A statistical comparison of the AAA asteroids with the other asteroid populations

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Abstract. In this paper a statistical comparison of the AAA asteroids with the other asteroid populations is presented and discussed. For the analysis the database of the osculating orbital elements (Epoch = 2451200.5) of the 47098 asteroids (February 1999) provided at the Lowell Observatory, Flagstaff, Arizona, U.S.A was used. Two kinds of distributions are presented: (1) The frequency distributions of the orbital elements e, i, ω, Ω and absolute magnitude H; (2) The distributions like a vs. e, H vs. i and H vs. r_{MIN}, where r_{MIN} is the minimum distance between the orbits of the Earth and an asteroid. The analysis was aimed to study some special features of the AAA asteroid population like its spatial distribution and size of the asteroids in it and to compare them with the other groups of asteroids.

Key words: asteroid – NEA population – main belt population

1. Introduction

At present (February 8, 1999), there have already been known 659 Apollo−Amor−Aten (AAA) asteroids. As some of them may be potential parent bodies of some meteor showers (Babadzhanov et al., 1990; Porubčan et al., 1992), a study of relations between this group of asteroids (the NEA group) and the others can help to build up a real picture of the population of possible parent bodies of known meteor showers. Some of these relations like the size distribution characteristics especially of the AAA with diameter less than 50 m have been studied theoretically by Rabinowitz (1994; 1997a; 1997b).

In this paper a statistical comparison of the AAA asteroids with the rest of asteroid population is discussed by comparing the distributions of the orbital elements and distributions a vs. e, H vs. i and H vs. r_{MIN}, where H is the absolute magnitude and r_{MIN} is the minimum distance between the orbits of the Earth and an asteroid. As a source of the orbital elements of asteroids the database maintained at the Lowell Observatory in Arizona, U.S.A. was used, which is one of the most actual databases of asteroids with known orbits. It contains osculating orbital elements of 47098 asteroids (Epoch = 2451200.5; February 8, 1999) and can be obtained via anonymous FTP (ftp.lowell.edu/pub/elgb/astorb.dat).

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2. Distributions of e, i, Ω, ω and H

From the catalogue astorb.dat 659 AAA asteroids can be separated. The distributions of the orbital elements e, i, Ω, ω and the absolute magnitude H are presented in Figs.1a-5a. Similar distributions, but for the whole catalogue of 47098 asteroids are presented in Figs.1b-5b.

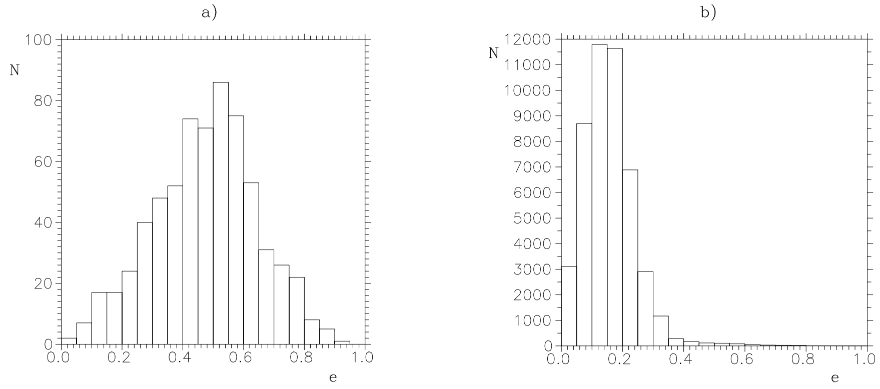

Figure 1. The distribution of eccentricity of the AAA asteroids (a) and all asteroids in the database (b).

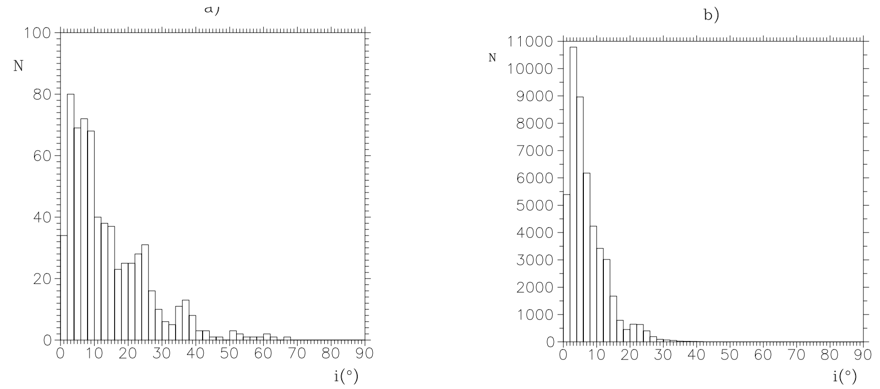

Figure 2. The distribution of inclination of the AAA asteroids (a) and all asteroids in the database (b).

Fig.1a and Fig.1b demonstrate completely different distribution of eccentricity of the AAA asteroids as a special group of asteroids and that of the whole database of 47098 asteroids. This is a consequence of the definition of AAA asteroids and it demonstrates the orbital period coherence as a kind of connection between majority of the AAA asteroids and the main belt asteroids. The distribution of perihelion distance of AAA asteroids has a peak near 1 AU (Kostolanský, 1999). Hence, the 0.5 "Gaussian" peak at the distribution

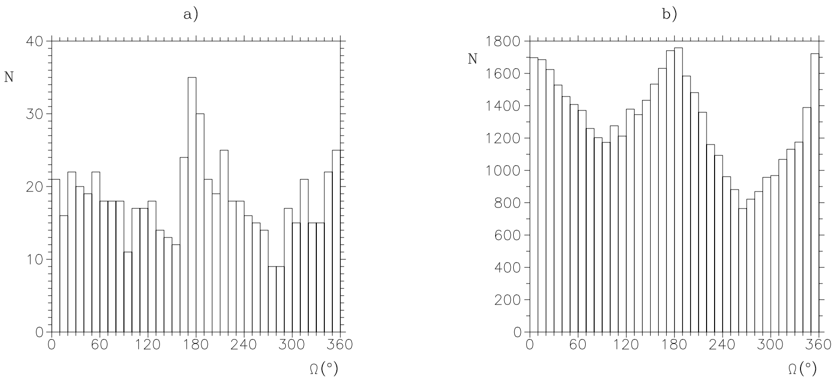

Figure 3. The distribution of ascending node of the AAA asteroids (a) and all asteroids in the database (b).

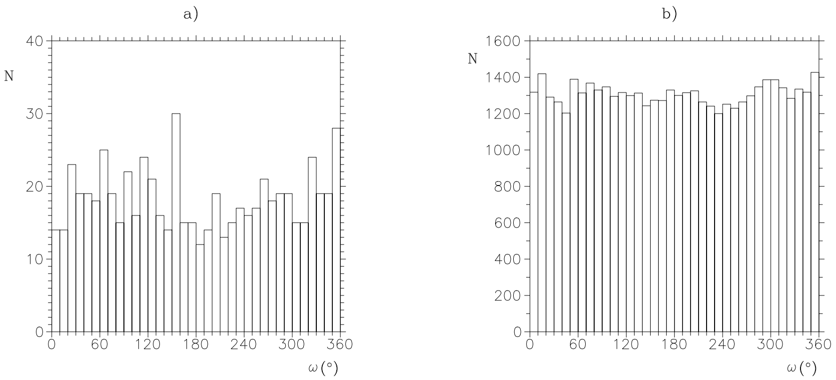

Figure 4. The distribution of argument of perihelion of the AAA asteroids (a) and all asteroids in the database (b).

of eccentricity of the AAA objects in Fig.1a indicates, that many of them have semi-major axis $a \approx 2$ AU. There is an orbital period coherence between these objects and the main belt asteroids with $a \approx 2$ AU. By comparing Figs.1a and 1b we can state that almost all known asteroids with $e > 0.5$ (the tail of the distribution of eccentricity in Fig.1b) are the members of the AAA group.

Unlike the distributions of eccentricity, the distributions of inclination are not completely different. Both of them shown in Fig.2a and Fig.2b are very similar with the peaks between $i = 2°$ and $i = 4°$, respectively.

One can infer that the observed distribution of inclination is probably one of the general characteristics of the whole population of asteroids. Since the distribution of inclination of all 47098 asteroids for $i > 4°$ is decreasing rather smoothly (Fig.2b), the two observed peaks at $i \approx 25°$ and $i \approx 37°$ for the AAA

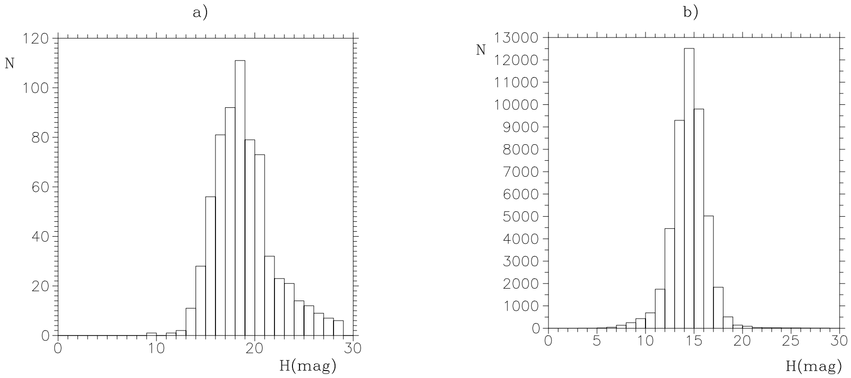

Figure 5. The distribution of the absolute magnitude H of the AAA asteroids (a) and all asteroids in the database (b).

group are probably not real and may result from observational effects.

With respect to spherical symmetry, the ascending node Ω and argument of perihelion ω could be in general distributed uniformly between 0° and 360°. Such a distribution can be observed in the case of ω (Fig.4a and Fig.4b), but not Ω (Fig.3a and Fig.3b). The distribution of ascending node of all asteroids is a harmonical one with maxima at $\Omega \approx 0°$ and $\Omega \approx 180°$. This course is not real and is caused probably by a combination of more selection effects. Some of them have been discussed by Kresák and Klačka (1989). There exist also some minor selection effects which can also influence the observed distribution of ascending node. For example, one of them is the effect of equivalence of the Earth's equator plane and orbital plane with $i \approx 23.5°$ and $\Omega \approx 180°$ at the moment of vernal or autumnal equinox (Kostolanský, 1999).

The distribution of magnitudes H presents an approximate information about the size distribution of asteroids, since H is fundamental photometric parameter which can be used as the absolute magnitude (Bowell et al., 1989). The distribution of H is plotted in Figs.5a (AAA asteroids) and 5b (whole database). One can note two features following from the distributions:

1) A typical main belt asteroid (with $H \approx +15$) is about 4 magnitudes brighter than a typical AAA asteroid, i.e. a typical main belt asteroid is roughly 6.3 times larger than a typical AAA asteroid;

2) Almost all known asteroids with $H > +19$ (the tail of the $H-$distribution in Fig.5b) are the members of the AAA group.

Both the items are the most likely a result of selection effects caused by limited possibilities of the observational techniques. Contrary to the NEO objects approaching to the Earth orbit, at the distances of the main belt asteroids only statistically larger bodies can be observed.

3. The a – e distribution

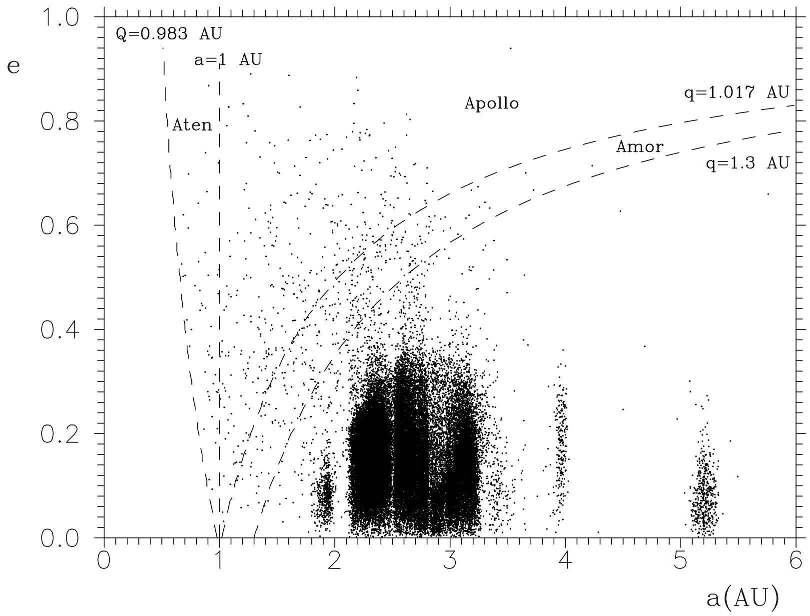

Figure 6. The distribution of semi-major axis vs. eccentricity of all asteroids in the database

The distribution of semi-major axis vs. eccentricity of the whole database of 47098 asteroids is plotted in Fig.6. Although the AAA objects are a special group of asteroids, they occupy a very large area in Fig.6. In the area for $q > 1.3$ AU, the main belt together with some special groups of asteroids of dynamical origin can be seen. They are the Hungarians (located below the 4:1 resonance - $a \approx 1.9$ AU), the Hildas (located at the 3:2 resonance - $a \approx 3.95$ AU) and Trojans (located at the 1:1 resonance - $a \approx 5.2$ AU). Fig.6 shows that none of these resonances influence asteroids in the area where are located AAA, i.e. the asteroids with higher eccentricity. Despite of this fact there are two wide regions with such an influence.

The first one is the Flora and Phocaea region between 4:1 ($a \approx 2.1$ AU) and 3:1 ($a \approx 2.5$ AU) resonances. Probably this region is composed of several small dynamical families (Binzel, 1989) and almost all the known Amor asteroids (and a part of the Apollo asteroids with $e < 0.6$) with $a \in (2.1AU, 2.5AU)$, about 110 AAA objects, are part of this region.

The second is the region between 3:1 ($a \approx 2.5$ AU) and 5:2 ($a \approx 2.8$ AU) resonances, containing about 30 AAA objects.

4. The H – i and H – r_{MIN} distributions

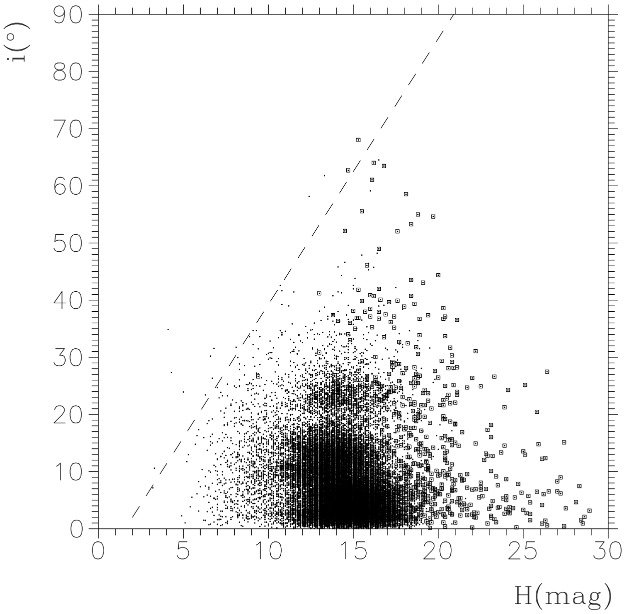

Figure 7. The distribution of the absolute magnitude H vs. inclination i of all asteroids in the database; squares - represent 659 AAA asteroids; dashed line - represents empirical functional dependence between the maximum i and H

The H vs. i distribution could delineate the width of the observed "disc" of asteroids around the Sun: small (and faint) asteroids are moving around the Sun on orbits with higher inclination and form an asteroidal "halo". As evident from Fig.7, this could be a real situation. Besides a few exceptional asteroids, the functional dependence between the maximum inclination i_{MAX} and absolute magnitude H for asteroids brighter than $+16^m$, i.e. $H < +16$, is almost linear and can be empirically stated as follows (dashed line in Fig.7):

$$i_{MAX}(^\circ) = 4.654 \times H(mag) - 7.31 \tag{1}$$

Since the population of brighter asteroids is known better, the effect described by Eq.(1) could be realistic. Thus, bright asteroids will be more populated near the ecliptic and their orbits could form a "disc" close to the ecliptic. A theoretical consequence of Eq.(1) is that faint asteroids with $H > +20.91$ ($i_{MAX} \approx 90^\circ$) might be found almost everywhere in space around the Sun independently with respect to the position of the ecliptic. These asteroids could form a Sun's asteroidal "halo".

In Fig.7 the AAA asteroids are designated by squares and an opposite situation can be observed in this group of asteroids: with the increasing H is i_{MAX}

decreasing. This is probably due to the selection effect based on the fact that small bodies with high i pass near the Earth just in a few hours and a chance to find them is with the increasing i decreasing. Hence, it is easier to observe AAA near to the ecliptic and with lower i.

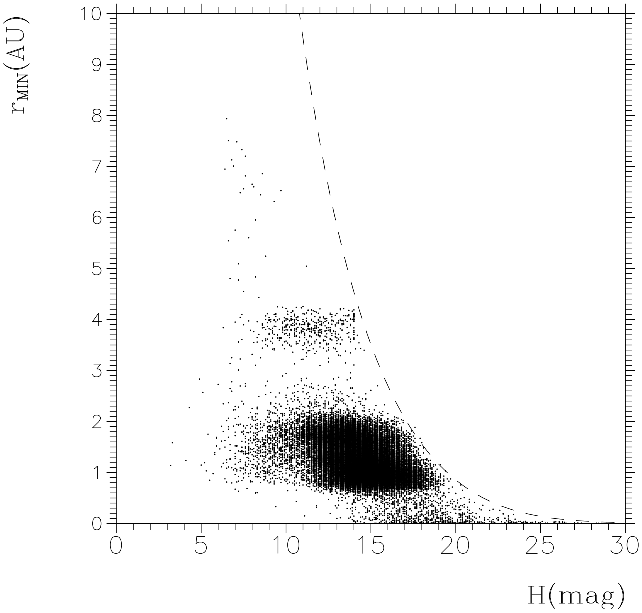

Figure 8. The distribution of the absolute magnitude H vs. minimum distance r_{MIN} for all asteroids in the database; dashed line - represents the objects which would have at the moment of their ideal opposition (i.e. $i = 0°$ and the distance between them and the Earth $= r_{MIN}$) brightness $+21^m$

In Fig.8 the H vs. r_{MIN} distribution is presented. The r_{MIN} is the minimum distance between the orbits of the Earth and asteroids and was computed from the osculating elements of asteroids (database) and the Earth (Newcomb theory - Abalakin et al., 1976) for the epoch 2451200.5 (January 22, 1999 - 0^h UT). In Fig.8 three groups of asteroids can be seen: the Trojans ($r_{MIN} \approx 4$ AU), the main belt asteroids (majority with $r_{MIN} \in \langle 1AU, 2AU \rangle$) and the AAA asteroids (majority with $r_{MIN} \in (0AU, 0.5AU\rangle$). The main belt asteroid group and the AAA are not discrete groups - there exists a smooth transition between them.

The dashed line in Fig.8 represents the objects which would have at the moment of their ideal opposition (i.e. $i = 0°$ and the distance between them and the Earth $= r_{MIN}$) brightness $+21^m$ and theoretically can be given as follows:

$$H(mag) = +21 - 5 \times \log\left[r_{MIN}\left(r_{MIN} - 1\right)\right], \tag{2}$$

where r_{MIN} is in AU. This empirically stated curve delineates a boundary between a blank area which apparently covers and makes inaccessible any infor-

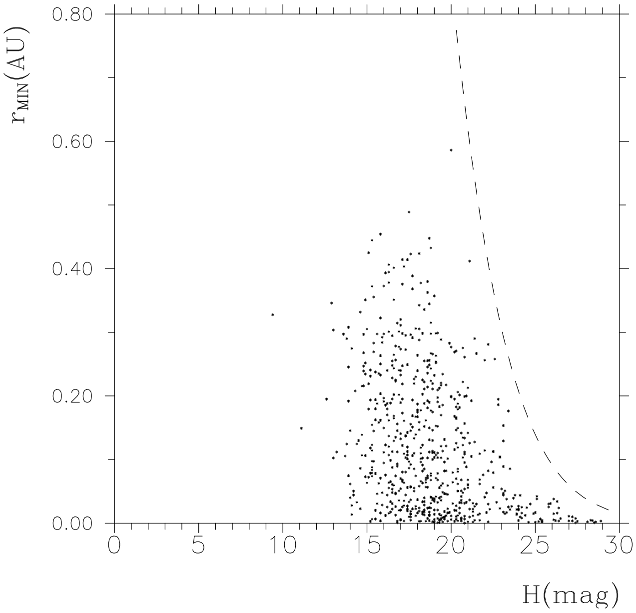

Figure 9. The distribution of the absolute magnitude H vs. minimum distance r_{MIN} of the known 659 AAA asteroids; dashed line - represents the objects which could have at the moment of their ideal opposition (i.e. $i = 0°$ and the distance between them and the Earth $= r_{MIN}$) brightness $+21^m$

mation about majority of faint asteroids. This blank area represents probably the strongest selection effect which exists due to limits of our observing technology. Thus, at the present time the AAA asteroids are the only source of information about faint and small asteroids.

On the other hand, the information about the largest asteroids is real through the whole r_{MIN} axis up to $r_{MIN} = 10$ AU.

In Fig.9, the same distribution with the same dashed curve, but only for the known 659 AAA asteroids is presented. There is not a high density of asteroids near the curve. Likely, this is not due to limits of the present observing techniques, but may be a result of observing programs aimed at searching for asteroids near the Earth. The problem of optimal search for asteroids has been studied theoretically by more authors (Taff, 1984; Rabinowitz, 1991). The H vs. r_{MIN} distribution shows that with the present observing techniques we still have inexhausted facilities especially in case of very faint and fast-moving AAA asteroids. These facilities could probably be usefully exhausted by a better coordinated and densier network of observatories.

5. Conclusion

The presented distributions show that the AAA asteroids and the other groups of asteroids are similar in more features. They have similar distribution of inclinations, a majority of the AAA asteroids is in period coherence with a part of the main belt asteroids and their observations are influenced by similar selection effects. Unlike the other groups of asteroids, the AAA group consists of asteroids with sizes from kilometres to metres. At the present time we have (and probably will still have for next few years) information only about small objects near the Earth due to limiting possibilities of our observational technology. The H vs. i distribution of larger asteroids (i.e. with $H < +15$) indicates the existence of an asteroidal "halo" consisting of small and faint asteroids ($H \geq +21$). Hence, a great part of small yet unknown AAA objects could orbit the Sun at high inclinations. Since these are potential parent bodies of the asteroidal meteor streams, their real influence not only on the observed meteor streams, but also on sporadic background can be much stronger than we assume.

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