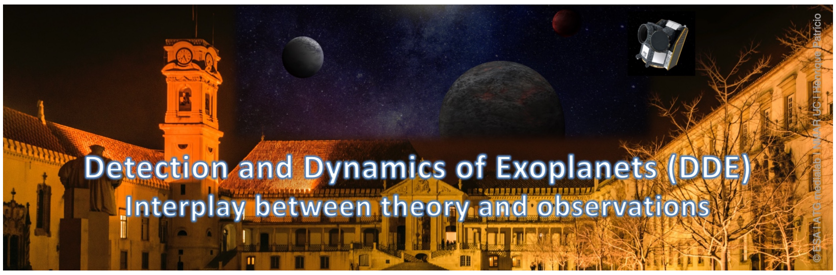

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Numerical approach to second-order canonical perturbation theory in the planetary n-body problem

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Extrasolar planetary systems commonly exhibit planets on eccentric orbits, with many systems located near or within mean-motion resonances, showcasing a wide diversity of orbital architectures. Such complex systems challenge traditional secular theories, which are limited to first-order approximations in planetary masses or rely on expansions in orbital elements—eccentricities, inclinations, and semi-major axis ratios—that are subject to convergence issues, especially in highly eccentric, inclined, or tightly-packed systems. To overcome these limitations, we develop a numerical approach to second-order perturbation theory based on the Lie transform formalism. Our method avoids the need for expansions in orbital elements, ensuring broader applicability and more robust convergence. We first outline the Hamiltonian framework for the 3-body planetary problem, and apply a canonical transformation to eliminate fast angle dependencies, deriving the secular Hamiltonian up to second order in the mass ratio. We then use the fast Fourier transform algorithm to numerically simulate, in an accurate way, the long-term evolution of planetary systems near or away from mean-motion resonances. Finally, we validate our methods against well-known planetary configurations, such as the Sun-Jupiter-Saturn system, as well as to exoplanetary systems like WASP-148 and TIC 279401253, demonstrating the applicability of our models across a wide range of planetary configurations. Joint work with Jacques Laskar and Federico Mogavero.

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