

HOW DIFFERENT INITIAL CONDITIONS CAN AFFECT THE ARCHITECTURES OF PLANETARY SYSTEMS

Beatrice Caccherano | b.caccheran@qmul.ac.uk

Team: Richard Nelson, Gavin Coleman



MOTIVATION

Understanding the formation and evolution of planetary systems is still an open question, and the current models are not able to describe the diversity of extrasolar planetary systems. Using *Mercury6* to perform N-body simulations of planetary system formation and evolution in a protoplanetary disc model, we aim to address the key question: **how do different initial conditions** - such as the initial position of planets, the dust surface density of the disc, and the speed of planetary migration- **influence the final architecture of planetary systems?**

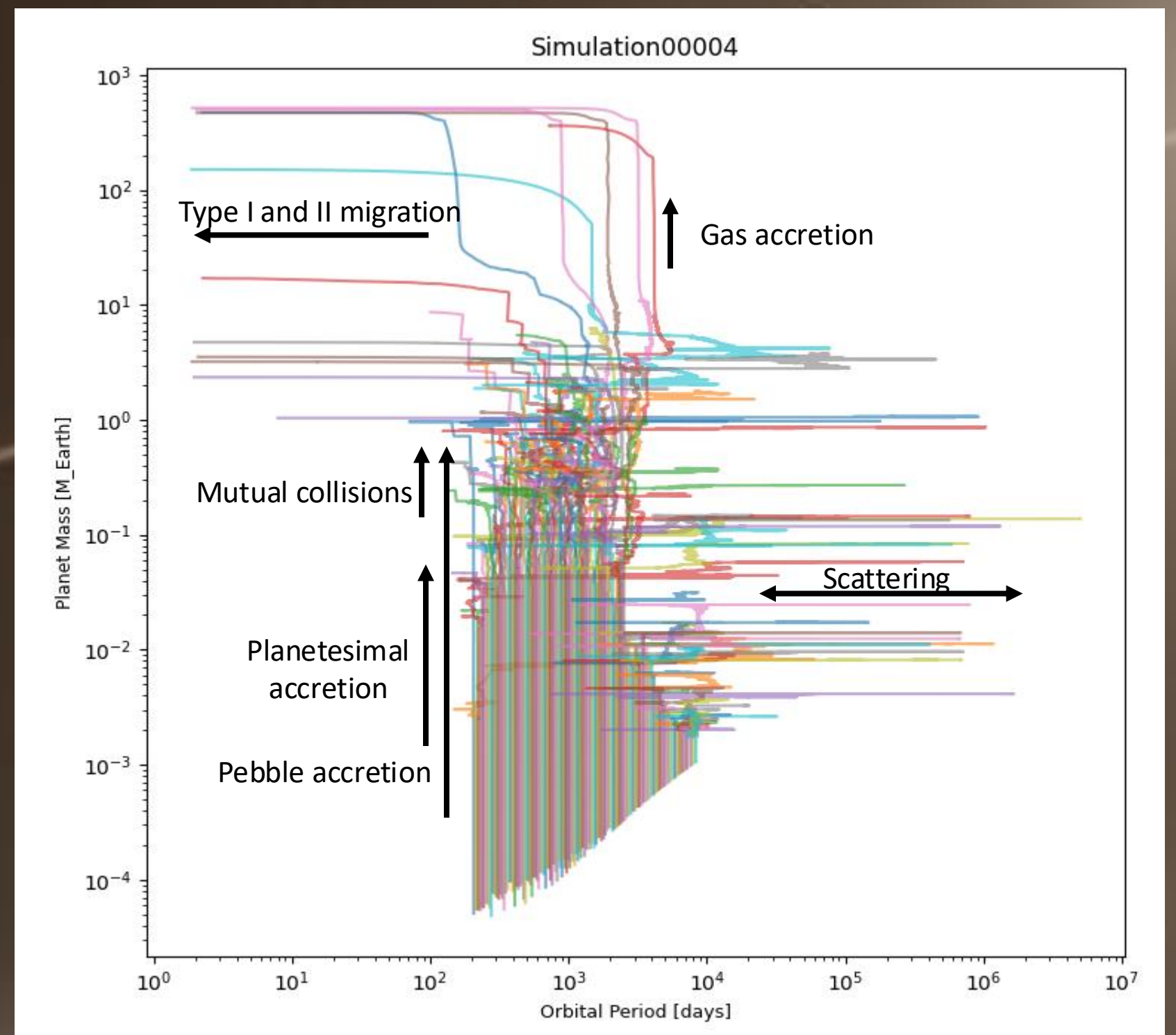
MODEL

Our model, based on the *Mercury6* code (Chambers 1999), has been previously adapted to include a planet formation and protoplanetary disc model (Coleman 2021). Particularly, it includes a 1D viscous disc model, in which the equilibrium temperature is determined by balancing multiple heating and cooling processes: stellar irradiation, background heating from the residual molecular cloud, viscous heating, and blackbody cooling.

In our simulations, from a given set of parameters, around **120 embryos** are formed at different locations in the disc. These embryos undergo:

1. pebble accretion;
2. planetesimal accretion;
3. scattering or mutual collisions;
4. migration towards the host star (type I and II migration);
5. gas accretion;

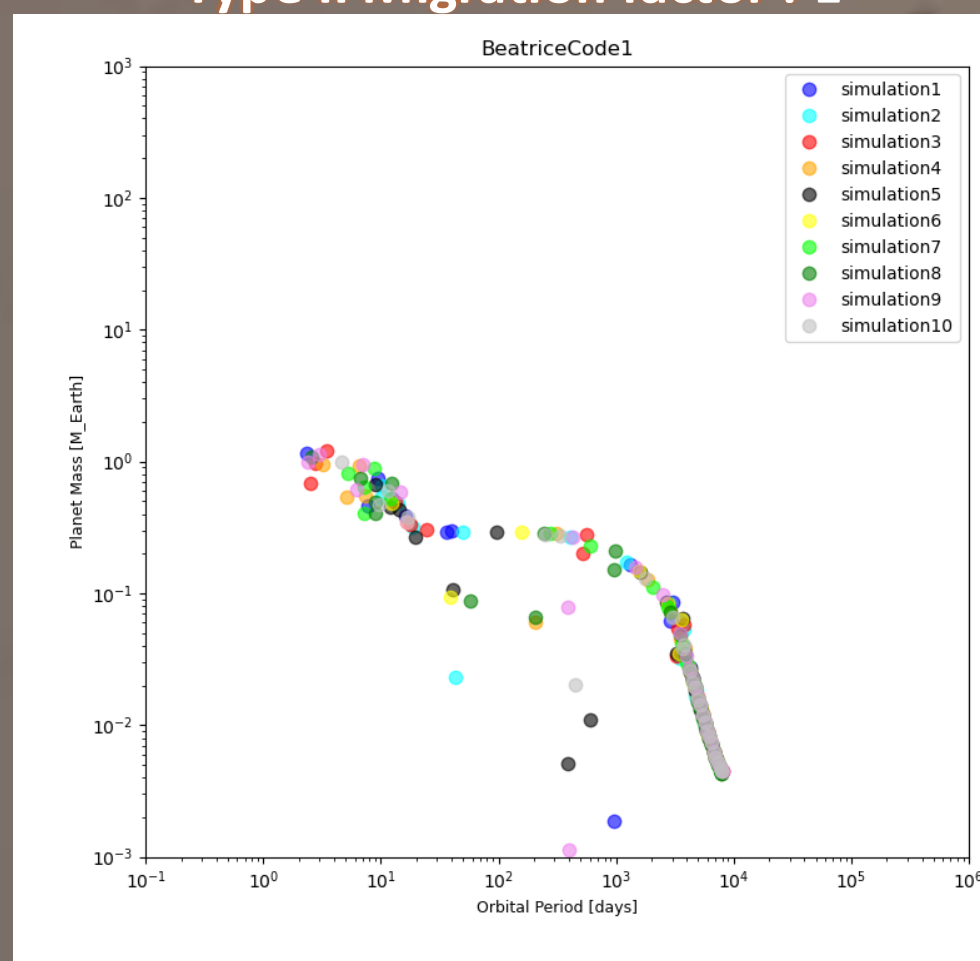
The figure on the right-hand side, shows the evolution of planet mass vs period from one of our simulations. It summarizes the above processes as indicated.



PRELIMINARY ANALYSIS

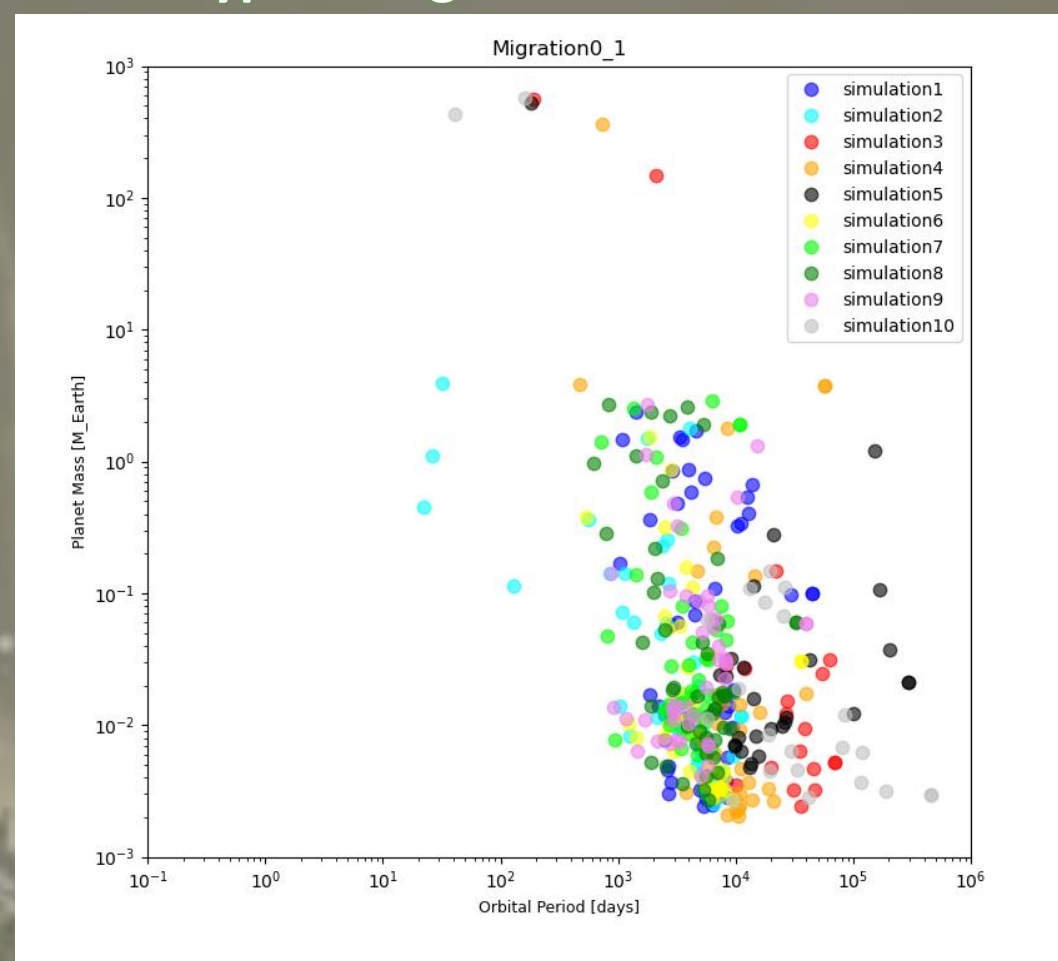
We ran 10 simulations for each of the parameter choices shown below, only varying the random number seeds that define the initial positions and velocities of the embryo's orbits when they form in the disc for each simulation. The three planet mass vs orbital period plots below show the final architectures for the three sets of initial conditions.

Disc mass: 7% Solar mass
Viscosity in the disc: 10^{-3}
Type I Migration factor : 1
Type II Migration factor : 1



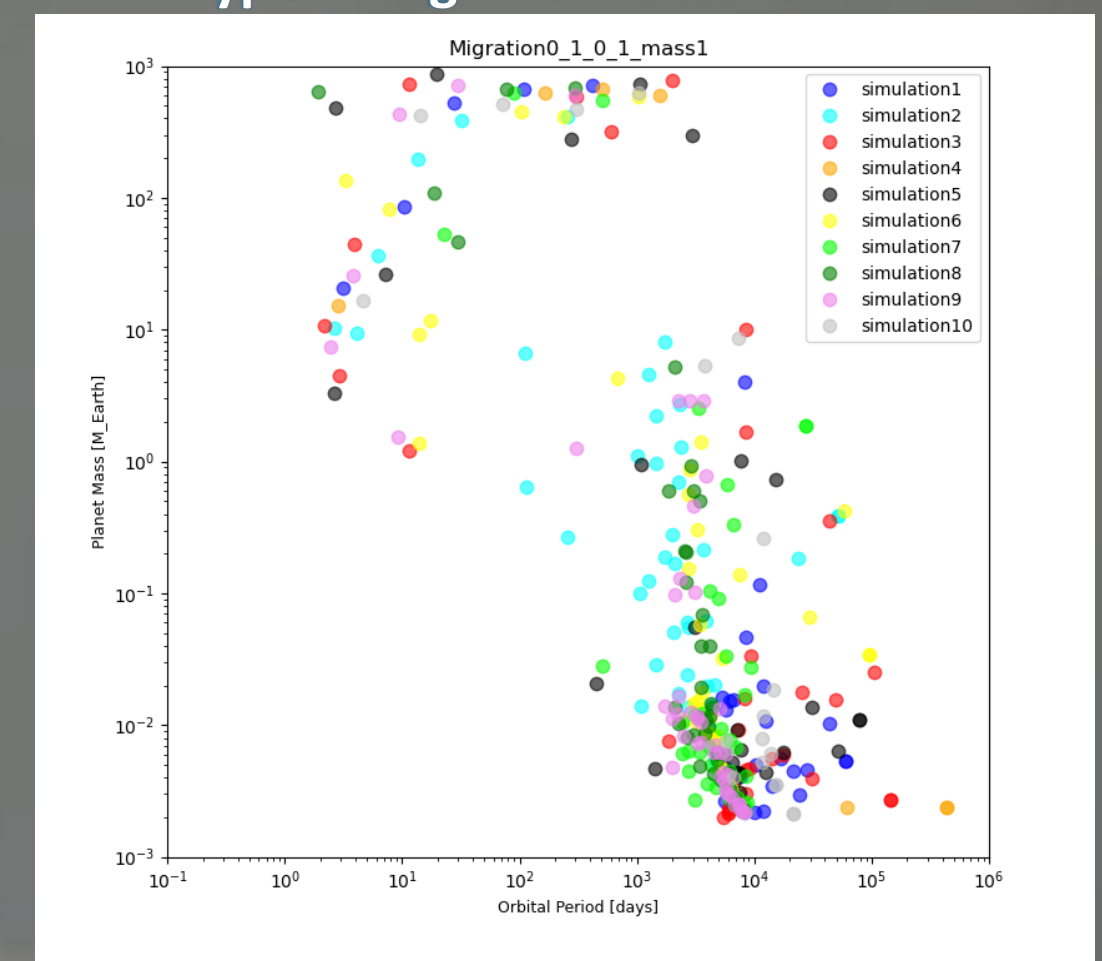
We observe a strong similarity between the planetary systems, where planets have interacted weakly and no giant planets have formed.

Disc mass: 7% Solar mass
Viscosity in the disc: 10^{-3}
Type I Migration factor : 0.1
Type II Migration factor : 1



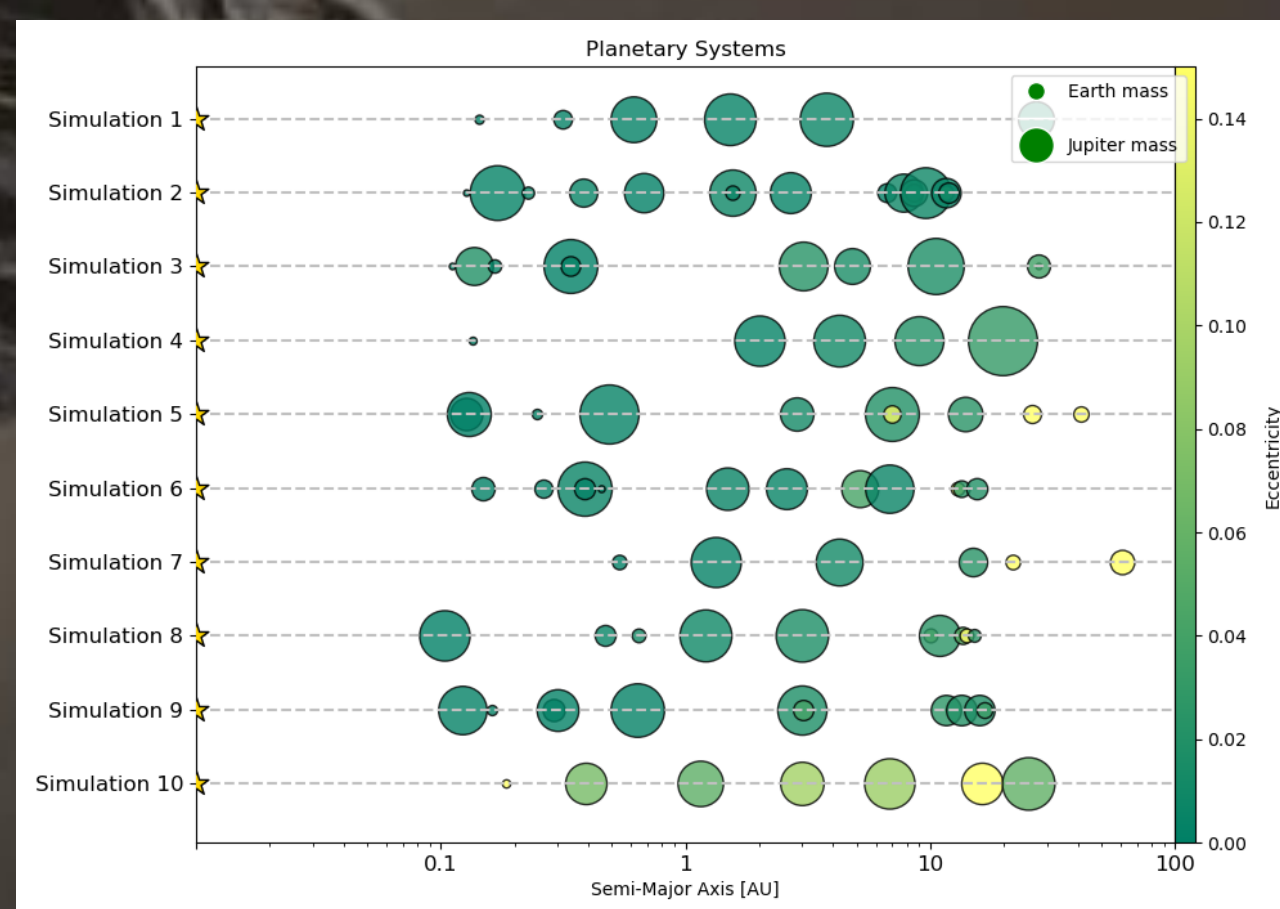
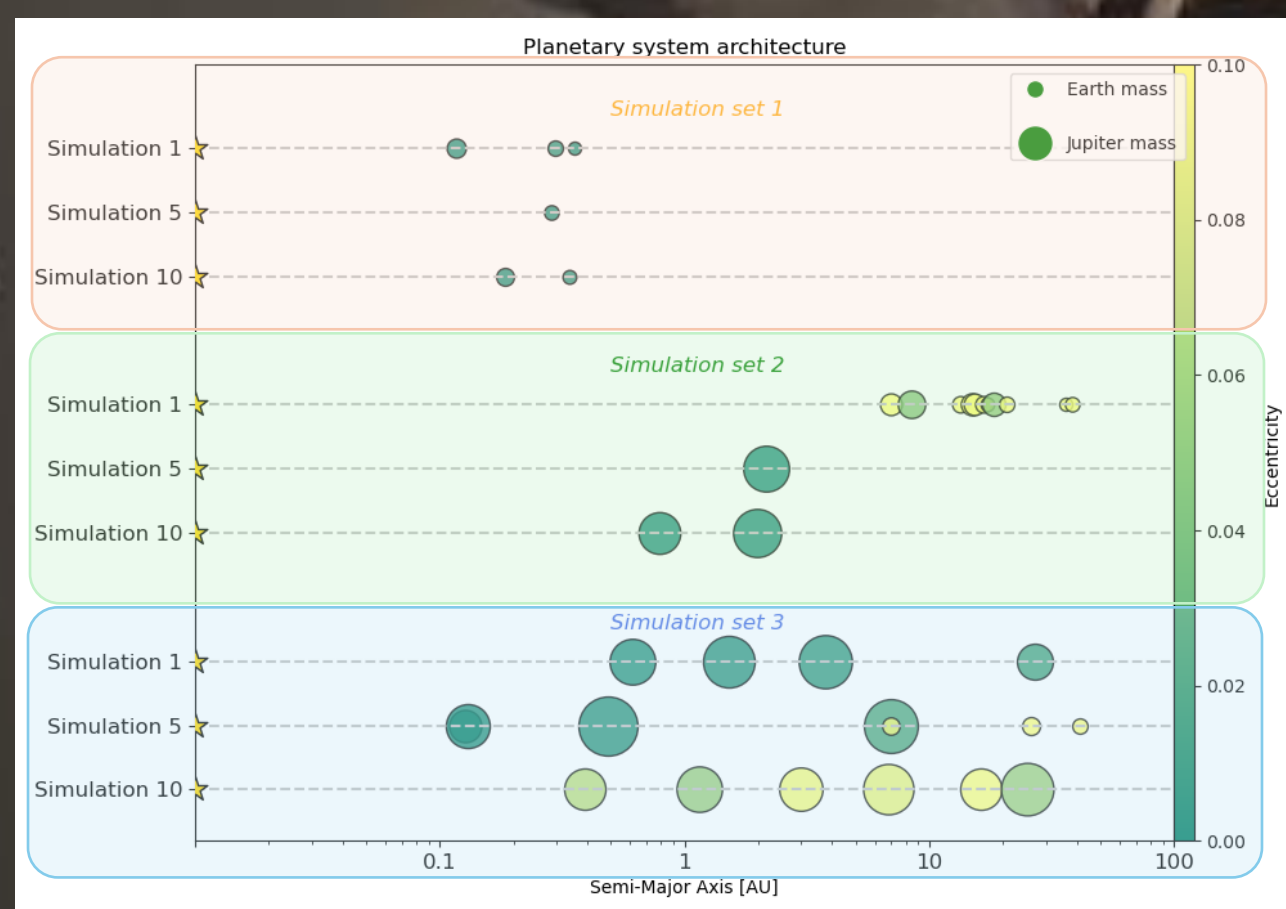
Slowing down the type I migration, we observe the formation of giant planets in some simulations and an increase in the gravitational interaction between planets during the late evolution stage.

Disc mass: 7% Solar mass
Viscosity in the disc: 10^{-3}
Type I Migration factor : 0.1
Type II Migration factor : 0.1



Slowing down both type I and II migration, we observe the formation of several giant planets and super-Earths in all simulations and increased interaction between planets because the larger number of giants.

The figure on the right shows a comparison between planetary system architectures where embryos are formed in the same positions, and the type I and II migration speeds decrease between the sets. Note the systematic variation in planetary systems architectures.



The figure on the left shows a comparison between planetary system architectures from simulations with the slowest type I and II migration speeds. The random number seeds defining the initial position of the embryos change between each simulation. Note the diversity of architectures that arise.

LONG TERM AIMS OF THE PROJECT

1. To understand how the architectures of planetary systems vary with systematic changes to the physical parameters that define initial conditions (e.g. disc mass, metallicity, etc.).
2. To determine how much variations can arise in system architectures from the same physical parameters that define initial conditions, due to nonlinear dynamics and planet-planet scattering.
3. To determine how this variations in architectures changes systematically with the physical parameters that define the initial conditions.
4. What are the implications of the above for interpreting observations of planetary systems in the context of planetary formation models (Mishra et al. 2023).

[1] Chambers, J. E., 1999, MNRAS, 304, 793–799. [2] Coleman, G. A. L., 2021, MNRAS, 506, 3596–3614. [3] Mishra, L., Alibert, Y., Udry, S., and Mordasini, C., 2023, A&A, 670, 68.