Circumbinary Planet's Orbital Evolution in a Dissipating Protoplanetary Disk

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Most of Neptune-class circumbinary planets discovered by Kepler locate just outside the dynamically unstable region around the host binary stars. They are considered to have been formed in the outer orbit and migrated to the current orbit rather than in-situ formation because their semimajor axises are within 1 AU. However, the inner edge of the circumbinary disk derived by numerical simulations is always inside the dynamically unstable region. Here we propose a scenario that the planet first migrated to the disk inner edge and then moved to the present orbit afterward. A planet near the disk inner edge (i.e., inside the unstable region) undergoes strong gravitational perturbations by the binary stars and the planet's orbit is excited. On the other hand, under the circumstances with enough amount of protoplanetry disk gas, the excitation of the orbit would be damped by the gas drag force. So, the planet's orbit would be determined by the force balance between the excitation and damping. As the disk gas dissipates, the planet would move to the outer orbit (i.e., just outside the unstable region).
We carried out N-body simulations for binary systems with eccentricity, mass ratio, and planet mass as parameters to examine the scenario. We found our scenario can reproduce the present circumbinary planets' orbits those locate just outside the unstable region. Planets tend to survive the orbital evolution more likely in less eccentric binary systems with e_{bin}<0.2. Most of binary systems hosting a circumbinary planet have eccentricities e_{bin}≦0.16, which is consistent with our results. Planet mass dependence is also examined for range from 0.0056M_J to 1.7M_J. Surviving rate was high for planets in mass range from 0.01M_J to 0.32M_J. Gas drag force is too weak for planets smaller than 0.01M_J to damp the orbital excitations. On the other hand, gas drag is too strong for planets larger than 0.32M_J so that the planets' orbits are not excited enough to push them outside the unstable region. Our results give constraints on mass and semimajor axis of circumbinary planets as well as eccentricity and mass ratio of the host binary.

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