Orbital evolution to eccentric close-in extrasolar planets

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We have investigated the formation of close-in planets through a coupling effect of mutual scattering and tidal circularization.

Many short-period giant planets are discovered outside of the solar system. These planets would have been formed at large distances beyond the ice line and migrated to shorter-period orbits. One possible mechanism of the migration other than type-II migration is scatterings by other giant planets. Scattering process can produce high eccentricities and inclinations of planets, while type-II migration cannot excite planetary orbits without nearby secondary large planets.

To study the origin of observed close-in planets, which have relatively large eccentricities but are not accompanied by nearby secondary large planets, we have carried out orbital integrations of three planets with Jupiter-mass, including the effect of tidal circularization. We have found that the short-period planets are formed at about 1/3 cases in our simulation after the planet scatterings. This is because that Kozai mechanism caused by outer planets repeatedly excites the eccentricity of the innermost planet during the three-planet orbital crossing. The eccentricity is often increased to values enough for tidal circularization to transform the inner planet to a close-in planet.

The formed close-in planets have a broad range of orbital inclinations including retrograde orbits. Most of the close-in planets have tidally-circularized eccentricities in the end, but few percent of them keeps large eccentricities, since the decrease of angular momentum increases the pericenter distance and the circularization timescale becomes longer than the system age. The process of planet scattering and tidal circularization can give a path for formation of close-in planets, in particular the close-in planets having moderate eccentricities and inclinations such as HD15176b.

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