Let's spin'em all

Keith A. Holsapple, Tomáš Henych

University of Washington, 352400, Seattle, WA 98195, United States

The Spin Question

What can the present asteroid spins tell us about the origins of the Solar System and about its collisional evolution in time?

Introduction

For the variety of data we know about the Main asteroid belt the **distribution of spins** may contain the most information to constrain its and the Solar System's prior history. Some have done studies of average spin, and there are history reconstructions based upon population distributions but not upon spin. This is a study to see what information can be obtained by careful calculations of spin histories leading from the origin of the Solar System for the present time.

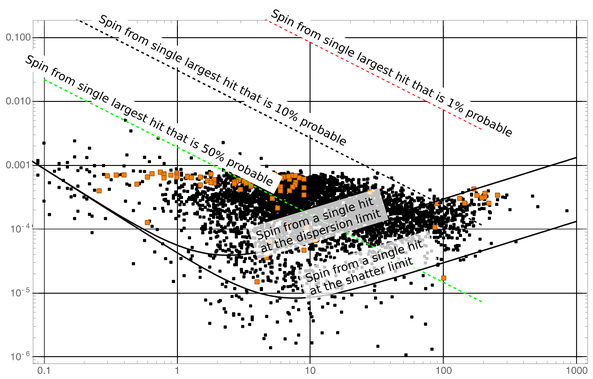

Figure 1: Spin distribution of the Main Belt asteroids (black squares) with binaries (orange squares). We also show the spin change caused 1. by the largest expected projectile at three probability levels (straight lines of various colors) and 2. by the projectile to barely cause a catastrophic disruption and catastrophic dispersion of the target, respectively (two solid black curves). The spin distributions show a variety of interesting features in addition to the now well-known gravity spin limit, especially for the large asteroids from 50 to 300 km diameter.

Monte Carlo approach

We created a **Monte Carlo model of individual asteroid spins subjected to random collisions** following Poisson statistics. Currently we concentrate on the **large Main Belt asteroids** ($D \gtrsim 100\,\mathrm{km}$), for the following reasons:

1. Most of them are primordial bodies from the early times of the Solar System evolution.
2. Only several large collisions in their lifetime have seriously affected their spin.
3. Their spin is not affected by the YORP effect.
4. We know all of them, including a few binaries, their rotations and projectiles to substantially change their spin.

What's new in our model compared to previous efforts

- We follow spins of individual asteroids.
- We do not assume small increments of spin added quadratically to existing spins.
- We account for the efficiency of angular momentum transfer according to laboratory experiments (Yanagisawa & Hasegawa, 2000) and depending upon the location and angle of the impact. On average only about 10% of the angular momentum is transmitted to the target.
- We do not average the impact conditions but instead we use random angles of impact, location of impact, distribution of impact velocities.

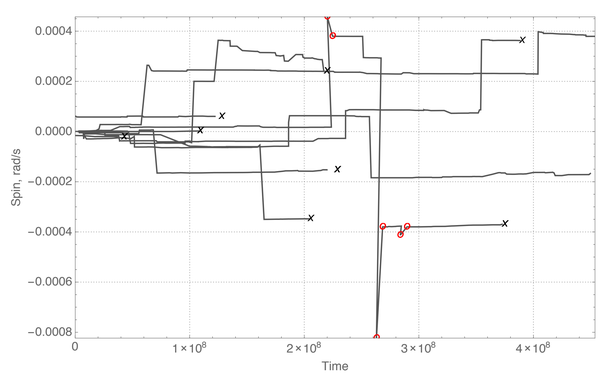

Figure 2: Typical spin histories in our simulations, a change of the target asteroid spin (rad/s) versus time (years). The red circles are collisions where rotational fission occurs (spin limit for a low-density elongated body of 0.0004 rad/s) and black x's are catastrophic dispersion occurences.

Model constraints

Classical:

1. The current SFD of the Main Belt asteroids as a result of a massive depopulation in early times.
2. The presence of Vesta's basaltic crust (and two large impact basins).
3. Number and size distribution of large asteroid families.

New ones:

1. The magnitudes of the mean spins as a function of diameter.
2. The accumulation of spins at the gravity and other possible spin limits.
3. The numbers and sizes of binaries.
4. The "V" shape to the maximum spins near 100 km size.
5. The general falloff of maximum spins above that 100 km.

Group L binaries

We also concentrated on the **group L binaries** and we found an **alternative formation scenario** for majority of them. Their main characteristics are:

1. large Main Belt binary asteroids
2. low secondary-to-primary mass ratio
3. usually low average densities
4. higher-than-average primary spin
5. moderate elongation of the primaries

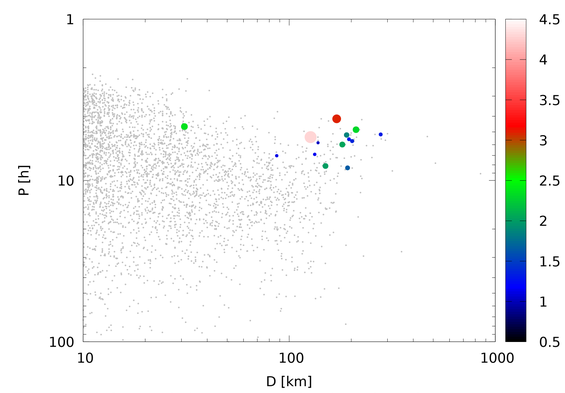

Figure 3: Group L binaries as displayed in the spin–diameter plot. Their densities, as derived by Carry (2012), are color-coded in the plot.

We propose a new formation scenario for a majority of group L binaries – **a rotational fission following the spin-up caused by a few large collisions**. The previous scenario of satellites formation in a catastrophic disruption may still be valid for some of those binaries (see Fig. 3). This scenario would explain the primary fast spin. Fission at a spin limit would not form a family, but either an original catastrophic dispersion or one after a fission could form a family. That would explain the presence (87 Sylvia) or absence (107 Camilla, 121 Hermione) of families for these binaries (Vokrouhlický et al., 2010).

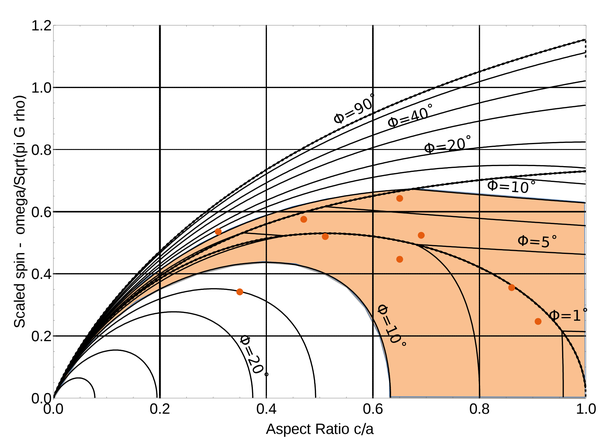

Figure 4: Spin limits of asteroids as a function of their elongation and material angle of repose. The group L binaries all fall on line suggesting very little angle of repose, such as would be expected for an icy body (Holsapple, 2007).

Results

Our current research has so far three main results:

1. Large asteroids achieve their final spin from a few large impacts, not an accumulation of many small impacts. For that reason we do not obtain Maxwell distributions.
2. Our simulations suggest that the present spin states of the large Main Belt asteroids could not have been achieved with the present population state. More spin may have been accumulated during accretion or perhaps collisions with other bodies during the Late Heavy Bombardment
3. Asteroids of 100-km diameter and larger are rarely dispersed in our model.

Open problems

Our results to date suggest that catastrophic disruption criteria depending substantially on **pre-existing spin** and/or **accumulation of damage** may be very important.

References

[1] Bottke, W. F. et al., 2005. Icarus **175**.

[2] Carry, B., 2012. Planetary and Space Science **73**.

[3] Holsapple, K. A., 2007. Icarus **187**.

[4] Vokrouhlický, D. et al., 2010. AJ **139**.

[5] Yanagisawa, M., Hasegawa, S., 2000. Icarus **146**.

Acknowledgements

This work was supported in part by NASA grants NNX10AG51G and NNX12AG18G.

Contact information

E-mail: holsapple@aa.washington.edu
Phone: +1 (206) 543-6198