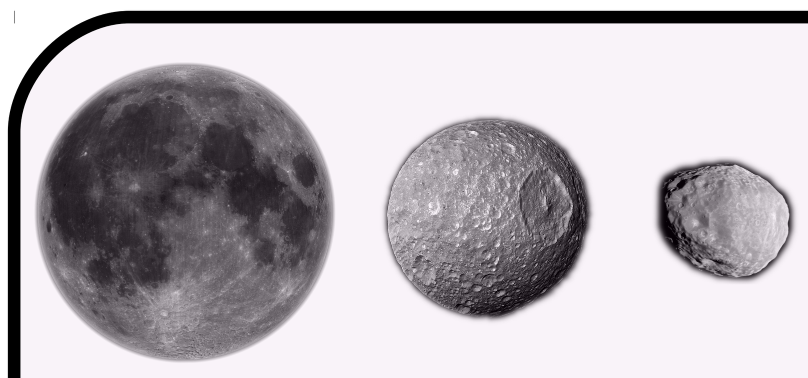
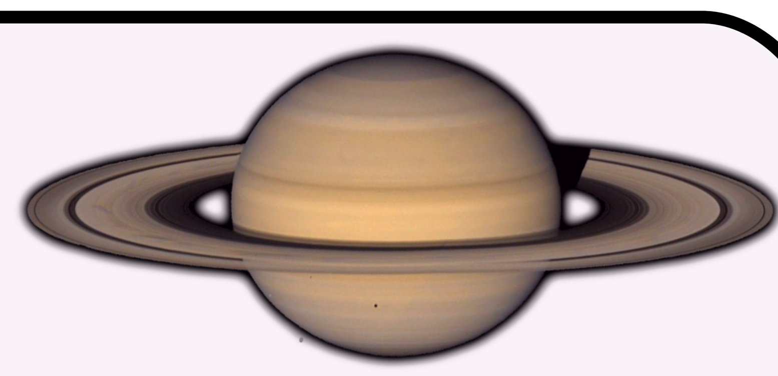


Satellite formation
from ancient massive rings



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Context : A *tidal disk* (disk of solids around a planet, in which tides prevent accretion) spreads beyond the Roche radius r_R. What happens ?

Result : First, 1 satellite accretes all the incoming material, until a critical mass. Then, a series of satellites form, migrate, and merge.

Conclusion : This ***analytical*** model explains the structure of Saturn's system, but also applies to Uranus, Neptune... and the Earth !

Prerequisites and notations :

$q = M_{satellite} / M_{planet}$, $D = M_{disk} / M_{planet}$, **r** = satellite's orbital radius, T_R = orbital period at r_R.

$\Delta = (r-r_R)/r_R$, F = the flux of material crossing r_R (assumed constant), $\tau_d = M_{disk} / (F\, T_R)$.

Due to interactions with the disk, a satellite migrates outwards, at a rate proportionnal to $qD\Delta^{-3}$.

(Lin & Papaloizou 1979, Goldreich & Tremaine 1980)

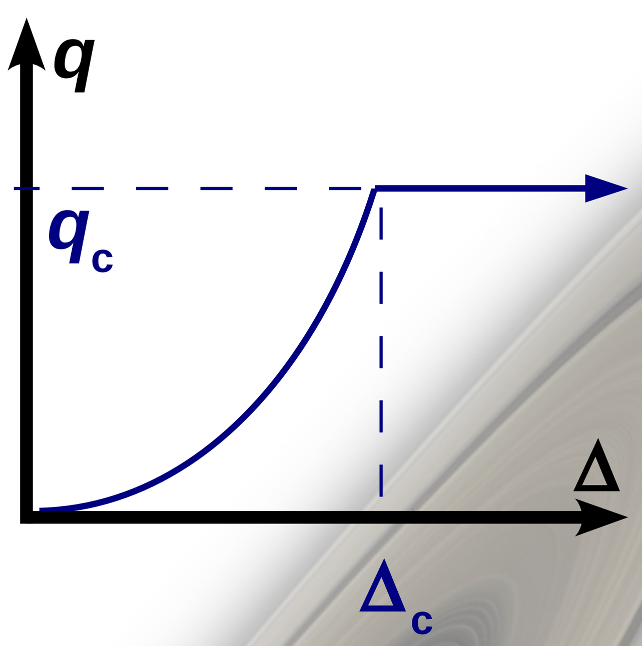
Continuous regime :

The first body forms by gathering all the incoming material : $M_{satellite}(t) = F \times t$.

As it migrates, $q = (3^3/2^6\tau_d)^{1/2}\, \Delta^2$.

This stands as long as the satellite is not too far from the disk, *i.e.* : $\Delta < 2r_{Hill}/r$. This gives :

$$\Delta < \Delta_c = (3/\tau_d)^{1/2}$$
$$q < q_c = \sim 2\, \tau_d^{-3/2}$$



After q_c or Δ_c is reached, the satellite goes on migrating outwards at constant mass, and a new satellite forms.

Pyramidal regime :

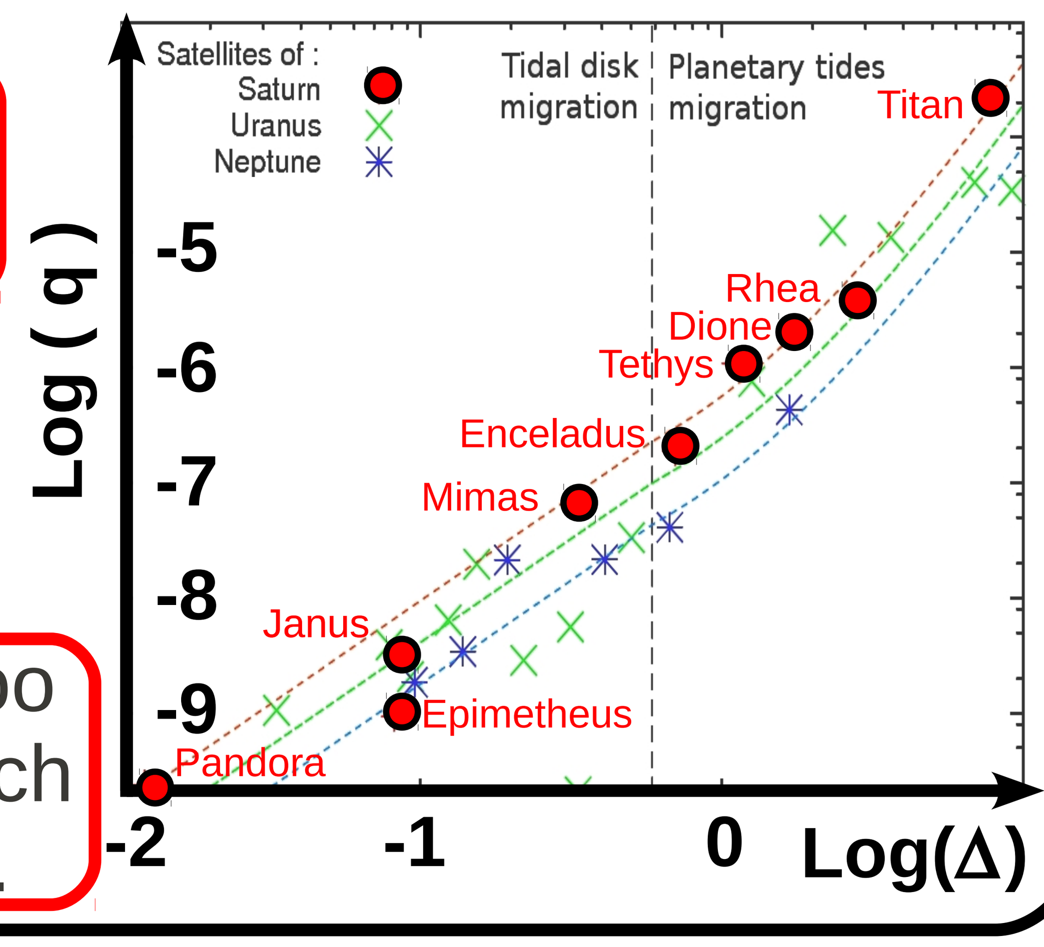
Satellites of mass q_c are produced every δt, at Δ_c , and migrate outwards. As their migration speed decreases, they merge in pairs, producing regularly $2q_c$ bodies, who merge further, and so on...

In this process :

$$q \propto \Delta^{9/5} \quad \text{for } \Delta<0.58$$
$$q \propto r^{3.9} \quad \text{for } \Delta>0.58$$

This matches the Saturnian, Uranian, Neptunian systems.

→ Uranus & Neptune too had big rings from which their satellites formed.

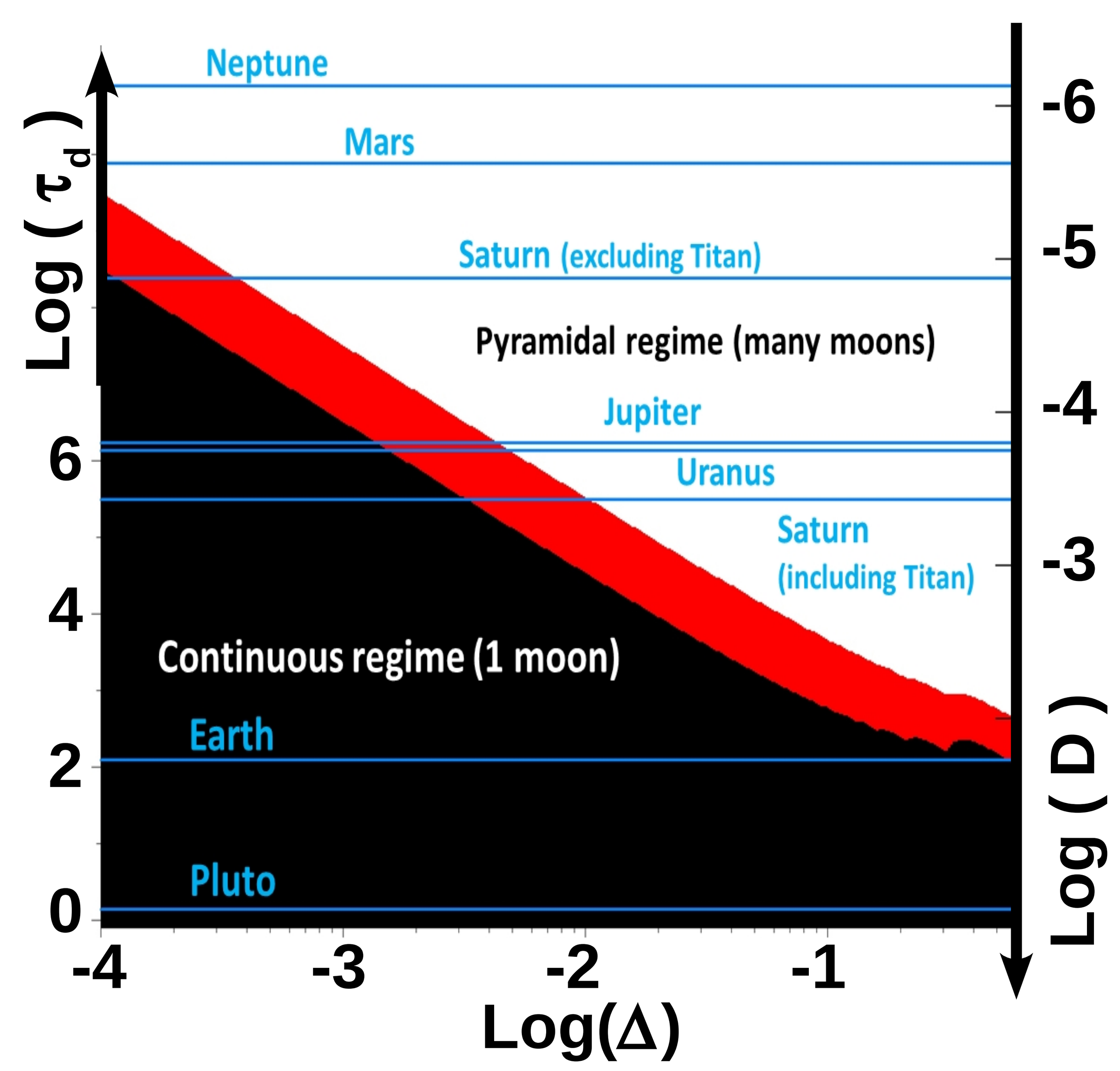


Application :

For each planet of the Solar System, consider a *Miminum Mass Satellites Tidal Disk* , with **D**=150% times the total mass of present regular satellites.

D is linked to τ_d (thus Δ_c and q_c) via a relation between the disk surface density and its viscosity (Daisaka et al 2001).

- **Giant planets :** small **D**, large τ_d, small Δ_c, q_c: the pyramidal regime dominates → many satellites of increasing mass starting from the Roche radius.
- **Moon forming disk :** large **D**, small τ_d → q_c =~**D** : continuous regime, the Earth should have only 1 big Moon!



Reference : Crida & Charnoz 2012, *Science*. See also : Charnoz et al. 2010, 2011.