SKY DISTRIBUTIONS OF OORT CLOUD COMETS DURING AND OUTSIDE OF SHOWERS

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The orbits of comets in the Oort cloud are constantly perturbed by the Galactic tidal field and frequent weak ("background") stellar encounters (1,2) and occasionally by close stellar encounters which can induce showers. For comets with semimajor axes $a \lesssim 20,000$ AU, five times as many enter the planetary region due to the Galactic tide and background stars than would due to background stars alone (3). Many more can enter during showers and their sky distribution is principally determined by the track of the shower-inducing star, not by the Galactic tide and background stars. For comets with $a \gtrsim 20,000$ AU, the flux following the close passage of a star is generally only somewhat elevated compared to the background, and usually does not constitute a "shower" or period of intense flux. The sky distribution of comets that enter the planetary region following a close stellar passage is strongly affected by the Galactic tide and background stars. Below we present some results showing the interplay between Galactic tide and stars in determining the distribution of comets.

Figure 1 is a histogram in Galactic latitude, b, of the aphelion vector of comets with $a = 20,000$ AU that enter the planetary region with $q < 2$ AU. The histogram is derived from simulations described in Heisler (3), using 10,930,000 comets. The comets represented in figure 1 are those that enter the inner planetary region with $q < 2$ AU during "background" times, namely when the comet flux $< 3R_B$, where R_B is the average background flux. [Details for computing R_B are given in Heisler (3)]. If the Galactic tide were the sole source of perturbation to comets, one would expect depletions at the Galactic equator and poles. Figure 1 shows the expected depletions, but there are many more comets at southern latitudes than at northern ones. Furthermore, in a simulation with $a = 13,000$ AU there is no signature of the Galactic tide for $q < 2$ AU. Apparently, stellar perturbations are important in determining the latitude distribution of comets with $a \lesssim 20,000$ AU and small perihelia. Most small a comets that enter the "loss cone" ($q < 10$ AU) do so with perihelia ~ 10 AU; these comets enter the loss cone due primarily to the Galactic tide. However, the very few small a comets that penetrate far into the loss cone with $q \sim 2$ AU do so because of stellar perturbations. In any time interval the distribution of such comets will be determined by the strongest stellar encounters, not by the Galactic tide. These are not "shower" inducing stars, just the strongest events that occur in a prescribed time interval.

We have also investigated the distribution of cometary aphelia after a close stellar passage. Figure 2 shows the sky distribution of $a = 30,000$ AU comets that have their perihelia reduced to < 10 AU as a result of the close stellar encounter but with no other sources of perturbation. They are plotted in an Aitoff projection. The $1.5\,M_\odot$ star follows a trajectory perpendicular to the Galactic plane at 40 km/s and with Galactic longitude $\ell = 90°$ and closest approach to the sun of $p = 20,000$AU. The figure is derived from a simulation of 70,400 highly eccentric comets distributed uniformly in J^2, the square of the angular momentum, over 13% of the phase space just outside of the loss cone. The loss cone is defined as that area of phase space where orbital perihelia $q < 10$ AU. There is a conspicuous gap near the stellar trajectory, shown dashed, and a larger gap on the opposite side around $\ell = 270°$. These gaps occur because the net velocity perturbation (i.e. the difference between the kick to the Sun and individual comet) in these regions is principally in the radial direction and thus does not affect angular momentum. The comets that are most efficiently sent into the loss cone are those with aphelia 90° away from the star and receive a mostly tangential change in velocity. The gap around $\ell = 270°$ is probably

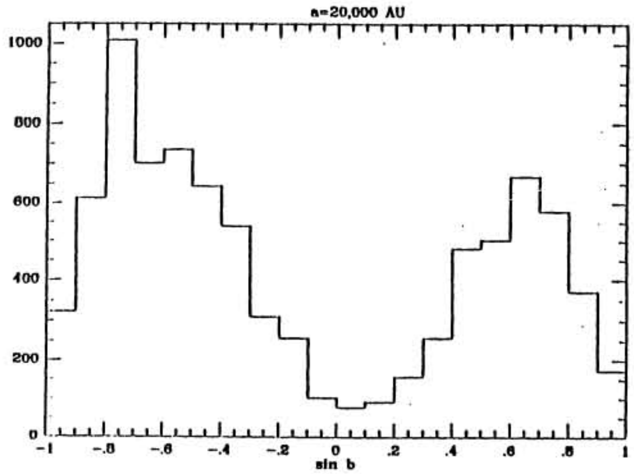

Figure 1: Histogram in Galactic latitude of $a = 20,000$ AU comets with $q < 2$ AU from a simulated cloud of 10,930,000 comets, outside of showers.

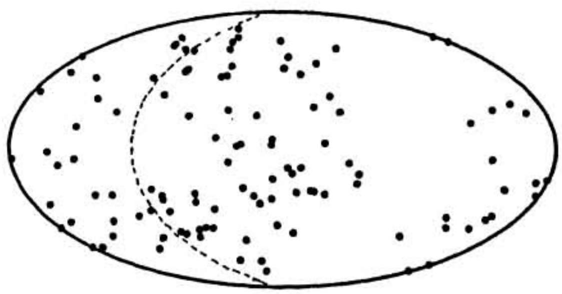

Figure 2: Aitoff projection of a shower of $a = 30,000$ AU comets perturbed to orbits with $q < 2$ AU as a result of a close stellar encounter. The stellar trajectory is shown dashed. There are no Galactic tidal or background stellar perturbations.

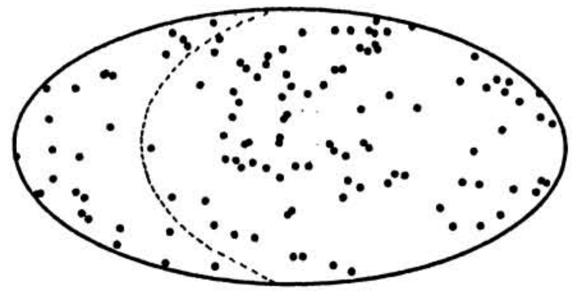

Figure 3: Same as figure 2, but including the perturbations due to the Galactic tide and background stars and counting all comets that enter within 5 Myr after the close encounter.

larger because comets in those regions are further away from the stellar trajectory and receive a smaller net velocity change. If there are subsequent perturbations from the Galactic tide and other random stars, then over the course of 5 Myr these gaps fill in partially (figure 3). Thus, the signature of the shower star is quickly eroded. However, during the first million years comets with $a \lesssim 10,000$ AU enter the loss cone tightly clustered about the stellar trajectory.

These results imply that the sky distribution of comets visible from the Earth probably shows some degree of clustering and asymmetry at all times that is due to the influence of the strongest occuring stellar encounters. However, the degree of clustering is probably small even after close stellar encounters, since the distribution soon returns to its background state.

REFERENCES

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