The Oort Cloud

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ABSTRACT

Views of the large-scale structure of the solar system, consisting of the Sun, the nine planets and their satellites, changed in 1950 when Oort (Oort 1950) demonstrated that a gigantic cloud of comets (the Oort cloud) is located on the periphery of the solar system. From the flow of observed comets of $\simeq 0.65$ yr.$^{-1}$ AU^{-1}, the number of comets in the cloud was estimated at $N_o \simeq 2 \cdot 10^{11}$. Oort estimated that the semi-major axes of the orbits of comets belonging to the cloud must lie within the interval $4 \cdot 10^4$ AU $\lesssim$ a $\lesssim 2 \cdot 10^5$ AU. This interval is now estimated to be $2\text{–}3 \cdot 10^4 <$ a $< 5\text{–}10 \cdot 10^4$ AU (see Marochnik *et al.* 1989).

The original estimate of the Oort cloud's mass was made on the hypothesis that the nuclei of all comets are spherical with a mean radius value on the order of R = 1 kilometer and a density of $\rho = 1^2/\text{cm}^3$. This produced an Oort cloud mass of $M_o = 0.1\ M_\oplus$ (Oort 1950). Therefore, the comet cloud that occupies the outer edge of the solar system appeared to be in a dynamically zero-gravity state, having no effect on the mass and angular momentum distribution in it.

However, the estimate of the Oort cloud's mass was gradually increased (see below). We cannot rule out at this time the possibility that the Oort cloud has a concentration of mass comparable to the aggregate mass of the planets, in which the bulk of the solar system's angular momentum is concentrated (Marochnik *et al.* 1988).

THE OORT CLOUD'S MASS

The value of $N_o \simeq 2 \cdot 10^{11}$ (Oort 1950) was yielded without accounting for observational selection. Everhart (1967) was apparently the first to account for the effects of observational selection, having estimated the "true flux" of "fresh" comets as 4.7 yrs.$^{-1}$ AU^{-1}. This generated the estimate of $N_o \simeq 1.4 \cdot 10^{12}$. Monte Carlo modeling of the dynamics of the Oort cloud's comets (Weissman 1982; Remy and Mingrad 1985) also yielded figures within the interval $N_o = 1.2–2 \cdot 10^{12}$.

Weissman's analysis (1983) of the mass spectrum of comets in the Oort cloud demonstrated that the increase in the number of comets by an order in comparison with the original estimate of the Oort cloud is primarily due to comets of low mass and a large absolute value of H^{10}. According to Weissman's estimate (1983), $N_o \simeq 1.2 \cdot 10^{12}$ for comets whose absolute values are $H_{10} \leq 11.5$. With a density of nucleus matter $\rho = 1^2/cm^3$ and a surface albedo of $A = 0.6$, Weissman (1983) yielded $M_o \simeq 1.9\ M_\oplus$, an average mass on the spectrum for a typical comet of $<M_w> 7.3 \cdot 10^{15}$g and a corresponding radius of the nucleus of $<R_w> \simeq 1.2$ kilometers. In addition, $N_o^w/<M_w> 1.6 \cdot 10^{12}$.

Hughes (1987; 1988) however, demonstrated that Everhart's data (1967) had apparently been subjected to the effects of observational selection, since the index of the corresponding distribution function of long-period comets (LP) for absolute values (and, consequently, by mass; see below) is dependent upon perhelion distances and the epoch in which these comets are observed. If this is true, then doubt is cast over the estimate based on Everhart's data (1967) of the number of comets in the Oort cloud, generated by extrapolating the observed flux in the region of the largest values. In this case, we must return to the estimate of $N_o \simeq 2 \cdot 10^{11}$, obtained on the basis of direct observations, without taking into account the effects of observational selection. However, the mean mass of a typical "new" comet must also be estimated using direct observations, without extrapolation in the region of small dimensions and comet nucleus masses.

Direct observations of 14 bare nuclei of long-period comets (i.e., observations at great heliocentric distances) produced, according to Roemer (1966), a mean radius of $\overline{R}_{LP} = 4.2$ kilometers. Similarly, a mean radius of $\overline{R}_{LP} = 5.8$ kilometers was found for 11 comets with bare nuclei, selected by Svoren (1987) from a total number of 67 long-period comets. Both of these $\overline{R}_{LP}$ values were yielded on the hypothesis that the mean albedo of long-period comets $\overline{A}_{LP}$ is equal to $\overline{A}_{LP} = 0.6$, in accordance with the computation done by Delsemme and Rud (1973). A nucleus mass of $\overline{M}_{LP} \simeq 5 \cdot 10^{17}$ at $\rho = 1$ g/cm^3 corresponds to the average of these two values of $\overline{R}_{LP} = 5$ kilometers. For a more probable value of the density of the matter of a nucleus of $\rho \simeq 0.5$ g/cm^3 (Sagdeev *et al.* 1987)

$$\overline{M}_{LP} \simeq 2.5 \cdot 10^{17}. \quad (1)$$

Analysis of the mass spectrum of long-period comets using Hughes data (1987, 1988), i.e., without taking into account the effects of observational selection, generates a mean LP-comet mass for the spectrum (Marochnik *et al.* 1989) of,

$$< M_{LP} > \simeq 1.2 \cdot 10^{17} g, \quad (2)$$

this virtually (with an accuracy to a factor of ~ 2) coincides with (1) - and the mean values of $\overline{M}_{LP}$ according to observations of bare nuclei of LP-comets with the same albedo value of $\overline{A}_{LP} = 0.6$.

The closeness of the mean spectrum value $< M_{LP} >$ to the mean observed value $\overline{M}_{LP}$ is understandable in this case (as opposed to the case where the effects of observational selection are taken into account). Actually, in hypothesizing the effect of observational selection, we find the number of comets in the Oort cloud N_o to be an order greater than directly follows from the value for the flux of observed LP-comets (see above), due to low-mass comets of low luminosity. This should considerably reduce the value $< M_{LP} >$ as compared with $\overline{M}_{LP}$. The fact that this is true can be seen by comparing the value Weissman generated (1983) of $< M^W_{LP} > = 7.3 \cdot 10^{15}$g with (1). At the same time, when we only use the flux of observed comets, it is clear that $< M_{LP} >$ and $\overline{M}_{LP}$ cannot differ so greatly, which follows from comparing (1) and (2).

At the same time, estimates of the Oort cloud mass M_O in both instances differ little since, despite the fact that the value of $< M_{LP} >$ according to (2) is an order greater than $< M^W_{LP} >$, N_o is an order less than N^W_o. A direct estimate based on (2) gives us:

$$M_o = N_o \cdot < M_{LP} > = 2 \cdot 10^{11} \cdot 1.2 \cdot 10^{17} g \simeq 4M, \quad (3)$$

which is approximately twice as large as M_o generated by Weissman (1983). It is, however, a value of the same order. Therefore, if we refrain from "battling" for exactness in the coefficient values on the order of two (which is completely unjustified with the framework of ambiguities in observed data), we can then conclude that both approaches (accounting for and not accounting for the effect of observational selection) produce values of one order for the Oort cloud mass of $M_o \simeq$ 2-4 $M_\oplus$, with a mean albedo of the nuclei of long-period comets of $\overline{A}_{LP}$ 0.6.

At the same time, direct measurements of the albedo of Halley's comet give us an albedo value of $A_H = 0.04^{+0.02}_{-0.01}$ (Sagdeev *et al.* 1986). If we hypothesize that comets in the Oort cloud have an albedo which on the average approaches A_H, then this must lead to an appreciable

overestimation of the mass of M_o. Since the mass of the nucleus of a comet is $M \sim A^{-3/2}$, reduction of albedo by 0.04/0.6 = 1/15 times triggers an increase in the mass of the average comet and consequently, the mass of the entire Oort cloud by (15)3/2 $\simeq$ 58 times. Naturally, this must produce radical cosmogonic consequences. We will note that this circumstance was first noticed by Weissman (1986). Having assumed that $\overline{A}_{LP} = 0.05$, he found that $M_o \simeq 25\ M_\oplus$. The corresponding estimate by Marochnik *et al.* (1988) produced $M_o \simeq 100\ M_\oplus$.

What is the reasoning for hypothesizing that the values of $\overline{A}_{LP}$ and A_H are approximately equal?

We will first of all note that the mass of the "mean" short-period (SP) comet cannot be greater than the mass of the "mean" LP-comet. That is, the following ratios must be fulfilled:

$$\overline{M}_{LP} \gtrsim \overline{M}_{SP}; < M_{LP} > \gtrsim < M_{SP} >, \tag{4}$$

if, of course, we do not presuppose that LP- and SP-comets have varying origins (Marochnik *et al.* 1988). This study demonstrated that the measurements made during the Vega mission of the mass and albedo of Halley's comet (M_H and A_H) are typical for SP-comets, and approach the mean values of:

$$A_H \simeq \overline{A}_{SP} \simeq 0.04, \tag{5}$$

$$M_H \simeq \overline{M}_{SP} \simeq 3 \cdot 10^{17}.$$

At the same time, an estimate of the loss of mass by Halley's comet during its lifetime has demonstrated that its initial mass was, probably, an order greater than its contemporary mass (Marochnik *et al.* 1989) and this (owing to M_H's convergence with typical mass values for SP-comets) allows us to hypothesize that the mean mass of a comet in the Oort cloud must be, apparently, at least an order greater than the present values of $\overline{M}_{SP}$ and $< M_{SP} >$ in accordance with (4).

On the other hand, according to Hughes (1987; 1988), the functions of comet distribution by their absolute values for LP- and SP-comets are homologous. In other words, the cumulative number of comets $N_{cum}(H_{10})$ (i.e., the aggregate number of comets whose absolute values of $\leq H_{10}$) for LP- and SP-comets have the appearance in the logarithmic scale of straight lines of equal inclination up to the corresponding inflection points in the spectra. These "knees" in the spectra of LP- and SP-comets have values of $H_K^{LP} = 5.8$ and $H_K^{SP} = 10.8$, respectively (Hughes 1987). In the regions of $H_{10}^{SP} > H_K^{SP}$ and $H_{10}^{LP} > H_K^{LP}$, "saturation" occurs: the curves acquire a very gentle slope. The values of H_K^{LP} and H_K^{SP} are close to the mean

value for the spectra, and in the regions $H_{10}^{LP} < H_K^{LP}$ and $H_{10}^{SP} < H_K^{SP}$ the effects of observational selection are minor.

The relationship between the absolute values of H_{10} and the masses of LP- and SP-comets were explored by a number of authors (Allen 1973; Öpik 1973; Newburn 1980; Whipple 1975; Weissman 1983).

We will use Weissman's data (1983) who produced the following dependency from Roemer's data (1966) for LP- and SP-comets:

$$\log M_{LP} = 19 - 0.4H_{10} + \frac{3}{2} log \left(\frac{\overline{A}_{LP}}{0.6} \right) + \log(\rho/lg/cm^3) \qquad (5a)$$

$$\log M_{SP} = 20.5 - 0.3H_{10} + \frac{3}{2} log \left(\frac{A_{SP}}{0.05} \right) + \log(\rho/lg/cm^3). \qquad (5b)$$

From (5a) we find the ratios of masses corresponding to the "knees" in the LP- and SP-comet spectra to be equal to:

$$\frac{M_K^{LP}}{M_K^{SP}} = 0.18 \cdot \left(\frac{A_{LP}}{0.6} \right)^{-3/2} \left(\frac{A_{SP}}{0.04} \right)^{3/2}. \qquad (6)$$

It clearly follows from (6) that the albedo value of $\overline{A}_{LP} = 0.6$, assumed for LP- comets, directly contradicts (4). Formula (6) can be rewritten as:

$$\frac{M_K^{LP}}{M_K^{SP}} = 10.8 \cdot (A_{SP}/A_{LP})^{3/2}. \qquad (7)$$

Therefore, the mean mass of LP-comets can only be an order greater than the mean current mass of SP-comets on the condition that

$$\overline{A}_{LP} \simeq \overline{A}_{SP}. \qquad (8)$$

We will note that there are also physical reasons for hypothesizing the close values of $\overline{A}_{LP}$ and $\overline{A}_{SP}$. A low albedo is a consequence of the formation of a thin layer of dark material on the surface of the comet nucleus. Data from laboratory experiments on irradiation by energy protons of low-temperature ices (that contain H_2O, CH_4, and organic residues) demonstrate the formation of a black graphite-like material (Strazzula 1986).

As Weissman has pointed out (1986b), the effect of galactic cosmic rays on comet nuclei in the Oort cloud (before their appearance in the region of the planetary system) must, for the aforementioned reason, lead to the formation of a sufficiently thick crust from the dark, graphite-like

polymer. The latter acts as a "cometary paste" binding the nucleus surface against sublimation.

It is our view that owing to the low heat conductivity of this polymer layer, a low albedo of the surface of comet nuclei can be maintained by a layer thickness of several centimeters. Due to the low volatility of this layer and its "sticky properties," the latter must also be conserved as the comet shifts into a short-period orbit.

Therefore, if we are to propose that the hypothesis (8) is correct, we can estimate the mass of the Oort cloud to be a value of $M_o \simeq 100\ M_\oplus$ (with an accuracy of up to a factor on the order of two).

HILL'S CLOUD MASS

It has currently been deemed likely that the canonical Oort cloud is only a halo surrounding a dense, internal cometary cloud. This cloud contains one to two orders of cometary nuclei greater than the halo with an outer boundary corresponding to the semi-major axis, $a_e^c = 2\text{–}3 \cdot 10^4$ AU (Hills 1981; Heisler and Tremaine 1986). It is a source which delivers comets to the halo as the latter is depleted when the Sun approaches closely passing stars and gigantic molecular complexes in the galaxy (GMC) and under the impact of the galactic tidal effects. The internal cometary cloud is sometimes called the Hills cloud. The outer boundary of the Hills cloud is defined quite clearly, as Hills demonstrated (1981), since comets with semi-major axes of $a < a_e^c$ do not fill the loss cone in the velocity space delivering them to the planetary system region of the solar system, where they have been recorded through observation. According to Hills, the value of a_e^c is weakly dependent on the parameters input into the formula to determine this value (an indicator of the degree of 2/7). Therefore, the value of $a_e^c \simeq 2 \cdot 10^4$ AU is defined with sufficient certainty. Bailey (1986) also later generated the same value for the outer inner cometary cloud (ICC) boundary prior to this; he considered interaction with GMC instead of convergence with stars, as Hills had done. Furthermore, if the tidal effect of the "galaxy's vertical gravitational pull" is taken into account, we have, according to Heisler and Tremaine (1986) an estimate of $a_e^c \simeq 3 \cdot 10^4$ AU.

The location of the inner boundary of a_i^c is considerably less definite. An extreme estimate, performed by Whipple (1964) produces $a_i^c \gtrsim 50$ AU. At the same time, by hypothesizing that comets are formed in the outer regions of the protosolar nebula, Hills (1981) estimated the inner boundary of the core as $a_i^c \simeq 3 \cdot 10^3$ AU.

What is the mass of the Hills cloud? Let us designate the number of comets in it as N_{core}, so that

$$N_{core} = \beta \cdot N_o. \tag{9a}$$

Then

$$M_{core} = \beta M_o, \tag{9b}$$

where the value of β is not clearly known.

What can be said about the value of β? Simple extrapolation for the core of the law of comet distribution around the semi-major axis in the halo for the original Oort model and a somewhat refined version produce, according to Hills' estimate (1981), $\beta = 20$ and $\beta = 89$, respectively.

Proposing that comet formation occurs in the Uranus-Neptune zone, Shoemaker and Wolfe (1984) and Duncan *et al.* (1988) generated $\beta = 10$ and $\beta = 5$, respectively, in their numerical experiments. The internal boundary of the core in the latter instance was equal to $3 \cdot 10^3$ AU; this fits with Hills' estimate (1981).

However, it was proposed in these computations that the total mass of comets scattered by Uranus and Neptune is minor when compared with the masses of the planets. Clearly, this is not true if the reasoning put forward in this paper is sound. For this reason, the results generated by the authors mentioned here apparently require clarification.

Assuming, nevertheless, the region of parameter alteration as:

$$\beta = 5 - 10, \tag{10}$$

we find the mass of the Hills cloud approximately

$$M_{core} \simeq 500 - 1000 M_{\oplus}. \tag{11}$$

Figure 1 represents schematically the probable mass distribution in the solar system for $\beta = 10$, in the case of a massive Oort cloud.

ANGULAR MOMENTUM DISTRIBUTION IN THE SOLAR SYSTEM

If the Hills and Oort clouds are truly as massive as follows from the above estimations, then: (1) comet formation could hardly have occurred in the Uranus-Neptune zone, as is frequently considered, since as such a large mass was ejected to the periphery of the solar system, the planets should have moved considerably closer to the Sun (Marochnik *et al.* 1989); (2) since comet formation apparently took place in the rotating protoplanetary disk (if, of course, we rule out the hypothesis of cometary cloud capture during the Sun's formation through GMC) (Clube and Napier 1982), then since the angular momentum is conserved, the greater portion of it must,

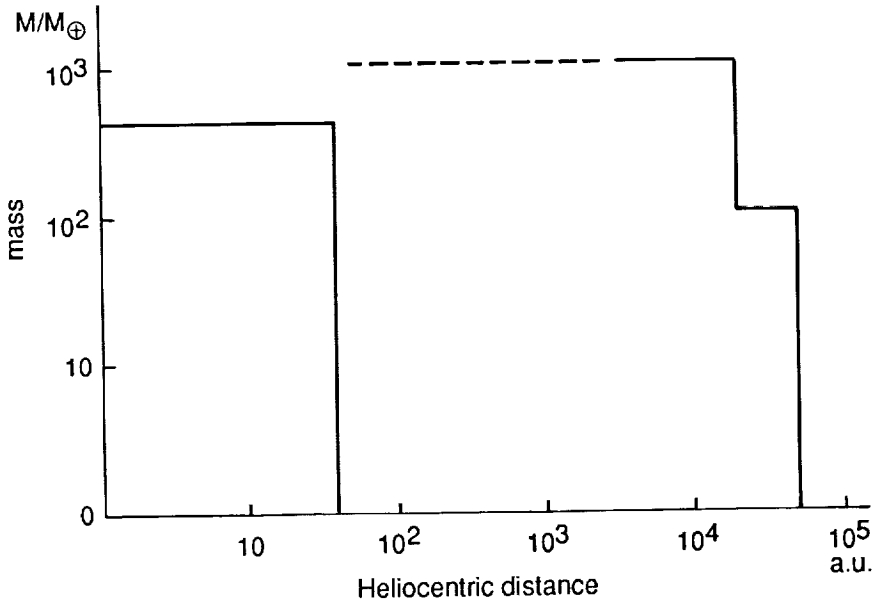

FIGURE 1 Histogram of the probable mass distribution in the solar system. A planetary system with a mass of $\Sigma M_{planet} = 448\ M_\oplus$ is located in the region of heliocentric distances where $r \leq 40$ AU. The Oort cloud with a mass of $M_o \simeq 100\ M_\oplus$ is located in the zone of $2 \cdot 10^4 \leq r \leq 5 \cdot 10^4$ AU. A Hills cloud with a mass of $M_{core} \simeq 10^3\ M_\oplus$ is located in the region where $r \leq 2 \cdot 10^4$ AU. The internal boundary r_i^c of the Hills cloud is ambiguous. According to data from Hills (1981) and Duncan *et al.* (1988), $r_i^c \simeq 3 \cdot 10^3$ AU. However, neither can we exclude the value $r_i^c \simeq 50$ AU (Whipple 1964).

apparently, be concentrated in the massive Oort and Hills clouds, and not the planets.

According to Marochnik *et al.* (1988) the Oort cloud's angular momentum can be written as

$$J_o = 4/3 M_o (G M_\odot \alpha_{min})^{1/2} (1 + \alpha^{-1/2}) - 1, \tag{12}$$

where the original Oort model is used (Oort 1950) for the function of comet distribution by energies ($n = 2$); $\alpha = \alpha_{max} / \alpha_{min}$; α_{min} and α_{max} denote the minimum and maximum possible semi-major axes of cometary orbits. Since the Oort cloud is thermalized by passing stars, integration occurs in (12) for all possible eccentricities ($0 \leq e \leq 1$).

Assuming that $M_o = 100\ M_\oplus$, $\alpha_{min} = 2 \cdot 10^4$ AU, $\alpha_{max} = 5 \cdot 10^4$ AU, we find that

$$J_o = 3 \cdot 10^{51} g \cdot cm^2/s. \tag{13}$$

For the assumed parameter values, the angular momentum of the halo is on the same order as the minimum possible angular momentum of the protosolar nebula before it loses its volatiles (Hoyle 1960; Kusaker *et al.* 1970; Weidenschilling 1977) and an order greater than the present angular momentum of the planetary system. $\Sigma J_{planet} \simeq 3 \cdot 10^{50}$g cm^2/s. Estimate (13) fits with the hypothesis of the *in situ* formation of comets, and thus generates the upper limit of the Oort cloud's possible angular momentum.

The lower limit will clearly be seen if we suppose that comet formation occurred in the Uranus-Neptune zone. Assuming, for example, that $\alpha_{min} =$ 25 AU, $\alpha_{max} = 35$ AU, and supposing that the initial comet orbits in this case are nonthermalized and circular, we find that

$$J_o = 1.5 \cdot 10^{50} g cm^2/s.$$

Therefore, the interval in which Oort cloud angular momentum may lie can be written as:

$$1.5 \cdot 10^{50} g cm^2/s < J_o < 3 \cdot 10^{51} g cm^2/s. \quad (14)$$

In any case, as we have seen:

$$J_o \gtrsim \Sigma J_{planet}. \quad (15)$$

Let us now estimate the angular momentum for the Hills cloud. Since it is apparently nonthermalized, its angular momentum J_{core} is equal to (Marochnik *et al.* 1989):

$$J_{core} = 2M_{core}[GM_{\odot}\alpha^c_{min}(1-e^2)]^{1/2}(1+\alpha_c^{-1/2})^{-1}, \quad (16)$$

where, as in conclusion (12), the classical Oort model is used: (n = 2), α^c_{min} and α_c modify the core.

Let us consider two extreme cases: (a) all the comets in the Hills cloud move along circular Kepler orbits (e = 0), and (b) all the comets in it move along sharply elongated, circumparabolic orbits (e < 1). In the case where e = 0, assuming $M_{core} \simeq 10^3$ $M_{\oplus}$, $\alpha^c_{min} = 3 \cdot 10^3$ AU, $\alpha^c_{max} = 2 \cdot 10^4$ AU, we find:

$$J_{core} \simeq 2 \cdot 10^{52} g \cdot cm^2/s. \quad (17).$$

Estimate (17) agrees with the suggestion that comets are formed *in situ* and gives us an upper limit for the value J_{core} (for estimating the momentum, present values of α^c_{min} and α^c_{max} are used). In the case where e $\lesssim$ 1, we need to rewrite (16) in terms of perihelion distances of q = a(1 − e), that is, using the ratio

$$\alpha^c_{min}(1-e^2) \simeq 2q_{min}, \quad (18)$$

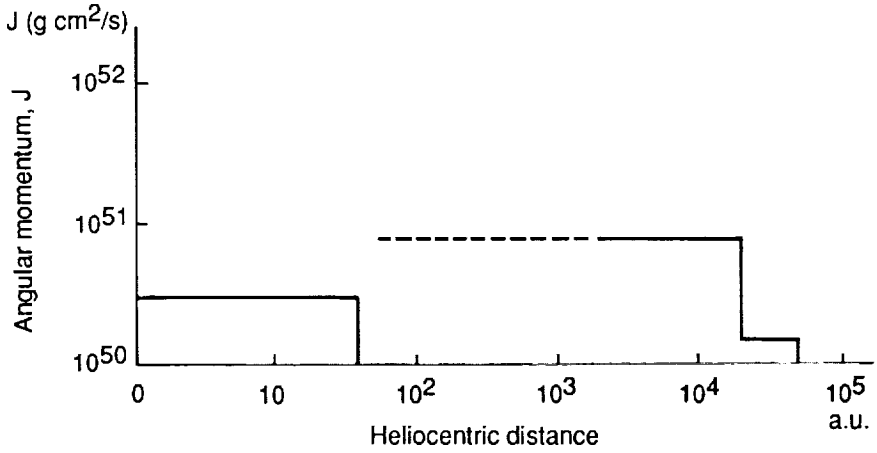

FIGURE 2 Histogram of the probable distribution of angular momentum in the solar system. A cometary system with a total angular momentum of $\Sigma J_{planet} = 3 \cdot 10^{50}$ is located in the region of heliocentric distances of $r \leq 40$ AU. An Oort cloud with a mass of $M_o = 100\ M_\oplus$ and angular momentum of $J_o = 1.5 \cdot 10^{50}$ g cm^2/s is situated in the zone of $2 \cdot 10^4 \leq r \leq 5 \cdot 10^4$ AU. A Hills cloud with a mass of $M_{core} = 500\ M_\oplus$, an internal boundary that is ambiguous ($50 \lesssim r_i^c \lesssim 3 \cdot 10^3$ AU) and an angular momentum of $J_{core} = 3 \cdot 10^{51}$ g·cm^2/s is located in the zone of $r \leq 2 \cdot 10^4$ AU.

where q_{min} denotes the perihelion distances of the comets' cores, which have minimum semi-major axes $\alpha_{min}{}^c$. The lower limit for J_{core} can be produced, supposing that the formation of the comets of the Hills cloud occurred in the Uranus-Neptune zone. Assuming that $q_{min} \simeq 25$ AU, we find from (16), and taking into account (18), that:

$$J_{core} \simeq 3 \cdot 10^{51} g cm^2/s.$$

Therefore, for the angular momentum of J_{core}, we can write the following estimate:

$$3 \cdot 10^{51} < J_{core} \left(\frac{M_{core}}{10^3 M_\oplus} \right)^{-1} < 2 \cdot 10^{52} \frac{g \cdot cm^2}{s}. \qquad (19)$$

The angular momentum of J_{core} is, therefore, very large: one to two orders greater than the contemporary angular momentum of the entire planetary system ΣJ_{planet}. However, its value still does not exceed the limits of the upper estimate of the possible initial angular momentum of the protosolar nebula (Marochnik *et al.* 1988).

Figure 2 shows angular momentum distribution in the solar system in the case where the Oort and Hills ($\beta = 5$) clouds are not too massive.

THE COMETARY CLOUD AROUND OTHER STARS

The picture we have described of the structure of the solar system apparently does not contradict IRAS data on observations of infrared excesses in stars of the circumsolar vicinity of the galaxy.

As Backman notes (personal communication), IRAS data shows that thin clouds of solid particles are spread out over distances of up to 700 AU near the stars α Lyrae and β Pictoris, and, possibly, up to 10^4 AU, respectively.

According to Smith's data (1987), optical observations of β Pictoris point to the presence around this star of an elongated (radius $\simeq 11^{50}$ AU) and a thin (projected thickness is h $\simeq$ 50 AU) disk. According to data from Smith and Terrile (1984), optical observations of β Pictoris may also be evidence of the presence of a zone of transparency with a radius of about 30 AU around this star.

Of the 150 main sequence stars in Glize's catalogue, and which were examined by Backman (1987), 18% demonstrated infrared excess at a level of 5 sigma. This exceeds the extrapolated photospheric flow. According to Backman's analysis (1987), this may indicate the presence of thin clouds of solid particles spread out over distances of 10 + 1000 AU from the respective stars.

The presence of elongated disks of fine solid particles spread out over distances of hundreds and thousands of AU from the respective stars is most likely evidence of the presence in these regions of bodies of cometary dimensions for which the sublimation of volatiles and mutual collisions may offset the accretion of dust grains from these regions by light pressure and the Poyting-Robertson effect during the lifespan of a star (Weissman 1984; Harper *et al.* 1984; O'Dell 1986). As Beichman has noted (1987), the masses of disks around the stars are apparently the most difficult values to determine. A huge spread in estimates exists for β Pictoris: from $M_{disk} \simeq 10^{-2}\ M_\oplus$ for dust grains of equal dimensions to $M_{disk} \simeq 3 \cdot 10^3 M_\oplus$ for an asteroid-like distribution of them (Aumann *et al.* 1984; Weissman 1984; Gillet 1986).

Therefore, the data of infrared observations of stars near the solar vicinity of the galaxy do not apparently clash with the proposed model of the structure of the solar system. Attempts to make some stronger assertions would be too speculative at this point.

CONCLUSION

Assuming as typical for long-period comets the albedo value of Halley's comet, we come to the conclusion that the Oort cloud must be extremely

massive ($M_o \simeq 100\ M_\oplus$). This mass must be located in the region of the semi-major axes of the orbits:

$$2 - 3 \cdot 10^4 AU \lesssim \alpha \lesssim 5 - 10 \cdot 10^4 AU.$$

The hypothetical Hills cloud is located in the region $\alpha < 2 - 3 \cdot 10^4$ AU. It has a mass of $M_{core} = \beta M_o$, where the value β may generally be included in the ranges of $0 \leq \beta \leq 100$.

The extreme case of $\beta = 0$ fits with the general hypothesis of the absence of the Hills cloud. The case where $\beta = 100$ agrees with the other extreme hypothesis of the highly massive core.

In limiting ourselves to the values of $\beta = 5 - 10$, we find the Hills cloud mass of $M_{core} = 500 - 1000\ M_\oplus$, which must have a value of $a_e^c = 2{-}3 \cdot 10^4$ AU as an outer border. The internal boundary of the Hills cloud is indefinite.

Therefore, the hypothesis of the low value for the albedo of comets in the Oort cloud brings us to the conclusion that at the outer edge of the solar system there may be an invisible material in the form of cometary nuclei whose mass, ΣM_{comet}:

$$\Sigma M_{comet} \gtrsim \Sigma M_{planet}, \tag{20}$$

where $\Sigma\ M_{planet}$ denotes the total mass of the planetary system.

The second conclusion states that the cometary population, and not the planetary system accounts for the bulk of the solar system's angular momentum. On the basis of (14) and (19) we can write the following, which is analogous to (20):

$$\Sigma J_{comet} \gtrsim \Sigma J_{planet}, \tag{21}$$

where ΣJ_{comet} denotes the total angular momentum of the cometary population. Let us note in conclusion that if (20) and (21) are correct, the cosmogonic scenarios for the solar system's origin call for considerable refinement.

ACKNOWLEDGMENT

We are deeply grateful to Alan Boss and Paul Weissman for their important comments, and to Vasilii Moroz and Vladimir Strel'nitskii for their insightful discussion, and to Georgii Zaslavskiy for his input regarding individual aspects of this study.

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