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Sweeping Secular Resonances in the Kuiper Belt Region 2

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We investigated orbital excitations of Kuiper Belt objects (KBOs) caused by the sweeping secular resonances during the depletion of the primitive solar nebula. From linear analyses, we found that the secular resonances sweep the Kuiper Belt region. We also found that the inclinations of KBOs are excited to the observational level by the sweeping secular resonance. The inclinations of the KBOs are excited easier than the eccentricities. The mean value of the observed eccentricities is smaller than that of the observed inclinations. Then, our secular resonances well explain this difference of their magnitudes. For the excitation of the eccentricities and the inclinations to the observed level, the required timescales are about hundreds of millions of years.

We have investigated orbital excitations of Kuiper Belt objects (KBOs) caused by the sweeping secular resonances during the primitive solar nebula depletion. The distribution of KBOs is roughly separated into two regions. They are inner belt region and outer (classical) belt region. In the inner belt, both the eccentricities and the inclinations are largely excited. Root mean squares of the eccentricities and inclinations attained about 0.2 and 0.23, respectively. Almost all bodies in this region are in mean motion resonances with Neptune. On the other hand, the eccentricities of the KBOs in the outer belt are substantially smaller than 0.2, and the root mean squares is only about 0.1. The inclinations of the KBOs in the outer belt are nearly equal to those of the inner belt. These large values are not explained by present planetary perturbations alone. Although many studies were done to explain the origin of these large values, the origin of the large inclination is not still well known.

As for the excitation mechanism, we consider the sweeping secular resonances. Secular resonances occur when the proper frequency associated with the longitude of the perihelion or that of the ascending node of an object coincides with one of the eigenfrequencies of the planetary precessions. Considering the Sun and four Jovian planets in the present solar system configuration, seven secular resonances exist beyond the location of Neptune. The nebula potential would significantly alter the locations of the secular resonances. As the nebula is depleted, the secular resonances move from the initial locations to the present locations. When the secular resonance passes through, the eccentricities and inclinations of the bodies are excited. This paper reinvestigates the effects of the sweeping secular resonances with both sides of numerical and analytical.

The region where the secular resonance sweeps depends strongly on the mass distribution of the proto-planetary system. The considering system consists of the Sun, four Jovian planets, a massless particle, and the nebula. For the 'starting' nebula model, the minimum mass solar nebula extending to 150AU was basically employed. We assume the nebula orbits cylindrical symmetrically around the Sun and is also symmetrically with respect to the ecliptic plane. We also assume the nebula is depleted exponentially with time and uniformly.

We found that the inclination of KBOs is excited to the observational level by the sweeping secular resonances. Generally the inclination of KBO is excited easier than the eccentricity. This is because the inclination's resonances migrate slower than the eccentricity's resonances do. The observed value of the eccentricity is naturally smaller than that of the inclination. The eccentricity and the inclination of the outer KBOs are distributed almost in the region of $e<0.2$ and $i<0.6$ radian. Then, our secular resonances well explain this difference of their magnitudes. For the excitation of the eccentricity and the inclination to the observed level, the required timescales of the nebula depletion become approximately the same. These timescales are about hundreds of millions of years. The observed concentration of KBOs to the location of the 3:2 mean motion resonance, however, can not be explained by our mechanism of the sweeping secular resonance alone. If the location of the 3:2 resonance migrates by planetary migration (Malhotra 1993,1995) after the nebula depletion, the KBOs in inner belt are captured into the 3:2 resonance. This capture mechanism can not work effective for the body with large eccentricity. On the other hand, even if the inclinations of the KBOs are high, the trapping mechanism is effective. Therefore, our model has advantages because the KBOs' eccentricity is not
excited so large.