# Thesis subject

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Subject's title: Constraining the formation and evolution of Solar System small bodies

Subject description: Small bodies in our planetary system comprise asteroids, giant planet Trojans and irregular satellites, Centaurs, Trans-Neptunian objects (TNOs), and comets (Fig. 1). While small bodies represent only a tiny fraction of the total mass of the planets, their large numbers, diverse compositions, and orbital distributions provide powerful constraints for planetary system formation models that complement - not duplicate - those collected from exoplanets and disks observations. Decades of observations have provided a preliminary understanding of the architecture of our Solar System and of the compositional distribution among inner (<5AU; see Fig 1 and Vernazza & Beck 2017 for a review) and outer Solar System small bodies (e.g., Barucci & Merlin 2020). These observations have revealed a number of puzzling features in each dynamical population of small bodies, including the compositional distribution and diversity of the asteroid belt, the inclination distribution of the Jupiter and Neptune Trojans, and the peculiar orbital distribution of Trans-Neptunian Objects. These findings have paved the way to new models of the formation and evolution of the Solar System, notably the Nice and Grand Tack models (e.g., Tsiganis et al. 2005, Walsh et al. 2011; see Nesvorný et al. 2018 for a review). In short, this first-generation of observing and modeling efforts - coupled with the discovery of hot extrasolar planets orbiting close to stars - was instrumental in imposing migration of giant planets as a major step in the dynamical evolution of our Solar System. On the basis of these data, the idea of a static Solar System history has dramatically shifted to one of dynamic change and mixing. Whereas it is now understood that important migration episode(s) did occur early in the history of the Solar System, a clear understanding of how the planetary orbits evolved, including the timing and nature of the migration episode(s), is currently missing.

The main objective of the PhD will be to test various scenarios of the dynamical evolution of the inner and outer Solar System (e.g., Walsh et al. 2011 and Brož et al. 2021 as two extreme examples) by means of i) computing the orbital evolution of assumed primordial small-bodies populations under the effect of protoplanet migration; ii) comparing the results with spectrophotometric observations and up-to-date modeling of the surface composition of small bodies throughout the Solar System; iii) taking into account isotopic anomalies in meteorites (e.g., Warren 2011, Kruijer et al. 2017), which indicate among others a separation of major reservoirs. Consequently, it shall be possible to address fundamental questions, in particular, "**Where did the main compositional classes of small bodies form?**", ''**What was the compositional gradient in the Solar System at the time of planet formation?**'', or ''**What was the composition of the building blocks of the telluric planets and the giant planet cores?**''.

In this work, we suggest to use the following numerical methods: i) radiative hydrodynamical (RHD) simulations, based on the Fargo code (Masset et al. 2000, Chrenko et al. 2017) to describe the gas/pebble disks, their structure from 0.1 to ~100 au, and growth of protoplanets; ii) N-body models with prescribed migration and gas drag (Duncan et al. 1998, Brož et al. 2021), to describe the long-term motion of protoplanets, planetesimals, or small-sized pebbles.

A detailed understanding of the governing partial differential equations and their numerical solution (FVM) will be necessary. Programming skills in C will be also necessary for all modifications of the RHD models, as well as understanding of the parallelization (MPI). The student will gain a multi-disciplinary knowledge of physics of the Solar System; he/she will be able to utilize state-of-the-art models.

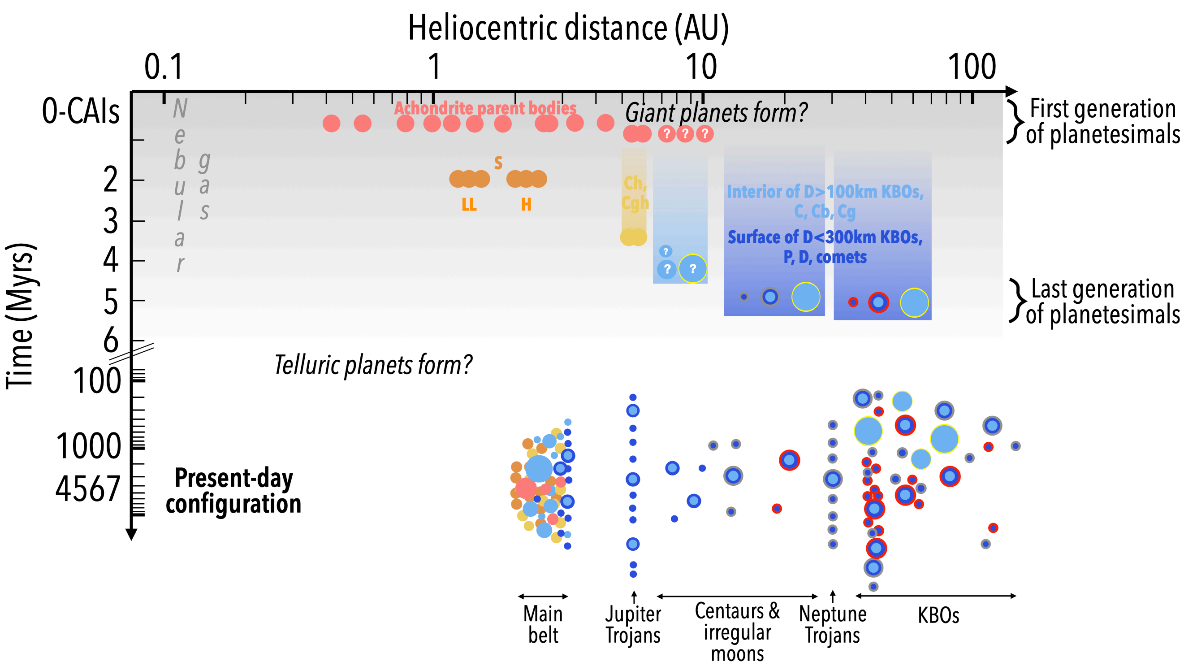


*Figure 1: (From Vernazza et al. 2021) Postulated sequence of events tracing the time, place, and duration of formation of the main compositional classes of small bodies (top) to present-day observed characteristics (bottom; vertical spread reproducing roughly the distribution of orbital inclinations). The accretion duration is shown as gradient boxes ending at the fully formed bodies. The formation location of the main classes of small bodies remains – as of today – purely speculative and one of the thesis' objectives will be to constrain them precisely.*