ASTEROIDS: SPINS AND SHAPES

Claes-Ingvar Lagerkvist

Astronomiska observatoriet
Box 515
751 20 Uppsala
Sweden

ABSTRACT
There is a difference in rotational properties between asteroids of various taxonomic types. The M and CMEU asteroids increase their spin with diameter and rotate much faster than asteroids of types C and S of the same diameter do. There is a difference in spin between the C and S types but the faster spin for the S asteroids larger than 150 km in diameter is probably not statistically significant. For both C and S asteroids the spin increases with diameter, but in a much less pronounced fashion than for types M and CMEU. The curve for the S asteroids is remarkably flat for asteroids smaller than 100 km.

The CMEU asteroids are more irregular than other types of asteroids. Both C and S asteroids have larger amplitudes for diameters about 100 km.

The family asteroids smaller than 100 km in diameter have a faster spin than non-family main-belt asteroids of the same size. Family asteroids show an increase of spin and lightcurve amplitude with decreasing diameter.

INTRODUCTION

Rotational properties of asteroids are closely connected to the origin and evolution of these bodies. According to the most widely held opinion the spin properties are aquired mainly by collisional processes, which are known to have been in operation throughout the history of the asteroid belt. The first, primordial asteroids are commonly considered to have originated through planetesimal accretion, and the build-up of rotation by such a process has been investigated by Giuli (1968) as well as in the collisional theory by Harris (1979). Most asteroids are probably the results of collisional fragmentation and their spin has been aquired both at the breakup collision and through subsequent collisional evolution and possibly for some asteroids further by tidal dissipation.

Clearly the evolution of the asteroid belt is reflected in the distribution of spin rates and shapes of the asteroids - perhaps their most easily observable bulk properties. During recent years major observational efforts have been made to extend the data base.

Mc Adoo and Burns (1973) claimed to have found a faster spin for the smaller asteroids but the growth of data on rotational properties of

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asteroids during the last decade allowed Renschen (1978), from a study of data on asteroids of taxonomic type S, to find an increase of spin rate with size.

Harris and Burns (1979), using data for 182 asteroids, considered the difference in rotation period between S and C asteroids (S:$9^{h}.38$, C:$11^{h}.59$) to be significant and interpreted this in terms of the collisional theory of Harris (1979) to be due to a difference in the mean densities between the two types of asteroids. For the M asteroids Harris and Burns noted a tendency for faster rotation than for other types of asteroids. The sample of rotation periods used by Harris and Burns contained, however, all kinds of asteroids. The most important selection effects may well have been that they did not distinguish between family asteroids and other main-belt asteroids and that they included data for Amor and Apollo asteroids in their analysis. From their whole sample Harris and Burns found a tendency for the smaller asteroids (mainly non C asteroids) to rotate faster than the larger asteroids.

Tedesco and Zappalà (1980) tried to obtain a more bias free sample for their analysis of the rotational data, including in their discussion only data for ordinary, non-family, main-belt asteroids, obtained by photoelectric photometry. In a table they presented rotational data for 134 asteroids. They investigated the spin of the S and C asteroids, for which they found a mean rotational period of $9^{h}.4$ and $11^{h}.6$, respectively. In the diameter range where S and C asteroids are of equal frequency they found no difference in spin between the two groups of asteroids. They took this as an indication that the same is true for all diameter ranges, which might, however, lead to spurious results, They concluded that since the difference in spin rate was only 1.6σ it was not statistically significant. They therefore considered it safe to analyse the combined data for the S and C asteroids, their conclusion being the same as Renschen (1978) had found from his investigation of the S asteroids. The difference in results from Harris and Burns (1979) and Tedesco and Zappalà is mainly due to the way the data have been chosen. This has been commented on in a joint paper by Burns and Tedesco (1979).

Farinella et al. (1981b), dividing the asteroids into different size ranges, found an increase of spin with diameter and noted that the S and C types had different distributions of the spin rates. They further found, contrary to Harris and Burns (1979), that there was evidence for a non-Maxwellian character of the spin distribution.

When they analysed the data for the M and CMEU asteroids Lagerkvist and Rickman (1981) found a faster spin (3.4 ± 0.4; 4.0 ± 0.4 rev/day) than asteroids of type S and C have. They also noted that the M and CMEU asteroids tend to avoid memberships in the Hirayama families.

Zappalà et al. (1982) confirmed the results of Lagerkvist and Rickman and tried to interpret the fast spin of those asteroids as due to collisional fragmentation of large, differentiated parent bodies. The small M and CMEU asteroids would then be single fragments of the core while there also would be a major contribution of fast-rotating self-gravitating "rubble-piles" among the larger bodies. In the theory of Farinella et al. (1981a) the asteroids with fast spin and large amplitudes are loosely consolidated collisional products with angular momentum large enough to shape the bodies either as Jacobi ellipsoids or

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binary systems in gravitational equilibrium. Another possibility is that these bodies have high densities, as predicted by the collisional theory of Harris (1979).

Dermott and Murray (1982) used a more sophisticated method to study the relationships between spin and diameter by using running means to calculate the spin for each diameter interval. For S, C and M asteroids they found an increase of spin with diameter and they also stated that the difference in spin for the S and C asteroids was statistically significant.

SPIN RATE VERSUS TAXONOMIC TYPE AND DIAMETER

In the present investigation the same data base was used as that used by Tedesco and Zappalà (1980) and Dermott and Murray (1982). The ambiguities and errors in the table of Tedesco and Zappalà were corrected and the table was extended with observations by the Uppsala group (unpublished) and with those published during 1981 and 1982 by other groups. The analysis was made from a total sample of 51 asteroids of taxonomic type C, 50 of type S, 12 of type M and 11 of type CMEU. All these are main-belt, non-family asteroids with reliable periods determined by photoelectric photometry. The list is not printed here in order to save space.

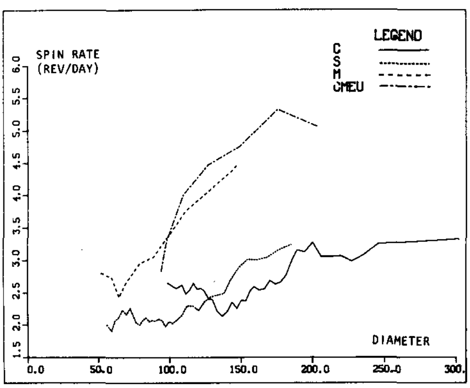

Figure 1. Running mean of spin rates plotted versus mean diameter for taxonomic types C, S, M and CMEU. The corresponding means of the mean errors are 0.3, 0.2, 0.5 and 0.6.

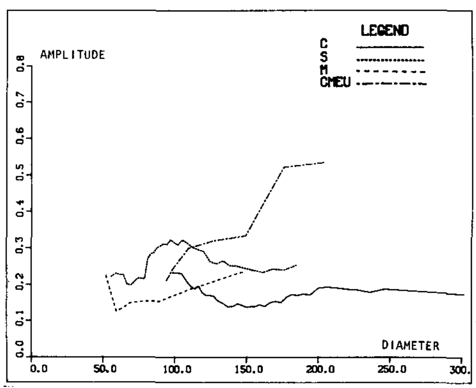

Figure 2. Running mean of amplitudes plotted versus mean diameter. The means of the mean errors are 0.02, 0.04, 0.03 and 0.09.

The method with running means used by Dermott and Murray (1982) was applied to generate figure 1. For taxonomic types M and CMEU 5 asteroids were used to calculate the mean diameter and mean spin rate for each running box. For asteroids of type C and S 15 asteroids were used. For figures 3-4 these numbers are given in the upper right hand corner. The curve for each taxonomic type is only plotted out to the last point where the running box contained the full number of data points. As may be seen in figure 1 the spin rates of the M and CMEU asteroids are faster than for those of types S and C of equal diameters. There is a difference in

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the size distributions of M and CMEU asteroids for which rotational data exists in the sense that a large number of M asteroids are smaller than asteroids of type CMEU. For both M and CMEU asteroids a clear increase of spin with diameter may be noted.

Rotational data exist for more small S than C asteroids and the diameters of the S asteroids in figure 1 range between 50-200 km, while for the C asteroids the diameters lie between 100-275 km. The increase of spin with diameter is clearly noted for both these types. For asteroids smaller than about 125 km the C asteroids on the average spin faster than the S asteroids do but for the larger asteroids those of type S spin faster. One conclusion from figure 1 is that there is a difference in the spin of C and S asteroids but not in the sense that S asteroids spin faster for all diameters.

LIGHTCURVE AMPLITUDES VERSUS SIZE AND TAXONOMIC TYPE

The results for the lightcurve amplitudes are presented in figure 2, which has been derived in a manner similar to figure 1 and by using the same data base.

In general the amplitudes of the S asteroids are larger than those of the C asteroids. Both these curves are remarkably similar and both show an increase of the amplitudes for asteroids with diameters of about 100 km. Large asteroids of both C and S types have small amplitudes. The amplitudes for the CMEU asteroids are much larger than those of other types for diameters larger than 150 km and show an increase in amplitude with diameter.

These results are partly in conflict with those of Tedesco and Zappalà (cf Table II in their paper), who found no correlation between taxonomic type and lightcurve amplitude. They studied the correlation between amplitude and diameter by computing the mean amplitudes for five ranges of the diameters. The larger amplitudes for the CMEU asteroids were noticed by Lagerkvist and Rickman (1981) but not the dependence on diameter for this type of asteroids.

FAMILY ASTEROIDS

Family asteroids are generally believed to be the results of breakup collisions in the asteroid belt. The origin of the spin of the family asteroids is therefore different from that of the main-belt asteroids built up by successive impacts of smaller asteroids. This should be reflected in the distributions of spin and amplitudes for these two groups of asteroids. Since no definite way exists to distinguish between family asteroids and ordinary main-belt asteroids several problems arise when deciding to which group an asteroid belongs. Tedesco (1979) found evidence that the spin of the members of the first three Hirayama families were faster than that of ordinary main-belt asteroids of the same size.

Figure 3 demonstrates the variation of spin with diameter for family asteroids (only members of the Hirayama families H1-H9 have been considered) and for ordinary main-belt asteroids. Asteroids of type M and CMEU have been excluded since they have a much faster spin than other asteroids, as was demonstrated above. The method with running means has been used here as well. The two curves in figure 3 cross each other somewhere at diameters of about 100 km but for asteroids smaller than this the family asteroids spin faster than main-belt asteroids of the same size do. For the family asteroids there is also an increase of spin with decreasing diameters. Figure 3 contains asteroids of all types, except for M and CMEU, but if only S asteroids are considered in order to have a more homogenous sample the same result is obtained from this much smaller data sample.

Figure 4 presents the corresponding curves for the lightcurve amplitudes. For the amplitudes, as well, there is an increase of the curve with decreasing diameters for the family asteroids. For the main-belt asteroids the most pronounced feature is the maximum at a diameter of 100 km, as may be seen in figure 2 for the C and S asteroids separately. Another peak occurs for diameters of about 160 km. It should be remembered that since only asteroids in the Hirayama families have been considered it is possible that the group of non-family asteroids still contains members of some other families, and maybe also of some other origin, which might influence the results from figures 3 and 4.

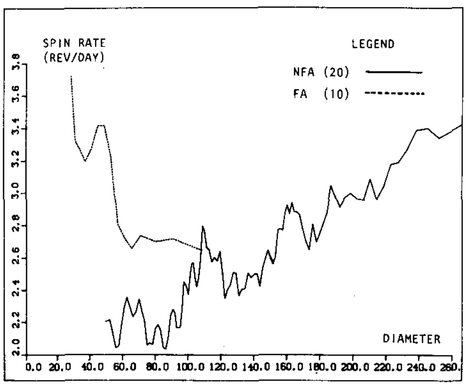

Figure 3. Running mean of spin rates plotted versus mean diameter for field asteroids and family asteroids. The means of the mean errors are 0.3 and 0.5 rev/day, respectively.

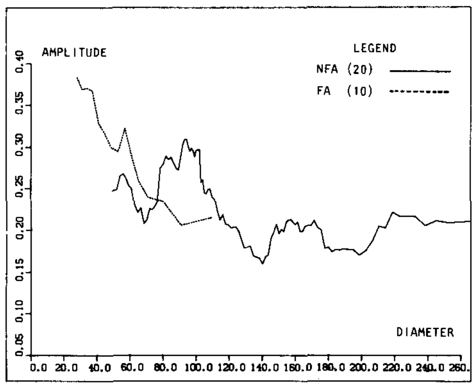

Figure 4. Running mean of lightcurve amplitudes plotted versus mean diameter. The means of the mean errors are 0.03 and 0.04, respectively.

The data may be extended to smaller asteroids by the inclusion of photographic data. The results are then essentially the same as was demonstrated in figure 3 but are now extended down to diameters of 20 km. The curve for the non-family asteroids still shows an increase of spin with diameter.

If the smaller asteroids are collisional fragments, as is implied by some collisional models, the big difference of the spin rates of the small, field asteroids and the family members must be explained. Are the field asteroids earlier members of now-dissolved families? The rotation of these asteroids must then have been slowed down from an initial fast value obtained at the collisional breakup. Or do collisions causing family asteroids give a faster spin than those catastrophic collisions

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which cause scattered field asteroids? A simpler model is obtained if one assumes, contrary to common belief, that many asteroids down to very small sizes are primordial bodies. These are then the field asteroids, in contrast to the family asteroids caused by catastrophic collisions. Accretion then causes an increase of spin with diameter for the field asteroids. This view also has some support since the amplitude data (figure 4) show that the family asteroids are more irregular than the ordinary field asteroids of the same size are.

The M and CMEU asteroids in this data sample are nearly all non-family main-belt asteroids and constitute a problem for this model. Do they originate from disruptive events of differentiated bodies (Farinella et al. 1981a) or is it possible to interpret their fast rotation as due to higher mean densities as predicted by the collisional model by Harris (1979)?

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DISCUSSION

WHIPPLE: My calculations of the mean spin periods for comet nuclei give 15^h, longer than the mean for any group of asteroids. Also the mean period increases with mass (brightness) in contrast to that for asteroids. Do you feel that this is strong evidence that comets do not contribute to Earth-crossing asteroids?

LAGERKVIST: No, my opinion is that before drawing any conclusions one should have more rotational data for Earth-crossing asteroids.