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CHAOTIC DIFFUSION IN THE VERITAS FAMILY REGION

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Abstract. Veritas family region in the outer part of the asteroid main belt comprises a stochastic zone due to overlapping of the harmonics of (5, -2, -2) three-body resonance. Dynamics in the region is strongly chaotic and governed by a diffusion equation of the Fokker-Planck type. The mean squared displacement of an action-like variable grows linearly with time, at a rate given by the value of the diffusion coefficient. Thus, computing the diffusion coefficients, one can derive the diffusion rate and estimate the age of the family.

We integrated the orbits of 100 clones for each object in the (5, -2, -2) region. For each orbit we obtained the time series for the proper elements, and the value of the diffusion coefficients in e and i. The values of the diffusion coefficients we found indicate a very short age for this family, in agreement with previous results based on different approaches.

1. INTRODUCTION

Veritas family region in the outer part of the asteroid main belt has been recently recognized as being quite complex in terms of the local dynamics. It is hence also potentially resourceful regarding the physical consequences of chaotic behavior detected in the motion of even the largest members of the family. Several studies were performed in an attempt to understand the dynamical mechanisms at work, resonances involved, the time scales of chaotic diffusion giving rise to macroscopic effects, and the resulting implications for the possible age of this family (e.g. Milani & Farinella 1994, Milani et al. 1997, Nesvorný & Morbidelli 1998a, 1998b, Knežević & Pavlović 2002), so that at present we have a fairly complete and reliable general picture, as well as plausible explanations for several most straightforward specific questions.

The main generator of the strong chaos in the region appears to be the three body mean motion resonance $(5, -2, -2)$. The fast diffusion in the phase space of proper elements is primarily due to the overlapping of the harmonics of this resonant multiplet, but to some extent also to the other high order mean motion resonances located in the region (Nesvorný & Morbidelli 1998a, Knežević et al. 2003). Using the "chaotic chronology" method, proposed by Milani & Farinella (1994) and based on an estimate of the characteristic epoch of exit of chaotic family members from the region in the phase space occupied by the family, the upper limit to the age of Veritas family has been estimated to be on the order of some tens of millions of years, quite certainly well below 100 Myr. The exact age of the family, which might be as young as $15 - 20$ Myr according to some more recent results (Knežević & Pavlović 2002), could, however, not be firmly established in this way.

In this paper we present results of a new study, which makes use of an approach based on the idea of chaotic chronology, but using different tools. We, namely, computed the coefficients of diffusion to better define the rates of change of proper elements, and then derived an estimate of the time span needed to spread the chaotic members of the family to their present mutual distances. We therefore first established the dynamical state of the family members by computing the Lyapunov Characteristic Exponents for each of them, then we classified these members into four distinct groups according to their chaoticity and location, to finally estimate the coefficients of diffusion over an ensemble of a hundred clones per each strongly chaotic body, determining in this manner the corresponding rates in proper eccentricity and proper inclination. The diffusion in semimajor axis was not accounted for, because it saturates fast due to the limited width of the connected stochastic zone.

2. CHAOTIC DIFFUSION AND THE AGE OF THE FAMILY

Coefficients of diffusion are computed from a simple relation of the form:

$$D(X) = \frac{< (\Delta X)^2 >}{2\delta t} \tag{1}$$

where $< (\Delta X)^2 >$ denotes the ensemble average of a mean square displacement of an action-like variable X (in our case either proper eccentricity e_p, or proper inclination i_p) over all chaotic objects, computed as function of time. We assume that random walk in the space of proper elements is governed by a diffusion equation of Fokker-Planck type (Murray & Holman 1997), so that displacement grows linearly with time and $D(X)$ can straightforwardly be derived as the slope of a least-squares fit.

Computing the time series of proper elements by means of an analytical algorithm (Milani & Knežević 1994) and averaging the displacement over all the comprised bodies and their clones, we derived the diffusion rates reported in Knežević et al. (2003; see Fig. 3), that is $D(e_p) = 0.38 \cdot 10^{-11}$ yr^{-1} and $D(sini_p) = 0.76 \cdot 10^{-12}$ yr^{-1} for the eccentricity and (sine of) inclination, respectively. Assuming zero initial spread of chaotic members in the phase space, as well as their current separation ($\Delta e_p \simeq 7.2 \cdot 10^{-3}$; $\Delta \sin i_p \simeq 2.5 \cdot 10^{-3}$), one easily infers that the age of the family should be 27 Myr according to the eccentricity rate, and 16 Myr from the rate in inclination (Fig.1). In view of the approximations and assumptions involved in the procedure, and of a purely stochastic nature of the chaotic behaviors, it is rather obvious that these results do not provide an accurate age of the family, but only a plausible order of magnitude estimate. Thus the agreement of the two obtained values can be considered as quite satisfactory, indicating a probable age for the Veritas family of a couple of tens of millions of years.

This result might appear as somewhat surprising, since it suggests rather young age for the family originated from a break-up of a sizable object (parent body of the Veritas family has been around 150 km in diameter). The probability to have such an event so close in the past is not very high according to standard collisional models (one disruption per 300 Myr; see Milani & Farinella 1994), but it is certainly not negligible. Analysis of the unbiased distribution of the epochs of first exits from the region in the phase space occupied by the Veritas family (Fig. 2) indicates also about the same age for the family. In general, recent catastrophic disruptions in the main

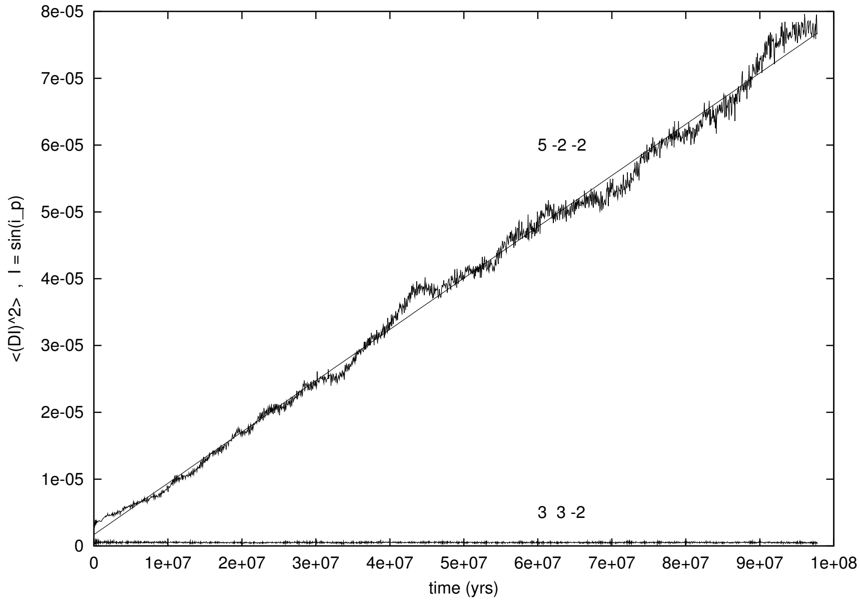

Figure 1: The mean square displacement in $\sin i_p$ as a function of time. The slope of the linear fit implies an age of the family of 16 Myr, in agreement with an estimate obtained from the histogram on Fig. 2.

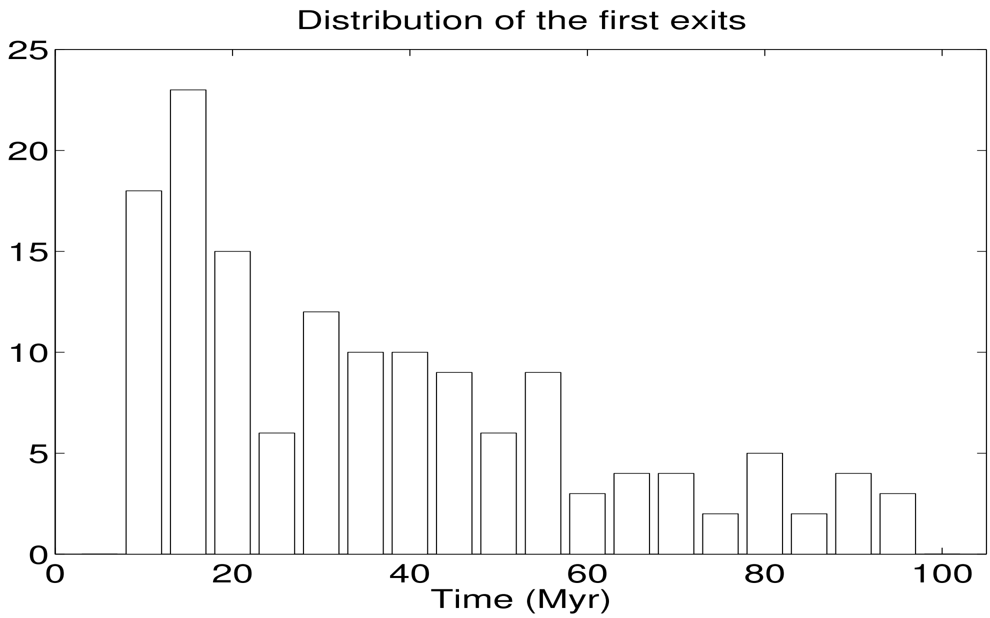

Figure 2: The distribution of the epochs of first exits from the region occupied by the family indicates an age of $15 - 20$ Myr.

belt appear not to be so rare as previously believed. Nesvorný et al. (2002) thus reported on the possible existence of a sub-family in Koronis region, as young as 6 Myr.

Spectral differences among the members of Veritas family observed by Di Martino et al. (1997) are interpreted by them as indicative of the genetic relationship of the family members and of an outcome of a single collisional episode. They suggest a "core-type" fragmentation of a precursor body with thermally altered interior as the most plausible scenario, which, on the other hand, does not put any constraints on the possible age of the family. The alternative explanation of the differences of spectra as possibly due to space weathering, would imply different exposure times of family members, shorter for objects coming from the interior of the parent body and longer for the fragments from the parent's surface, but again imposing no obvious lower limit on the family age.

We can therefore conclude that, to our best present knowledge, Veritas family appears to be comparatively young, in particular in view of its presumed origin from a sizable parent body. Our results appear to suggest some 20 Myr as the most probable value for the age.

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