



Orbital Dynamics of Multiplanet Systems



SUMMARY.

The long-term dynamical stability of multiplanet systems is a fundamental question in planetary science. This project investigates the orbital dynamics of exoplanetary systems hosting three or more planets, selected from current observational catalogs. The equations of motion are integrated numerically. Chaos indicators — including the Fast Lyapunov Indicator (FLI), the Mean Exponential Growth factor of Nearby Orbits (MEGNO), and Lagrangian Descriptors (LD) — are computed to characterize the orbital dynamics and assess the long-term stability of the observed configurations.

— Scientific Context —

The discovery of thousands of exoplanetary systems has revealed a rich diversity of multiplanet architectures. Understanding whether these systems are dynamically stable over gigayear timescales — and what orbital configurations allow long-term coexistence — is a central problem of modern planetary science. Analytical and semi-analytical methods (e.g. mean-motion resonances, secular theory) provide important insights, but direct numerical exploration of the phase space remains indispensable, particularly for compact or near-resonant systems.

— Objectives —

Upon completion of this project the student will be able to:

- retrieve and interpret orbital data from exoplanet catalogs (NASA Exoplanet Archive, exoplanet.eu);
- formulate and implement the gravitational N -body equations of motion in a suitable reference frame;
- apply high-accuracy numerical integrators (e.g. REBOUND, custom RK78 or symplectic schemes) to long-term orbital simulations;
- compute and interpret variational chaos indicators: FLI, MEGNO, and Lagrangian Descriptors;
- present results in the form of a scientific report and oral defence.

— Work Programme —

Phase 1 — Bibliographic study (*weeks 1–3*). Review of the literature on N -body dynamics, mean-motion resonances and chaos indicators. Selection of target systems from the exoplanet catalogs according to criteria of scientific interest

Phase 2 — Numerical tools (*weeks 4–6*). Implementation or adoption of a suitable N -body integrator. Learn to use Python for numerical integration and computation of chaos indicators. Use particular C-code software.

Phase 3 — Dynamical mapping (*weeks 7–11*). Numerical integrations for various undetermined parameters and estimation of survival times. Identification of resonant configurations and phases of stability or instability.

Phase 4 — Analysis & writing (*weeks 12–16*). Writing of the thesis report; preparation of the oral presentation.

— Prerequisites —

- Classical and analytical mechanics (Lagrangian/Hamiltonian formalism).
- Ordinary differential equations; basic numerical analysis.
- Programming proficiency in Python or C++.

- Basic knowledge of celestial mechanics (orbital elements, Kepler's laws) is an advantage.

— Deliverables —

- Written thesis report (~30–50 pages).
- Oral defence presentation (20 min + questions).

— Key References —

- Murray & Dermott, *Solar System Dynamics*, Cambridge UP, 1999.
- Dvorak R. (ed), *Extrasolar Planets*, Wiley-VCH, 2008.
- Foutzopoulos K., *MSc-thesis* voyatzis.webpages.auth.gr/SeniorThesis/mfoutzopoulos2023.pdf, 2023

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Research interests: Celestial mechanics, orbital dynamics, dynamical systems, chaos indicators, N -body simulations, ESA Hera mission.