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# Dynamics of the Hungaria asteroids

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ABSTRACT

To try to understand the dynamical and collisional evolution of the Hungaria asteroids we have built a large catalog of accurate synthetic proper elements. Using the distribution of the Hungaria, in the spaces of proper elements and of proper frequencies, we can study the dynamical boundaries and the internal structure of the Hungaria region, both within a purely gravitational model and also showing the signature of the non-gravitational effects. We find a complex interaction between secular resonances, mean motion resonances, chaotic behavior and Yarkovsky-driven drift in semimajor axis. We also find a rare occurrence of large scale instabilities, leading to escape from the region. This allows to explain the complex shape of a grouping which we suggest is a collisional family, including most Hungaria but by no means all; we provide an explicit list of non-members of the family. There are finer structures, of which the most significant is a set of very close asteroid couples, with extremely similar proper elements. Some of these could have had, in a comparatively recent past, very close approaches with low relative velocity. We argue that the Hungaria, because of the favorable observing conditions, may soon become the best known sub-group of the asteroid population.



## 1. The Hungaria region

The inner edge of the asteroid main belt (for semimajor axes $a < 2$ AU) has a comparatively populated portion at high inclination and low to moderate eccentricity: it is called the *Hungaria region*, after the first asteroid discovered which is resident there, namely (434) Hungaria. The limitation in eccentricity allows for a perihelion large enough to avoid strong interactions with Mars, see Fig. 1; since the eccentricity of Mars can change, as a result of secular perturbation, in the range between 0 and 0.12 (Laskar et al., 2004b), there is a strip shown in the figure, where this interaction takes place, with a very obvious trend in number density from essentially zero where the objects are Mars crossing all the time to the maximum density where Mars crossing is a very rare event. The high inclination also contributes by keeping the asteroids far from the ecliptic plane most of the time, see Fig. 2.

The other boundaries of the Hungaria region are less easy to understand on the basis of osculating elements only. However, a dynamical interpretation is possible in terms of secular perturbations, namely there are strong secular resonances, resulting from the perihelion of the orbit locked to the one of Jupiter, and to the node of the orbit locked to the one of Saturn. This, together with the Mars interaction, results in a dynamical instability boundary surrounding the Hungaria region from all sides, sharply separating it from the rest of the main belt.

This boundary can be crossed by asteroids leaking out of the Hungaria region, even considering only gravitational perturbations, but a small fraction of Hungaria are on orbits subject to this kind of unstable chaotic mechanisms. Thus the region is populated by asteroids which are, for the most part, not primordial but native to the region, that is fragments of a parent body which disrupted a long time ago.

The above argument fully explains the number density contrast between the Hungaria region and the surrounding gaps, regardless from the possible existence of an asteroid collisional family there. Still there is a family, first proposed in Lemaitre (1994), including (434) Hungaria, with strong evidence for a common collisional origin: this we call *Hungaria family*. It includes a large fraction of the Hungaria asteroids, but by no means all of them; there is no firm evidence for other families in the Hungaria region.

There are indications of internal structures inside the Hungaria family. These could belong to two types: *sub-families* and *couples*. A sub-family is a sub-group, of family asteroids more tightly packed than the surrounding members, which results from a breakup of a member of the original family at an epoch later, possibly much more recent, than the family formation event. A couple consists in just two asteroids, extremely close in the orbit space: the most striking property is that in some cases it is possible to find a very close approach of the two asteroids in a comparatively recent past,

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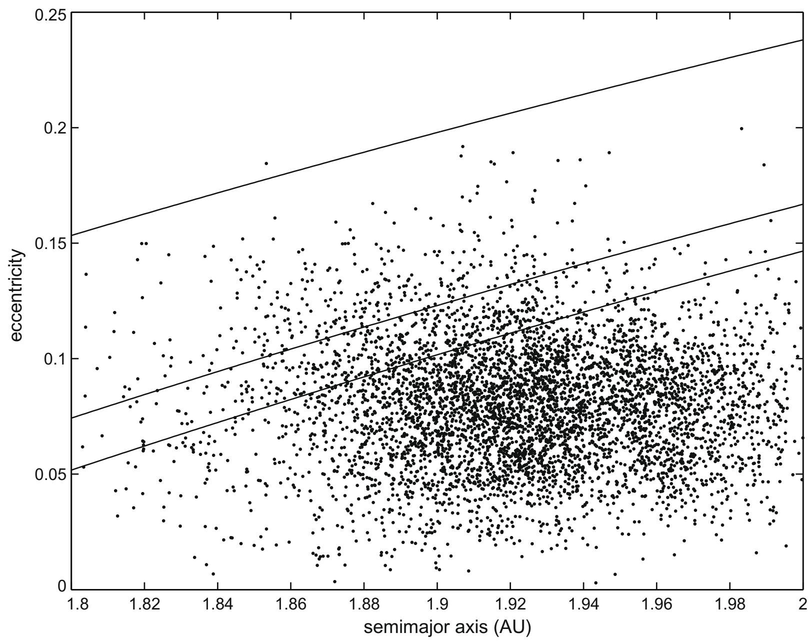


**Fig. 1.** Osculating orbital elements semimajor axis and eccentricity for the 5025 Hungaria asteroids currently known and observed over multiple oppositions. In this plot we show 2477 numbered and 2548 multi-opposition Hungaria, selecting from the current catalogs (updated May 2009) the orbits with $1.8 < a < 2$ AU, $e < 0.2$ and $I < 30°$. The lines indicate where the perihelion would be at the minimum, current and maximum aphelion distance of Mars, in order of decreasing eccentricity for the Hungaria.

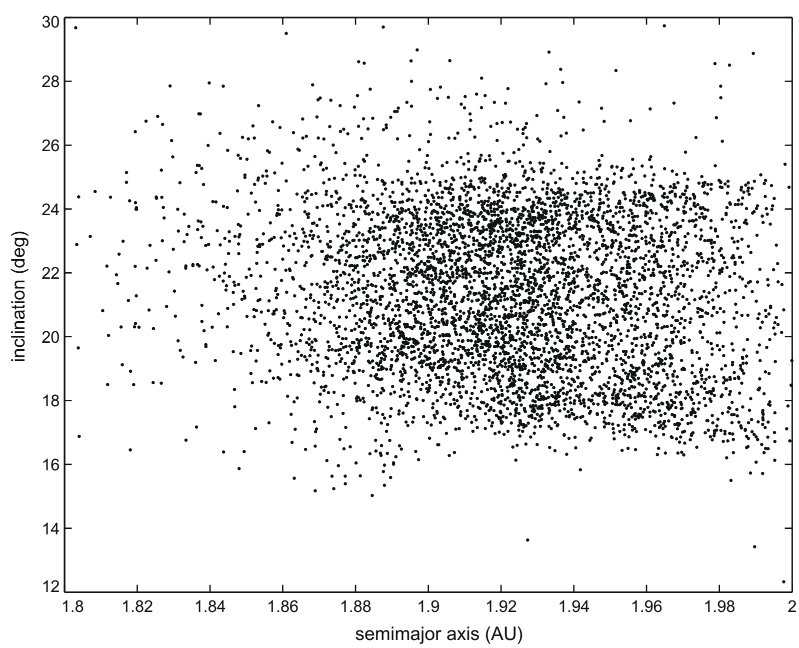


**Fig. 2.** Osculating orbital elements semimajor axis and inclination for the same 5025 Hungaria asteroids of Fig. 1.

with a relative velocity at the closest approach much lower than the one expected for a collisional fragmentation.

All the above statements are not fundamentally new, in that many papers and presentations to meetings have argued along the same lines. The problem up to now was that there was no way to obtain a firm conclusion on many of these arguments and a rigorous proof of most statements about the Hungaria. This resulted from the fact that all sort of relevant data, such as proper elements, location of resonances, color indexes, rotation state information, constraints on physical properties such as density and thermal conductivity, were either lacking or inaccurate and inhomogeneous. The abuse of the information content of these low quality data to extract too many conclusions is a risky procedure. On the other hand there are indeed many interesting problems on which we would like to draw some robust conclusions.

When the present paper was almost complete, the paper by Warner et al. (2009) became available from Icarus online. This paper contains useful work, and the main results are in agreement with ours. However, many of the conclusions of that paper are weak for lack of accurate data: indeed the authors have made a great effort to make statements which can be reliable at least in a statistical sense. Thus we have found in this reading confirmation for the need of the work we have done for this paper, which is different in method and style more than in subject: our goal is to ob-