THE ORIGIN OF THE SPINS OF KUIPER BELT OBJECTS

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We have developed a simple model to study the collisional evolution of the spins of Kuiper Belt objects (KBOs). We find that the observed spins of KBOs larger than $\sim 200\,\mathrm{km}$ cannot be explained by collisions, if the objects had no spin at the end of the primary growth phase. This suggests that large KBOs must have attained their spin rates very early in their evolution. If the accretion process was not entirely isotropic, and contributed angular momentum to the growing KBOs, we find that a $\sim 10\%$ asymmetry in the net angular momentum of accreted planetesimals would explain the observations. However, if the accreted planetesimals were comparable in size to the growing body, no anisotropy is required because the accretion of individual particles can produce significant spin changes.

1. Motivation

Kuiper Belt objects (KBOs[1]) collide on timescales smaller than the age of the solar system. Their physical and dynamical properties should therefore show signatures of such encounters. KBOs grew by accretion[2] of dust condensates in about $\sim 100\,\mathrm{Myr}$. This time was set by the formation of Neptune, which excited relative velocities thus averting further accretion.

Table 1. Spin rates of large KBOs.

Object	Designation	Radius [km]	P [hr]	Ref.
	2003 AZ_{84}	450	13.44	3
20000	Varuna	490	6.34	4
42301	2001 UR_{163}	510	–	3
55637	2002 UX_{25}	545	–	3
55636	2002 TX_{300}	625	16.24	3
50000	Quaoar	650	17.69	5
28978	Ixion	655	–	3,6
	2003 EL_{61}	750	3.9	7

Since then collisions have been the main interaction between KBOs. If the accretion process supplied zero average torque to the growing bodies, angular momentum conservation should lead to these objects having little spin by the end of the growth phase. This is different from the what is observed today, where 5 out of the 8 largest KBOs ($r \sim 500\,\mathrm{km}$) with measured rotation have spin periods below 20 hr (Table 1). This has led us to investigate the effect of collisions on KBO spin rates, in the last ~ 4 Gyr.

2. The model

Our model follows one KBO at a time, as it collides with the surrounding bodies, for 4 Gyr time. The collisional environment, described by the total mass, size and velocity distributions of KBOs, determines the total number, and the character of individual collisions. Changes in the target's mass and spin rate are calculated for each individual collision, as a function of several parameters describing individual objects and the enviroment. After all collisions have been accounted for we register the final spin and mass of the target, and can start the process all over again. By running the model several times with the same initial conditions, we obtain a Monte Carlo estimate of the distribution of spins that a particular set of parameters generates.

3. Results and Discussion

The main result discussed here is that collisions did not significantly change the spins of KBOs with radii $r > 200\,\mathrm{km}$. The reason is that in the last $\sim$4 Gyr, these objects did not collide with large enough projectiles to alter their spin angular momentum. Figure 1 illustrates this result: it shows the final spin rate distribution for 500 km-radius KBOs predicted by our simulations. The KBOs start with no spin. The Figure shows that if 500 km bodies have negligible spin by the end of the formation epoch, collisions would only spin them up to $P \sim 300$ hr after 4 Gyr. As our simulations fail to reproduce the

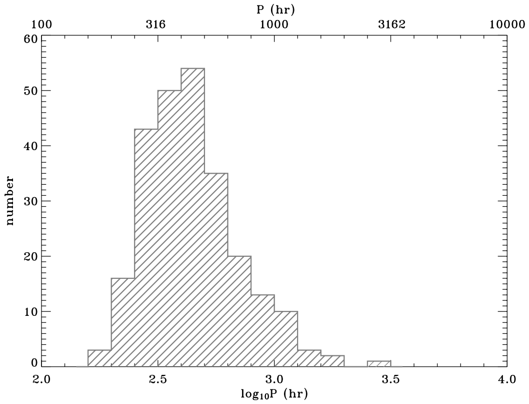

Figure 1. Distribution of final spins for 250 bodies of initial radius $r = 500\,\mathrm{km}$.

observed spin rates, we conclude that large KBOs must have had similar spins to what they have today at the start of the collisional evolution.

4. Anisotropic accretion

A possible mechanism to spin up large KBOs during the growth phase is anisotropic accretion. To find out the amount of anisotropy required to explain the spins of the largest KBOs we simulated the growth of a body initially 5 km in radius, by accretion of smaller projectiles, until it reaches $r = 500\,\mathrm{km}$. Anisotropy is parameterized by $\langle z \rangle$, defined as the normalized mean angular momentum brought into the target by each projectile. The value of $\langle z \rangle$ determines the allowed projectile impact geometries: if $\langle z \rangle \approx 0$ then accretion is nearly isotropic and projectiles bring no net torque, while with $\langle z \rangle \approx 1$ all projectiles tend to spin the target in the same direction. The mass of each projectile is set to a constant fraction, k, of the instantaneous mass of the growing body. The projectiles impact velocity is the escape velocity of the target, and they always adhere. This appropriately simulates the runaway accretion phase, when relative velocities are small. Figure 2 shows how the spin rate evolves as the KBO grows, for different pairs $(\langle z \rangle, k)$. An equilibrium spin rate is attained very quickly in all cases, which does not depend on the initial spin rate. Fluctuations in the spin rate due to individual projectiles are considerably smaller both with increasing $\langle z \rangle$ and decreasing k. Also, the closer $\langle z \rangle$ is to 1 the faster the final spin. Values $\langle z \rangle \sim 0.1$ would explain the spin rates shown in Table 1. The ratio of projectile mass to target mass, k, only influences the final spin of the grow-

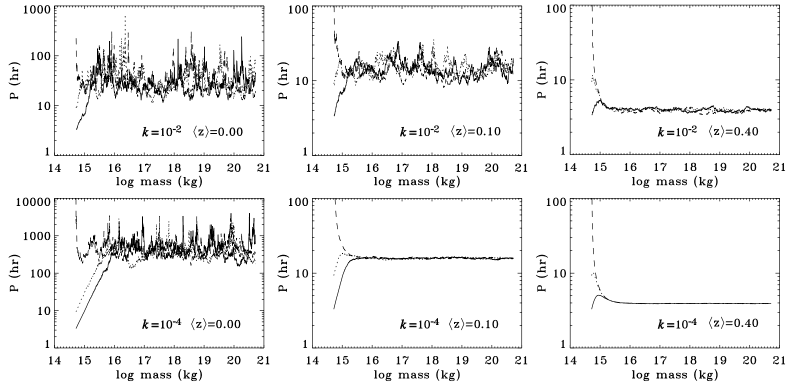

Figure 2. Evolution of target's spin period, as it grows, for six combinations of $\langle z \rangle$ and k. Different lines correspond to target's initial spin period $P \approx 3.3\,\mathrm{hr}$ (solid), $P = 9.23\,\mathrm{hr}$ (dotted), and no initial spin (dashed).

ing KBO for nearly isotropic accretion, i.e., if $\langle z \rangle \approx 0$. Ratios $k \gtrsim 0.01$ also explain the measured spin periods, even under completely isotropic growth. This corresponds to a ratio of projectile to target *radius* of $k^{1/3} \approx 0.2$.

5. Summary

Our main conclusions are: (1) Collisions have not changed the spins of the largest KBOs ($r > 200\,\mathrm{km}$) in the last $\sim 4\,\mathrm{Gyr}$: their present spins must have been set by the end of the accretion phase; (2) A 10% anisotropy in the accretion process can produce the observed spins of KBOs; (3) If the (last) planetesimals accreted onto the large KBOs were at least 20% of the size of the growing bodies then isotropic accretion can explain the observations.

References

1. Luu, J. X. & Jewitt, D. C. 2002, ARA&A, 40, 63
2. Kenyon, S. J. & Luu, J. X. 1999, AJ, 118, 1101
3. Sheppard, S. S. & Jewitt, D. C. 2003, Earth Moon and Planets, 92, 207
4. Jewitt, D. C. & Sheppard, S. S. 2002, AJ, 123, 2110
5. Ortiz, J. L., Gutiérrez, P. J., Sota, A., Casanova, V., & Teixeira, V. R. 2003, A&A, 409, L13
6. Lacerda, P. and Luu, J. 2005, AJ, in press.
7. Rabinowitz, D., Brown, M., & Trujillo, C.. 2005, AJ, in press