GLOBAL MODELS OF PLANETARY SYSTEM FORMATION

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Introduction

With the current number of confirmed exoplanets standing at 723 and over 2000 candidates awaiting confirmation, explanations for the formation and history of these systems are clearly required. We examine the ability of the oligarchic growth scenario, coupled with disc-driven migration, to form planetary systems similar to those observed.

Our Model

We have adapted the Mercury-6 N-body symplectic integrator (Chambers 1999) to include the following:

- A thermally evolving viscous disc model.
- Planetary migration: Type I and II, including corotation torques and their possible saturation (Paardekooper et al 2011) and the influence of orbital eccentricity and inclination.
- Gas disc dispersal induced by photoevaporation.
- Gas accretion onto cores with masses in excess of 3 M_{Earth} (Movshovitz et al 2011).
- An enhanced capture radius for planetesimals accreting onto protoplanets due to atmospheric drag (Inaba & Ikoma 2003).

Simulations

We ran a suite of simulations with initial conditions consisting of 0.2 M_{Earth} planetary embryos and planetesimals embedded in gaseous discs, orbiting around Solar mass stars. We considered disc masses equal to 1, 3 and 5 times minimum mass models (MMSN) and planetesimal sizes of 1 and 10 km. Photoevaporation rates of 1, 10 and 100 times nominal values were considered. Metallicities of Solar and 2x Solar were considered. Simulations were run for either 10 million years or until the gas disc was fully dispersed, whichever was longer. A total of 72 simulations have been performed.

General Results

Our results show that multiple-planet systems are more likely to form in lower mass discs, as shown in Table 1. Higher mass discs were found to contain only single planet systems, along with systems with no survivors. The causes for a lack of surviving planets in higher mass discs include:

- Increased rates of planetary growth through planet-planet and planet-planetesimal collisions leading to faster inward migration.
- Formation of gas giants that undergo inward type II migration – shepherding material inward.

Figure 4 shows an example of a multiple planet system formed in a low mass disc (top panel), whilst also showing a single surviving planet in a higher mass disc (lower panel). It is noted that lower mass discs produced planets of lower mass due to the reduced availability of planetary building blocks.

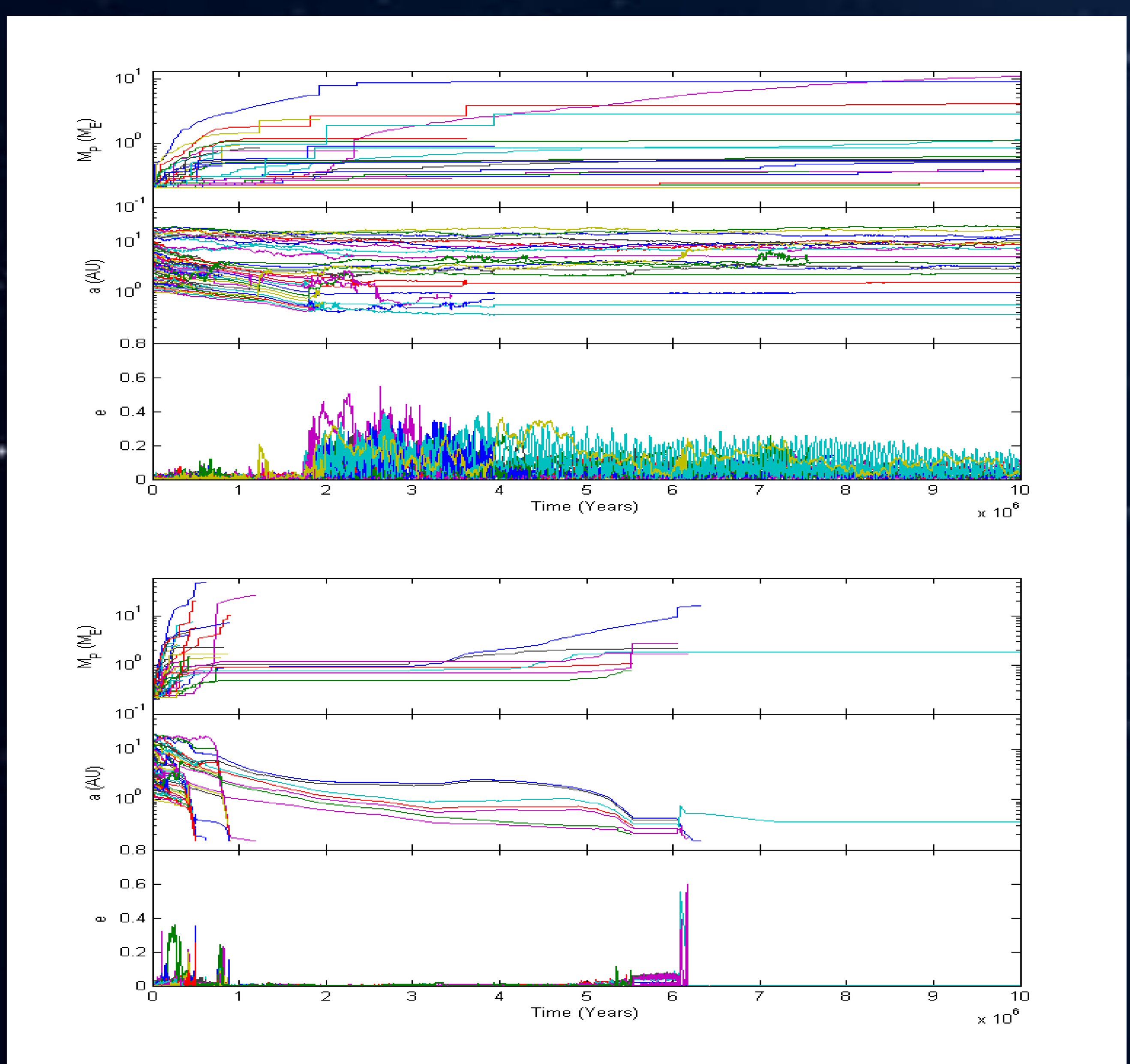

Figure 4 – Plots showing planetary masses, eccentricities, and semi-major axis for planets in 1*MMSN simulation (top), and 3*MMSN simulation (bottom)

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Comparisons with observations

Figure 1 shows a comparison of our surviving planets with confirmed exoplanets. The mass distribution of these surviving planets is shown in the upper panel of Figure 2. The simulations form numerous intermediate mass planets that undergo type I migration into the star, and a number of giant planets that experience type II migration leading to the same fate. The mass distribution of these lost planets is shown in the lower panel of Figure 2. We note that the results show an abundance of Earth mass planets, along with numerous super-Earths and Neptunes, that survive migration. The majority of these are in multi-planet systems originating in low mass discs.

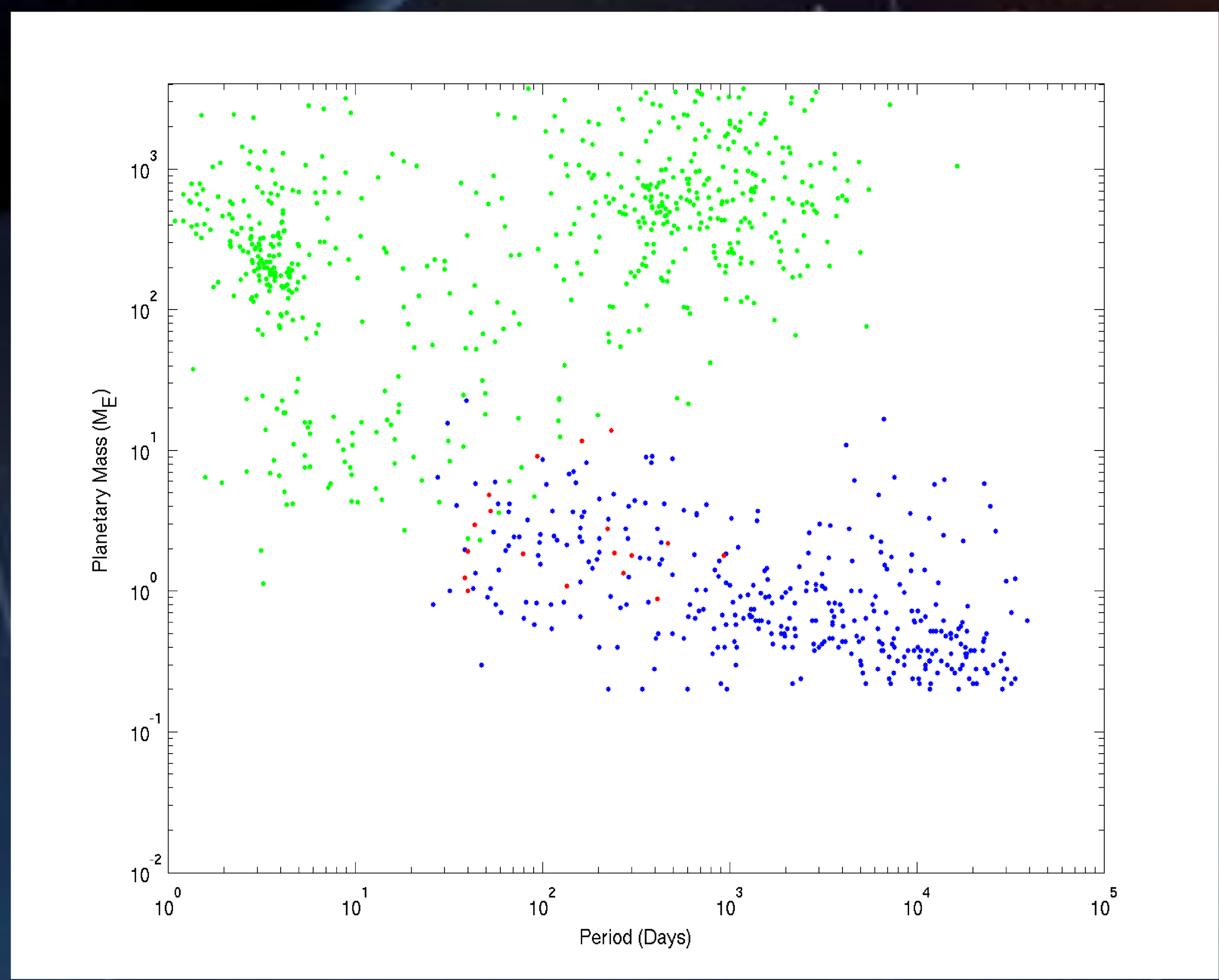

Figure 1 – Planetary Mass v Period Plot showing: Confirmed planets (green), Simulated 1MMSN planets (blue), Simulated 3MMSN planets (red).

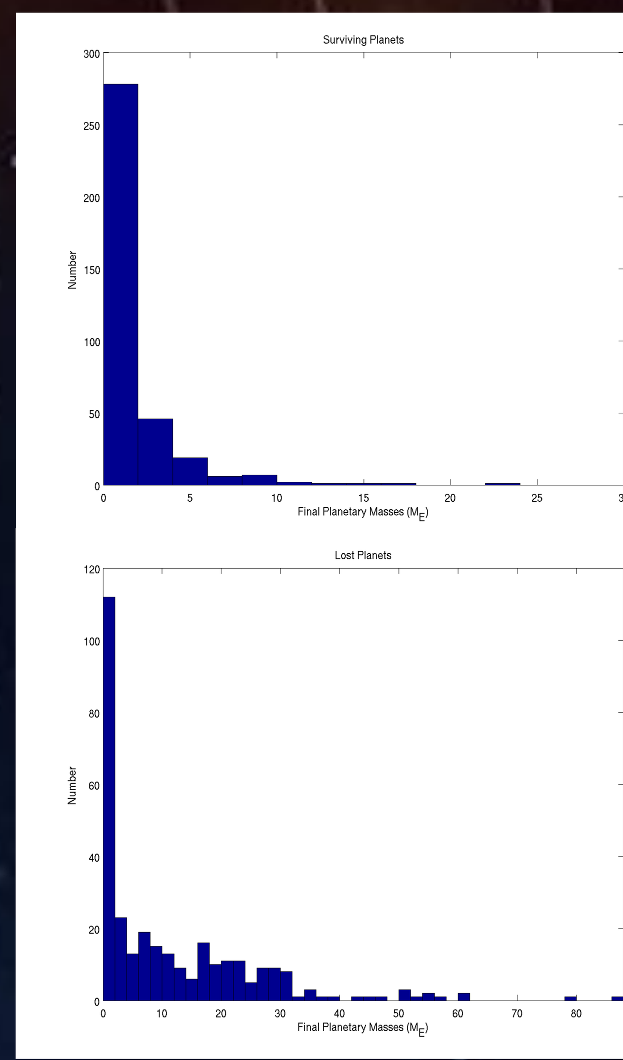

Figure 2 – Histograms showing lost planets and surviving planets from simulations.

Forming Giant Planets

Our results show that giant planets only form in more massive discs (≥3*MMSN), but none of them survive type II migration because they tend to form early while the discs are sufficiently massive to drive large-scale migration (examples are shown in the lower panel of Figure 4). These giants form when a group of protoplanetary cores form and start accreting gas while sitting at zero-torque radii in the disc where corotation torques prevent rapid inward migration. Gas accretion causes the masses to grow sufficiently large for the corotation torques to become ineffective (see Figure 3 for example). After migrating inward via type I, these planets enter regions where the disc thickness is small enough to allow gap formation. Type II migration then drives them into the star in all cases.

MMSN mass	Average percentage of surviving planets
1	35 %
3	2 %
5	1 %

Table 1 –Average number of surviving planets for tested different MMSN disc models.

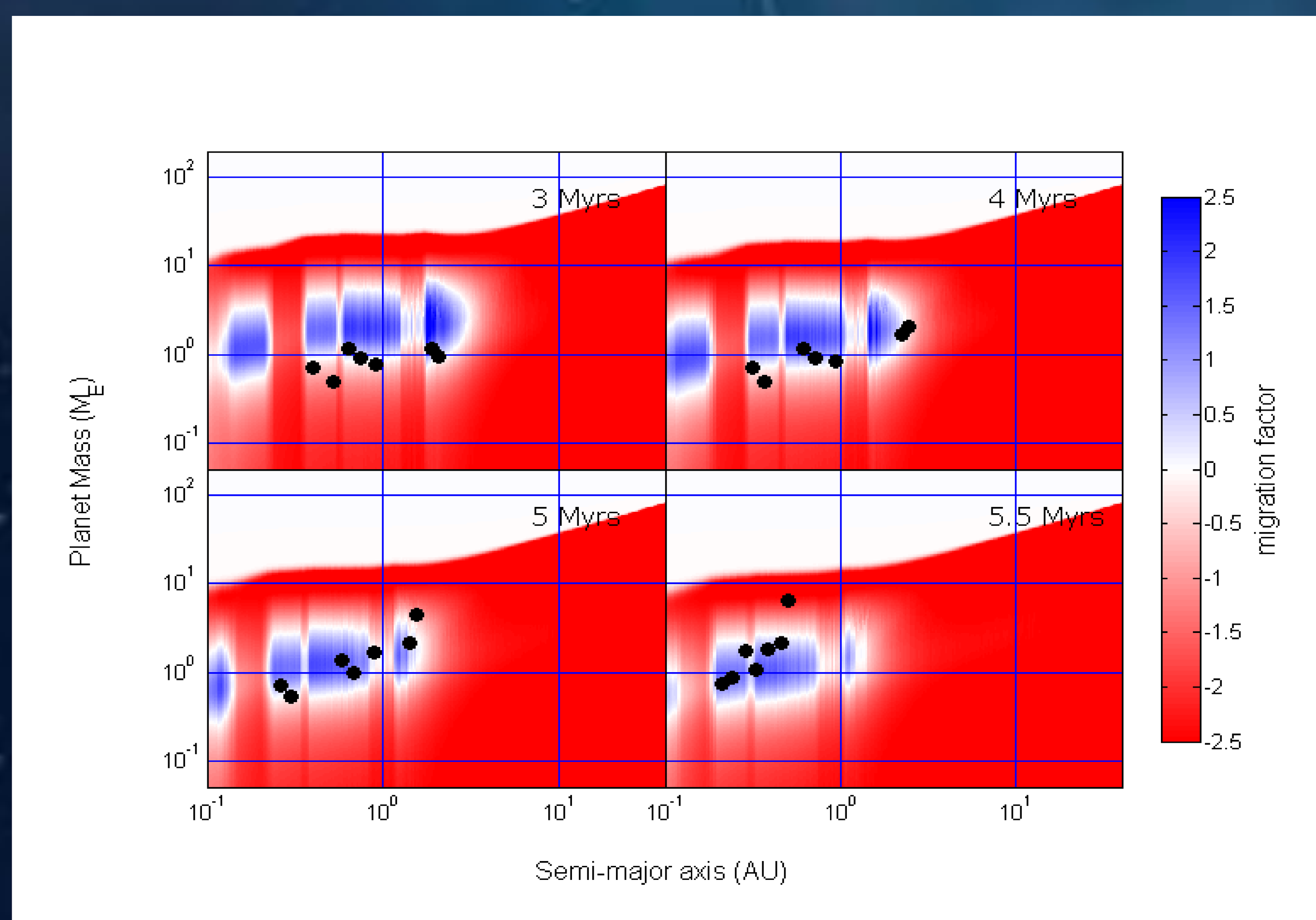

Figure 3 – Migration plots showing migration tendencies for a 3*MMSN disc with protoplanets highlighted in black

Conclusions

- Smaller mass discs are more likely to form multi-planet systems than higher mass discs due to faster growth and increased migration effects in higher mass discs.
- Our simulations show that numerous Earth to Neptune mass planets survive and are located across a wide radial range (0.2-20 AU).
- Giant planets form more frequently in higher mass discs, but always migrate into the central star.

Future Work

- Inclusion of a more accurate model for gas accretion onto planetary cores.
- Examination of a broader range of initial conditions.
- Inclusion of a more realistic sized distribution of planetesimals.
- A more sophisticated disc model taking account of possible variations in effective viscous stresses.

References

Hellary and Nelson, 2012, MNRAS, 419, 2737
Paardekooper et al, 2011, MNRAS, 410, 293
Chambers, 1999, MNRAS, 304, 793
Movshovitz et al, 2011, Icarus, 209, 616
Inaba & Ikoma, 2003, A&A, 410, 711
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