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Formation of retrograde extrasolar planets

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About 25% of the discovered extrasolar planets have orbital periods smaller than 1 week. These are called as the close-in planets. Jovian or Neptunian type planets in this location are likely to be formed at large distance from their host stars and migrated to shorter period orbits. Sky projected angles between a stellar equator and a planetary orbit are measured for 20 transiting planet using Rossiter-McLaughlin technique. About half of them are in highly inclined orbits. This misalignment is hardly explained by Type-II migration, which is most contributing mechanism to planetary migration.

Starting with three planets orbiting around a solar mass star in circular orbits, I have numerically investigated how planetary orbits evolve by a combination effect of mutual scattering and tidal circularization for understanding the inclination distribution. Dynamical tides corresponding to planetary normal modes and inertial modes, relativity, gravity of the central star, and mutual gravity of planets are included in simulations.

I obtain the close-in planets in about 24% of runs. The formed close-in planets have a broad range of orbital inclinations. The probability of retrograde orbit is 29%. Approximately 83% of the close-in planet are formed during planet-planet scattering phase. That means they tend to have very short tidal evolution timescale and they tend to be totally circularized. On the other hand, about 17 % of the close-in planets are formed after the scattering phase. They tend to have longer tidal evolution timescale. Since their eccentricities are gradually increased by the secular interaction or the Kozai mechanism exchanging the inclination and eccentricity, they tend to be in prograde orbits or in near polar retrograde orbits. The retrograde planet with moderate inclination and high eccentricity is rare, since they need to be scattered to very limited region of orbital parameters during orbital instability stage.

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