Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-P26 Room:Convention Hall Time:May 20 18:15-19:30

Tidal orbital evolution of retrograde hot jupiters

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Recently, retrograde hot jupiters with orbits run counter to the spin of their central stars have been discovered. For such a hot Jupiter with large orbital inclination, it is hard to think that the planet formed in-situ on a proto-planetary disk or, that it moved to the present position by the interaction with disk gas after planet formation, because the planetary orbit is kept almost align with the disk plane in these processes. Then, the "slingshot scenario" have been proposed as a likely formation scenario of these planets. In this scenario, a gas giant planet with highly elliptical orbit with large inclination has once formed by gravity scattering among gas giant planets formed in a proto-planetary disk. And then, the tidal action of its central star induces the orbital evolution to hot Jupiter.

There remain questions, however, in the processes of such tidal action. For example, tidal action is modelled by assuming dynamical tide in some previous works, because the orbital evolution begins from a highly elliptical orbit (e.g. Nagasawa et al. 2008). However, as the eccentricity becomes small with orbital evolution, it would become appropriate to consider equilibrium tide. In addition, the strength of tidal friction has still been poorly constrained.

This study presents our theoretical analysis of the tidal orbital evolution of six hot Jupiter whose primary stars' ages are known and attempts to estimate likely processes of tidal action and the intensity of tidal friction.

In the tidal interaction, the vector sum of angular momentums of planetary orbit, stellar rotation and, planetary rotation is preserved. Moreover, the angular momentum of planetary rotation is too small to affect the evolutionary pathway. Since the orbital angular momentum of a retrograde planet is always conveyed to that of stellar rotation, the past orbit should have larger angular momentum than the present. That is, the evolutionary pathway kept the current orbital angular momentum has the smallest pericenter distances. For each of the six planets, the time constants of the pericenter passage during such preserving evolutionary pathway are longer than that of planetary free oscillation. This shows that an equilibrium tide model is appropriate for these planets.

By using the equilibrium tide model(Eggleton 1998), numerical calculations of orbital evolution backward in time for the age of each planetary system is performed. Since the tidal dissipation constant which specifies the strength of tidal friction has large uncertainty, it is taken as a parameter. Its value which may reproduce the orbital evolution from an extended elliptical orbit to the present orbit is obtained exploratory.

For each planet, there exists solutions whose early orbit meets the conditions expected from a slingshot scenario (An semi-major axis before the age of a system is 2-3 AU. It does not collide with a central star on the way of orbital evolution). The dissipation constant that agrees with the above conditions can be constrained in a narrow range for each planet. It appears that there is a correlation between planet radius and dissipation constant. The dissipation constant of Jupiter derived from the orbital dynamics of Jovian satellites also follows this correlation.

Using acquired value of dissipation constant, the past tidal heating rate is also estimated. The six retrograde planets may have received tidal heating 0.05-2 times as strong as central star radiation for the earliest billions of years. Furthermore, the orbits of these planets are maintained over the next billions of years or more without falling to the central stars. This would be conformable with the fact that many hot Jupiters exist.