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# Saturn's decisive role in the formation of the Galilean system

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## Abstract

The four massive Galilean satellites are believed to have formed within a circumplanetary disk during the last stages of Jupiter's formation. However, no consensus exists regarding the origin and delivery mechanisms of the building blocks of the forming satellites. The opening of a gap in the circumsolar disk should have indeed efficiently isolated Jupiter from the main sources of solid material. However, a reservoir of planetesimals should have existed at the outer edge of Jupiter's gap, where solids were trapped and accumulated over time. Here we show that the formation of Saturn's core within this reservoir, or its prompt inward migration, allows planetesimals to be redistributed from this reservoir towards Jupiter and the inner Solar System, thereby providing enough material to form the Galilean satellites and to populate the Main Belt with primitive asteroids. We find that the orbit of planetesimals captured within the circumjovian disk are circularized through friction with gas in a compact system comparable with the current radial extent of the Galilean satellites. The decisive role of Saturn in the delivery mechanism has strong implications for the occurrence of massive moons around extrasolar giant planets as they would preferentially form around planets within multiple planet systems.

## 1. Context

The Galilean satellites orbiting around Jupiter are generally seen as a by-product of the giant planet's formation. They are believed to accrete in a circum-jovian disk during the final stages of Jupiter's own accretion. However, the origin and delivery mechanism of the building blocks of the moons is debated. In fact, the proposed mechanisms, either (1) capture/ablation of large planetesimals in the direct vicinity of Jupiter [1] or (2) delivery of small dust grains entrained with the gas accreted by Jupiter [2], seem incompatible with the recent developments of the theory of giant planets formation. At the time when satellites supposedly formed, Jupiter should have carved a deep gap in the circum-solar disk whose outer edge acted as a dust trap which would efficiently filtered dust grains, making (2) unlikely to provide enough material to build the moons over time. On the other hand, the formation of planetesimals require specific conditions [3] which were very unlikely met in the direct vicinity of Jupiter whereas already formed planetesimals would have been quickly scattered away by gravitational interactions with the forming giant, leaving Jupiter's vicinity empty by the time the satellites should form.

The dust trap located at the outer edge of Jupiter's gap provides suitable conditions for the formation of planetesimals. Dust grains would accumulate there over time and collapse into larger objects, building-up a reservoir of solid material close to Jupiter. However, these planetesimals would initially reside outside of Jupiter's gravitational reach and a mechanism is needed to deliver them. Here we show that the formation of Saturn would have allowed the delivery of objects to the circum-jovian disk. Either Saturn would have formed directly at the outer edge of Jupiter's gap and scattered the planetesimals in its vicinity or it could alternatively have formed further out and migrated inward, thereby pushing material towards Jupiter as its inward 2:1 and 3:2 mean motion resonances swept the reservoir.

## 2. Results

We conducted N-body simulations including Jupiter, its circum-planetary disk, a circum-solar disk and either a growing (case 1) or migrating Saturn (case 2). Planetesimals were distributed in a narrow annulus at the outer edge of Jupiter's gap and were considered as test particles. The effect of gas drag onto planetesimals (either from the circum-solar or circum-jovian disk) was included considering these objects have a

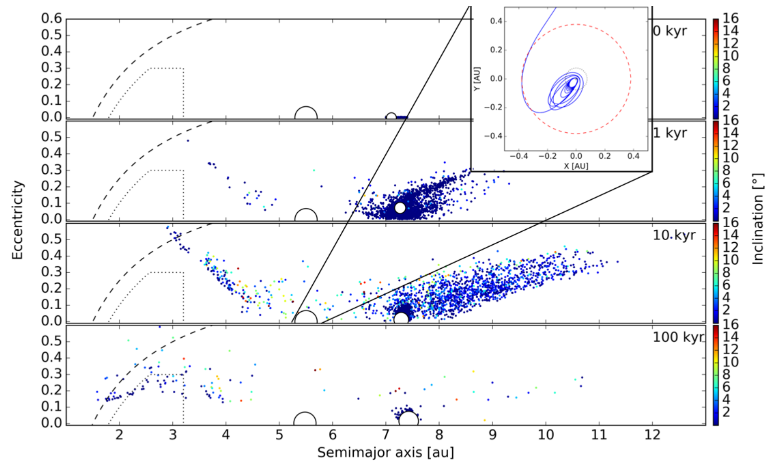


Figure 1: Snapshots of the evolution of planetesimals in a simulation where Saturn is growing at the outer edge of Jupiter's gap. The dotted box shows the extension of the main asteroid belt and the dashed line shows orbits with perihelion $q < 1.5$ au (i.e., orbits that cross the region of terrestrial planets' embryos). The box in the upper right part shows an example of orbital evolution of a captured objects in a XY plane centered on Jupiter. The red dashed circle is Jupiter's Hill sphere and the black dotted circle is the extension of the circum-jovian disk.

radius of 100 km. Planetesimals were considered captured and removed from the simulations if they were found on a bound orbit with respect to Jupiter with a semimajor axis $\leqslant 0.2\ R_{\rm H}$, where $R_{\rm H}$ is Jupiter's Hill radius.

Figure 1 shows the evolution of the system in a case 1 scenario. Saturn's growth allows an efficient redistribution of the planetesimals, a fraction of which are captured within the circum-jovian disk through gas drag (upper right box shows an example of a prograde capture around Jupiter) while some objects are scattered toward the inner Solar System. For both cases 1 and 2, we find that $\sim$10–15% of the planetesimals end up captured by Jupiter, with roughly equivalent amount of prograde and retrograde objects, and $\sim$1% of the planetesimals are implanted in the asteroid belt. Subsequent evolution of captured objects reveal that planetesimals captured on initially retrograde orbits are rapidly lost to Jupiter whereas those captured on prograde orbits are circularized through gas drag in a compact system whose radial extension is comparable to that of the current Galilean system.

## 3. Conclusion

Our results suggest that the building blocks of the Galilean satellites originated from a reservoir of objects located at the outer edge of Jupiter's gap. A fraction of these primordial objects are likely still present in today's asteroid belt. These asteroids are probably the parent bodies of the carbonaceous meteorites collected on Earth which were early on separated from the non carbonaceous parent bodies by Jupiter [4]. The decisive role played by Saturn implies that analogues to the Galilean moons in extrasolar systems would mainly, if not only, form around giant planets within multiple planet systems.

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