THE ROTATION RATES OF VERY SMALL ASTEROIDS: EVIDENCE FOR "RUBBLE PILE" STRUCTURE A. W. Harris, Jet Propulsion Laboratory

I have recently updated my data base of asteroid rotation rates. The new file includes reliable rotation periods of 688 asteroids, which are plotted *vs.* diameter in Fig. 1. Most of the trends reported earlier remain apparent in the expanded data set. In this paper I concentrate on the rotation statistics of the smallest asteroids, $D < 10$ km. The main conclusion is that there are no asteroids rotating fast enough that they are in a state of tension, that is, that they would fly apart if they had no tensile strength. In earlier studies, it was not clear whether this is because small asteroids indeed have no tensile strength, or only because such fast rotation is statistically improbable enough that one would not expect to find an end-member of the distribution spinning faster than that limit. A histogram of the spin distribution of the smallest asteroids of the present expanded data set indicates that the distribution at the fast end of rotation frequency is in fact truncated, thus implying that even these small asteroids have no tensile strength, that is, they are not monolithic, and may be "rubble piles".

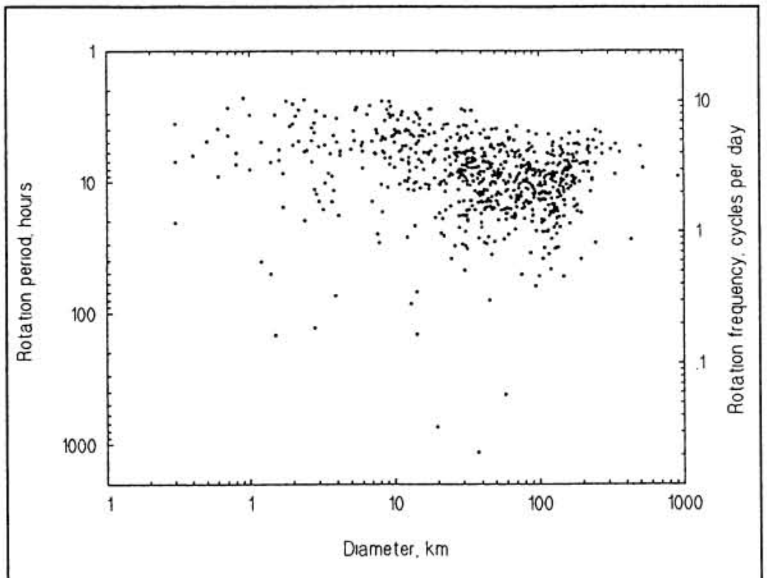

Figure 1. Rotation rate *vs.* diameter for 688 asteroids.

A rotating sphere will be everywhere in a state of compression as long as the rotation frequency does not exceed the surface orbit frequency about the sphere. This is simply the equivalent of saying that the centrifugal acceleration at the equator is less than the acceleration of gravity. For an elongated body, spinning about its short axis, the acceleration of gravity at the tip of the long axis is reduced approximately by the axis ratio, b/a, compared to that of a sphere of the same density and radius a. The centrifugal force is of course the same for a sphere or a prolate body of the same spin rate and long axis. Thus the critical density, ρ_c, below which an elongate body rotating with spin period P will "fly apart" is:

$$\rho_c \approx \left(\frac{3.3^h}{P}\right)^2 \left(\frac{a}{b}\right) \approx \left(\frac{3.3^h}{P}\right)^2 (1+\Delta m).$$

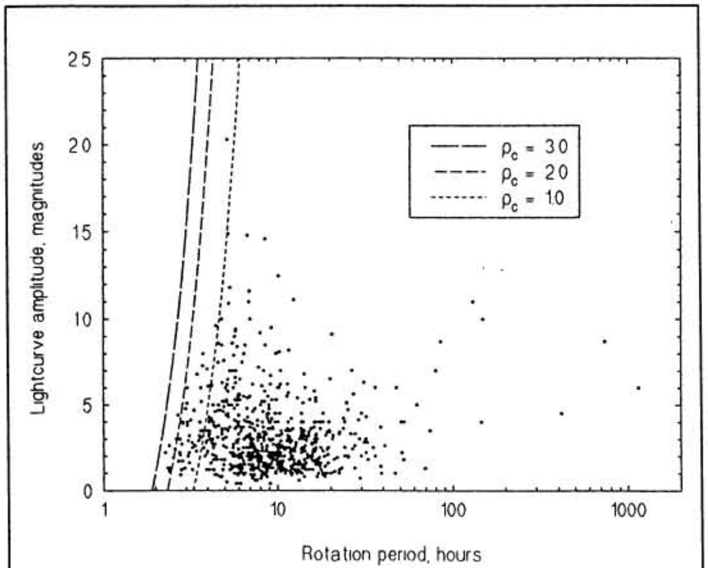

Figure 2. Lightcurve amplitude vs. rotation frequency.

In the rightmost expression, we have substituted for the axis ratio a very approximate relation in terms of the lightcurve amplitude in magnitudes, Δm. Figure 2 is a plot of the same 688 rotation rates, this time *vs.* the maximum amplitude of lightcurve variation. I also plot the curves of the above equation for $\rho_c = 1.0$, 2.0 and 3.0 gm/cm^3. Note that there is a trend for the very fastest spinning asteroids to have low amplitude of variation, as one would expect if the rate of spin is limited by a lack of tensile strength. Also, it is noteworthy that no asteroids spin faster than the critical spin rate for a density of ~2.7 gm/cm^3. Thus it appears plausible that no asteroids are observed with

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more rapid spin because they in general have no tensile strength -- that is, most if not all of them are "rubble piles."

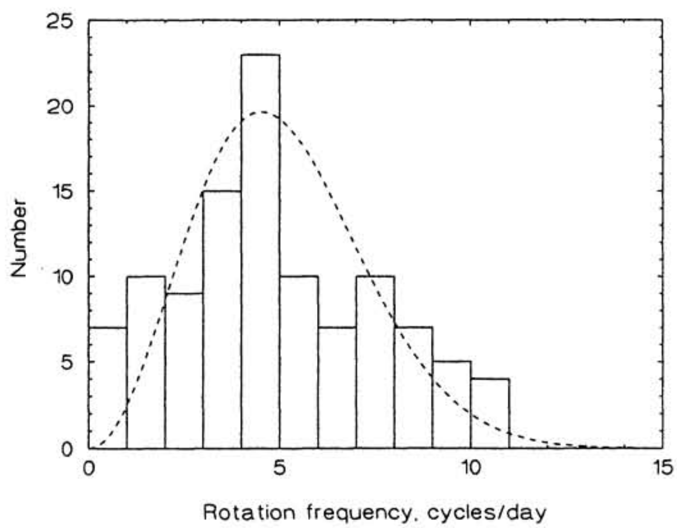

Figure 3. Histogram of rotation frequency, $D < 10$ km.

We next examine a histogram of the spin rates of the smallest asteroids, plotted in Fig. 3. It is apparent in Fig. 1 that the mean spin rate of larger asteroids is slower than that of the smallest ones, but the mean appears to be fairly constant for $D < 10$ km, hence the choice of that size limit. In Fig. 1, I have also plotted the 3-dimensional Maxwellian distribution normalized to the RMS spin rate, 5.54 cycles/day ($P = 4.33$ hours), and the total number of asteroids, 107. Clearly the fit is not good, indicating that the distribution is not well represented as a single collisionally evolved ensemble. The excess of slow rotators, in the left-most two bins, remains a mystery. Here I want to point out that the right-most few bins are also over-populated, and in particular it appears that the distribution is abruptly truncated, at exactly the rotation frequency one would expect if the asteroids are somewhat under-dense for solid rock and possess no tensile strength, that is, if they are "rubble piles."

Certainly this is not a new hypothesis. When I first began studying rotation rates, I suggested on theoretical grounds that the mean rotation frequency should turn up below some diameter, becoming inversely proportional to diameter in the strength-dominated (as opposed to gravity-dominated) regime [1]. The trend toward faster rotation that appeared at ~10-50 km seems to have completely petered out below 10 km, and there appears to be no real trend toward still faster rotation among the really small asteroids, < 1 km in diameter, which further argues for very low strength. For some years now I have been seeking the *Holy Grail* of an asteroid spinning so rapidly that it clearly is strength-dominated and in a state of tension, as one would expect of a monolithic meteoroid. Apparently that threshold is still beyond our grasp, but it remains a worthy goal.

REFERENCE: [1] Harris, A. W. (1979) *Icarus* **40**, 145.