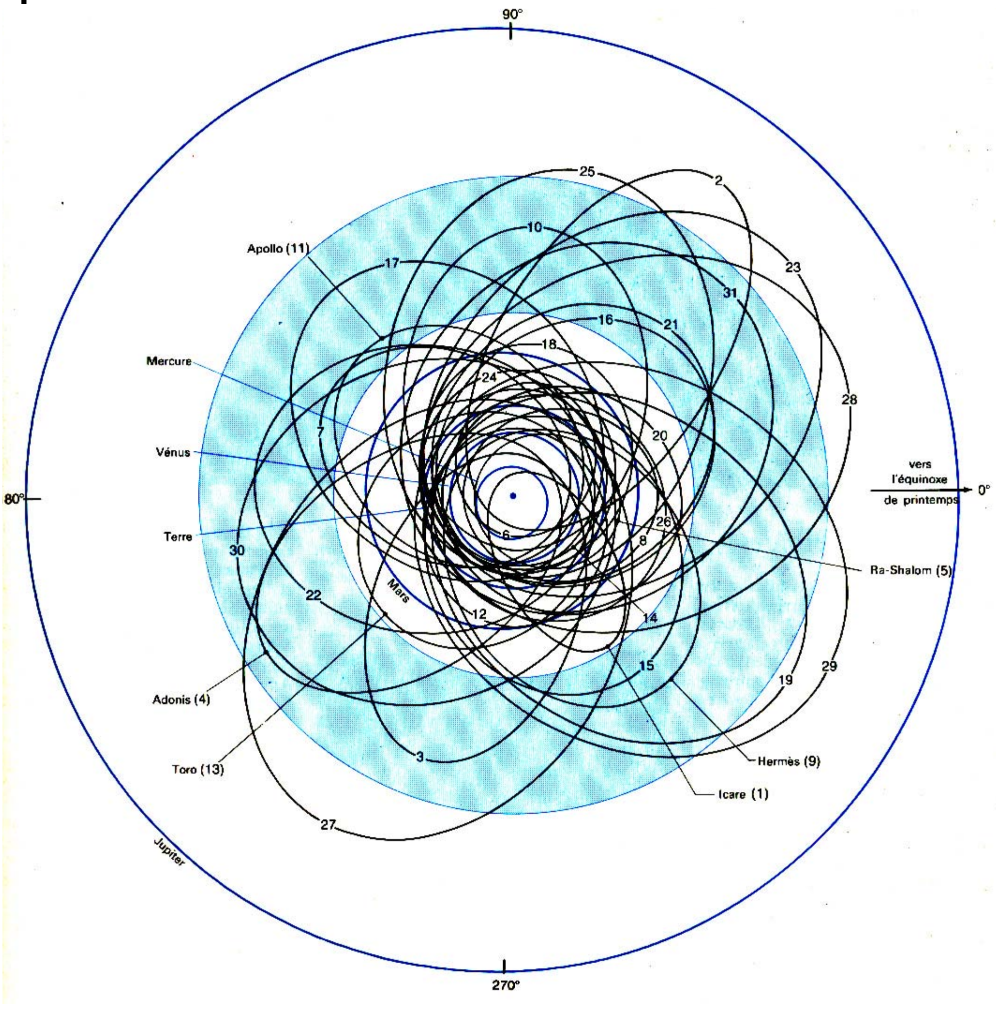
Shepherding of F ring by mini-satellites Pandora & Prometheus

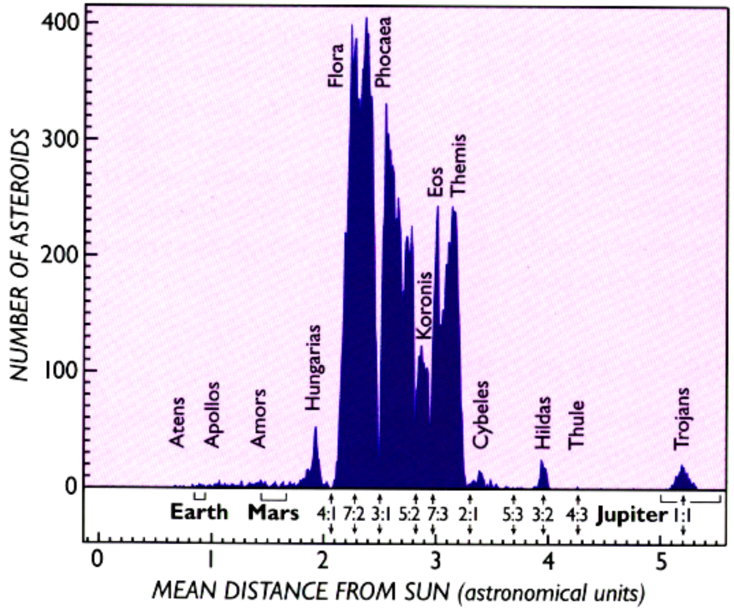


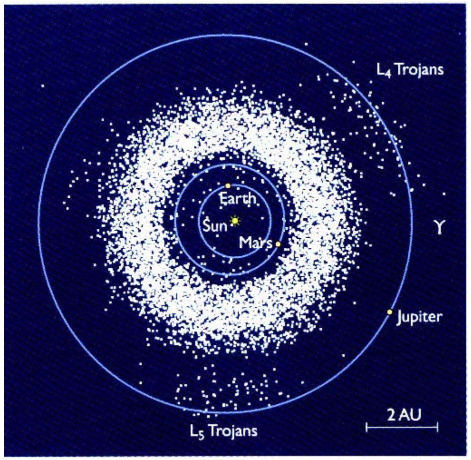
Waves in F ring generated by shepherds

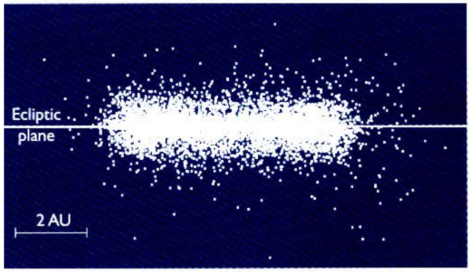
STRUCTURE of ASTEROID ORBITS

These orbits are typically highly elliptical, show a strong concentration near the planetary plane, with mean orbital radius concentrated in the range 2-3 AU; & yet, very strong resonant interaction with Jupiter is shown in the orbital periods.

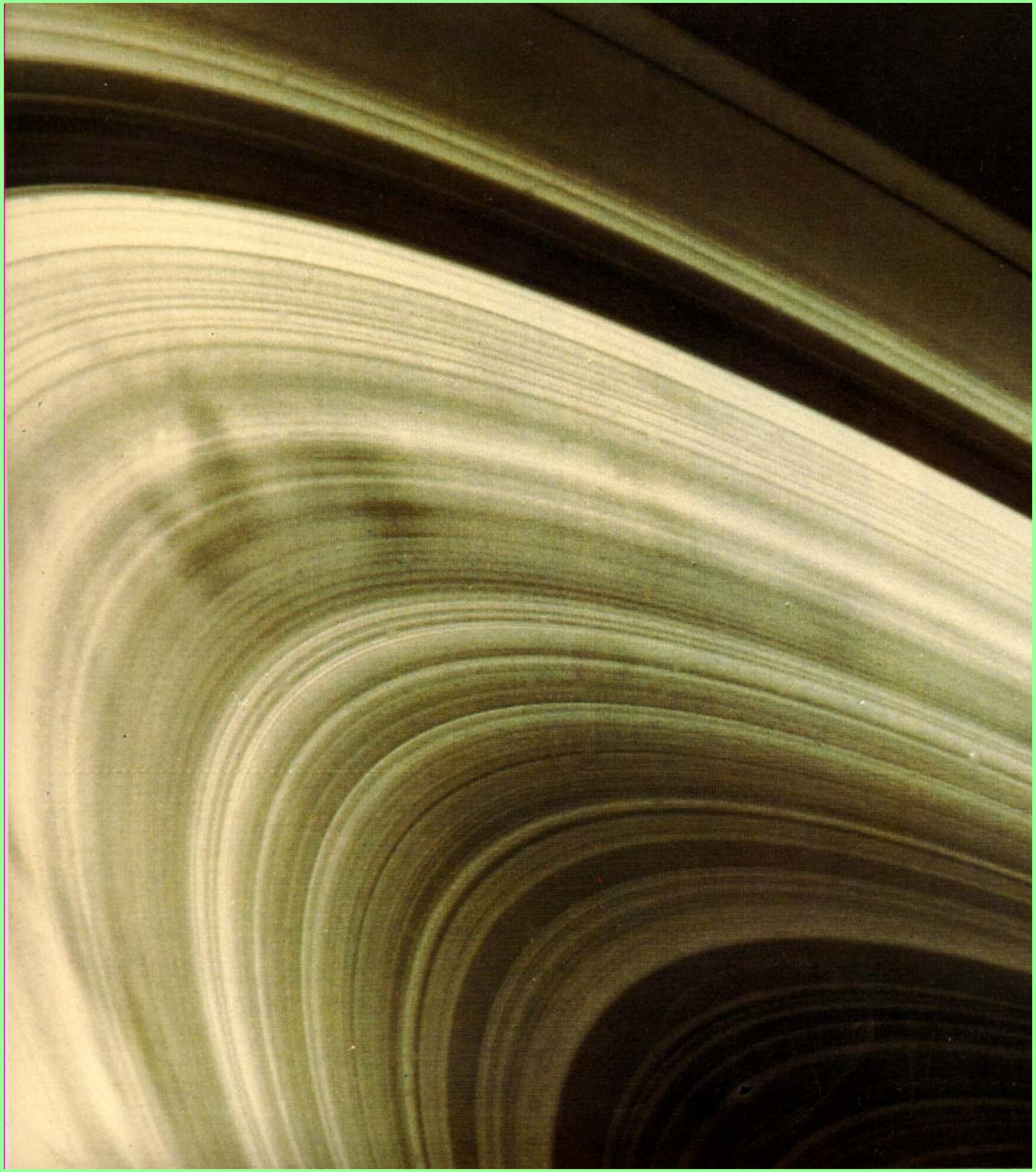








ELECTROMAGNETIC PHENOMENA



"Spokes" observed by Voyager 2 in 1981, in the B ring.

A dramatic discovery of the Voyager 2 probe was the presence of very large (10,000 km) & rapidly-varying (10-20 mins) radial patterns moving accross the rings, now called 'spokes'. These are patterns of dust in interaction with rapidly-moving magnetic fields, which lift the dust for brief periods off the ring plane. The patterns (but not the dust) move at up to 15 km/s (500,000 km/hr) relative to the ring particles.

The dust cannot last for long in the rings- the interaction with fields, radiation, and the solar wind cause dust particles to spiral into the planet. They are continually being replenished by collisions between the ring particles, which range in size from 1-2 cm up to 10 m, with an inverse power law distribution of sizes.

The rings particles are mainly dirty snowballs, with changes of composition as one moves radially out- indicating very long-term stability in the gross ring structure.

Incredibly, the rings are apparently only a few tens of metres thick, although they are slightly deformed by waves and by Interaction with Saturn's rings. If the rings were scaled to the size of greater Vancouver, they would be as thick as rice paper!