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The Late Accretion of Jupiter and the Jovian Early Bombardment

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Abstract

The Galileo mission revealed that Jupiter's atmosphere is enriched in noble gases and C, N, S respect to solar composition. Different processes have been suggested to explain this enrichment and link it to the history of the giant planet. Here we show the preliminary results we obtained in studying the capture of solid material from the protoplanetary disk by Jupiter across the Jovian Early Bombardment, the bombardment triggered by the formation of the giant planet, and discuss the role of the inner and outer Solar System as sources for the captured material.

1. Introduction

Since the Galileo mission probed the atmospheric composition of Jupiter, we know that the giant planet is characterized by a factor 2-4 enhancement of C, N, S and Ar, Kr and Xe [1,2]. Moreover, we know that the bulk composition of Jupiter in enriched (3%-13%) in high-Z elements respect to solar (2%) composition [3]. The initial idea that this enrichment is a reflection of the actual formation mechanism of the planet (nucleated instability vs. gravitational instability, see [4] for a discussion) is still debated but is giving space to the idea that the enrichment is an effect of the environment the giant planet formed and initially evolved (see [5] for a discussion). In particular, the enrichment in noble gases has been suggested to be due to the accretion of nebular gas from a circumsolar disk in an advanced (H and He depleted) stage of evolution [6]. To explain the C (and O, N, S) enrichment of Jupiter, a late accretion of planetesimals during the capture of the nebular gas has instead been suggested [1,7]. In this work, we will focus on the latter mechanism in light of the recent results on the effects of Jupiter's formation on the protoplanetary disk [8,9,10].

2. Primordial or Late Delivery?

The data we presently possess seem to point to a primordial origin of this enrichment. During the Late Heavy Bombardment (LHB), for example, it has been estimated that Jupiter would have accreted only 0.15 Earth masses of solid material [11], therefore far less than what is required to explain the currently observed enrichment. A back-of-the-envelope calculation easily shows us that the 3.98 Ga long period that separates us from the LHB likely played an even smaller role due to the paucity of bodies on Jupiter-crossing orbits. Assuming the flux of comets observed hitting Jupiter over the last 20 years (i.e. about 1 every 5 years), even a stable flux of impactors the estimated size of comet Shoemaker-Levy 9 (i.e. 5 km in diameter) would deliver to Jupiter about 0.01 Earth masses of solid material. As a consequence, it is likely that the bulk of the present-day enrichment of Jupiter predates the LHB.

3. The Jovian Early Bombardment

[12] was the first to suggest in his work that the formation of Jupiter would cause a reshuffling of the solid material (i.e. the planetesimals) composing the protoplanetary disk. This idea was later explored by [13] and [14], who studied the injection of material from the outer solar system into its inner regions, with a focus on the implications for the asteroid belt. More recently, [8,10], while studying the same subject, observed that the orbital resonances with Jupiter in the inner solar system play a role that is comparable to that of their outer solar system counterparts. These resonances, and particularly the 3:1 and the 2:1, can also extract material from the inner Solar System and inject it on Jupiter-crossing orbits.

4. Preliminary Results from our Toy Model

As the flux of material extracted from the inner solar system could represent a significant fraction of the total mass delivered to Jupiter, we decided to further investigate how the dynamical evolution of the protoplanetary disk is linked to the enrichment of the giant planet. Our setup was similar to the one of the previous, similar investigation of [15], but instead of including all four giant planets we focus only on Jupiter, which because of its mass we assumed to be the first giant planet to form. Moreover, we focus only on the first 2 Ma after the formation of the giant planet but we extended our disk of test particles from 1 AU to 10 AU. We found that in such a short timespan, Jupiter could capture about 0.5 Earth masses from the whole extension of our disk. Moreover, about 30% of the captured mass originated from the region comprised between 1 AU and 4 AU, where we assumed our Snow Line.

5. Summary and Conclusions

Even in the limit of the simplistic toy model we used in this preliminary investigation, we can easily see that the first handful of Ma after the formation of Jupiter likely played an important role in the enrichment of the giant planet due to the higher population of planetesimals inhabiting the protoplanetary disk. Further, more detailed investigations of this subject are therefore needed in order to gain a deeper insight to the compositional evolution of this giant planet in view of the arrival of the JUNO mission.

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