国立天文台天文シミュレーションプロジェクト成果報告書

N-body Simulation of the HL-tau System

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Background – Puzzling Origin of Hot Jupiters(HJs) and Atacama Large Millimetre Array's(ALMA) Observation on HL-tau

Among exoplanets discovered so far, there are many Jupiter-size planets that are extremely close to the main star. These so-called HJs are hard to be explained by the conventional in-situ planet formation model because a contradictorily much larger orbit is necessary to have the sufficient mass-accretion for such a massive planet to form. One of the latest models proposed to solve the contradiction was the **dynamical scattering followed by tidal migration** (Nagasawa & Ida 2011), but great uncertainty still remained as no realistic initial conditions were available to initialise the simulations. ALMA changed the picture by successfully identifying **the concentric ring structure** on the HL-tau proto-planetary disk, which were commonly interpreted as a result of mass accretion caused by proto-planets. Therefore, it will be a large improvement to start the simulation from ALMA's observation and see whether HJs can be produced on this realistic basis.

Research Methods We run the simulation on the opensource N-body integration code REBOUND (Rein & Liu 2011). The initial orbit of each planet was deduced from the gaps in HL-tau system. We randomise the planet phases and assign different **mass distributions** to planets as well. We adopt and implement the tidal circularisation model from Ivanov & Papaloizou (2007). When a planet becomes very close to the star(<0.2AU), we marked the planet as **HJ candidate** and switched on the tidal effect. Each system was evolved up to 1 Gyrs, and finally we statistically analyse the simulation results to investigate on the distribution of the orbital parameters and efficiencies of HJs production.

Progress**:** We have finished **100 simulations** (Fig 2) and reproduced the previous result of the final

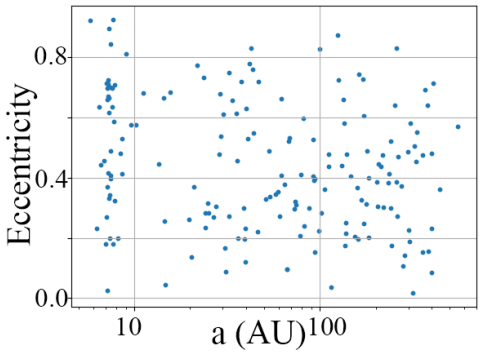

Figure 1: Distribution of remaining planets' eccentricity against semi major axis (AU) in 100 simulations

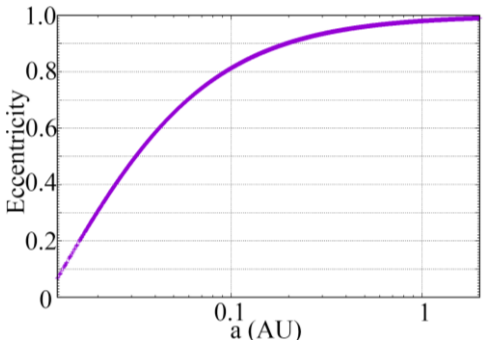

Figure 2: Simulated tidal evolution of eccentricity against semi major axis(AU)

distribution of planets (Simbulan 2017), which showed 13.2% of total planets became HJ candidates. We finished incorporating the tidal model and started testing the model on the closed-in planet (Fig 3) to show the tidal evolution. We have improved the initial mass assignments and simulated the corresponding cases.