Reconstructing the spin distributions of main-belt asteroids

K. Holsapple[1]

[1]University of Washington 352400, Seattle, WA 98195, USA

INTRODUCTION: We now have spin data for almost six thousand asteroids, each value being a result of that asteroid's history. Some features of that distribution are now evident. The gravity spin limit at the period of about 2.3 h for asteroids with a diameter greater than a few kilometers is well established (Harris 1996, Pravec and Harris 2000, Holsapple 2001, and others). The strength of smaller asteroids as inferred from the "fast spinners" has been presented by Holsapple (2007), Sanchez and Scheeres (2014), and others. Several statistical analyses of the database have been presented (e.g., Pravec and Harris 2002). Here that database is used as a means of investigating the prior history of the asteroid belt.

THEORETICAL APPROACHES: A way to understand the data is to attempt to reproduce it using theoretical models and numerical simulations of the physics of the processes that created it. Such studies have evolved since McAdoo and Burns (1973) first suggested collisions as a source of the spins; they include Davis et al. (1979), Dobrovolskis and Burns (1984), Harris (1979), Davis et al. (1989), Farinella et al. (1992), Henych and Pravec (2013), and others. These analyses are based upon averaging the effects of a number of individual impacts into a given target asteroid.

I retrace the path and analyses of those authors in this work, but make important modifications and updates. The primary elements introduced in those prior studies include: 1) a population of asteroids in a given space; 2) a distribution of impact velocities and angles; 3) the efficiency of angular-momentum transfer in an impact; 4) the loss or gain of mass and angular inertia; 5) the amount, direction, and speed of the cratering ejecta. The characteristics of the ejecta are especially important: they determine the "angular-momentum drain" first identified by Dobrovolskis and Burns (1984). It is caused by the preferential escape of ejecta in the downrange spin direction.

Here I revisit, update, and improve the analysis of those authors. The ejecta analysis is upgraded to include recent results on ejecta scaling (Housen and Holsapple 2011, Holsapple and Housen 2012). I use some recent experimental results about the efficiency of the angular momentum transfer efficiency (e.g., Yanagisawa and Hasegawa 2000) for oblique impacts. I also use more recent population estimates.

Those considerations determine the outcome of a given single impact into a target asteroid. To estimate the cumulative effects of multiple impacts, one can take averages over the distributions of the impact velocities and angles. That was done in the above references; the key assumption was of a quadratic accumulation of spin magnitudes from averaged single impacts. However, here that approach is rejected, for two reasons. First, because of the momentum drain effect, the result of any one impact is not independent of the prior ones. The spin-up of a body is not a result of multiple random events. Second, it has been found that the current spin of an asteroid is more likely caused by a very few large impacts and not by an accumulation of random small ones. So, instead of a quadratic accumulation over averages, I've performed Monte Carlo analyses of the effects of a large number of impacts into a large number of target asteroids. The outcomes are distributions of spin versus asteroid size, which can then be compared to the actual data.

SOME RESULTS: Analyses to date are interesting. First (and as found by others), the spins of the large asteroids cannot have resulted from impacts with the current population. Second, both the average spin and the maximum spin at any given size falls off with increasing asteroid size. Third, there exist "average equilibrium spin states", defined by a curve of spin versus diameter. For asteroids spinning faster than that state, the average next impact will always slow the spin; but for an asteroid with a spin below that state, the average impact will increase its spin. There are reasonable parameter choices that result in the average equilibrium curve consistent with the average spins, and with the resulting distributions centered along that curve. Then there is also a "maximum equilibrium spin curve" defined as the maximum possible spin an asteroid can attain, again as a function of asteroid size. That bounds the upper limit of asteroid spins, and has a downward power slope of 0.65. The fact that the maximum equilibrium curve intersection with the gravity limit curve occurs right at the 10 km upper bound of the data for binary asteroids strongly suggests that it is collision spin-up and not YORP that creates the spins that result in binaries. Finally, a single large impact into an asteroid with a pre-existing average spin can easily reduce its spin to near zero. That may explain the excess of slow spinners (as compared to Maxwellian) for the spin distributions of the asteroids with diameters larger than 10 km. These results and others will be presented at the conference.