NEPTUNE: N-body Exoplanet Prediction Using TTV for Unseen Exoplanets

Nath, Arushi (School: Bloor Collegiate Institute)

Traditional exoplanet detection methods often overlook multi-planet systems containing long-period or non-transiting planets due to observational biases favoring short-period transiting planets. NEPTUNE bridges this gap by analyzing Transit Timing Variations (TTVs) of known planets to detect, characterize, and assess the habitability of possible unseen companions. NEPTUNE used N-body simulations to generate TTV signals for over 80,000 multi-planet systems, capturing gravitational interactions across different orbital timescales for each system—from long-period resonances to short-period synodic (planetary conjunction) effects. Simulation results feed into a Random Forest machine-learning model to produce informed priors for Bayesian inference. This novel approach accelerates Bayesian Markov Chain Monte Carlo convergence by up to 800% compared to no priors, reducing computational demands. N-body simulations revealed that resonant signals correlate with the unseen planet's mass and eccentricity, while synodic signals are eccentricity-independent. By applying multi-period TTV analysis, NEPTUNE breaks degeneracies between planetary mass and eccentricity, yielding a unique solution with quantified uncertainties. NEPTUNE was validated using Kepler-46b TTV data, successfully recovering the known unseen companion Kepler-46c's orbital period (57 days), eccentricity (0.01), and mass (110 Earth masses), closely matching NASA's published values. Furthermore, NEPTUNE's analysis of understudied Kepler-1710b data suggests the existence of an undetected ~31 Earth-mass planetary candidate, prompting follow-up analysis by the Kepler TTV group. Integration with data from NASA's TESS mission and ESA's ExoClock initiative is expanding NEPTUNE's capability to detect unseen exoplanets.

Awards Won: