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Spin vectors of asteroids: Updated statistical properties and open problems

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ABSTRACT

Only in a limited number of cases the observations supply complete information on the spin vectors of asteroids. A complex analysis is required to compute the orientation (latitude and longitude) of poles, and often multiple solutions and strong discrepancies among the outcomes of different methods are present. The spin vector catalog, maintained at Poznan observatory, lists the available (presently less than 200, and not always unambiguous) pole data.

The statistical analysis of the data, published in 2007, is now becoming obsolete, due to a significant growth of the database. In the present paper we update the analysis, confirming several features already highlighted by the previous paper, and finding some new results.

In particular, the excess of prograde vs. retrograde Main Belt asteroids is now significant for all cataloged bodies smaller than 100 km. The rarity of poles close to the ecliptic plane, resulting from the previous analysis, but recently questioned, is confirmed, with a fundamental contribution of bodies smaller than 40 km.

Only after a future – both qualitative and quantitative – improvement of the database, such as that expected to come out from forthcoming space missions, such as GAIA, we will be able to obtain a statistically robust scenario, hopefully free from possible relevant selection effects.

1. Introduction

The photometric lightcurves of asteroids provide information about their rotational properties (period of rotation and orientation of the spin axis). Photometric observations have been complemented and verified by means of a variety of other observational techniques (i.e. radar observations and spacecraft flybys).

Early statistical analyses of the asteroid spin vector distributions, based on about 30 asteroids, were performed by Magnusson (1986, 1989, 1990) and Drummond et al. (1988, 1991). Further analyses have been performed by Pravec et al. (2002, 83 objects) and Skoglov and Erikson (2002, 73 objects).

The database of asteroid spin vectors (Kryszczynska et al., 2007, see also the website http://vesta.astro.amu.edu.pl/Science/Asteroids/), originating from the one created by Magnusson, is now maintained at Poznan observatory, and is regularly updated. Consequently, the number of listed objects grows over time. New data, and a more elaborate analysis of the previous data, allow us to estimate the pole orientation of new objects. The "growth rate" of the database has been significantly large in the last few years: thus the results of a statistical analysis performed using the catalog, updated to the present time, may be different from those obtained a few years ago (Kryszczynska et al., 2007, hereinafter referred as Paper I). This repeated analysis is not only useful to compare the present findings with the previous ones, but also to identify the most relevant open problems, in view of the forthcoming expected huge stream of new data, due to space missions, in particular to the scheduled ESA project GAIA (de Bruijne, in press). The estimate of several thousand asteroid spin vectors is listed among the mission targets: it means an expected increase of the data by almost two orders of magnitude (Cellino, this issue, and other papers in this issue).

It is also important to discuss the possible sources of selection effects, due to specific methods, as a possible explanation of different results outcoming from similar analyses (Marciniak and Michalowski, 2010). A significant improvement of the dataset, not only in terms of quantity, but also in terms of *quality*, is required to overcome this kind of difficulties.

2. The Poznan database

The spin vector database maintained at Poznan (for a detailed description see Paper I) reports, when possible, synthesis estimates for the spin orientation (latitude and longitude) and the sidereal period of rotation.

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Table 1
Comparison between the 2006 and the 2011 catalogs. The overall increase of MB objects is of the order of 50%, while the number of MB bodies smaller than 40 km is larger by a factor 2.6. No relevant changes are present concerning other groups of MB objects (large inclination or eccentricity, fast rotation).

Objects	N (catalog 2006)	N (catalog 2011)	Perc. variation
MB—all	92	139	+51
NEA	21	25	+19
MB—$i>10^\circ$	33	50	+51
MB—$e>0.15$	41	56	+37
MB—$T<8$ h	56	84	+50
MB small (< 40 km)	12	31	+158

The synthesis estimates are computed taking into account all the results obtained with different methods and at different times. In some cases the estimate is an average value (obviously a moderate scatter among the existing estimates is required); in other cases a recent reliable computation overrules older estimates. The procedure has some subjective features, but no significant systematic errors should come out; maybe the averaging operation decreases the probability of values very close to the extremes (for instance, $\pm 90^\circ$ for the latitudes); however, our statistical analyses are not detailed enough to be affected.

The analysis of the "time evolution" of the data, i.e. the estimate, on a five-years timescale, of both the overall growth of the "size" of the database, and of the possible qualitative variation of the statistical properties, is one of the main tasks of this paper. The variation may depend on the selection effects connected to the observation and data analysis techniques (in case of a significant evolution of the methods) or on the evolution of the mean properties of the sample (for instance, "new" bodies may be smaller in the average). In this latter case the results may also furnish a first perspective insight in the next future, when forthcoming prominent projects (especially space missions) will inject a huge amount of new data.

Results presented in this paper are based on the version of 2011.05.06. of Poznan database, which is the fifth update after the version used for Paper I, updated 2006.04.20, and thus quoted as "2006 catalog".

The first step of this analysis can be summarized by Table 1. We see that the overall number of Main Belt asteroids with known spin vector parameters has increased as much as 50%, while the number of NEA has increased more slowly. The groups of objects which were analyzed in detail in Paper I (high inclination or eccentricity, fast rotation) represent essentially the same percentage of the whole sample in both catalogs. The only relevant change concerns the "small" Main Belt asteroids (defined as being smaller than 40 km); their number has been more than doubled, and their relative abundance passes from about 1/7 to almost 1/4. Consequently the variation of statistical properties – if any – could be affected by the increased weight of this subsample. Moreover, the statistical analysis restricted to this subsample is now more significant.

3. Results

A synthesis of the relevant results is given in Fig. 1, where the angular distribution of the poles is represented. The figure, as in Paper I, has been designed to put into evidence the deviations from a uniform distribution. The longitude is "normalized": the nominal value is multiplied by the cosinus of the latitude; thus the loci of equal longitude are vertical sinusoids, similar to meridians, while the loci of equal latitude are parallel horizontal

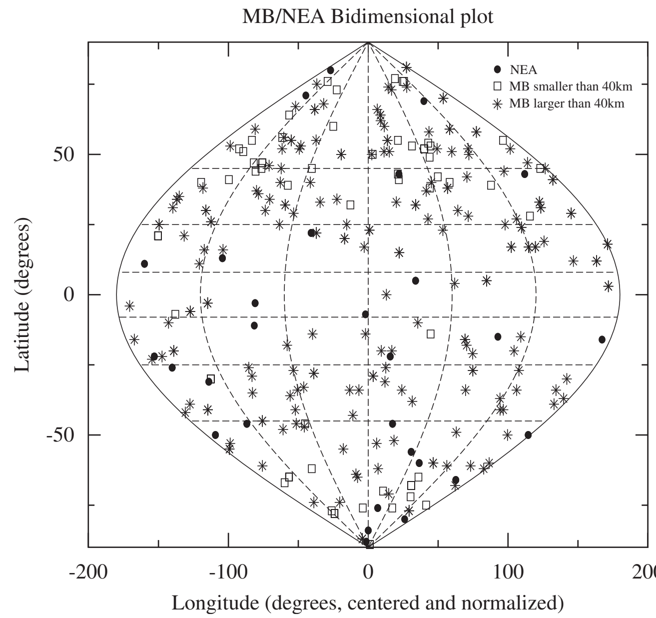

Fig. 1. The figure represents, in a sinusoidal equal-area carthographic representation, the bi–dimensional pole distributions of asteroids. The horizontal dashed lines separate the latitude bins previously discussed, and the vertical curves separate the normalized-longitude bins (here the longitude values range from -180° to 180°, thus the nominal values have to be diminished by 180°). See text for further information. The NEAs are represented as filled circles, while the MB asteroids larger than 40 km are represented by stars. The MB asteroids smaller than 40 km are represented by open squares. The asteroids with ambiguous pole determination (see text) are represented twice.

lines (both of them dashed in the figure). They divide the surface into different regions, each corresponding to the same area: if the poles are randomly oriented, an equal number of points is expected to populate every region. Note that in the case of ambiguous pole determination the body is represented by two points; however, we have tested that this (unavoidable) bias does not affect the qualitative features of the distribution, which we are going to discuss. The population of the regions represented in the figure is not uniform, ranging from a minimum value of 1 to more than 10. The figure evidences a systematic clustering of the latitudes far from the ecliptic, involving in particular the "small" MB asteroids (diameter smaller than 40 km; open squares). The retrograde (lower part of the figure) NEAs are more numerous, while in the Main Belt there is an excess of prograde bodies (upper hemisphere). For what concerns the longitudes, the third (from the left) meridian strip is depopulated; however, the statistical significance is uncertain, and no obvious physical interpretation can be suggested.

While no significant news come out in the latitude distribution of NEAs, compared to previous results (La Spina et al., 2004), the latitude distribution of MB, and its qualitative features, i.e. the prograde excess and the latitude clustering towards the poles, deserve more scrutiny.

In Fig. 2 we represent the cumulative excess of prograde MB asteroids as a function of the decreasing size. Note that no excess of retrograde bodies is present for any size.

We see that the excess begins to be statistically significant (exceeding one standard deviation) around 100 km, and increases for smaller bodies. More data are required to exclude a 3σ stochastic fluctuation. Note that in Paper I we found a statistically relevant excess only for intermediate sized (about 100 km) asteroids, and not for smaller bodies.

We will discuss the issue concerning the latitude clustering in the next section.