The Astrophysics of Planetary Systems: Formation, Structure, and Dynamical Evolution
Proceedings IAU Symposium No. 276, 2010
A. Sozzetti, M. G. Lattanzi & A. P. Boss, eds.

doi:10.1017/S1743921311020679

Forming short-period earth-like planets via a collision-merger scenario

Sheng Jin[1,3], Jianghui Ji[1,2] and Chris G. Tinney[2]

[1]Purple Mountain Observatory, Chinese Academy of Sciences,
Nanjing 210008, China email: jijh@pmo.ac.cn

[2]Department of Astrophysics, School of Physics,
University of New South Wales, NSW 2052, Australia

[3]Graduate School of Chinese Academy of Sciences,
Beijing 100049, China email: qingxiaojin@gmail.com

Abstract. We present a new formation mechanism to produce short-period Earth-like planets in the late stage of planet formation, through a collision-merger scenario. In this scenario, a planetary embryo is directly thrown into a close-in orbit after a collision with another embryo, and then the larger merged body is seized by the central star as a hot Earth-like planet.

Keywords. methods: n-body simulations, celestial mechanics, planetary systems: formation

1. Introduction

It is now widely accepted that short-period planets cannot have formed *in situ*, but rather must have migrated to their current orbits from a formation region much farther from their host star (Lin *et al.* 1996). The formation scenarios for short-period Earth-like planets are also associated with the migration of gas-giant planets (Raymond *et al.* 2006; Terquem & Papaloizou 2007). While in our dynamical simulations for planetesimal evolution in later stage of planet formation, we find a mechanism is revealed by which the collision-merger of planetary embryos can kick terrestrial planets directly into orbits extremely close to their parent stars.

2. Simulation setup and results

Extrasolar planetary systems that harbor pairs of Jupiter-to-Saturn-mass companions are of particular interest to researchers (Gozdziewski 2002; Zhang *et al.* 2010). We have therefore performed 30 simulations to investigate such a system architecture using the MERCURY package (Chambers 1999) for the following two systems:

• **Simulation 1** - two giant planets with initial orbital parameters to emulate the OGLE-06-109L system (Gaudi *et al.* 2008). 500 planetary embryos and planetesimals with total mass $10\,M_\oplus$ were distributed between $0.3\,\mathrm{AU} < a < 5.2\,\mathrm{AU}$ and with $e < 0.02$. Each of the 26 runs evolved over 400 Myr.

• **Simulation 2** - two giant planets with initial orbital parameters to emulate the 47 Uma system (Fischer *et al.* 2002). 648 planetary embryos with total mass of $5.14\,M_\oplus$ were distributed in the region $0.3\,\mathrm{AU} < a < 1.6\,\mathrm{AU}$ with $e < 0.02$. Each of the four runs evolved over 100 Myr.

All simulations exhibit a classical planetary accretion scenario in their late stage formation (Chambers 2001). Figure 1 shows the evolution process of one formed close-in planet in **Simulation 2**. Such a collision-merger mechanism for close-in terrestrial planets happened in $\sim 20\%$ of the total runs. In some cases the short-period planet was

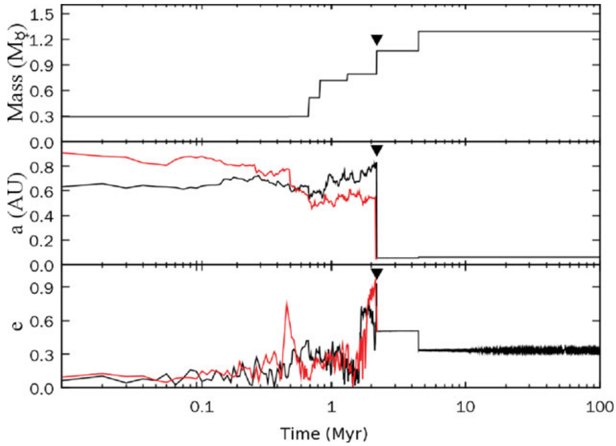

Figure 1. Mass, semi-major axis and eccentricity evolution of the short-period terrestrial planets that emerges from **Simulation 2**

kicked into an inner orbit at a very early stage, and subsequently accreted a majority of the mass available in nearby orbits. This shows that the key role of this mechanism is to throw one body into short-period orbits (Ji *et al.* 2011) at the collision.

3. Discussion

In actual cases collision could have a result that ranges anywhere from merger, like partial fragmentation or complete shattering (Wetherill & Stewart 1993). However, the collision-merger scenario might still be reasonable as it does not require perfect accretion. Rather it depends on the collisions pushing the resultant body inward so that the central star could grasp it. Moreover, the planetesimal disk in the simulations is less massive than that of the Minimum Mass Solar Nebula (Hayashi 1981), which could consist of billions of small bodies, to accordingly increase the probability of this mechanism.

Acknowledgements

This work is financially supported by the National Natural Science Foundation of China (Grants 10973044, 10833001), the Natural Science Foundation of Jiangsu Province, and the Foundation of Minor Planets of Purple Mountain Observatory.

References

Chambers, J. E. 1999, *MNRAS*, 304, 793
Chambers, J. E. 2001, *Icarus*, 152, 205
Fischer, D. A., *et al.* 2002, *ApJ*, 564, 1028
Gaudi, B. S., *et al.* 2008, *Science*, 319, 927
Gozdziewski, K. 2002, *A&A*, 393, 997
Hayashi, C. 1981, *Progress of Theoretical Physics Suppl.*, 70, 35
Ji, J. H., *et al.* 2011, *ApJ*, 727, L5
Lin, D. N. C., Bodenheimer, P., & Richardson, D. C. 1996, *Nature*, 380, 606
Raymond, S. N., *et al.* 2006, *Science*, 313, 1413
Terquem, C. & Papaloizou, J. C. B. 2007, *ApJ*, 654,1110
Wetherill, G. W. & Stewart, G. R. 1993, *Icarus*, 106, 190
Zhang, N., Ji, J. H., & Sun, Z. 2010, *MNRAS*, 405, 2016