Migration mechanism of proto-Neptune

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Abstract: An outward orbital migration of Neptune in early solar system history provides an efficient mechanism for shortening the planet growth time as well as sweeping up large numbers of Trans-Neptunian objects into Neptune’s mean-motion resonances. There are several works about migration of Neptune, Gomes et al. 2004, Ida et al. 2000. We call their migration mechanism as several planet model and self migration model respectively. Several planet model represent whole migration migration process, but their model is too complicated so it’s hard to understand the basic mechanism. Self migration mechanism investigate between only one planet and planetesimals. In this model, very heavy planetesimal disk is needed to the Neptune migration because they assume just one scattering. This restriction reduce the exchanging angular momentum per unit mass. So they need heavier disk than minimum mass model. In both model, they have an serious problem that is residual planetesimals. Gomes et al. 2005 show one of the answer of it, but it needs specific situation that Jupiter and Saturn being in 2:1 mean motion resonance. We need more natural model to dissipate planetesimals. We investigate the basic mechanism of orbital migration in an ideal situation that two giant planets (say Jupiter and Neptune) revolves around the Sun within a swarm of planetesimals and numerically integrated the orbital evolution of planetesimals with various orbital elements and find net angular momentum exchange. Planetesimals around Neptune are scattered and stochastically increase their eccentricities. Some of them are finally scattered by Jupiter and remove from feeding zone of Neptune. Then the net angular momentum was transferred from the removed planetesimals to Neptune. This is the basic mechanism of outer migration of Neptune. In our model, planetesimal experiences several encounter with Neptune, so exchanging angular momentum per unit mass become larger than self migration model. In another view, we notice that Jupiter scatters all planetesimals at almost same place in a-e plane. It means we can easily estimate exchanging angular momentum $L$ as

$$L = \sqrt{\beta \epsilon \frac{t_e}{t_e^2}} (L_i - L_{sc})$$  \hspace{1cm} (1)

$L_i$ and $L_{sc}$ are angular momentum per unit mass of initial point and scattering point. $t_e$ is encounter time. We can estimate the scattering point as a crossing point of perihelion contour line

$$a_p(1-e) = \alpha + a_J,$$ \hspace{1cm} (2)

and Jacobi integral contour line

$$J_N = \frac{a_N}{2a_p} + \sqrt{\frac{a_p}{a_N}(1-e^2)}.$$ \hspace{1cm} (3)

$\alpha$ and $\beta$ are numerical coefficient determined as a function of mass of Planets.

References

Hayashi et al. (1985) *Protostars and Planets II*,1100-1153