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The New Generation Planetary Population Synthesis (NGPPS): Comparison with the HARPS GTO survey

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Introduction

Understanding planetary formation is principally a theoretical task. However, the relevant processes that occur during this phase are poorly constrained, from how solids grow from dust to Earth-like planets or cores of giant planets, to how planetary migration affects the architecture of the systems. To determine if these model represent the reality, we need to compare them with observations.

Planetary formation and evolution models have many unknowns. As individual systems of extrasolar planets provide a low number of data, the comparison has to be performed at the population level to provide meaningful constraints on the models. Here, we present a framework for this purpose. It encompasses the Bern global model of planetary formation and evolution, the distribution of protoplanetary disc properties to perform planetary population synthesis, and the comparison of the synthetic planetary population with the combined Coralie-HARPS GTO survey *[1]*.

Methodology

The Generation III *Bern* model is a global model of planetary formation and evolution *[2]*. It tracks the relevant processes that occur during the formation and evolution of planetary systems.

The formation stage tracks the evolution of a viscous accretion disc, whose viscosity is provided by the standard α-parametrisation. Solids are represented by planetesimals, whose dynamical state is given by the drag from the gas and the stirring from the other planetesimals and the growing protoplanets.

A fixed number of protoplanetary seeds (1-100) are placed at the beginning of the formation. These protoplanets accrete planetesimals from the disc and cores of other protoplanets core upon collision. The gaseous envelope's structure is retrieved by solving the standard 1D internal structure equations. They allow to retrieve the envelope mass and the gas accretion rate (in the attached phase), or the radius (in the detached phase). The formation stages also include gas-driven planetary migration and the gravitational interactions between the protoplanets by means on an *N* -body.

Once the formation stage is finished, the model transitions to the evolutionary phase, where planets are followed individually to 10 Gyr. The planetary evolution model includes thermodynamical evolution (cooling and contraction), atmospheric escape, bloating, and migration due to tides raised on the star.

This model is used to compute a synthetic population of planetary systems. Observational data are used to constrain the initial conditions of the protoplanetary disc: their mass, metallicities (i.e. dust to gas ratio), radial extend and life times *[3]*. We selected the same number of systems as in the combined Coralie-HARPS GTO survey sample (822) so that we can also compare the absolute number of planets. We assume that each system is observed from a random direction to compute the inclination of the orbit of each planet. This enables to compute the effective mass Msin(i) of the planet. The detection probability of each planet is computed from completeness curves of the survey *[1]*.

Results

In the synthetic population, we detect 317 planets while 161 planets were detected in the actual combined Coralie-HARPS sample. Hence, the model forms about twice the number of planets that are observed. Nevertheless, the multiplicity (i.e. the mean number of planets per system) is similar in the two populations: The 317 synthetic planets are found around 204 stars, while the actually observed 161 planets are distributed in 102 systems. this indicates that the system architectures are more similar than the absolute frequencies.

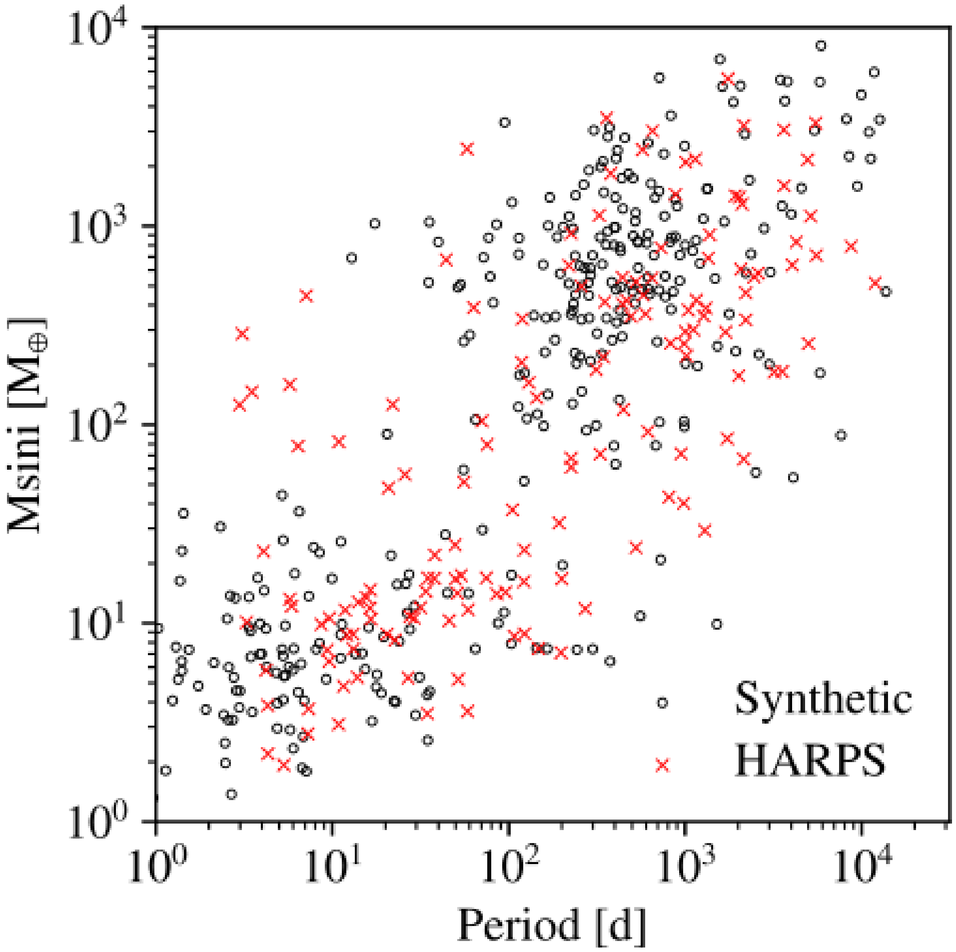

Figure 1: Mass-period diagram

The mass-period diagram (Figure 1) shows the planets in the synthetic population (black circles) and the ones found in the Coralie-HARPS survey (red circles). The two populations have similar clusters on super Earths at about 10 days and giant planets at about 1000 days. However, the synthetic planets are more concentrated in these regions and there are relatively few synthetic planets in between or hot-Jupiters.

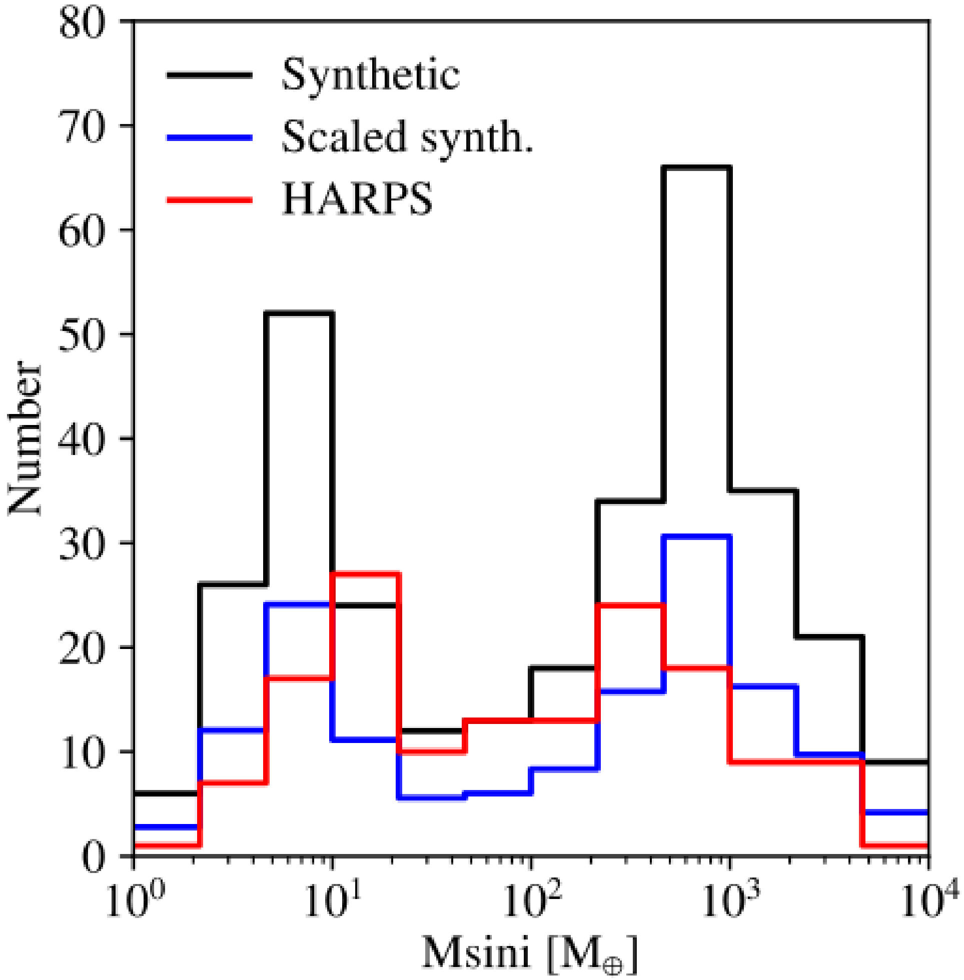

Figure 2: Mass histogram

The mass histogram (Figure 2) shows for the synthetic population (black), the observed sample (red), and the synthetic population scaled so that it has the same total value as the observed sample (blue). It reveals that both super-Earths and giant are too numerous in the synthetic population. However, there is disproportionately more giant planets coupled to a lack of Saturn-mass planets in the synthetic population.

Discussion

The whole framework provides a powerful framework to quantitatively constrain models of planetary formation and evolution. We obtained that our model *[2]* is too efficient by a factor two in absolute terms, although the mean multiplicity is similar in the two samples (synthetic and observed). This excess of planets is caused by an overabundance of giant planets coupled with a relative lack of planets at intermediate masses (20 to 200 M_{Earth}), which suggest that the gas accretion rate in our model is too high.

It is possible to statistically compare many more quantities, such as eccentricity or stellar parameter like its metallicity to see if the metallicity effect (e.g., *[4]*) is retrieved in the synthetic population. Also, different system architectures or (anti)correlated occurrence of different planet types can be compared. We will present these results during the conference.

In case the synthetic population does not retrieve the trends of the observed sample, it means that the formation model needs to be modified. Once the observed population can be satisfactorily reproduced, we can 1) determine how the physical processes work to form exoplanetary systems and 2) make predictions about the underlying population.

Our global model predicts the quantities necessary for comparison with different observational techniques, such as radius for transits and luminosity for direct imaging. We have parallel efforts to perform comparison with other surveys, such as Kepler *[5,6]* or SPHERE *[7]*.

References

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