Star Passages Through the Oort Cloud

Paul R. Weissman

Jet Propulsion Laboratory
Pasadena, CA 91109 USA

Abstract: Stars passing through the Oort cloud eject comets to interstellar space and initiate showers of comets into the planetary region. Monte Carlo simulations of such passages are performed on a representative distribution of cometary orbits. Ejected comets generally lie along a narrow tunnel "drilled" by the star through the cloud. However, shower comets come from the entire cloud, and do not give a strong signature of the star's passage, except in the inverse semimajor axis distribution for the shower comets. The planetary system is likely not experiencing a cometary shower at this time.

Oort (1950) first recognized that the solar system was surrounded by a cloud of comets, perturbed by random passing stats. Hills (1981) suggested that close stellar passages could excite the cloud and send showers of comets into the planetary region, particularly if there existed a dense inner cloud of comets which are not observed except when such major perturbations occur. Hut et al. (1987) and Fernandez and Ip (1987) modeled the dynamical evolution of such showers, showing that the intense pulse of comets into the planetary region decayed in 2-3 x 10^6 years.

Other dynamical studies have demonstrated the importance of galactic tidal perturbations on the steady-state evolution of the Oort cloud (Byl 1983; Heisler and Tremaine, 1986). However, only penetrating star passages and close approaches by giant molecular clouds can cause the major perturbations which result in cometary showers.

To investigate the effects of penetrating stellar passages, a Monte Carlo simulation model of the Oort cloud was constructed. The model notes the change in orbital elements of comets resulting from the passage of a single stat at a given closest approach distance and velocity. The perturbations 011 the cometary orbits and on the Sun are calculated using the classic impulse approximation, $\Delta V = 2GM_*/DV_*$, where G is the gravitational constant, M_* and V_* are the mass and velocity respectively of the perturbing star, and D is the closest approach distance of the star to the' comet 01' the sun. Orbital elements for the comets arc chosen randomly using the semimajor axis and eccentricity distributions found by Duncan et al. (1 987), and assuming, random inclinations and mean anomalies. initial perihelia are restricted to distances greater than 50 AU and aphelia to distances less than 2×10^5 AU, A typical Oort cloud constructed in this fashion is shown in Figure 1.

An example of results for a one solar mass star passing at 30 km s^{-1} through a hypothetical cloud of 2 x 107 comets, at a closest approach distance to the Sun of 104 AU, are shown in Figure 2. The instantaneous location of comets ejected to interstellar spat.c are shown in Figure 2a, which is a view looking, "clown" on the path of the star. The ejected comets generally lie close to the star's path, within about 10^3 AU, where the net velocity perturbation exceeds the escape velocity from the solar system, as predicted by earlier studies (Weissman, 1 980). This is shown even more clearly in Figure 2b which is a view along the star's velocity vector. Most of the ejected comets lie along a narrow tunnel "drilled" through the Oort cloud.

The fraction of ejected comets for this case is 8.5 $\times 10^{-5}$ of the total cloud population. The mean hyperbolic velocity of the ejected comets is 0.28 km s-'. Additionally, 2.3×10^{-4} of the cloud population is perturbed to aphelia greater than 2×10^5 All. 'J 'hese orbits are beyond the Sun's sphere of influence and will likely be lost to interstellar space,

The location of comets perturbed by the same stellar passage to perihelion distances less than 10 AU are shown in Figure 2c, which is again a view looking "down" on the star's path, and Figure 2ct, which is the view along the stellar velocity vector. in this case, the entire Oort cloud is excited and comets enter the planetary region from all directions. The majority of comets come from semimajor axes greater than the minimum approach distant.c of the star to the Sun, indicative of the tidal nature of the perturbation. The dense inner Oort cloud is not easily excited unless a star passes directly through it. The fraction of comets perturbed to $q < 10$ AU for this case is 1.1×10^{-4} of the total cloud population. Most of those comets will be ejected to interstellar space by Jupiter and Saturn within 5 to 10 returns.

The star passage pumps energy and angular momentum into the Oort cloud, as described by Weissman (1991). The total binding energy of the comets is reduced by a factor of 2×10^{-4}. The total angular momentum o f the cloud is increased by $1.2. \times 10^{-3}$.

Hypothetical cases for different stellar masses, velocities, and closest approach distances were also studied, Results are shown in Figure 3. The fraction of the cloud population ejected to interstellar space as a function of closest approach distance is shown in Figure 3a, for two different stellarmass/velocity ratios. The fraction of comets perturbed to $q < 10$ AU are shown in Figure 3b, and the fraction lost to aphelia> 2×10^{5} AU are shown in Figure 3c. 1 n al l cases, the loss fractions are monotonicall y decreasing functions of encounter distance. Smal l variations in the curves are the result of statistical noise in the Monte Carlo simulations.

An important question for cometary dynamics is whether the solar system is currently experiencing an enhanced flux of comets from the Oort cloud. Examination of the distributions Of orbital elements from a hypothetical comet shower caused by a stellar passage at 5×10^{3} AU does not show substantial departures from random. '1 'his is especially true when trying to compare the model results to the distributions for the observed lm~g,-period comets, which are in limited numbers and are observationally biased.

However, the inverse semimajor axis distribution, $1/a_0$, for the hypothetical cometary shower shows a clear signature of many orbits with semimajor axes less than 2 x 104 AU, which is not seen for the observed long -period comets. The signature is even stronger if one only considers comets arriving in the planetary region in the first 10^6 years after the star's passage. Thus, the solar system does not appear currently to be experiencing a cometary shower, bad on the observed distribution of I/a. for the lonp,-period comets.

F urther exploration of the relevant parameter space for star passages through the Oort cloud is currently underway. This work was supported by the NASA Planetary Geology and Geophysics Program and was performed at the Jet I'repulsion laboratory.

References:

Byl, J. 1983. Galactic perturbations on nearly parabolic cometary orbits. Moon & Planets **29**, 121-13'7.

Fernandez, J. A., and Ip, W.-H. 1987. Time dependent injection of Oort cloud comets into Earth-crossing orbits. Icarus 71, 46-56.

Heisler, J., and Tremaine, S. 1986. The influence of the galactic tidal field on the Oort comet cloud. Icarus **65**, 13-2.6.

Hills, J. G. 1981. Cored showers and the steady-state infall of comets from the Oort cloud. Astron. J. **86**, 1730-1740.

Hut, 1'., Alvarez, W., Elder, W. 1'., Hansen, T., Kauffman, E. G., Keller, G., Shoemaker, E. h4., and Weissman, I'. R. 1987. Comet showers as possible causes of stepwise mass extinctions. Nature 329, 118-126.

Oort, J. H. 1950. The structure of the cloud of comets surrounding the solar system and a hypothesis concerning its orig in. Bull. Astron. Inst. Netherlands **11**, 91-110.

Weissman, P. R. 1980. Stellar perturbations of the cometar y cloud. Nature **288**, '242-243.

Weissman, 1'. R. 1991. The angular momentum of the Oort cloud. Icarus **89**, 190-193.

Figure Captions

Figure 1. Hypothetical Oort cloud constructed for the Monte Carlo simulation, based on the orbital element distributions of Duncan et al. (1987).

Figure 2. Location of comets in a hypothetical Oort cloud, lost to various dynamical end-states: a) comets ejected to interstellar space, view from "above" the star's path; b) ejected comets, view along the star's path; c) comets perturbed into the planetary region, q < 10 AU, view from above the star's path; d) comets perturbed to q < 10 AU, view along the star's path. Ejected comets all come from close to the star's path, whereas comets perturbed to q < 10 AU come from the entire Oort cloud.

Figure 3. Fraction of the Oort cloud population lost to various end-states as a function of stellar encounter distance, for two different stellar mass and velocity combinations: a) fraction ejected to interstellar space; b) fraction perturbed into the planetary region, q < 10 AU; c) fraction perturbed to Q > 2 x 10^5 AU.

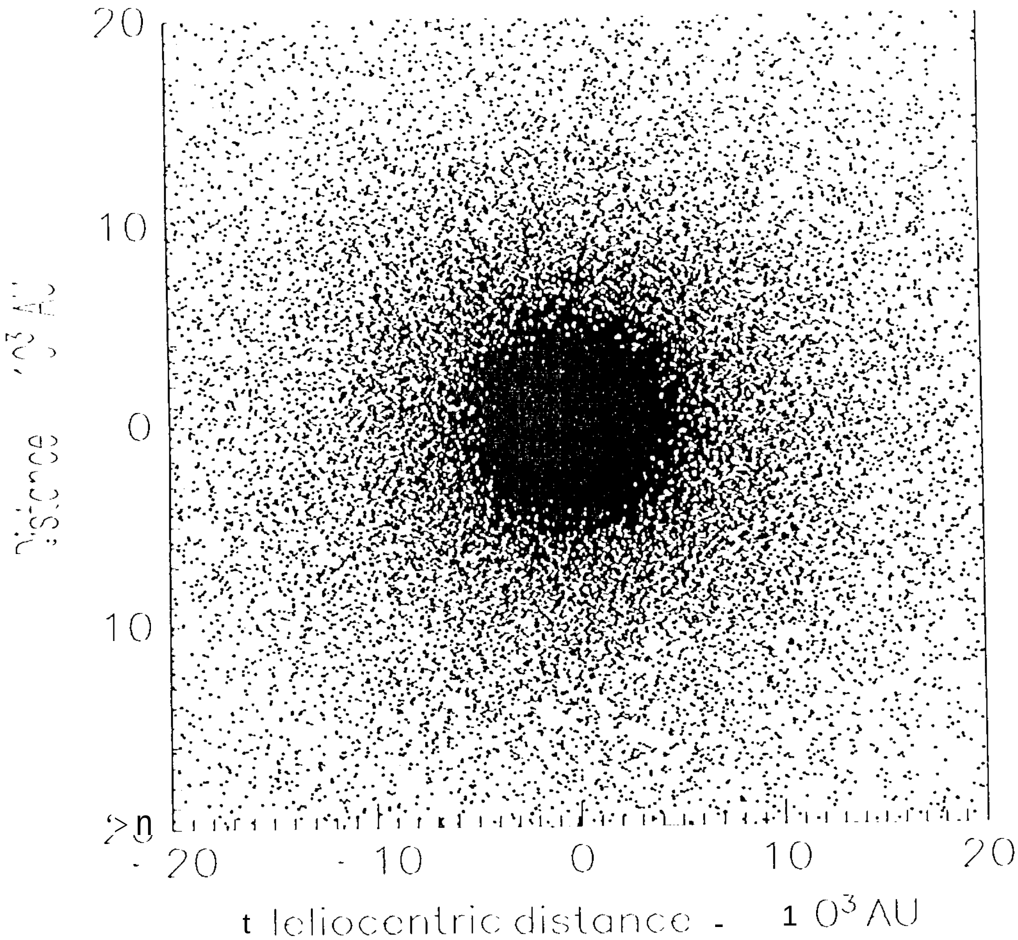
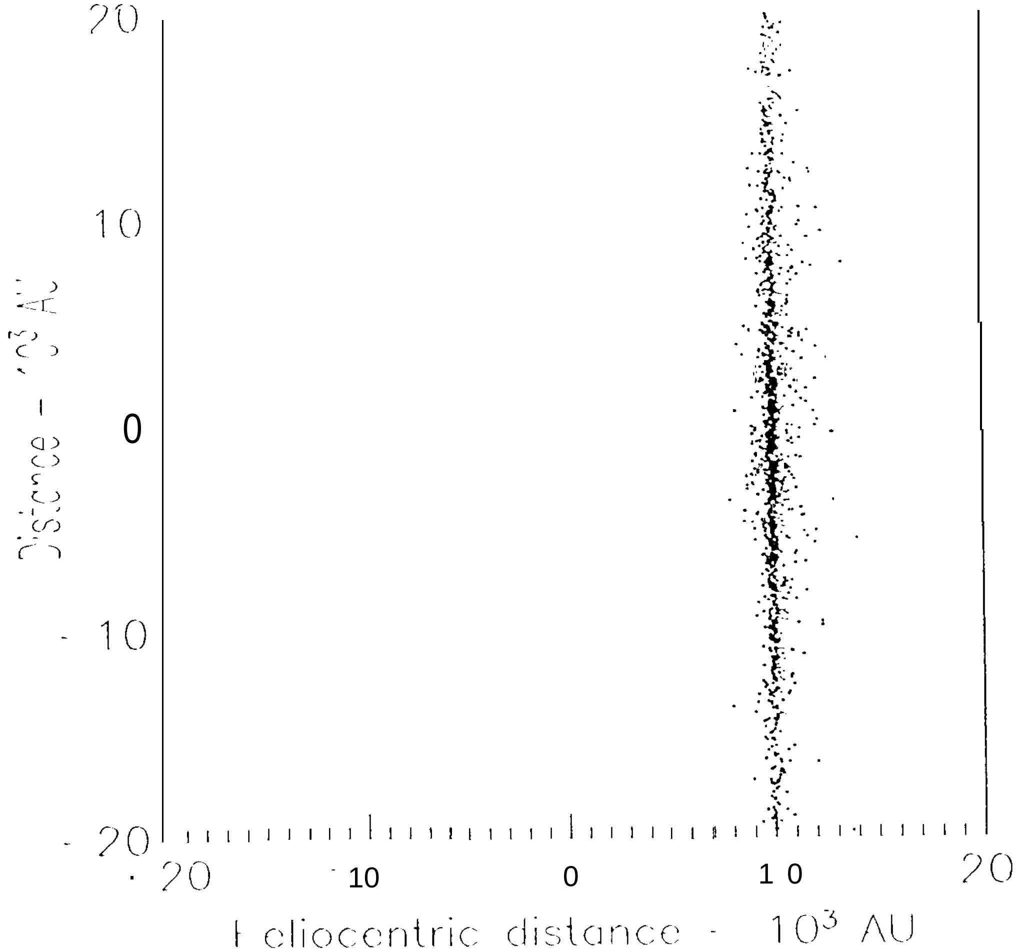
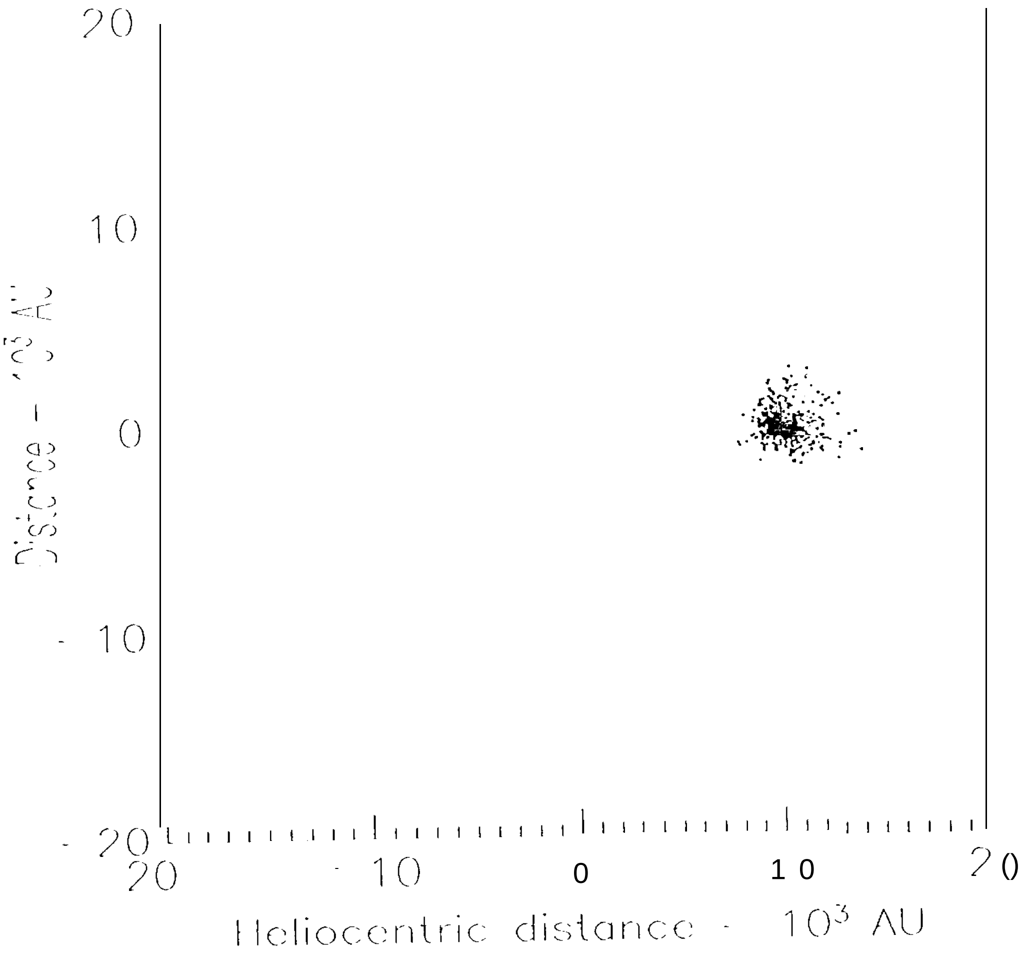

20
10
0
10
20
-20
-10
0
10
20
Heliocentric distance - 10^3 AU
Distance 10^3 AU

Figure 1.



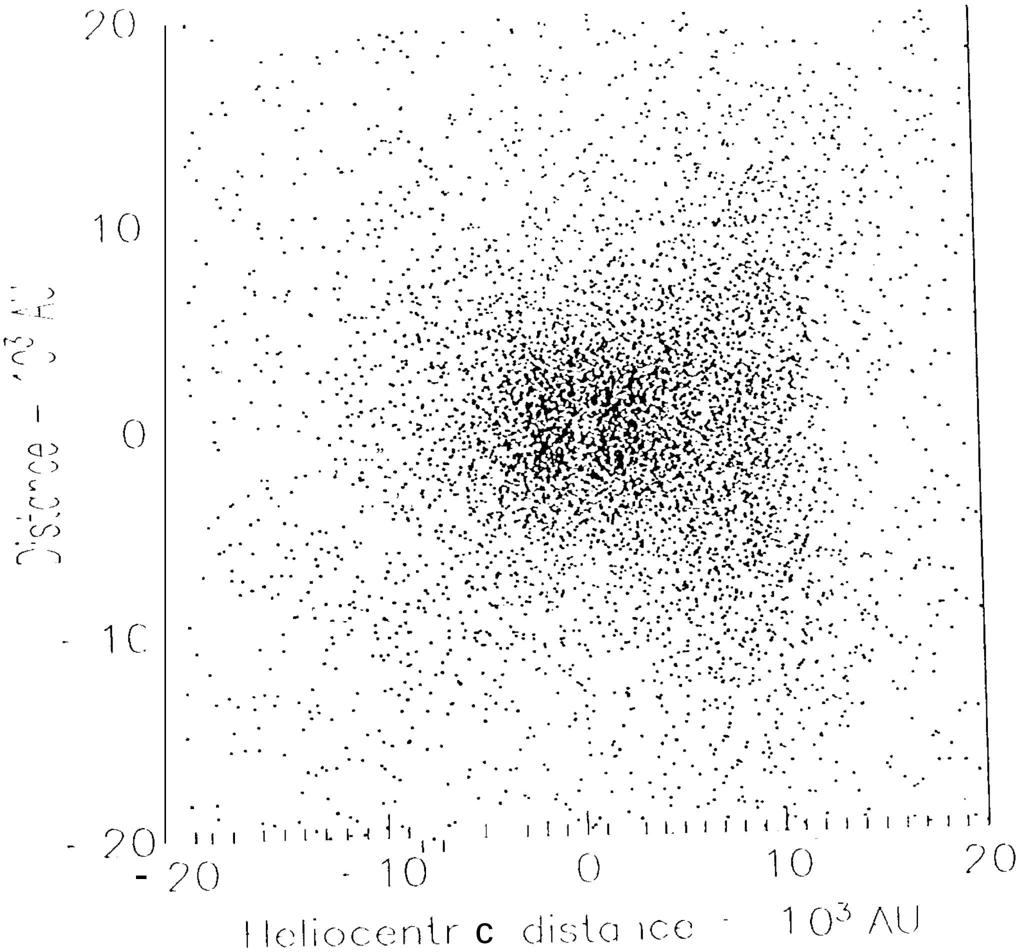
20
10
0
- 10
- 20
Distance - 10³ AU
- 20
10
0
1 0
20
Heliocentric distance - 10³ AU

Figure 2a.



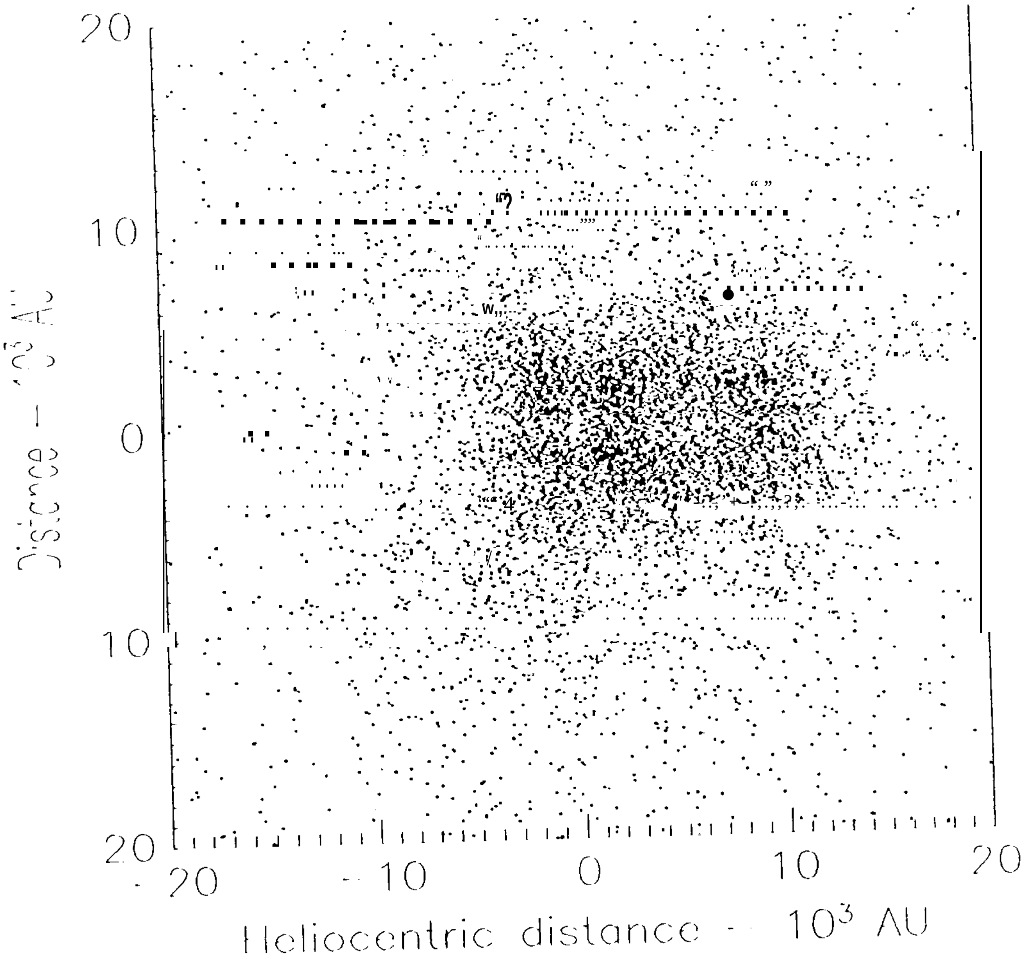
20
10
0
- 10
- 20
Distance - 10³ AU
20
- 10
0
10
20
Heliocentric distance - 10³ AU

Figure 2b



20
10
0
- 10
- 20
- 20
- 10
0
10
20
Distance - 10^3 AU
Heliocentric distance - 10^3 AU

Figure 2c.



20
10
0
10
20
Distance - 10³ AU
-20
-10
0
10
20
Heliocentric distance - 10³ AU

Figure 2d.

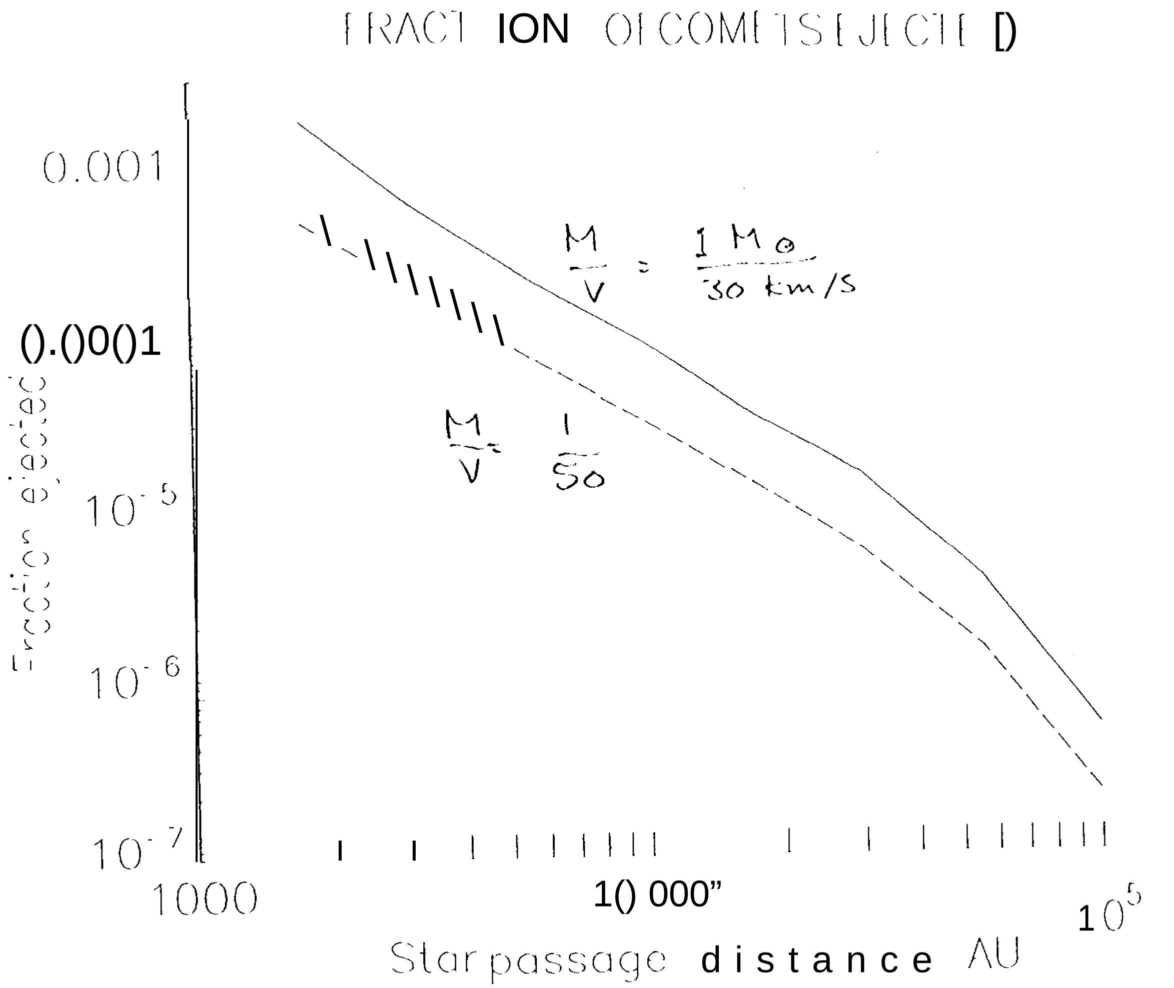

FRACTION OF COMETS EJECTED
0.001
0.0001
10^-5
10^-6
10^-7
Fraction ejected
M/V = 1 M⊙ / 30 km/s
M/V = 1/50
1000
10 000
10^5
Star passage distance AU

Figure 3a.

FRACTION OF COMETS TO q < 10 AU

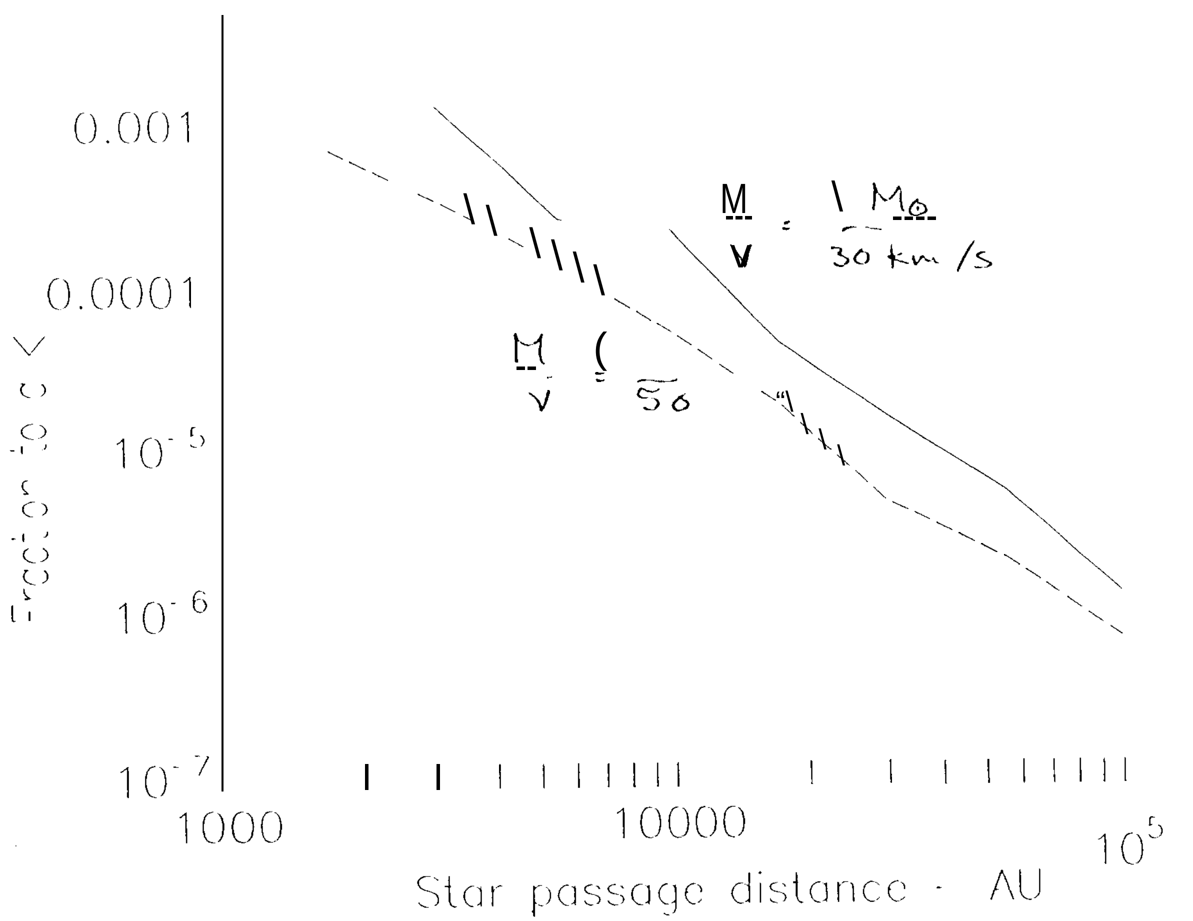


Figure 36.

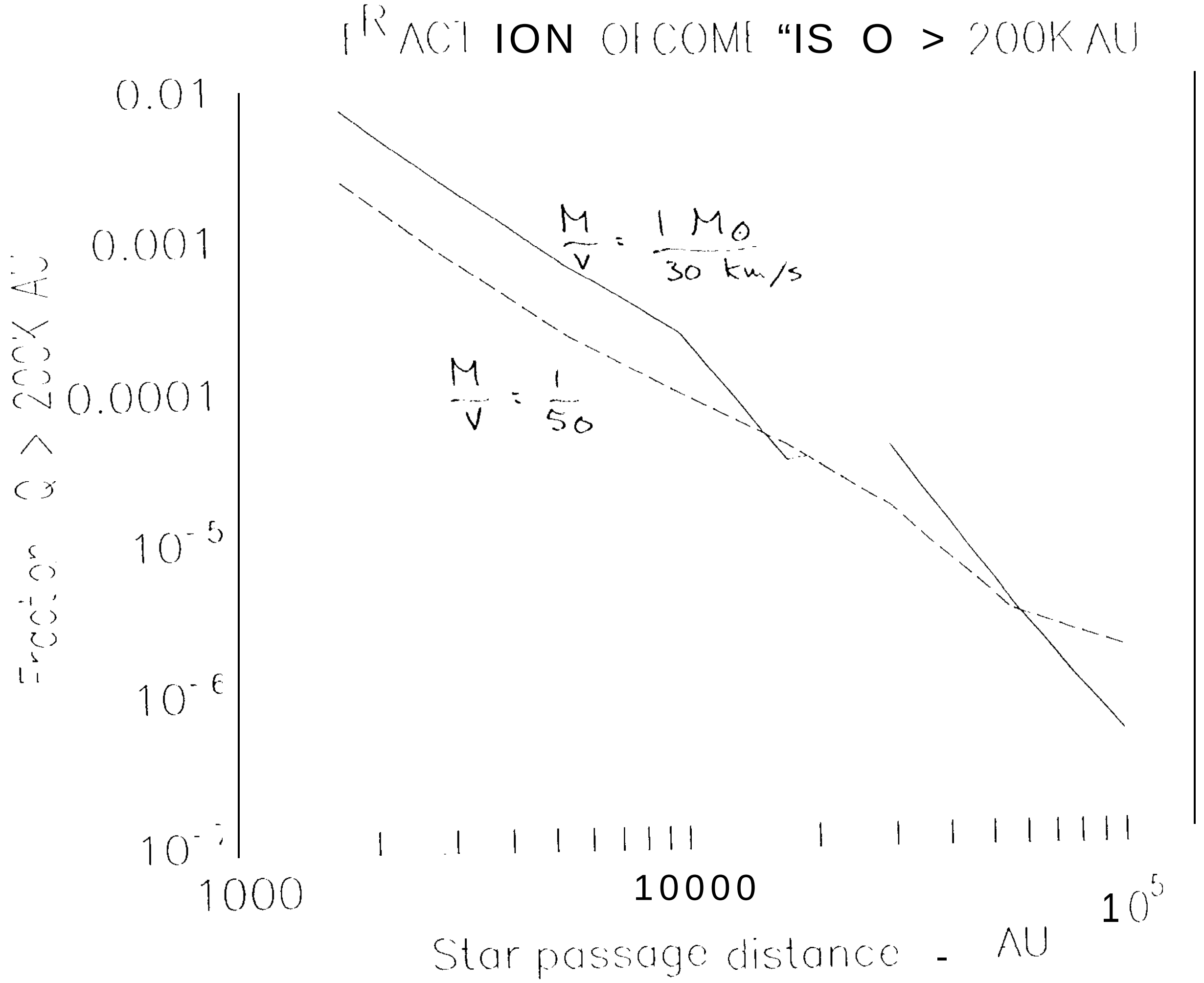

FRACTION OF COMETS Q > 200K AU
0.01
0.001
0.0001
10^-5
10^-6
10^-7
1000
10000
10^5
Star passage distance - AU
M/V = 1 M⊙ / 30 km/s
M/V = 1/50

Figure 3c