The preferred direction of perihelion points of long-period comets

A review
(An extract from the author's dissertation)

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Received: September 5, 1997

Abstract. The presented paper is an overview of the problems related to the preferred direction, if any, in the distribution of long-period comet perihelion points, as well as of the observational selection effects in the comet discoveries affecting the distribution. This preferred direction is studied with respect to the origin of comets. (The paper is, in fact, an extract from the author's PhD dissertation dealing with this topic.)

Key words: cosmogony – origin of comets – observational selection effects

1. Introduction

The question of the origin of comets is one of the fundamental questions of cometary astronomy. In spite of the considerable efforts of astronomers studying comets, this question has not been answered yet. Several hypotheses have been worked out. However, each of these has certain weaknesses and, therefore, none can be definitively regarded as correct.

The hypotheses of comet origin can be divided into two main groups: the hypotheses assuming their origination within the Solar System, and those assuming their interstellar origin. The hypotheses of the first group assume that comets were created from the same material as the Sun, planets and asteroids. On the contrary, the interstellar origin hypotheses assume the creation of comets outside of the Solar System, whereby they were captured in more or less random events in the Oort and Hills clouds. Such random events could be the passages of the Solar System through a spiral arm of the Galaxy, a molecular or other cloud of interstellar matter, or, simply, continual captures of comets during the motion of the Solar System within the Galaxy. In our context, we must also mention Lyttleton's hypothesis (1948) which assumes comets were formed as a consequence of gravitational focusing of interstellar material by the Sun, as it crossed the interstellar clouds.

Contrib. Astron. Obs. Skalnaté Pleso **28**, (1998), 5 – 21.

As mentioned at the very beginning, the question of the comets' origin has still not been answered, satisfactorily. The shortcomings of the first as well as of the second group of hypotheses, can be briefly described as follows (our description is mainly based on Weissman's review of 1985). The hypotheses of comet origin in the Uranus-Neptune region have to assume that both the planets not only prolonged, but also shortened the orbits of comets at their ejections into the Oort cloud. Hence, they not only had to supply orbital energy to, but also drew energy from the comets, whereby the energy transfer had to be in equilibrium. No mechanism of equilibrium energy transfer has so far been suggested. The problem of unacceptable loss of orbital momentum was first pointed out by Marochnik et al. (1988). The problem becomes even more transparent, if we do not analyse the loss of the momentum, but, directly, the loss of orbital energy of both the planets at comet ejection (Neslušan, 1992).

The "in situ" hypothesis, suggested by Cameron in 1973, modified in 1978, assumes that the comets were formed at the edge of a massive proto-planetary accretion disc at distances of hundreds to thousands of astronomical units (AU). Its drawback is the an absence of a mechanism, which would change initially more or less circular orbits of the created comets into highly eccentric orbits. Moreover, it is unclear how the massive proto-planetary disc could have disappeared at large distances, outside the region of disturbances by planets.

Of the hypotheses of interstellar origin, we can now practically regard as rejected Lyttleton's hypothesis published in 1948. Strictly considered, it is questionable whether it belongs to the interstellar origin hypotheses. All the authors dealing with the problem of comet origin have associated it with that group, however. The hypothesis is incorrect, because it does not explain, inter alia, the observed distribution of reciprocal semi-major axes of long-period comet orbits. According to its concept, the comet cloud would have had to be located at distances of the order of 10^1 to 10^3 AU (without any possibility of correction).

All other hypotheses of interstellar origin in common faces the important fact, that no original orbit of a long-period comet is known to be so highly hyperbolic that it could not be explained by the acceleration of the comet along an eliptical orbit in the Oort cloud due to the perturbation of a near star, which ejected the comet from the cloud to the central region of the Solar System. Or, that it could not be explained as an error in determining its reciprocal semi-major axis (Marsden et al., 1978; Everhart and Marsden, 1983, 1987; Marsden, 1990). Extremely hyperbolic original orbits are lacking completely. A certain preferred direction coincident with the motion of the Solar System among neighbouring stars, from which the long-period comets would come significantly more frequently than from other directions, is also absent.

A certain, less pronounced, preferred direction in the distribution of the directions of the perihelia and, thus, aphelia of long-period comets has, however, been found by several authors (see Sect. 2). Its orientation roughly corresponds with the solar apex. This fact has been presented to support the interstellar origin of comets. But we must immediately point out that none of the authors has taken into account, or has considered adequately the influence of observational selection effects in comet discoveries. We should mention that the authors of papers concerning this topic usually considered the standard apex direction of solar motion in the Galaxy, relatively to the set of the majority of A to G spectral type stars, included in the catalogues of radial velocities and proper motions. Only, the Japanese authors, Hasegawa and Yabushita, considered the basic apex direction of solar motion relatively to the so-called "local standard of rest", in which the mean motion of A, gK, and dM spectral type stars, moving at the most frequent velocities in the near vicinity of the Sun, is zero.

Another group of authors (a review of their papers is briefly given in Sect. 3) found, that the observational selection effects are rather important in comet discoveries. Moreover the fact that the majority of comets has been, and even now is being discovered from the northern hemisphere of the Earth, being well known, it is impossible to expect any long-term mutual elimination of the selection effects.

The solution of the problem of the existence of a preferred direction in the distribution of long-period comet perihelion points, being in coincidence with the solar apex, would help to answer the fundamental question of the origin of comets: Were the comets formed in the Solar System, or outside it?

2. The preferred direction in perihelion distribution

The non-uniformity in the distribution of directions of long-period comet perihelia was probably firstly noticed by Bode in 1812 in a sample of 98 orbits. The statistics of perihelia he made exhibits a larger number of perihelia located in the direction of the Geminids and Cancer constellations than in the direction of the Saggitarius and Capricornus constellations. The Bode's paper was eventually followed by papers by Brorsen (1852), Lardner (1853), and Hausean (1873). Their authors found that the perihelia are relatively more concentrated in the sectors between ecliptic latitudes 200° to 282° and 70° to 102°. The statistics of perihelion directions and the description of their distribution, using the characteristic ellipsoid, were first presented by Oppenheim in 1922. He already worked with a sample of 306 orbits and also found a certain preferred direction in the distribution. The observational effects in comet discoveries had not been taken into account that time. The Oppenheim's work was followed by the studies of Bourgeois and Cox (1932, 1933, 1934), who corrected the distribution with respect to observational conditions related to the discoveries of the individual comets (we mention this correction in more detail below, in describing Hurnik's paper (1959)), when they constructed the ellipsoid of distribution of perihelion directions.

After Second World War, the distribution of perihelion directions of long-period comets (with orbital periods exceeding 200 years) was analyzed by Tyror (1957) using a sufficiently large database containing 448 cometary orbits. Tyror concluded that the distribution departs from randomness, the preferred direction deviating from the solar apex by about 18.5°. In evaluating the significance of the departure of observed from the random distribution, he compared the observed with the theoretical Poisson distribution. This author suggested a coincidence between the preferred perihelion direction and the plane of the Galaxy, because he found that the direction and galactic pole mutually deviate by about 78°, which differs from the right-angle by only 12°. The observational effects are not analysed in Tyror's paper. He conceded that the data used were probably influenced by these effects, but he regarded the influence as negligible. He presented his results as arguments supporting Lyttleton's accretion hypothesis of comet origin.

Two years later, Hurnik published his paper (1959). The author drew on the papers by Bourgeois and Cox from the beginning of thirties. He used the cometary orbits published in Yamamoto's catalogue (1936), from which he chose 451 orbits with eccentricities higher than 0.9. He also constructed the ellipsoid of perihelion distribution corrected with respect to the conditions prevailing at comet discoveries. He took these conditions into account by correcting the numbers of perihelia in the individual directions in the sky with respect to the probability of discovery of the individual comets. The probabilities are different for various comets due to different geometrical conditions at the time of discovery. In other words, Hurnik's distribution ellipsoid, analogously to that of Bourgeois and Cox, would be independent of the probability of discovery of any comet from the Earth, assuming that the observers would be distributed uniformly on its surface. The implicit assumption of this uniformity indeed causes the correction to be inadequate, because the selection effects tend to eliminate each other in the case of uniform distribution of the observers. It is then not surprising that Hurnik alone, comparing the corrected with the uncorrected distributions of perihelion directions, concluded that both the distributions differ negligibly from one another. This can only be expected, if the real distribution of perihelion directions approaches the random.

Hurnik judged the significance of the departure of the observed distribution of perihelion directions from the random distribution by comparing theoretical and observed distribution ellipsoids, i.e. by determining the O−C values ("observed minus calculated"). He claimed the departure from randomness to be significant and the pole of distribution to be coincident with the motion of the Sun. However, to confirm the interstellar origin of comets on the basis of his conclusions definitively, he admitted at the same time that the following was necessary: 1. to make a detail analysis of the premises on which the method of Bourgeois and Cox, also used by himself, is based; 2. to take into account the irregular scattering of observers on our globe, as well as the seasonal irregularities.

Oja (1975) studied the distribution of perihelion directions of 73 comets with high eccentricities of original orbits, i.e. the orbits before the comets entered the region of planetary disturbances. Specifically, the reciprocal semi-major axes of these orbits were less than 10^{-4} AU^{-1}. He found that their distribution centre deviated from the solar apex only by about 7°. He also found a preferred plane of the distribution which made an angle only of about 20° with the plane of the Galaxy. Observational effects were not mentioned in his paper.

Tomanov (1976) analyzed the distribution of directions of long-period comets theoretically from the point of view of the diffuse hypothesis of comet origin (van Woerkom, 1948). He analysed the distribution of the direction expected if the comets were captured from interstellar space, if the Sun moved peculiarly among neighbouring stars as is well-known. The theoretical analysis, given in the first part of his paper, was followed by the determination of the parameters of a theoretical description of the distribution made on the basis of a set of 500 real cometary orbits with orbital periods exceeding 500 years. The orbits were taken from his own catalogue (Tomanov, 1973). Based on these parameters, Tomanov concluded, inter alia, that a relatively higher concentration of perihelia exists at the solar apex, the concentration being higher for the bright new comets (with absolute brightness $H_{10} \leq 6^m$) than the less bright comets ($H_{10} > 6^m$). (However, the absolute brightnesses used were determined by Vsekhsvyatskij's method (1958), i.e. not reliably, as we shall demonstrate later. With respect to it, the last conclusion is discussable.) These facts should support the interstellar origin of comets. The author, moreover, considered the gravitational influence of the Galaxy nucleus on the motion of captured comets. Selection effects were not mentioned in Tomanov's paper.

From our point of view of the problem, Hasegawa's paper (1976) is interesting. Hasegawa concentrated on studying the distribution of the aphelia of long-period comets and the coincidence of the preferred direction of this distribution with the solar antapex. Hasegawa, in contrast to other authors, considered not the standard, but the basic motion of the Sun. He was, moreover, interested in the possible coincidence of the distribution with the plane of the Galaxy. Hence, he described the aphelion distribution not only in the ecliptic, but also in the galactic co-ordinate system, as well as in the co-ordinate system organically fixed to the basic motion of the Sun with the z-axis orientated in the direction of this motion. To evaluate the deviation between the observed and random distribution, he still considered the theoretical Poisson distribution in his paper – in contrast to the paper co-authored by Yabushita (see below), where Fisher's method was considered. With his own conclusion, Hasegawa proved the coincidence between the aphelion distribution and solar antapex. With respect to the deficit of aphelia in the galactic plane in the constructed dependence of the number of aphelia on galactic latitude, he did not regard the concentration of aphelia in the galactic plane as significant, although he conceded its existence. It should be mentioned that he did not try to explain the deficit.

Hasegawa was the first to divide the set of 397 long-period comet orbits used, from Marsden's catalogue (1972), into the groups of the comets discovered from the northern and southern Earth's hemispheres. For every comet of both the groups, he constructed separately the dependence of the number of aphelia on the latitude in the mentioned co-ordinate system fixed to the basis motion of the Sun. But the north-south asymmetry in the numbers of observers in both the Earth's hemispheres was considerably obscured due to the considered low declination of the direction of this motion of only 20°. In the histogram of the dependence for the group of comets discovered from the southern hemisphere, the concentration of aphelia increased, in spite of this was shifted from the antapex with latitude $-90°$ to latitudes of about $-40°$. And the fact that the concentration was increased in the celestial hemisphere adjacent to the antapex, is only proof of increased aphelion concentration in the sector of ecliptic latitudes around roughly 100°, which corresponds with the concentration maximum of perihelia in the opposite direction observed by other authors. This is no proof of the coincidence of the concentration of aphelia with the antapex.

Hasegawa's paper was followed by papers by Yabushita. In the first paper, Yabushita (1979a) tested the distribution of directions of long-period comet perihelia in the sky to determined whether it was random. He used Fisher's method (1953) as the test. The method is based on modelling a random distribution and its special projection, in which the z-axis of the unit vector of the given modelled direction is represented as a function of the projection of that vector into the x-y plane. The real distribution of directions (often only its centre) is then compared with the modelled distribution (its centre). Yabushita tried to take into account the selection effects in the comet discoveries by dividing the used set of 503 long-period orbits from Marsden's catalogue (1972) into two groups: into comets with perihelia northward and southward of the ecliptic. It should be pointed out that not even respecting the selection effects in this manner is adequate, because the comets discovered by the observers from the northern as well as from the southern hemisphere of the Earth occur in both groups. The consequence of the north-south asymmetry in the discoveries is thus largely obscured.

Yabushita arrived at results similar to those of the preceding authors of this group. He found that the departure from randomness in the distribution of perihelion directions of all 503 comets is remarkable. If the set is divided into both the comets with perihelion distance shorter than 1 AU and longer than 1 AU, and each of these subsets is further divided into the two groups of comets with perihelia northward and southward of the ecliptic, the departure from randomness is then insignificant only for the comets with perihelia northward of the ecliptic, which are distanced more than 1 AU from the Sun. Yabushita also used Fisher's method to determine whether the coincidence between the preferred direction in the perihelion distribution and the solar apex was significant. Similarly to Hasegawa, he considered the basic, not standard, apex. He found that both directions coincide significantly for the comets with perihelion distance larger than 1 AU. For the other comets this coincidence is questionable. The division of the set of comets into the groups with perihelia northward and southward of the ecliptic does not eliminate the selection effects in the way desirable and, thus, the result is practically the same as if no selection effects were considered. The author drew on this fact to conclude that the selection effects may be neglected in determining the preferred direction in the distribution of perihelia, or in proving its coincidence with the solar apex.

The second paper by Yabushita (1979b) was a modification of the first, and the author presented practically the same result. He did not mention the selection effects in this paper. However, he also found that the gravitational field of the Galaxy significantly affects the comets whose orbits had the longest semi-major axes.

The previous papers by Hasegawa and Yabushita were followed by their joint paper (Yabushita and Hasegawa, 1981). In this paper, they dealt, in more detail, with the distribution of perihelion directions of comets brighter as well as fainter with respect to their absolute brightness. They divided the set used into the bright (absolute brightness $H_o \leq 6.9^m$) and faint ($H_o \geq 7.0^m$) comets. And again, they subdivided these into the groups with perihelia northward and southward of the ecliptic. The division of the set into bright and faint comets was based on their assumption that the bright comets should be affected by the selection effects only slightly. According to them, none of these comets should avoid being detected by an observer even in the southern hemisphere, as opposed to the faint comets. They took the values of the absolute brightnesses from Vsekhsvyatskij's monograph (1958). We should mention that these values can hardly be regarded as reliable. Svoreň (1981) determined the absolute brightnesses on the basis of extreme observations, without any theoretical assumptions regarding the behaviour of the apparent brightness, for each individual comet separately, hence the values he determined can be regarded as much more reliable. And he found no correlation between his values and those of Vsekhsvyatskij. Hasegawa and Yabushita then found, paradoxicaly, that it was indeed the perihelia of the faint comets that were distributed more or less uniformly. As regards the bright comets, they proved the fact, already well-known, that the distribution of their perihelion points remarkably differs from the random. They worked with the help of Fisher's method mentioned above.

For the sake of completeness, we add that Yabushita dealt with the problem of the distribution of perihelion directions once more in his paper published in 1985. Besides the set originally used, he also used a set of 67 comets which were new in Oort's sense. Applying the same procedures, he obtained practically the same results.

A very important paper, in which the distribution of long-period comet perihelion points is analyzed, is that by Bogard and Noerdlinger published in 1982. They emphasize, although the existence of the Oort cloud comets has been proved, that it imposes only a minor constraint on the origin of the comets, of which the cloud consists. They attempted to confirm the possible interstellar origin of the comets by statistical analysis of three groups of directions characterizing the cometary orbits: the directions of the normals of orbital planes, the directions of perihelion points, and the directions of velocities in the perihelion. The authors used 542 orbits of long-period comets from Marsden's catalogue

(1979). They discussed the set used and their conclusions were the following: There can be only a few short-period comets among the parabolic, poorly determined orbits. The fact that these orbits could be important, should be taken into account only if the statistics of the orbits exhibits a coincidence with the ecliptic, toward which the orbits of short-period comets are generally inclined. Further, the authors mentioned the fact that some long-period comets included were not "new" in Oort's sense. But this fact is not important, because the planets significantly affect only the semi-major axes, perihelion distances, and eccentricities of the orbits whose orbital periods exceed 200 years. The planetary perturbances have no significant influence on the spatial orientation of these orbits. This means that the location of the orbital plane and the line of apsides change only negligibly. Finally, they discussed the phenomenon of splitting of cometary nuclei. Because of the latter, the authors excluded 7 of the 8 comets of the Kreutz group from the initial set. Another 6 problematic pairs of orbits were retained because the statistics would not be affected substantially even if these were split bodies, or second observed return of the same body.

They studied the significance of the departure from randomness by constructing a graph of the binomial distribution and comparing it with the calculated – theoretical – binomial distribution. To smoothen the constructed dependences affected by random fluctuations, they divided the map of the sky into 200 grid boxes, the division being made for 100 different orientations of the map. The averages of the mutually corresponding boxes then form a basis to construct the binomial dependence. Their graphs indicate that, whereas the distribution of directions of the normals of orbital planes and that of the directions of the perihelion velocities do not depart from the actually random distribution significantly, the distribution of directions of the perihelion points in this sense does. The preferred direction lies 18.9° from the solar apex. The authors used the fact that the preferred direction departed as much as 45.4° from the North Pole, to argue against the importance of the selection effects in determining the preferred direction. According to them, if the selection effects were important, then the direction should be located in the vicinity of the North Pole, because of the historical preponderance of northern hemisphere observers, as well as of observational equipment and, consequently, of potential discoverers of comets.

Further, they suggested that the presented asymmetry in the numbers of potential discoverers of comets was not important in the search for the preferred direction also because the deviations between the preferred directions they found, using a larger number of orbits were smaller than the corresponding deviations found by Tyror and Hurnik earlier. Had the selection effects affected the result significantly, there would have been no reason to improve it. In spite of the claims that the selection effects were insignificant, Bogard and Noerdlinger did not make any definitive conclusion, and eventually admitted that an analysis of the dependence of the distribution of orbits at terrestrial places of discovery of the individual comets would still be useful.

For the sake of completeness of this section, we also mention the paper by

Khanna and Sharma (1983). They, in fact, repeated the work by Tyror (1957) using a more numerous set of 523 long-period comets. They determined the departure of the preferred direction from the solar apex: 9.6°. Similarly to Tyror, they confirmed that the perihelion points were concentrated at the preferred plane, and that its inclination to the galactic plane was about 9°. Both Indian authors also briefly summarized the results of some previous authors attempting to support the hypotheses of interstellar origin of comets. Probably, influenced by these papers, they did not consider the influence of the selection effects on the result to be important, and, consequently, they did not mention them.

In spite of the negative result in the determination of the preferred direction of comet aphelion directions, we can also associate the paper by Lüst (1984) with the papers of the first group. The paper, moreover, differs from the majority of the earlier papers in the set of comets used. The author, similarly to Oja (1975), used only 223 comets with well-determined original orbits. At this point, it should be immediately pointed out that the determination of these orbits requires relatively advanced observational equipment, which was mostly available in the northern hemisphere of the Earth. Therefore, the result has to depend on the observational selection effects. As the author did not consider them, the conclusion he drew that no preferred direction of aphelia existed, which would coincide with the solar antapex, can scarcely be regard as proved. Besides this conclusion, however, Lüst discovered, independently of the selection effects, that there is a deficit of aphelia around the galactic plane and galactic poles in the group of comets with the reciprocal semi-major axis in the interval $-7.34\times10^{-4}\ AU^{-1} < 1/a < 8.9\times10^{-5}\ AU^{-1}$ and, to a lesser degree also in the interval $1.42\times10^{-4}\ AU^{-1} < 1/a < 8.5\times10^{-4}\ AU^{-1}$ (or $1/a < 2.7\times10^{-3}\ AU^{-1}$ – depending on the perihelion distance).

3. Selection effects in comet discoveries

The dependence of the discovery of a comet on its orbital geometry and, thus, on the location of the discoverer on the Earth's surface was first pointed out by Holetschek in 1891. Using a sample of 317 comets, known at that time, he proved that the prevailing part of the comets passed their perihelia, when the difference between the ecliptic longitude of the perihelion and the Earth's longitude minimum. One could see from his statistics, for example, that twice as many comets passed their perihelia up to the longitudal difference of 30° than in the interval of the longitudal difference from 30° to 60°, and that the number of passages further decreased in the next 30° difference intervals.

A detailed analysis of the observational selection effects was first made by Everhart in 1967. His first paper (Everhart, 1967a) represents an extensive study of conditions of long-period comet discoveries. Specifically, 337 long-period comets discovered between 1840 and 1967 were taken into account. Everhart considered the magnitudes, angular distances from the Sun, directions in the sky, zenith angles, sky brightness near the horizon, and many other factors at the time of their discoveries. The purpose was to understand observational selection effects as well as possible.

Based on these factors, the author depicted the positions of comets in the sky, when these could first be observed from the Earth (theoretical positions of discoveries), and when these could last be observed. In both cases, observability in the night sky by an observer equipped with average observational equipment for visual observations was assumed (as such the author considered a telescope whose objective had a diameter of 0.25 *m* and 40-fold magnification) taking into account the conditions mentioned above. He compared the positions obtained with the distribution of the positions at the times of the actual discoveries as well as at the times, when the comets could best be observed from the Earth. He found that the majority of the comets could have been first observed (70% comets in direct and 81% in retrograde orbits) and also was discovered (51% in direct and 69% in retrograde orbits) in the morning sky. He assumed that the asymmetry was caused by a more precise survey of the night sky before dawn. Moreover, he indicated that an important role could also be played by the geometry of mutual motions of the Earth and comets. The magnitude curve before the perihelion rises more steeply when the comet is in the morning sky.

Everhart criticized the procedure of calculating the probability of comet discovery in dependence on observational conditions by Bourgeois and Cox (1934) as well as that by Vsekhsvyatskij (1958), and he himself suggested and introduced a new procedure. His analysis of the selection effects indicates that the influence of these affects on the distribution of known cometary orbits is crucial. It should be pointed out that in this paper Everhart still used the absolute brightnesses determined by Veskhsvyatskij's method (1958). The values obtained in this way are not reliable, as already mentioned above. To a degree, these biased the times at which a given comet could be observed first, best, and last.

In another paper, Everhart (1967b) determined the distribution of the number of comets in dependence on their perihelion distance and absolute brightness (he determined this quantity from the behaviour of the apparent brightness, not by Vsekhsvyatskij's method) for 256 long-period comets. Using the statistics of the quantities characterizing the conditions at the time of the discoveries, he also derived the probability function of comet discovery. This function again provides the relationship between the probability and perihelion distance, as well as between the probability and absolute brightness. The other orbital elements were averaged. On the basis of this function, the intrinsic distributions of numbers in the dependence on perihelion distance and absolute brightness were found. Using these distributions and respecting the selection effects, the author attempted to explain the Holetschek effect and, at the same time, the asymmetry in the distribution of the arguments of perihelion latitude he found by him – the distribution had a maximum around 90° and a minimum around 270°. Moreover, he demonstrated that neither the distribution of the longitudes of nodes, nor that of the inclinations of orbits to the ecliptic was affected by the selection effects – both the distributions were more or less uniform.

Another rather extensive and important study of the selection effects was published by Pittich in 1969. He dealt mainly with the behaviour of the brightness of a comet and its consequent visibility from the Earth, the phase of the Moon and elongation of the comet from the Sun at the time of its discovery, and the geographical distribution of the observers (which, however, was not analysed with the help of data on the individual discoverers). In his study, he also took into account the variability of the equipment used in the comet discoveries. This has caused the data to be inhomogeneous. Considering the selection effects, he determined the relative probabilities of the comet discoveries for various combinations of the selection parameters mentioned. He used the data on 537 comets (436 discovered visually and 101 photographically) discovered between 1750 and 1967. The analysis made indicates the importance of improving the observational equipment used to discover comets. The improvement influenced the probability of the discovery. For example, whereas only comets brighter than 6^m were being discovered around 1750, comets brighter than 16^m were being discovered around 1950. Consequently, the number of discovered comets increased considerably. Similarly to the limiting brightness at the time of discovery, the distance of the mean comet from the Sun increased considerably over this period, from roughly 1.2 *AU* before 1750 to roughly 5.5 *AU* (a few discoveries beyond 6 *AU*) after 1950. Pittich found a significant difference in the distribution of elongations between the visual and photographic discoveries. The largest number of comets were discovered visually at elongations of about 50°, photographically at elongations of about 160°. He further found a correlation between the phase of the Moon and the number of comets discovered. The last conclusion in his paper was that about the ratio of the comets discovered from the northern and southern Earth's hemispheres. Pittich confirmed that about three times as many comets were discovered from the northern than southern hemisphere, even at the time when his paper was published. As in Everhart's papers, it is also possible to conclude here that the influence of the selection effects on comet discoveries and, consequently, on the distribution of known cometary orbits is crucial. Moreover, there also exist other selection effects, besides those described by Everhart earlier.

A paper representing a review of the selection effects in comet discoveries was published by Kresák in 1975. In spite of the review character – a summary and discussion of the results of other authors – the author also presented several new original contributions to the problem. He suggested a co-ordinate system rotating with the Earth in its revolution around the Sun instead of the already mentioned distribution ellipsoid suggested by Oppenheim (1922) and improved by Bourgeois and Cox (1932, 1933, 1934). Moreover, he suggested dividing the set of cometary orbits into two groups with respect to perihelion distance q, because he found that the selection effects depended on this distance. According to Kresák, the effects do not practically occur for comets in orbits with $q < 0.5$ *AU* and are mostly present for those in orbits with $0.5\ AU < q < 2.0\ AU$. The Holetschek effect disappears for the comets in orbits with $q > 2\ AU$ (roughly). The only significant selection effect in the case of these comets is the excess of the number of observers in the northern hemisphere in comparison with their number in the southern. In view of the rather easy correction of this only selection effect, Kresák suggested using the orbits of these comets in investigating any real departure of their distribution from randomness in future, when a sufficient number of such orbits will be well-known. A sufficient number of such orbits is not known at the present. The number of orbits with $q > 2\ AU$ does not exceed one hundred.

In his paper, Kresák constructed the zones of visibility and invisibility of comets in the rotating co-ordinate system mentioned above. The main conclusion of the paper, particularly emphasized by the author, is the claim that all the large-scale, all-sky irregularities in the spatial distribution of the orbits of long-period comets can be explained by observational bias of the random distribution. On any lower than all-sky scale, it is possible to expect quite large irregularities caused by the gravitational action of near and randomly passing stars on the Oort cloud, and also irregularities due to the accumulation of comets in similar orbits caused by the splitting of their parent nucleus (e.g., the Kreutz group).

Svoreň (1988) analysed the influence of the non-uniform distribution of observational equipment on the Earth's surface, as well as its gradual improvement, on so-called extreme observations of comets, i.e. observations at large heliocentric distances (beyond $2.5\ AU$). Inter alia, he found that 86% extreme observations were made from the Earth's northern hemisphere. The average apparent brightness of these observations was 17^m in the northern and only 13^m in the southern hemisphere. Although, as he himself mentions, the pre-perihelion extreme observations are affected by the asymmetry in the distribution of large telescopes in the hemispheres to a lesser degree than the post-perihelion extreme observations.

4. The tidal action of the Galaxy

The authors, who have analyzed the selection effects in comet discoveries, usually assumed a priori the random distribution of the long-period comet perihelion points. In several papers published during last two and a half decades (Antonov and Latyshev, 1972; Byl, 1983; Lüst, 1984; Yabushita, 1985; Morris and Muller, 1986; Heisler and Tremaine, 1986; Todrija, 1986a, 1986b; Antonov and Todrija, 1987; Delsemme, 1987; Matese and Whitman, 1989; Heisler, 1990; Brunini, 1993; Matese and Whitmire, 1997), several authors have, however, shown, theoretically as well as on the basis of observations, that the sphericity of the Oort cloud should be or is detectably deformed by the tidal action of the Galaxy. This deformation can, of course, occur in a comet cloud consisting of captured interstellar comets as well as of those originated within the Solar System. Hence, it has no principal significance in the search for comet origin. Nevertheless, this fact has to be mentioned in analyzing the distribution of the comet perihelion points.

5. The results of the dissertation

The review of the problem presented, selected from the author's dissertation (Neslušan, 1995), can be completed with the results of the dissertation itself. In it, the author used the orbits of comets discovered after 1500 from Marsden's catalogue (1989). Additional information on the dates and places of comet discoveries was gained from Vsekhsvyatskij's monograph (1958) as well as its supplements (Vsekhsvyatskij, 1967; Vsekhsvyatskij and Il'chishina, 1974; Vsekhsvyatskij, 1979; Andrienko and Karpenko, 1987), Porter's and Marsden's annual reports on comets, and the IAU Circulars.

The main conclusion of the dissertation is the following (its derivation and more detailed presentation has already been published in English in (Neslušan, 1996)). A significant departure from randomness in the distribution of long-period comet perihelion points exists, as observed by several authors earlier (see Sect. 2), but it is only apparent, i.e. it is caused by the observational selection effects. These bias the distribution and the departure appears as a consequence of the asymmetry in the numbers of comets discovered from the northern and southern Earth's hemispheres. The actual departure from the random distribution is negligible and is caused by the tidal action of the Galaxy on the Oort cloud, which has also been found by other authors earlier (see Sect. 4). Since the vector of motion of the Sun is not orientated towards the Galaxy disc, one can immediately conclude that the main conclusion supports the hypotheses of comet origin within the Solar System.

To derive the main conclusion, we confirmed some earlier results, on the one hand, and came up with some new partial results, on the other. The new results can be summarized as follows:

(1) Based on the statistics of long-period comet discoveries in the individual months of year, a marked variation, of up to $\approx 100\%$, in the number of discoveries from month to month has been shown. A more detailed analysis indicated that, in three partial successive periods, the variation was a consequence of statistical fluctuations – the numbers of discoveries in the individual months of the year, especially those from the southern hemisphere, are very low.

In view of these low numbers, it is impossible to prove any symmetry in the variations in the discoveries from both hemispheres. Consequently, it is impossible to prove or reject Everhart's conclusion (1967a) on the seasonal variation in comet discoveries due to observational effects.

(2) Kosai and Nakamura (1991) found that the comets had been discovered mostly at small angular distances from their perihelia. In the dissertation, it

was reported that the dependence of the number of discoveries on the angular distance does not change in time, in spite of the significant improvement of observational equipment, which is a selection effect (Pittich, 1969). In the three successive partial periods, 41%, 51%, and 43% comets were discovered up to angular distances of 45°, and 74%, 81%, and 78% comets up to angular distances of 90°, respectively.

(3) The statistics of discoveries of comets with perihelia in the northern and southern sky, made separately for the comets discovered from the northern and southern Earth's hemispheres, demonstrates a strong influence of the north-south asymmetry in the distribution of observers and observational equipment on the Earth's surface, on the distribution of long-period comet perihelion points. The relative abundance of perihelia in a given celestial hemisphere correlates well with the relative abundance of comets discovered from the corresponding hemisphere of the Earth. Consequently, the preferred direction of perihelion points of the comets discovered from the northern (southern) Earth's hemisphere is situated in the northern (southern) sky. The positions of both the preferred directions are roughly symmetrical to the equator.

(4) It is shown that the preferred direction of perihelion points of the comets discovered in a given month of the year moves along a closed curve in the sky during year. The ecliptic longitude of the points of this curve ranges from 0° to 360°.

(5) By summarizing partial conclusions (3) and (4), one can certainly claim the dependence of the preferred direction of perihelion points on a mean local night sky and, thus, on the distribution of places of comet discoveries on the Earth's surface. The preferred direction of perihelion points of comets discovered from a certain bordered area of the Earth's surface during a limited time interval is roughly identical to the centre of the night sky sky in the middle of the interval.

(6) The departure from randomness of the perihelion point distribution is significant as other authors have already found (see Sect. 2). However, we found, in contrast to them, that the departure is caused, to a crucial degree, by the observational selection effects. The evolution of the departure is studied in three successive periods. In each of these periods, the same number of long-period comets has been discovered. The significance of the departure decreases to a discussable level in the last period, when the ratio of discoveries from the northern and southern hemispheres was nearest to unity and, thus, the impact of the selection effects was lowest.

(7) We tried to eliminate the asymmetry in the numbers of comet discoveries from the northern and southern Earth's hemispheres, and a possible really existing preferred direction in the distribution of long-period comet perihelion points was subsequently determined. The elimination was based on assigning corrected weights to the individual comets, such that the sum of the weights of the comets discovered from the Earth's northern hemisphere equaled the sum of the weights of the comets discovered from the southern hemisphere. The weights replace the numbers of comets discovered from each hemisphere. Consequently,

the determined preferred direction is situated in the southern sky and its coincidence with the solar apex disappears.

(8) The elimination mentioned in item (7) is not quite complete. A new selection effect was found, when the coincidence of the distribution of perihelion points with some basic planes in space was investigated. From a given place of the Earth's surface, the parts of the sky farther from the appropriate pole are visible, on an annual average, for a shorter time than those nearer to the pole. The circumpolar region is visible longest – through the year. If the observations are distributed more or less uniformly in the appropriate visible part of the sky, the highest probability of a discovery is then in that part of the sky, which is visible, and thus observed longest.

A significant increase in the concentration of perihelion points was found in the vicinity of the North Pole as compared to the other parts of the sky. (This fact, as well as its explanation has recently been given in (Neslušan, 1997) in detail.) No increase was detected in the vicinity of the South Pole. However, we know that mainly the perihelion points of the comets discovered from the southern Earth's hemisphere are located there, and that the number of comets in this group is statistically too low.

Acknowledgements. This work was supported, in part, by VEGA – the Slovak Grant Agency for Science (grant No. 5100).

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