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The Jovian Early Bombardment and the collisional erosion of primordial asteroids

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Abstract

The formation of Jupiter triggered the Jovian Early Bombardment, the first bombardment event in the history of the Solar System. The Jovian Early Bombardment was caused by the appearance of the orbital resonances with Jupiter both in the inner and the outer Solar System. The Jovian Early Bombardment is relatively short, the bulk of the bombardment taking place in about 1 Ma, but it is extremely violent due to the higher population of planetesimals existing at the time in the regions affected by the resonances. In all scenarios we considered, primordial asteroids whose size did not exceed 200 km were collisionally eroded during the Jovian Early Bombardment. Moreover, a radial migration of the order 0.5 AU or greater of the planet while forming would have caused also primordial asteroids the size of Vesta to be stripped of a significant fraction of their mass.

1. Introduction

We simulated the dynamical evolution over 2 Ma of a template of the forming Solar System composed of the Sun, the accreting Jupiter, a swarm of planetesimals spanning between $2-8$ AU and a set of target bodies located in the inner asteroid belt [2]. The aim of our simulations was to estimate the effects of the formation and the likely contemporary migration of Jupiter on the collisional evolution of the primordial asteroids existing in the asteroid belt at the time of the Solar Nebula. Across the first 1 Ma, Jupiter's core is assumed to accrete from a Mars-sized embryo of 0.1 $M_{\oplus}$ to the critical size of 15 $M_{\oplus}$ [1]. Across the second 1 Ma, Jupiter is assumed to rapidly accrete its gaseous envelope, increasing its mass with a e-folding time of 5000 years [1]. To evaluate the effects of Jupiter's migration, we considered four different scenarios: Jupiter forming at its present position and Jupiter migrating inward by 0.25 AU, 0.5 AU and 1.0 AU with a e-folding time of 5000 years [1, 2]. The planetesimals are initially located on low-eccentricity and low-inclination orbits and, in the dynamical model, are represented by 6×10^4 massless particles [2]. The size-frequency distributions of the planetesimals we considered are those due to their formation in a quiescent or in a turbulent nebula and that due to to the primordial collisional evolution of the asteroid belt [1]. We evaluated the probabilities of the planetesimals impacting the target bodies through a statistical approach [1] while the effects of the impacts were estimated using the scaling-laws from [3, 4, 5].

2. The Jovian Early Bombardment

The formation of Jupiter caused a phase of primordial bombardment we named the Jovian Early Bombardment (JEB in the following [1, 2]). While the migration of Jupiter enhances the intensity of the JEB due to the sweeping of the resonances across the asteroid belt, the formation of the giant planet is necessary and sufficient condition for triggering the JEB [1, 2]. Planetesimals from both the inner and the outer Solar System participate to the JEB, but the leading role in determining the fate of primordial asteroids is played by the planetesimals affected by the $3:1$ and the $2:1$ resonances with Jupiter [2]. If Jupiter's migration was limited (i.e. less than 10^{-1} AU), a significant role is played also by the $3:2$ resonance. The survival of the primordial asteroids to the JEB depends on the size distribution of the planetesimals populating the Solar Nebula, their location respect to the $3:1$ and the $2:1$ resonances and the extent of Jupiter's migration. Examples of the collisional evolution of primordial planetesimals with diameters of 100 km, 200 km and 500 km during the JEB are shown in Table 1 and Table 2 respectively for impactors formed in a quiescent disk and for collisional evolved impactors [2].

3. Summary and Conclusions

Our results show that the formation of Jupiter triggered the first primordial bombardment across the asteroid belt and that the migration of Jupiter can

Table 1: Jovian Early Bombardment due to planetesimals formed in a quiescent disk on target bodies at 2.30 AU [2]. Eroded mass is in units of the target mass.

Migration Scenario	N_{coll}	Critical Impacts	Eroded Mass
	100 km	target	
0.00 AU	289.07	1.01	1.79
0.25 AU	396.42	0.01	1.65
0.50 AU	482.85	0.01	5.02
1.00 AU	940.55	14.63	55.14
	200 km	target	
0.00 AU	653.45	0.00	1.63
0.25 AU	908.41	0.00	0.25
0.50 AU	1083.75	0.00	0.74
1.00 AU	2300.67	0.00	27.30
	500 km	target	
0.00 AU	2261.79	0.00	0.02
0.25 AU	2860.79	0.00	0.01
0.50 AU	3439.61	0.00	0.03
1.00 AU	6659.37	0.00	0.26

Table 2: Jovian Early Bombardment due to collisionally evolved planetesimals on target bodies at 2.30 AU [2]. Eroded mass is in units of the target mass.

Migration Scenario	N_{coll}	Critical Impacts	Eroded Mass
	100 km	target	
0.00 AU	1722.40	0.06	2.72
0.25 AU	2401.77	0.12	0.62
0.50 AU	3138.36	0.26	1.87
1.00 AU	7962.99	0.75	93.21
	200 km	target	
0.00 AU	3855.44	0.00	0.13
0.25 AU	5420.12	0.04	0.16
0.50 AU	7404.21	0.24	0.26
1.00 AU	20071.18	1.22	2.30
	500 km	target	
0.00 AU	13082.84	0.00	0.01
0.25 AU	16942.56	0.00	0.01
0.50 AU	23396.39	0.00	0.04
1.00 AU	59462.51	0.01	0.42

significantly enhance the intensity of this Jovian Early Bombardment. Our results also clearly highlight the fact that, due to the more abundant population of the asteroid belt at the time of the Jovian Early Bombardment, cumulative erosion plays a more important role than that of critical impacts in determining the fate of the planetesimals. Such effects, not included in previous studies of the collisional history of the asteroid belt, could help to explain the long equivalent time-scale (10 Ga instead of the real 4.5 Ga, [6]) needed to achieve the degree of collisional evolution of the present-day asteroid belt. Finally, our results suggest that the generally accepted view that most asteroids of about 100 km in diameter or larger are primordial may not be correct. The exact threshold size depends on the considered region of the asteroid belt, on the extent of Jupiter's migration, and on the size-frequency distribution of the planetesimals at the time of the Jovian Early Bombardment. We can generally state that, if the population of planetesimals in the Solar Nebula was dominated by objects smaller than 100 km, the threshold size can be of the order of 200 km. If, instead, the Solar Nebula was populated by planetesimals larger than 100 km, the threshold size can rise up to about 500 km. Bodies larger than these threshold sizes can however lose up to about half their mass if Jupiter migrated by 0.5 AU or more while forming.

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References

[1] Turrini D., Magni G., Coradini A. (2011), MNRAS, 413, 2439

[2] Turrini D., Coradini A., Magni G. (2012), ApJ, 750, 8

[3] Holsapple K. A., Housen K. R. (2007), Icarus, 187, 345

[4] Svetsov V. (2011), Icarus, 214, 316

[5] Benz W., Asphaug E. (1999), Icarus, 142, 5

[6] Bottke W. F., Durda D. D., Nesvorny D., Jedicke R., Mordibelli A., Vokrouhlicky D., Levison H. (2005), Icarus, 175, 111