Z102a A differentiable N-body code for dynamical modeling of multi-planet systems

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In multi-planet systems, mutual gravitational interactions between planets cause their orbits to deviate from strictly Keplerian motion. These dynamical perturbations encode valuable information about planetary masses—a fundamental yet often difficult-to-measure property. In many transiting exoplanetary systems, such interactions manifest as variations in the timing between successive transits, known as Transit Timing Variations (TTVs). By modeling these variations with N-body simulations, it is often possible to infer planetary masses that are otherwise difficult to determine using other techniques. However, these models typically involve dozens of parameters with strong degeneracies, making posterior sampling computationally challenging. Commonly used methods in the field, such as random-walk Markov Chain Monte Carlo (MCMC) and nested sampling, often struggle to efficiently explore such high-dimensional, curved parameter spaces.

To address these challenges, we have developed `jnkepler`, an open-source, automatically differentiable N-body code implemented in JAX. The code can compute transit times as well as other observables relevant to exoplanatary systems, along with their gradients with respect to planetary masses and initial orbital elements. This feature enables the use of gradient-based inference methods such as Hamiltonian Monte Carlo and the No-U-Turn Sampler to efficiently explore the posterior distribution. In this presentation, I will introduce the code, demonstrate its application to real TTV data, and discuss how its performance compares to other sampling methods such as random-walk MCMC and nested sampling.