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Global models of planetary system formation

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Abstract

We present the results of N-body simulations of planetary system formation coupled with a 1D disc model to explore various processes affecting planetary formation. These include collisional effects between numerous planetary bodies, simple prescriptions for disc-inducing planetary migration (types I and II), planetary accretion and planetesimal growth, and disc photo-evaporation. The aim of this work is to examine how planetary systems can arise from oligarchic growth in proto-planetary discs. We find that the majority of systems can form giant planets, but the majority of these planets rapidly migrate inwards and toward the central star until ultimately colliding with the star or being ejected from the system.

1. Introduction

Current observations of extra-solar planetary systems show a wide variety of systems sizes and structures. These range from short-period hot-Jupiters such as 51-Pegb, to long-period massive gas giants such as Beta Pictoris b. Multiple systems also appear to be common with examples including the Gliese 581 system hosting planets ranging from super-Earths to Neptune-mass planets. This wide variety of systems shows us that there are numerous physical processes acting within planetary formation on different time scales and lengths. In addressing the questions posed by this problem, global models of planetary formation that allow a wide variety of processes to occur simultaneously needs to be constructed. To do this we adapt a symplectic N-body code [1] in conjunction with previous adaptations [2] allowing simple prescriptions of planetary migration, planetesimal capture, gas-envelope accretion, planetary atmosphere structure, and disc dispersal over Myr timescales.

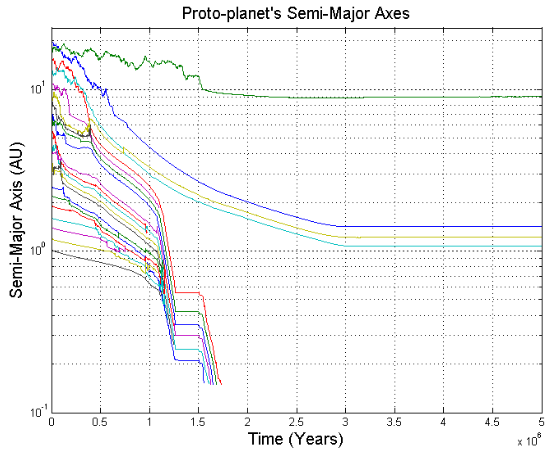
2. Models

Our simulations were performed using the Mercury-6 symplectic integrator [1] modified to include the adaptations mentioned in Section 1. We included a model for a radiatively-inefficient disc which allowed inward and outward planetary migration through the effects of corotation and Lindblad torques. A planetary accretion model was also included which allowed for an enhancement to the planetesimal capture radius due to atmospheric drag as well as a simple prescription for gas envelope accretion from the local gas disc through numerous regimes. Our model also allowed for disc dispersal through viscous evolution as well as photo-evaporation on a realistic timescale.

3. Results

From our results we see that large gas giants can form using our simple prescriptions but due to planetary migration and resonant migration they quickly migrate inwards towards the central star, before eventually colliding with the star or getting ejected. With the majority of giant planets being lost from the system, the final outlook of planetary systems within our simulations took the form of numerous Earth – Super-Earth mass planets surviving in a variety of distributions across their respective systems. Figure 1 shows an example for the change of semi-major axes for a selected simulation.

These results do show us that planetary formation is an extremely inefficient process as the majority of planets formed do not survive the full system formation process, and do not eventually become part of a multi-planet system. This is a clear problem our simulations have not yet been able to recreate an observed system containing at least a single gas giant size planet once formation processes have finished.



4. Summary and Conclusions

We have presented the results of planetary formation simulations that include models for planetary migration, planetary accretion, and disc dynamics. Our results have shown that planetary formation is extremely inefficient and does not currently agree with observed extra-solar planets and systems involving gas giant sized planets. They do show however that multi-planet systems can form and remain stable under a wide variety of initial conditions and formation dynamics.

References

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