EPSC Abstracts
Vol. 7 EPSC2012-548 2012
European Planetary Science Congress 2012

Are most regular satellites of the Solar System born from massive rings ?

A. Crida (1), S. Charnoz (2,3)
(1) Laboratoire Lagrange, Université de Nice Sophia-antipolis / C.N.R.S. / Observatoire de la Côte d'Azur (crida@oca.eu)
(2) Laboratoire AIM, Université Paris Diderot / C.E.A. / IRFU-SAp (3) Institut Universitaire de France

Abstract

We analytically describe satellite formation from the spreading of a massive ring of solid particles; beyond the Roche radius, new moons coagulate and migrate outwards because of gravitational instability and the disk's tides. We show that it naturally produces either a satellite system with a specific orbital architecture (that matches the Saturnian, Uranian and Neptunian systems) or only one massive satellite (in the Earth's case). We conclude that Uranus and Neptune, like Saturn, had massive rings in the past, from which their regular satellites formed, and that satellite formation from the spreading of a tidal disk is thus a generic mechanism in the whole Solar System.

1. Introduction

Giant planets' regular satellites have masses which increase with their orbital radius, starting at a few planetary radii, where the smallest bodies accumulate (see Fig. 1a). Current models of satellite formation, which start with an extended circumplanetary gaseous disk[1, 2, 8], cannot explain this peculiar characteristic structure.

Recently, we have shown that Saturn's small moons and mid-sized moons most likely formed from the spreading of Saturn's rings themselves [3, 4]. Here, we describe analytically this process, and show that it can be generalized to the ice giants, and the terrestrial bodies.

2. Satellite formation from the spreading of a tidal disk

A *tidal disk* is a dynamically cold disk of solid particles, in which accretion is prevented by the tidal forces from the central body. It extends to the Roche radius r_R beyond which, by definition, the self-gravity dominates over the tides.

A disk spreads. Its viscosity increases with its surface density [5], so that more massive disks have a shorter life-time T_{disk}.

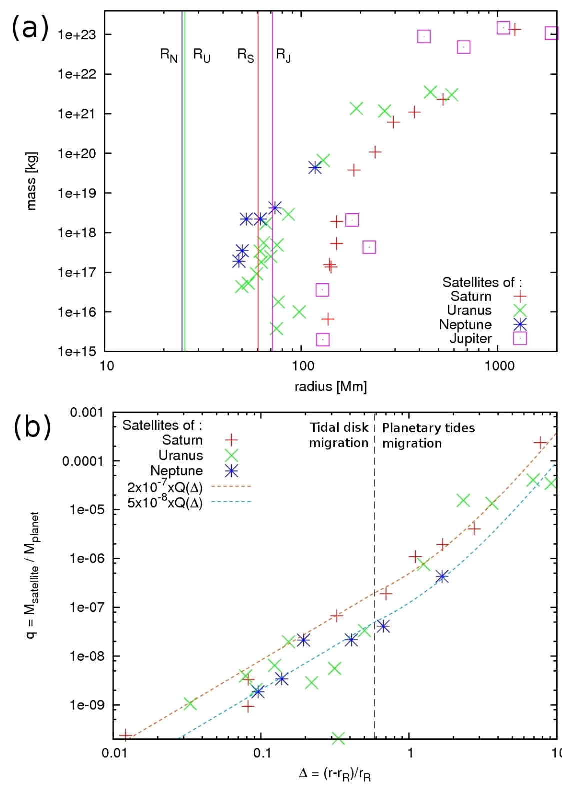

Figure 1: **(a)** Points: satellites masses versus orbital radius r. Vertical lines: planetary radii. The masses increase with r, starting from 0 at a few planetary radii, where the smallest bodies pile-up. **(b)** Satellite to planet mass ratios, versus distance to the Roche radius $\Delta = (r - r_R)/r_R$. A clear correlation appears, which is very well fitted by our model (dashed lines).

2.1. Continuous regime

The material that crosses r_R forms a satellite, that grows linearly while migrating away under the action of the tides from the disk[7]. We call this the *continuous regime*. It lasts as long as the outer edge of the disk is within gravitational reach from the satellite (that is 2 Hill radii). We find that this lasts about 10 orbits.

2.2. Discrete regime

Then, a new satellite forms, that migrates outwards and it caught by the first one. Thus, the first satellite keeps growing at the same rate, but through steps. We call this the *discrete regime*. It lasts about 100 orbits. In the end, the first satellite is too far to accrete the newly formed satellites, and migrates outwards with a constant mass M_d.

This critical mass decreases with T_{disk}. For instance, for the dense proto-lunar disk, this mass is of the order of that of the Moon, so that we expect only one satellite to form around the Earth, possibly with a smaller companion to be accreted later (in agreement with [6]).

2.3. Pyramidal regime

Around giant planets, M_d is small. Satellites of mass M_d are produced regularly, and migrate away, with a speed decreasing with distance. So, they approach each other and merge, forming satellites of mass $2M_d$, regularly. The products of these mergers migrate away, approach each other, and merge again... We call this hierarchical mergers history the *pyramidal regime*.

We show that at every generation, the normalized distance of the merger to the outer edge of the rings, $\Delta = (r - r_R)/r_R$) is multiplied by $2^{5/9}$. Thus, an orbital architecture settles, in which the number density of satellites is proportional to $1/\Delta$, and their masses are proportional to $\Delta^{9/5}$. When the migration of the satellites is dominated by tides from the planet and not from the tidal disk (that is beyond $\Delta = 0.58$), then we find that $M \propto r^{3.8}$.

This relation is plot in Fig. 1b. It matches the distribution of the satellites of Saturn, Uranus, and Neptune, and explains the pile-up of small satellites around r_R. This suggests that Uranus and Neptune also had massive rings in the past, from which their regular satellites were born.

3. Summary and Conclusions

We have analytically described satellite formation from the spreading of a tidal disk, identifying three different regimes that are successively encountered. This model is in very good agreement with the satellite systems of Saturn, Uranus, Neptune, the Earth and Pluto. This mechanism is therefore generic, and we think that most regular satellites of the solar system were born from massive rings.

References

[1] Canup, R., Ward, W. R.: Formation of the Galilean satellites: Conditions for accretion. Astron. J., 124, 3404-3423, 2002.

[2] Canup, R.M., Ward, W.R.: A common mass scaling for satellite systems of gaseous planets. Nature, 411, 834-839, 2006.

[3] Charnoz, S., Salmon, J., Crida, A.: The recent formation of Saturn's moonlets from viscous spreading of the main rings. Nature, 465, 752-754, 2010.

[4] Charnoz, S., Crida, A., Castillo-Rogez J. et al.: Accretion of Saturn's mid-sized moons during the viscous spreading of young massive rings: Solving the paradox of silicate-poor rings versus silicate-rich moons. Icarus, 216, 535-550, 2011.

[5] Daisaka, H., Tanaka, H., Ida, S.: Viscosity in a Dense Planetary Ring with Self-Gravitating Particles. Icarus, 154, 296-312, 2001.

[6] Jutzi, M., Asphaug, E.: Forming the lunar farside highlands by accretion of a companion moon. Nature, 476, 69-72, 2011.

[7] Lin, D.N.C., Papaloizou, J.: Tidal torques on accretion discs in binary systems with extreme mass ratios. MNRAS, 186, 799-812, 1979.

[8] Mosqueira, I., Estrada, P.R.: Formation of the regular satellites of giant planets in an extended gaseous nebula I: subnebula model and accretion of satellites. Icarus, 163, 198-231, 2003.