EPSC Abstracts,
Vol. 4, EPSC2009-370, 2009
European Planetary Science Congress,

Modeling the collisional evolution of Vesta and Ceres at the time of Jupiter's formation

D. Turrini (1), A. Coradini (1), G. Magni (2), S. Fonte (1)

(1) INAF - Istituto di Fisica dello Spazio Interplanetario, via Fosso del Cavaliere 100, 00133, Rome, Italy
(2) INAF - Istituto di Astrofisica Spaziale e Fisica Cosmica, via Fosso del Cavaliere 100, 00133, Rome, Italy

Abstract

Despite the recent achievements in the exploration of the Solar Systems and in the investigation of its formation and evolution, the history of its early phases is still poorly understood. Our research project aims to study the implications of Jupiter's formation on the evolution of the Solar System. We started our investigation from the region that will become Main Asteroid Belt, using Vesta and Ceres as our case studies due to their importance in the framework of Dawn space mission. We developed a scientific code to simulate the evolution of a template of the early Solar System and adapted it to the distributed computing approach. Through our simulations, we computed the collisional histories of the two dwarf planets in four different scenarios of Jupiter's dynamical evolution. Jupiter's timescales of accretion and migration deeply influenced the evolution of the two asteroids by changing the flux of impactors and the effects of the collisional events.

Introduction

Probing the history of the early Solar System is a difficult task both theoretically and observationally. The processes governing planetary and satellite formation (e.g. collisional accumulation and disruption, geochemical differentiation) and the later evolution of the planets and the satellites (e.g. atmospheric erosion, exchange processes) and of the Solar System as a whole (i.e. the Late Heavy Bombardment) erased most of the available information. However, dwarf planets in the Main Asteroid Belt are believed to have formed extremely soon in the history of the Solar System, possibly even before the formation of the planetary core of Jupiter. If this proves true, their present internal and surface structures could still bear information on that past period of their existence. In the next few years, Dawn space mission will visit two of the biggest dwarf planets in the Main Asteroid Belt: Vesta and Ceres. With this work we want to start a theoretical study of their early evolution to pave the road for the interpretation of the data that Dawn will supply.

The model

To explore the early collisional history of Vesta and Ceres we simulated the dynamical evolution of a section of the Solar System at the time of Jupiter's core formation and its subsequent phase of gas accretion. Our template of the forming Solar System is composed of the Sun, the accreting Jupiter, Vesta, Ceres and a disk of 8×10^4 massless particles representing the planetesimals. The optimal extension of the disk ($2 - 10$ AU) has been evaluated through a set of numerical experiments we performed to determine the radial region influenced by the Jovian perturbations over the timespan (10^6 years) we considered.

Jupiter's formation

Since the aim of this project is to study the evolution of the early Solar System, we simulated the formation of Jupiter through an analytical approach whose parameters have been derived from hydrodynamical simulations performed with the code described in [1]. The time assumed for the formation of Jupiter's core is 3×10^5 years. While this time is an order of magnitude smaller than realistic values, the approximation does hold since Jupiter's core does not significantly influence the collisional history of the asteroids until it reaches its critical mass. The gas accretion phase is reproduced more realistically: the assumed timescale of mass growth is 5×10^3 years (see [1] for further details) and the system is let evolve for 7×10^5 years. Since Jupiter could have undergone a substantial migration during its formation, we performed four different sets of simulations, in which we considered four different migration scenarios ($0, 0.25, 0.5$ and 1 AU).

Collisional evolution

The collisional histories of Vesta and Ceres have been reproduced statistically by evaluating the impact probabilities of the massless particles which crossed the orbits of the two asteroids. To do so, the instantaneous orbit of each asteroid is spread into a torus whose section if equal to the effective cross section of the asteroid (i.e. the geometrical cross section magnified by

EPSC Abstracts,
Vol. 4, EPSC2009-370, 2009
European Planetary Science Congress,

the gravitational focus factor). When a planetesimal crosses one of the asteroids' tori, the impact probability is the probability that both planetesimal and asteroid will occupy the same region at the same time. This probability can be evaluated as the ratio between the effective collisional time and the orbital period of the asteroid. The effective collisional time is the amount of time available for collisions and is evaluated as the minimum between the time spent by the asteroid and the planetesimal into the crossed region of the torus.

Parallelizing the code

One advantage of our modeling is the possibility to parallelize (or, more precisely, distribute) the evolution of this dynamical system in a straightforward way. Since the disk of planetesimals is composed of massless particles and since Jupiter's evolution is reproduced analytically, we were able to split each simulation into a set of sub-problems to be treated in parallel (embarrassing parallelism). In our implementation, we used a script-based, distributed computing approach by dividing the disk of planetesimals into a number of concentric rings containing a fixed amount of test particles. Each ring is then evolved independently under the influence of the forming Jupiter and the collisions with the two asteroids are recorded. At the end of the simulations, the script automatically merges and orders the results, supplying a representation of the evolution of the system as a whole. Through this approach, we have been able to run the equivalent of a 3-month long simulation with 8×10^4 massless particles by running a set of 8 sub-simulations with 10^4 massless particles each, every sub-simulation taking about 12 days to conclude.

Results

Our results showed that Jupiter's formation strongly shaped the evolution of the future Main Asteroid Belt. The collisional histories of both Vesta and Ceres show common features linked to the timeline of Jupiter's formation process. While Jupiter's core is forming, impacts on the two asteroids are dominated by those we called primordial impactors, i.e. low ($< 1\,km\,s^{-1}$) relative velocity collisions with planetesimals orbiting near-by the two asteroids. As soon as Jupiter starts to rapidly accrete mass by gas capture, resonant impactors do appear, the actual location of the resonances depending on the migration scenario considered (and thus on Jupiter's initial location). Resonant impactors are characterised by higher relative velocities, varying between $1 - 10\,km\,s^{-1}$. Jupiter's migration also influences the number of impactors hitting the two asteroids: the greater the inward displacement of the planet, the higher the number of impactors coming from the inner Solar System (i.e. rocky bodies) and the smaller that of bodies coming from the outer Solar System (i.e. volatile-rich bodies). While the number and the effects of low-velocity impacts due to primordial impactors do not depend on Jupiter's migration scenario, those of high-velocity impactors (both the resonant ones coming from the inner Solar System and the impactors coming from the outer Solar System) do. Impactors coming from the outer Solar System, while less abundant, are responsible for a significant fraction, if not the most, of the biggest craters produced on the two asteroids. Only in the most extreme migration scenarios the planetesimals in the inner Solar System are excited enough to produce craters the same size of those due to bodies coming from the outer Solar System. In the case of Vesta, the biggest craters are caused by collisions whose released energies are about $1/10$ of Vesta's self-gravitation energy. In the case of Ceres, instead, the most energetic collisions reaches only $1/100$ of the self-gravitation energy of the asteroid. For a detailed description of our results we refer the readers to [2].

Conclusion

In this project we modelled the evolution of the early Solar System through a N-Body code which takes into account the effects of Jupiter's formation. The structure of the code allowed us to apply the paradigms of distributed computing, creating a script-based parallel code through which we could achieve a higher resultion than previously possible. We successfully used the code to study the early evolution of Vesta and Ceres at the time of Jupiter's formation, simulating their collisional histories. The results we achieved, together with those we will obtain in the prosecution of our project, will aid in the interpretation of the data that Dawn space mission will supply in the next few years on Vesta and Ceres.

References

[1] Magni G., Coradini A., "Formation of Jupiter by nucleated instability", 2004, *Planetary and Space Science*, 52, 343-360

[2] Turrini D., Coradini A., Magni G., "Probing the history of Solar System through the cratering records on Vesta and Ceres", e-print ArXiv:0902.3579