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Formation of the Resonant Populations in the Kuiper Belt

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Abstract

Present-day Kuiper belt objects (KBOs) have most of their orbits within a relatively thick disk outside that of Neptune as they are located around heliocentric distances in the range 35–50 AU, where the whole Kuiper belt seems to have an abrupt end. On the basis of their orbital elements KBOs can be grouped into distinct dynamical classes, namely the classical, the resonant, and the scattered ones. Jiang & Yeh (2004, 2007) have proposed gas-drag-induced resonant capture in a protostellar disk analogous to the primordial solar nebula as a mechanism able to explain the dominant 3:2 resonant population observed in KBOs. de la Fuente Marcos & de la Fuente Marcos (2008) further investigated the drag-induced mechanism numerically. Our significant contribution is a hydrodynamic theory derivation of results obtained in Jiang & Yeh (2004, 2007) and de la Fuente Marcos & de la Fuente Marcos (2008) numerical simulations. An annulus of solid particles in an early sun–Neptune– gas disk system is studied. In such a centrally condensed, disk-shaped solar nebula, there is a systematic difference between the velocity of the gas, which is pressure supported, and that the solid component, which is not. The resulting relative motions of the gas and solids induce drag forces that produce a radially inward drift of the particles relative to the gas; drag forces cause the orbits of solid particles larger than dust grains to decay. On the other hand, the gravitational torque exerted by Neptune on the annulus is positive at the outer Lindblad resonances; Neptune's orbital momentum is transferred outward to solid particles. An applied gravitational torque increases the angular of the resonant proto-KBO element and thus leads to motion of the element at a larger radius. It is likely that a residual gas disk, with a mass compared to that of the giant planets, was present when formation of the Kuiper belt occured. Our analysis suggests gas-drag-induced resonant capture as a mechanism able to explain the observed resonant population of the Kuiper belt. We suggest that the resonant KBO populations are connected to cases where Neptune's gravitational torque exceeds the viscous torque, that is, the negative drift of solid particles due to the drag is counteracted by the positive drift due to the orbital Neptunian resonances. A separate investigation based on simulations is proposed to confirm (or deny!) our suggestion.

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