EPSC Abstracts
Vol. 6, EPSC-DPS2011-1696, 2011
EPSC-DPS Joint Meeting 2011

Stability of Giant Planet Moons during Planet-Planet Scattering Events

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Abstract

The large observed eccentricities of giant exoplanets provide evidence that most planetary systems have violent dynamical histories. Among the known mechanisms, planet-planet scattering is thought to have played the most important role in shaping the eccentricity distribution [3,4,6,9]. Here we directly simulate the orbital stability of satellites in orbit around giant planets during planet-planet scattering. During planetary close encounters, the approaching planet perturbs satellite orbits. Depending on the strength of encounters and satellites' orbital distances with respect to their parent planets, satellites may remain bound but undergo moderate eccentricity excitation and orbital distance modification, or they can be stripped from their parent planet. In some encounters, satellites can also be captured from another planet or the gas disk [8]. We present results of our systematic study of satellite stability for planets with different masses and mass gradients and orbital histories. We will map the final orbital distribution of exomoons and make testable predictions for the presence of exomoons around giant exoplanets.

1. Motivation

In search of habitable worlds outside our own solar system, we seek to find Earth-like planets and large moons of comparable size in the habitable zone. With current Kepler transit technique, we are now able to probe bodies down to 0.2 Earth masses [7]. We are therefore motivated to investigate the possible existence of moons around extra solar giant planets that migrate via planet-planet scattering. An analysis of satellite survival and capture rate during migration of the outer Solar System has been done in Nesvorný et al. 2007 [8], in which regular satellites typically survive because of lack of very close encounters to destabilize them in the Nice model they adopt. In this work, we look at systems that undergo very strong dynamical instability because observed high eccentricities of exoplanets imply violent dynamical instability in the past.

2. Methods

We use two to three giant planets with various masses and mass gradients based on planet-planet scattering models that match well the observed eccentricity distribution [3]. For two planet systems, we separate them by less than 3.5 mutual Hill radii to introduce instability into the system [2]. The satellites orbit around the giant planets with distances ranging from 0.0078 to 1 Hill radius. The minimum orbital semi-major axis is set so that it's safely outside 3 times the Roche limit and therefore no hydrodynamical simulation is needed to account for tidal effects such as mass loss [5]. We integrate them with the Bulirsh-Stoer algorithm from a symplectic integrator package called Mercury that can handle close encounters while conserving energy and momentum of the system. The integration continues for 10^5 to 10^6 years after the system's instability ends, to eventually evaluate if the survived satellites stay on stable orbit around giant planets.

3. Close encounter events

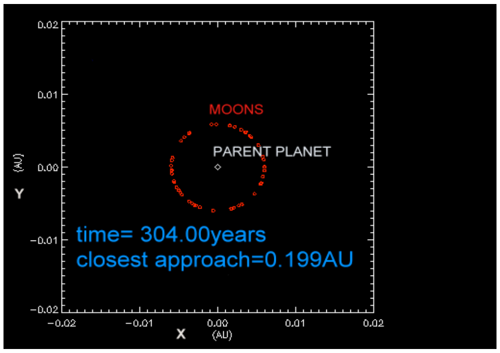

Fig. 1 The coordinate system is centered on the parent planet; moons orbit around their parent planet at 0.006AU. During and after this weak close encounter event, all the moons stay on stable orbit because the closest approach distance is too large to affect the moons' orbit.

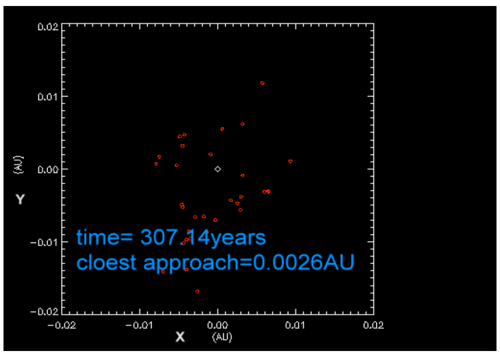

Fig. 2 In the same run as in fig. 1. During this strong close encounter event, the closest approach distance is less than the moons' orbit. All the moons undergo semi-major axis change and eccentricity exciation of different level.

Acknowledgements

This work was financed within the scope of the program "Incentivazione alla mobilita' di studiosi straineri e italiani residenti all'estero."

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