DIRECTIONAL DISTRIBUTION OF OBSERVABLE COMETS INDUCED BY A STAR PASSAGE THROUGH THE OORT CLOUD

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Abstract. We simulated the passage of a star through the Oort cometary cloud and analyzed the resulting sample of observable long period comets, noting strong asymmetries in the directional distribution of the perihelion points of those comets. We discuss the results previously published by Weissman (1996) for the same case. An explanation is suggested why the isotropic output can be obtained only for a very peculiar case. The "cometary shower" density variation with time is also presented and the time-dependence of the directional distribution is discussed.

Keywords: Comets, Oort cloud, stellar passages

1. Introduction

The results of simulating the passage of a star through the Oort cloud by Dybczyński (2002) and Weissman (1996) show some significant discrepancies. The present paper explains the source of these discrepancies and describes in more detail the time-dependence of several characteristics of the "cometary shower" induced by a single stellar passage through the Oort (1950) cometary cloud.

In his paper (hereafter WP) Weissman (1996) simulated the spherically symmetric cloud of comets according to the distributions found by Duncan et al. (1987) using a sample of 10^7 comets. He discussed an example of a close stellar passage, the effects of which were calculated by means of the classical impulse approximation. To present the results, Weissman used several plots, showing the instantaneous location of comets (in rectangular coordinates) at the moment of the stellar passage, separately for the ejected subsample and for the subsample perturbed to the perihelion distances less than 10 AU, which was the observability threshold assumed in WP.

During our extended investigation of the effects of the stellar and galactic perturbations on the Oort cloud of comets we attempted to repeat the simulation presented in WP, reproduce results published there and then investigate in detail the obtained observable subsample of comets to verify Weissman's conclusion, i.e., that there are no anisotropies in its distributions.

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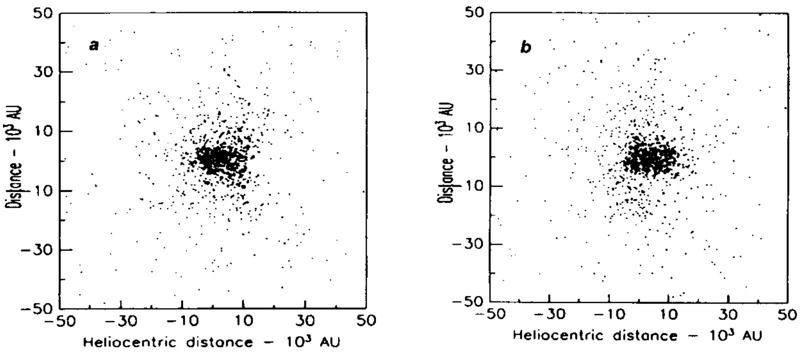

Figure 1. Original Weissman's plots, published in WP as Figures 2c and 2d (with kind permission from Kluwer Academic Publishers). Both axes describe the heliocentric distance of a comet in two different projections: (a) Onto the XY plane, (b) onto the YZ one (see text).

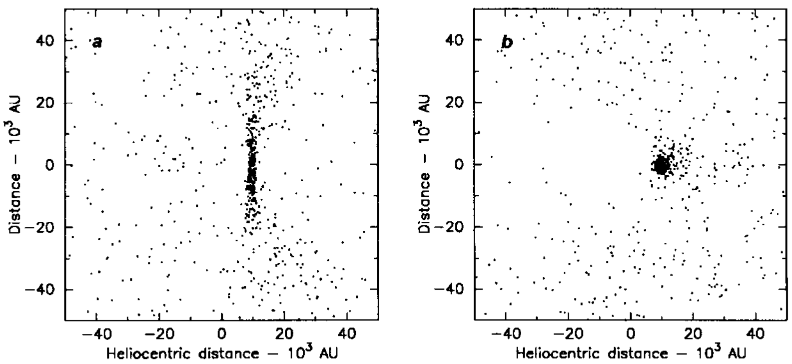

Figure 2. The positions of comets perturbed to $q < 10$ AU, obtained from our simulation for IB = 50 AU, with the same scale and projections as in Figure 1.

2. Observable Subsample

In WP the results of the close stellar passage are discussed in detail based on the example of one solar mass star passing through the simulated Oort cloud at 10 000 AU from the Sun with a velocity of 30 km/s. In his Figures 2a and 2b, Weissman showed the positions of comets ejected out of the cloud by the perturbation from the passing star in two different projections (on XY and YZ planes respectively). The coordinate system is oriented such that the stellar straight line path is parallel to the OX axis and the XY plane contains both the stellar path and the Sun. These plots are not very sensitive to the parameter values and can be easily reproduced.

A problem was encountered when we tried to repeat the results presented as Figures 2c and 2d in WP (reproduced here as Figure 1). *Using the same model and method as applied in WP we could not obtain plots even similar to those in WP.* We used the distribution of semimajor axis and the eccentricity from Duncan et al. (1987) and assumed spherical symmetry for the cloud and a uniform distribution of the mean anomaly. All these parameters are identical with those used in WP, except of probably negligible differences coming from the numerical reconstruction of the semimajor axis and eccentricity distributions on the basis of the plots presented in Duncan et al. (1987). We used the classical impulse approximation and an inner boundary (IB) of the simulated cloud equal to 50 AU whereas the value for the outer boundary (OB) was 2×10^5 AU, the same as in WP. The resulting distributions are presented in Figure 2.

Weissman stated in his paper, that comets observable as a result of the close stellar passage come to the solar vicinity from all directions. From Figure 2 it is clear that this is not the case. The anisotropy in the position distribution is clearly visible here and we will discuss the resulting anisotropies in the perihelion direction distribution for this subsample later. Comparing Figure 1 and Figure 2 we asked for the reason for such a drastic difference. The most peculiar feature in Figures 1a and 1b (and one very sensitive for IB changes) is the strong concentration of points, surrounding the position of the Sun. It is impossible to reproduce it using the IB value published in WP. It is almost impossible to obtain an observable cometary orbit, applying the stellar impulse to comets in the close solar vicinity but on Weissman's plots the majority of points are concentrated near the Sun. Varying the value of the inner boundary, we were able to reproduce the plots published in WP when IB was set to 10 AU.

We emphasize that all four parts of WP's Figure 2 can be reproduced perfectly with our code only when the inner boundary value is the same as the observability threshold, in this case 10 AU. Perhaps even more surprising is the sensitivity of the result to the precise value of the IB; even for IB = 10.5 AU the plots obtained are substantially different. The reason for this is that if IB is equal to the observability limit, arbitrarily small perturbations can make an orbit observable. The simulation described in WP seems to have been performed for an inner boundary value of 10 AU (instead of 50 AU as it is stated).

3. Time Dependence of the Directional Distribution of Perihelion Points

The asymmetries are clearly visible in the corrected plots (Figure 2). The use of the rectangular coordinates of comets at the moment of the stellar passage is however not very convenient and it is difficult to compare such statistics with the observed sample of long-period comets. In Figure 3 we therefore present the distribution of the perihelion directions (as points on the celestial sphere in an equi-areal projection) for the observable subsample of comets obtained in the same manner as for Figure 2, but enlarged in number to obtain a better readable plot. Stellar path parameters are shown in the upper left corner. The central part of this figure shows the cometary shower density histogram, which adds the time-dependence. This histogram shows the number of comets passing perihelion over each 20 000 year sub-interval. It clearly shows a significant cometary influx increase in the first

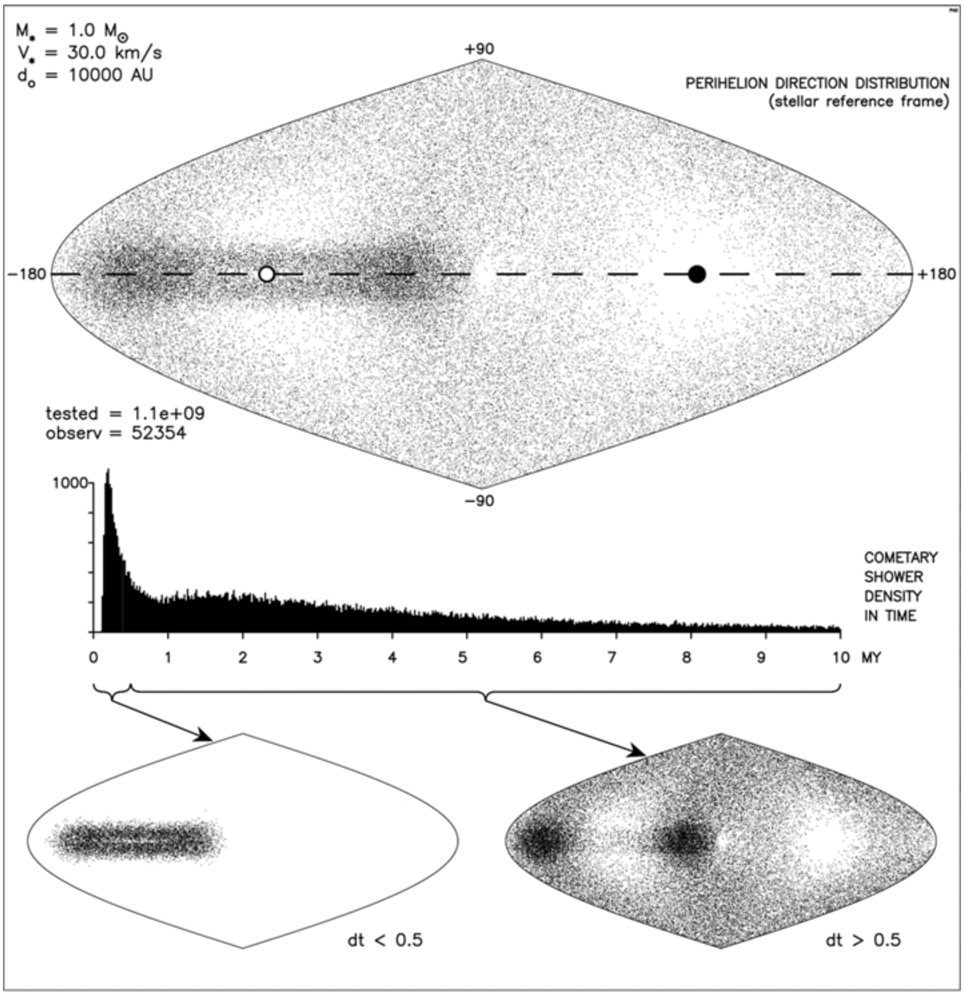

Figure 3. Perihelion points direction distribution.

500 000 years after the stellar passage. For a total number of comets of 1.1×10^9 in the simulated cloud the long-period observable comet influx reaches a number of 1000 observable comets (perihelion distance below 10 AU) per 20 000 years. When scaled to the widely accepted number of comets in the Oort cloud (about two orders of magnitude higher) it gives as much as five "shower" comets per year in the part of highest intensity of the "cometary shower". However, as the number of comets in the cloud is estimated on the basis of the current long-period cometary influx, the numbers presented above cannot be used to judge, whether we are currently experiencing an increased flux of comets owing to a recent stellar perturbation or a steady state one.

The answer may come from the lower part of Figure 3. It consists of two parts extracted from the main, upper plot: the left part presents the perihelion direction points only for those comets which arrive at perihelion no later than 500 000 years after the stellar passage. It should be stressed that the left plot consists of almost 20% of all simulated observable long-period comets obtained from the simulation. The rest of the simulated sample is presented in the lower-right part. From the lower-left part of Figure 3 one may conclude that the observed long-period comet population does not belong to the intense "cometary shower" part, because such a strong perihelion points direction concentration is not observed. However, reliable cometary observations are available only for the last two centuries which makes the "probing" subinterval very short in comparison to the duration of the shower.

From the above cometary influx estimations one should expect no more than about 50 "shower" comets in the observed population, taking into account that the observability threshold value used here (10 AU) is significantly larger than the practical instrumental limitations even a few years ago. More sophisticated studies of the observed long-period comet sample are probably needed to separate possible "shower" comets from the background flux.

The presented example of a stellar passage is by no means the best to produce perihelion direction asymmetries. On the contrary, more distant (and far more likely) stellar passages produce asymmetries that are much more prominent.

4. Conclusions

We presented the results of simulating the output of a close stellar passage through the Oort cometary cloud from the point of view of the directional distribution of the observable comets induced by this passage. We showed that except for a singular case the resulting distribution is significantly anisotropic. The concentrations of perihelion points align with the stellar heliocentric orbit and its anti-perihelion. This finding may be used to search for the recent stellar perturber fingerprints based on the observed long-period comet perihelion distribution irregularities. It should be stressed, however, that the directional characteristic of the "cometary shower" as well as its time dependence strongly depend on the geometry of the star path, mainly on the minimum distance between the star and the Sun. Before any attempts can be made to compare the simulation results with the observed long-period comet population, it is necessary to also include galactic perturbation into the model. A paper covering these aspects of the problem is in preparation.

A more detailed analysis of the presented example of the stellar passage as well as a discussion of the validity of the classical impulse approximation in this study (based on the comparison with the direct numerical integration) and discussion of the various end-state probabilities for the simulated sample of comets may be found in Dybczyński (2002).

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