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The discovery rate of new comets in the age of large surveys. Trends, statistics, and an updated evaluation of the comet flux

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Abstract. We analyze a sample of 58 Oort cloud comets (OCCs) (original orbital energies x in the range $0 < x < 100$, in units of 10^{-6} AU^{-1}), plus 45 long-period comets with negative orbital energies or poorly determined or undetermined x, discovered during the period 1999-2007. To analyze the degree of completeness of the sample, we use Everhart's (1967 Astr. J 72, 716) concept of "excess magnitude" (in magnitudes $\times$ days), defined as the integrated magnitude excess that a given comet presents over the time above a threshold magnitude for detection. This quantity is a measure of the likelihood that the comet will be finally detected. We define two sub-samples of OCCs : 1) *new comets* (orbital energies $0 < x < 30$) as those whose perihelia can shift from outside to the inner planetary region in a single revolution; and 2) *inner cloud comets* (orbital energies $30 \leqslant x < 100$), that come from the inner region of the Oort cloud, and for which external perturbers (essentially galactic tidal forces and passing stars) are not strong enough to allow them to overshoot the Jupiter-Saturn barrier. From the observed comet flux and making allowance for missed discoveries, we find a flux of OCCs brighter than absolute total magnitude 9 of $\simeq 0.65 \pm 0.18$ per year within Earth's orbit. From this flux, about two-thirds corresponds to new comets and the rest to inner cloud comets. We find striking differences in the q-distribution of these two samples: while new comets appear to follow an uniform q-distribution, inner cloud comets show an increase in the rate of perihelion passages with q.

Keywords. comets: general, Oort cloud, celestial mechanics

1. Introduction

Oort cloud comets (OCCs) are injected into the inner planetary region by the combined action of galactic tidal forces and passing stars (e.g. Rickman *et al.* 2008). External perturbers produce a smooth drift of the perihelia of near-parabolic comets in such a way that they can either be removed from or injected into the planetary region. In the latter case they can evolve dynamically over short time scales under the perturbing action of the Jovian planets until they are ejected to interstellar space. Comets with orbital periods $P > 200$ yr are generically referred to as long-period comets (LPCs).

The relative change in the comet's perihelion distance per orbital revolution as due to the tidal force of the galactic disk, $\Delta q/q$, goes as $a^{7/2}$ (e.g. Fernández 2005). For semimajor axes $a \sim 3.0 - 3.5 \times 10^4$ AU (orbital energy $x \sim 30$), the relative change in q of comets in very eccentric orbits ($q << a$) becomes $\Delta q/q \sim 1$, i.e. the comet can decrease its perihelion distance to near-zero values.

We can then distinguish two subclasses of OCCs: *new comets* with energies in the range $0 \lesssim x \lesssim 30$, which are those that can overshoot the Jupiter-Saturn barrier in a revolution, and the *inner cloud comets* with energies in the range $30 \lesssim x \lesssim 100$ which come from the inner Oort cloud, and that can reach the inner planetary region only after a smooth diffusion of their perihelion distances. Therefore, inner cloud comets are not new in a

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strict sense, since they probably visited the trans-jovian region before, though they may be new in the inner planetary region.

The estimation of the comet flux has been a very difficult task basically due to the incompleteness of comet discoveries, mainly for greater perihelion distances. Kresák and Pittich (1978) attempted to estimate the comet flux based on those comets that approached the Earth within 0.2 AU which they estimated to be a highly complete sample. They found a best fit for a comet flux $\nu(q)$ increasing with q, according to the law $\nu(q) \propto q^{1/2}$, at least valid within 4 AU of the Sun. Therefore, a very interesting point is to define how the rate of comet passages varies with q.

2. The discovery conditions

Our sample consists of 22 new comets and 36 inner Oort cloud comets discovered during 1999-2007, taken from Marsden and Williams's (2008) catalogue. For these comets we computed the difference ΔT between the discovery time and the time of perihelion passage, and estimated the absolute total magnitude H_o.

We can see in Fig. 1 the apparent total magnitudes and elongations of the Oort cloud comets discovered during the period 1999-2007. Most apparent total magnitudes at the time of discovery are in the range 17-20, whereas most elongations are greater than 90°, in contrast with discoveries by amateurs where elongations are usually smaller than 90° and brighter (total magnitudes $\sim 8-12$).

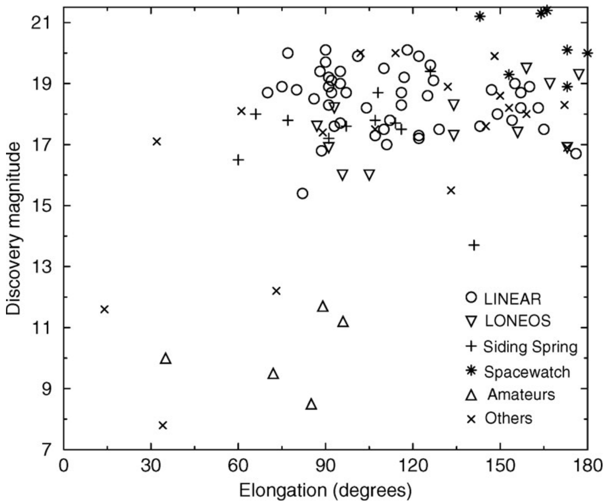

Figure 1. The discovery conditions of our sample of 103 comets. The absolute magnitudes were derived from the photometric data provided by the IAUCs and MPECs.

As seen in Fig. 2, there are many discoveries of faint comets near the Sun (total magnitudes $H_o \sim 10-19$), but only the brightest ones ($H_o \lesssim 10$) are discovered among the distant comets ($q \gtrsim 5$ AU). Even though the large surveys have led to the discovery of some faint comets ($H_o \gtrsim 10$), the number is nevertheless quite low suggesting that the population of faint, small LPCs is quite scarce, in agreement with previous results (Kresák and Pittich 1978, Sekanina and Yeomans 1984). We also plot those comets with undetermined or poorly known original orbital energies x, which mostly have low q-values, as the difficulty for determining accurate values of x arises from the strong perturbing action of nongravitational forces. We also find that the number of inner cloud comets

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increases within the range $3 \lesssim q \lesssim 7$ AU, whereas that for new comets keeps more or less constant within the considered q-range.

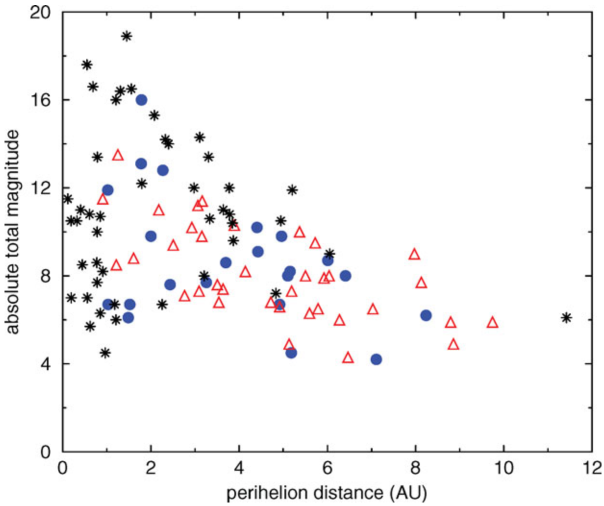

Figure 2. Absolute total magnitudes versus perihelion distances of: new comets (triangles), inner cloud comets (black dots), and comets with undetermined/innacurate original energies, though potential Oort cloud comets (stars).

3. The discovery probability

Any attempt to make a bias correction for completeness in the comet discovery record requires to know how likely is that a given comet be detected during its perihelion passage as a function of its absolute total magnitude, its perihelion distance, and the geometric configuration Sun-Earth-comet. One of the best attempts so far to compute the discovery probability has been performed by Everhart (1967). He defined the "excess magnitude" (S) as a quantity proportional to the discovery probability. The excess magnitude is expressed in units of magnitudes $\times$ days that the comet stays above a certain threshold magnitude H_{th}, and is expressed as

$$S = \int (H_{th} - H) dt \tag{3.1}$$

where H is the apparent total magnitude defined as $H = H_o + 5 \log \Delta + 2.5 n \log r$, where Δ is the geocentric distance, and r the heliocentric distance of the comet. We have adopted for the index $n = 3$ which is suitable for very active OCCs which usually brighten rapidly at great heliocentric distances followed by a much slower increase near perihelion (Whipple 1978). We adopted $H_{th} = 20$, which corresponds to the average bottom line of faintest comets that are discovered (see Fig. 1).

We find that the larger S, the earlier the comet is discovered on average (Fig. 3), which is an obvious consequence of its large brightness. We can say that for an excess $S \gtrsim 8000$ mag $\times$ days the great majority of comets are discovered before perihelion, which suggests that such comets will hardly pass undetected. Therefore, we can associate empirically excess magnitudes $S \gtrsim 8000$ mag $\times$ days with a discovery probablity $P \sim 1$. Furthermore, for $S \sim 2000 - 8000$ most comets are still discovered before perihelion which points to a high discovery probability P.

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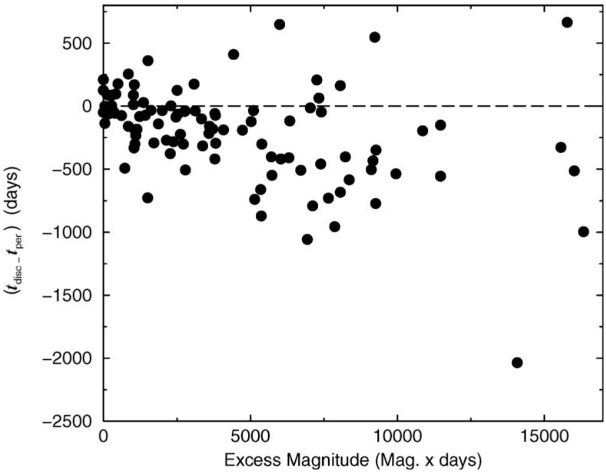

Figure 3. The discovery time (with respect to the time of perihelion passage) of the sample of 103 comets versus the excess magnitude.

4. The computed flux of Oort cloud comets. The distribution of perihelion distances

4.1. *New comets*

We have 11 comets with $q < 7$ AU and $H_o < 9$ discovered during 1999-2007. This sample shows excess magnitudes $\gtrsim 2000$ for most of the q-range, so we can expect for it a high degree of completeness. We may presume that some of the missing new comets (mainly in the range $0 < q < 1$ AU) may correspond to some of those whose original orbits could no be determined accurately due to the uncertain effect of nongravitational forces. This is the group that we have labelled as LPCs with unknown original x. Even considering missing detections and comets whose original x could not be determined, it does not seem to be more than a factor of two in the corrected population with respect to the observed one with computed original x. An educated guess would place the corrected population at about 25 ± 5 comets. The corrected distribution may still be compatible with an uniform one. Considering that 25 ± 5 new comets have passed perihelion in the range $0 < q < 7$ AU, distributed more or less uniformly in q, during a nine-year time span (1999-2007), the rate of passages of new comets can be estimated to be

$$\dot{n}_{new} = \frac{25 \pm 5}{9 \times 7} \simeq 0.4 \pm 0.08 \text{ yr}^{-1} \text{ AU}^{-1} \tag{4.1}$$

4.2. *Inner cloud comets*

The q-distribution shows in this case an increase with q, for the sample with $H_o < 9$, as well as for the most restricted sample of brighter comets with $H_o < 7$. The incoming flux in the innermost zone (say $q \lesssim 3$ AU) is well below that of new comets, say about half, with a large error bar given the smallness of the sample. We can then conclude that the ratio inner cloud/new comets should be about 0.5-0.7 within the zone close to the Sun ($q \lesssim 3$ AU), i.e.

$$\dot{n}_{inner} \simeq 0.25 \pm 0.10 \text{ yr}^{-1} \text{ AU}^{-1} \tag{4.2}$$

The discovery rate increases by a factor 3-4 in Jupiter's region.

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The fact that the q-distribution of new comets is compatible with an uniform one is consistent with the injection of comets from a thermalized random population (the Oort cloud). On the other hand, the increase of inner cloud comets with q is a signature of the action of the Jupiter-Saturn barrier which hinders most comets coming from the inner Oort cloud to reach the Sun's vicinity. On the contrary, new comets coming from the outer Oort cloud, and thus subject to large changes in q by external perturbers, can easily overshoot the Jupiter-Saturn barrier thus explaining their rather uniform q-distribution.

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