1. PHD PROJECT DESCRIPTION (4000 characters max., including the aims and work plan)

Project title:

Dynamic characterisation of multiple planetary systems from diverse observational data

1.1. Project goals

The general aim of the project is to comprehensively characterise selected multiple extrasolar planetary systems, taking into account activity of the host stars that can mimic and/or suppress the planetary signals in the radial velocity, astrometry or chronometry and even in the photometric lightcurves. This will be based on the optimisation of orbital models from observations of their stars using these techniques, subject to dynamical and astrophysical constraints such as long-term stability and planetary migration. Special attention will be given to resonant and near-resonant planetary systems.

1.2. Outline

Observational data for the 10000 extrasolar planets (https://exoplanets.org) discovered to date have been updated extensively by satellite missions (e.g., Kepler, TESS, GAIA) and ground-based programmes based on the radial velocity (RV), e.g. HARPS/N HIRES; photometry aimed at transiting planets (e.g, OGLE); astrometry (e.g., ALMA, GRAVITY) and direct imaging (SPHERE VLT, GPI). Partial results are already available from the astrometric mission GAIA, which observes 1.8 billion stars at 10+ yr intervals, and raw data are expected to be available in a few years.

These surveys provide measurements available in public archives (e.g. NASA, ESO). Their reduction and interpretation for individual cases is usually complex and computationally demanding, especially for multiple systems with more than two components [5-9]. Their remarkable diversification should be emphasised. Fundamental parameter distributions, such as the mass function, orbital period ratios and eccentricities, are still poorly understood due to various biases, including activity of the host stars [1-4]. The main motivation is therefore to improve these statistics through in-depth astrophysical and dynamical analysis, carried out with new and continuously time-extended observations, helping to constrain evolution and boundary conditions for the planet formation [5-10].

The project aims to investigate detailed orbital architectures and physical parameters (radii, masses, densities) in selected multiple systems, satisfying constraints of long-term dynamical stability or particular orbital evolution [5]. Data modelling, based on current astrophysical and statistical theory [1-4] will focus on the astrophysical characterisation and variability of the host stars influencing the observations. Of particular interest will be resonant planetary systems observed with complementary and combined techniques (e.g., radial velocity, transits, chronometry, imaging and astrometry). The requirements impose constraints on the initial conditions and physical parameters, still crucial given short observational intervals, non-uniform sampling, noise and systematic uncertainties. ***In this way, although the idea is not entirely new, the project moves from simple detection to possibly detailed characterisation, and takes up the challenge of answering some questions focusing on exoplanet formation and long-term evolution [10].***

1.3. Work plan

1. Understanding modern models of orbital architectures constrained by dynamical evolution (long-term stability and physical processes). This includes an introduction to the required theoretical and numerical techniques.

2. Selection of planetary systems that are poorly characterised in the literature, and collection of all available source data for these systems.

3. State-of-the-art statistical and dynamical analysis of the selected systems, consistent with their general architectures such as near/resonant configurations.

4. Search for general patterns in the parameter distributions that may shed more light on the statistical properties of the multiple systems.

1.4. Literature *(max. 10 listed, as a suggestion for a PhD candidate)*

1. Queloz, D., Henry, G. W., Sivan, J. P., Baliunas, S. L., Beuzit, J. L., Donahue, R. A., Mayor, M., Naef, D., Perrier, C., Udry, S.: No planet for HD 166435, 2001, A&A, 379, 279

2. A. P.Hatzes: Simulations of Stellar Radial Velocity and Spectral Line Bisector Variations: I. Nonradial Pulsations, PASP, 2002, 108, 839

3. A. P.Hatzes: Starspots and exoplanets, Astronomische Nachrichten, 2000, 323, 392

4. A. C. Cameron: Extrasolar planets: Astrophysical false positives, Nature 492, 7427, 48

5. F. Panichi, K. Goździewski & G. Turchetti: The reversibility error method (REM): a new, dynamical fast indicator for planetary dynamics, MNRAS 468, 2017

6. K. Goździewski & C. Migaszewski: The Orbital Architecture and Debris Disks of the HR 8799 Planetary System, ApJS 238, 2018

7. Goździewski K. & Migaszewski C.: An exact, generalised Laplace resonance in the HR 8799 planetary system, ApJ Letters 902, L40, 2020

8. K. Goździewski: The orbital architecture and stability of the μ Arae planetary system, MNRAS 516, 2022

9. Zurlo A., Goździewski K., Lazzoni C. i in.: Orbital and dynamical analysis of the system around HR 8799. New astrometric epochs from VLT/SPHERE and LBT/LUCI, Astronomy and Astrophysics 667, 2022

10. Howell, S. B.: The Grand Challenges of Exoplanets, Front. Astron. Space Sci., 2020

1.5. Required initial knowledge and skills of the PhD candidate

- A good background in celestial mechanics and dynamical systems theory, with previous and documented work on the dynamics of the Solar system and/or extrasolar planets.

- Analytical thinker, willing to work hard and learn and synthesise material from interdisciplinary fields (dynamical theory and astrophysics, statistics, optimisation, data analysis).

- A good background in numerical methods and programming (Python and C preferred)

1.6. Expected development of the PhD candidate's knowledge and skills

The PhD candidate will work on an important project in the rapidly developing field of astrophysics. His/her results may contribute significantly to the understanding of the origin and evolution of extrasolar planets. The PhD student will develop a deep theoretical knowledge in the field of astrophysics, dynamics and observational optimisation, as well as technical skills (programming, knowledge of instruments and astronomical databases) sufficient to be recruited in international projects once the PhD project is completed.