EPSC Abstracts
Vol. 13, EPSC-DPS2019-1806-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

The ground for the growth of giant planets' moons through pebble accretion

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Abstract

Regular satellites of the giant planets are thought to form in a gaseous disk surrounding the planet during the last stages of its formation. The proposed frameworks for the accretion of moons, mainly crafted to fit the properties of the Galilean moons around Jupiter, are difficult to reconcile with our current understanding of the processes involved in the building of planets. Here, we attempt at revising the formation of moons around giant planets and the Galilean system in particular.

Motivation

The formation of massive moons around giant planets is generally envisioned to take place in either an actively-supplied and gas-starved circumplanetary disk (hereafter CPD) [1, 2], or a more massive CPD containing enough material to readily build the satellite system [3, 4]. In the first case, it is assumed that the CPD is replenished with a mixture of gas and dust in solar proportions throughout the formation of the moons. However, the gravitational perturbation induced by a planet more massive than 10 to 20 $M_\oplus$ on its natal protoplanetary disk is known to efficiently filter the flux of dust grains [5], resulting in the subsequent accretion of dust poor gas. In the second case, it has been proposed that capture and ablation of planetesimals would deliver the solids necessary to build the moons prior to their accretion, which could be a consistent mechanism as recently suggested [6]. In both cases, it is assumed that the initially small dust grains in the CPD can grow to large enough sizes that they decouple from the gas and remain available for accretion. This is in contradiction with the fact that dust fragmentation and rapid inward drift due to gas drag are two bottlenecks to the growth of dust grains that prevent them from reaching decoupling sizes. The drift timescale of dust particles in the satellite formation regions is typically of the order of a few decades, which is really problematic for minimum mass models as the growth timescale of the moons should then be similarly short. The rapid inward drift of dust in the CPD result in a low dust-to-gas ratio that hinders the formation of large objects through the streaming instability [7], a mechanism usually invoked for the formation of planetesimals in protoplanetary disks. More consistent models of the formation of the moons of giant planets in a CPD thus need to be developed.

Outline of the model

Delivery of solids

It has been recently suggested that the building blocks of the Galilean satellites originated from a ring of planetesimals located at the outer edge of the gap carved by Jupiter in the circum-stellar disk [6]. The delivery of this material to the jovian CPD in this scenario proceeds through the stirring of the planetesimals towards Jupiter's feeding zone by a nearby massive object (such as Saturn's core) and subsequent gas drag-assisted capture in the inner portions of the CPD. In this framework, the building blocks of the moons would be large ($\sim$100 km) icy planetesimals which would be difficult to reconcile with the observed gradient in the composition of the Galilean satellites [8].

Here we study the gas drag-assisted capture of planetesimals located in the feeding zone of Jupiter and including the effect of ablation driven by friction with the gas. We find that most captured objects end up being completely ablated in the CPD, thereby delivering vaporized material that would quickly recondense into small dust grains. A small fraction ($\sim$10%) of planetesimals survive ablation and remain as large ($>$10 km) objects in the CPD.

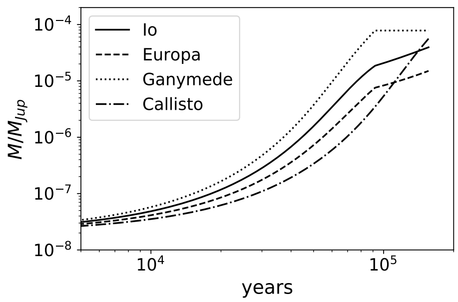

Figure 1: Example of the growth of the Galilean moons through pebble accretion. All the satellites are assumed to be in mutual mean motion resonances and the pebble flux through the CPD does not vary with time (although it would be expected to decrease as Jupiter empties its feeding zone). Ganymede reaches the pebble isolation mass and reduces the flux of pebbles for the inner moons Io and Europa. Callisto's growth is slower due to the fact that ablation provides less material there.

Accretion of moons

Ablation of planetesimals provide a source of dust grains that would grow to pebble sizes and rapidly drift inwards. However, the objects surviving ablation in the CPD are not massive enough to accrete these pebbles. The seed of the satellites would therefore initially grow by classical planetesimal (or here, satellitesimal) accretion. Pebble accretion would dominate over satellitesimal accretion once a seed reach a mass of $\sim 10^{-8}\,M_{\rm Jup}$ (the mass of the Galilean moons range from 2.5×10^{-5} to $7.8 \times 10^{-5}\,M_{\rm Jup}$). Thus, most of the growth of the moons would proceed through pebble accretion.

Inward type-I migration of the moons would however be difficult to outcompete, unless the flux of pebbles in the CPD is unreasonably high. Combined with the fact that the overall pebble accretion efficiency is of the order of $\sim 10\%$, the loss of satellites through migration should be prevented. It is indeed unlikely that several generations of satellites could have formed around a giant planet considering that about 10 times the mass of a satellite worth of pebbles should be processed through the CPD to allow its formation. The most likely scenario is that a magnetic cavity developed around Jupiter [9] which truncated the CPD and stalled the migration of the satellites [10]. It could then be envisioned that moons mainly grow by accreting pebbles while a chain of resonant orbits is already established, thereby allowing to reproduce the gradient observed among the Galilean moons if the snowline was located in between the orbits of Europa and Ganymede. The final mass of the satellites would be set by either the pebble isolation mass (most likely in the case of Ganymede) or the limited amount of mass processed through the CPD (see Fig.1).

References

[1] Canup, R. M., & Ward, W. R. 2002, AJ, 124, 3404.

[2] Canup, R. M., & Ward, W. R. 2006, Nat., 441, 834.

[3] Mosqueira, I., & Estrada, P. R. 2003, Icarus, 163, 198.

[4] Mosqueira, I., & Estrada, P. R. 2003, Icarus, 163, 232.

[5] Lambrechts, M., Johansen, A., & Morbidelli, A. 2014, A&A, 572, A35.

[6] Ronnet, T., Mousis, O., Vernazza, P., et al. 2018, AJ, 155, 224.

[7] Shibaike, Y., Okuzumi, S., Sasaki, T., et al. 2017, ApJ, 846, 81.

[8] Ronnet, T., Mousis, O., & Vernazza, P. 2017, ApJ, 845, 92.

[9] Batygin, K. 2018, AJ, 155, 178.

[10] Sasaki, T., Stewart, G. R., & Ida, S. 2010, ApJ, 714, 1052.