Abstract

In this thesis, we cover the assembly of terrestrial planets by means of N-Body simulations. We cover the growth of embryos from planetesimals within the first 10 million years as well as their late-stage stochastic assembly of terrestrial planets from embryos over the next 150 million years. During the first few million years, we also model the hydrodynamic and gravitational feedback of the gaseous protoplanetary disks on the planetesimals, embryos, and planets. By exploring a variety of initial planetesimal distributions, gas disk lifetimes, and orbits for giant planets, we establish their influence on the final orbital architecture of the planets, their feeding zones, and their expected water contents. In doing so, we pay particular attention to the statistical spread of simulations run as well as differences with to previous simulations which initialised from an initial embryos distribution instead of modelling their growth. We find four key results.

First, in simulations with giant planets, sweeping secular resonances are the main drivers that sculpt the architecture of the final system. In regions beyond the reach of giant planets or simulations without them, dynamics are driven by two-body dynamics between planetesimals, hydrodynamic drag and interactions with the gravitational potential of the disk.

Second, the orbits of the giant planets determine the evolution of the secular resonances. As such, systems with giant planets on eccentric orbits generate the most massive terrestrial planets (10 percent exceed $M_{90} \sim 1.27\ \mathrm{M}_{\oplus}$) on tight orbits (median semi-major axis $a_{50} \sim 0.86$ AU). If the giant planets are on circular orbit, terrestrial planets tend be less massive ($M_{90} \sim 1.02\ \mathrm{M}_{\oplus}$) and are on wider orbits ($a_{50} \sim 1.2$ AU). In systems without giant planets, terrestrial planets are the least massive ($M_{90} \sim 0.61\ \mathrm{M}_{\oplus}$) and on the widest orbits ($a_{50} \sim 2.4$ AU).

Third, terrestrial planets that form in the absence of giant planets appear, irrespective of disk profile and disk mass, extremely wet, and most host a few hundreds of terrestrial oceans worth of water. These values are above those previously reported from simulations, which is caused by the larger feeding zones we obtain when considering the planetesimals being embedded in a gas disk. Therefore, self-consistent growth of planetesimals embedded in a gas disk is essential when attempting to reconstruct the final chemical composition of planets. We do caution that the initial water contents as well as avenues for water loss during the planetary evolution are currently ill-constrained.

Fourth, the chaotic nature of the gravitational dynamics problems causes an even tiny ($<$ mm) initial displacement of a single planetesimal to propagate and completely diverge all planetesimals orbits in given simulation. Owing to perturbations induced by round-off errors, this means that every single simulation produces a different architecture of terrestrial planets. Therefore, individual simulations have no predictive power and only statistical properties taken over suites of simulations are meaningful.