The relative contribution of the Oort cloud and the scattered disc to the short-period comet population

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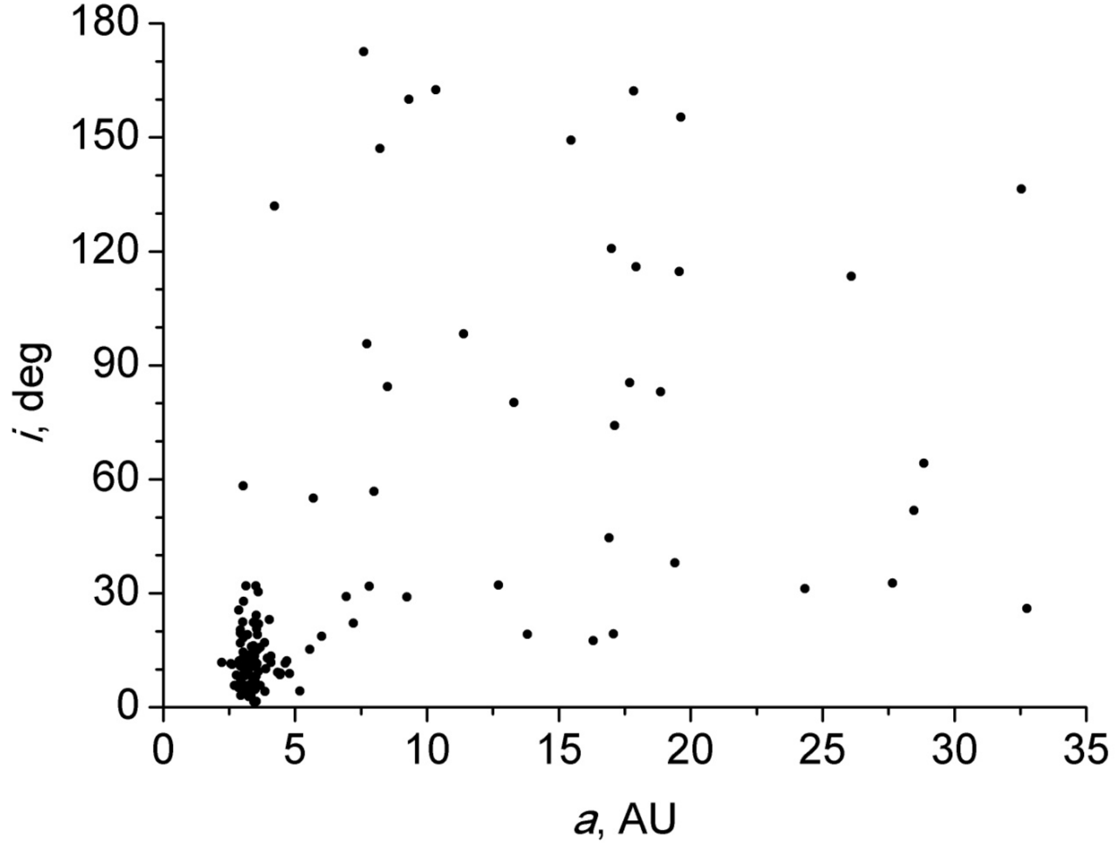
The origin of short-period comets

Explaining the origin of short-period (SP) comets (periods P <200 yr) is a long-standing problem.

a) 91 Jupiter-family comets (T>2, $0.1<q<1.5$ AU)

b) 38 Halley-type comets (T<2, $0.1<q<1.5$ AU)

Distribution of *a* and *i* for short-period comets with $0.1<q<1.5$ AU

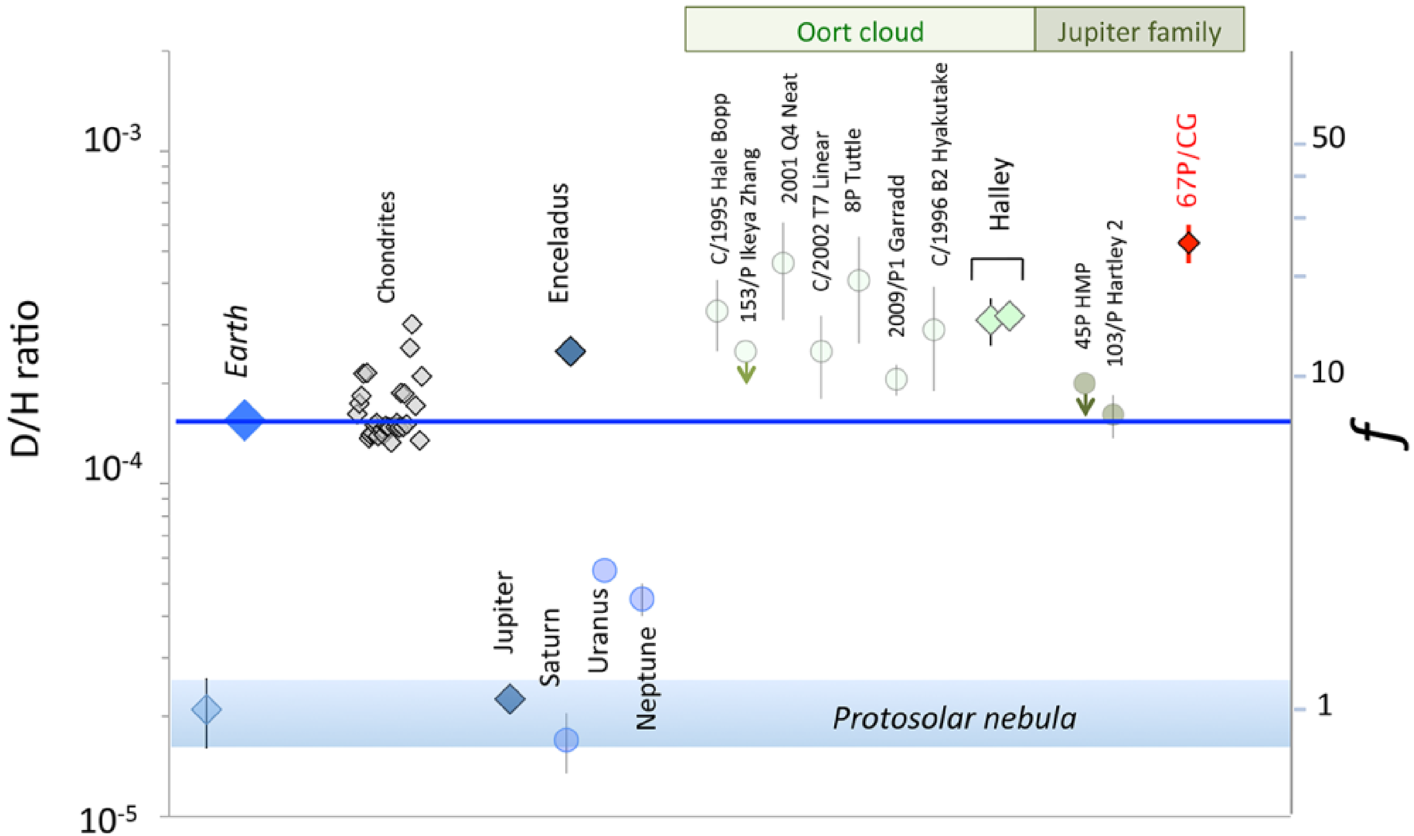


The majority of authors nowadays consider JF and HT comets to be physically as well as dynamically distinct classes, presumably formed in separate regions of the early Solar system and having different dynamical and physical evolutionary histories. Under this viewpoint, JF comets are often regarded as originating largely in the proto-planetary disc beyond Neptune, for example in or close to the Kuiper belt, and HT comets are regarded as objects captured from the Oort cloud.

First, it appears (Duncan, Levison 1997) that the scattered disc of primordial objects originally formed in the region of the major planets is the principal source of observed JF comets, rather than the classical Kuiper belt. Secondly, it seems (Emel’yanenko, Asher, Bailey 2013) that the Oort cloud gives a very significant contribution to the SP comet population.

Observations of the abundances of the volatile species H_2O, CO_2, and CO in comets show a wide range of abundance ratios and little if any systematic difference between Jupiter-family comets (JFCs) and long-period and Halley-type comets (LPCs and HTCs) (A’Hearn et al. 2012).

D/H ratio (Altwegg et al. 2014)



Definitions in this paper

The SP comets: q<1.5 AU, P<200 yr, including
JF comets (T>2) and HT comets (T<2).

The Centaurs: 5<q<28 AU, a<1000 AU (excluding a resonant trans-Neptunian objects and Trojans).

The scattered disc: q>30 AU, 50<a<1000 AU.

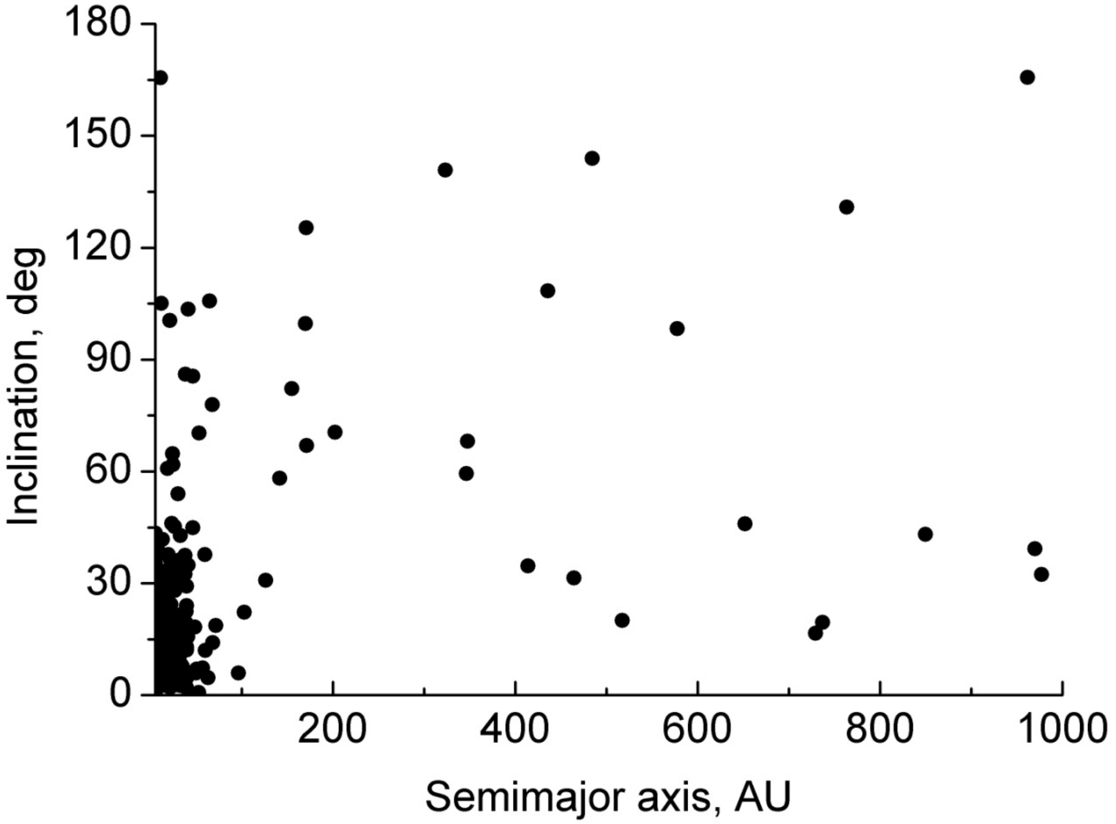
The near-Neptune high-eccentricity (NNHE) region: 28<q<35.5 AU, 60<a<1000 AU.

The Oort cloud: a>1000 AU, including
the inner part (1000<a<10000 AU) and
the outer part (10000<a<100000 AU).

Centaurs (5<q<28 AU, a<1000 AU, excluding resonant trans-Neptunian objects and Trojans)

Centaurs are an intermediate cometary population (including active comets and inactive apparent asteroids), some of them being en-route from the outer Solar system to near-Earth space and the SP comet region. As a transition population the Centaurs must be replenished from a more distant source, presumably located either in the trans-Neptunian region or the Oort cloud, and they play a pivotal role in constraining theories of the origin of SP comets.

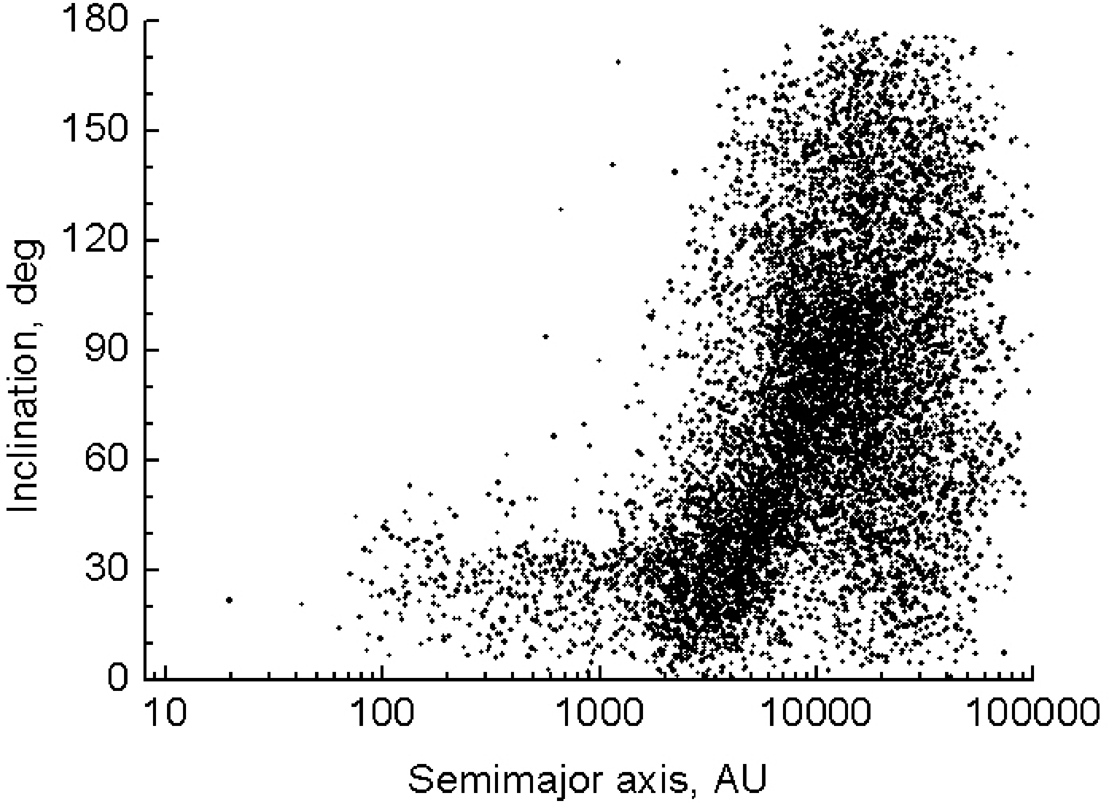
Distribution of the observed objects with $5<q<28$ AU, $a<1000$ AU, $\sigma_q<0.05$ AU (MPC)



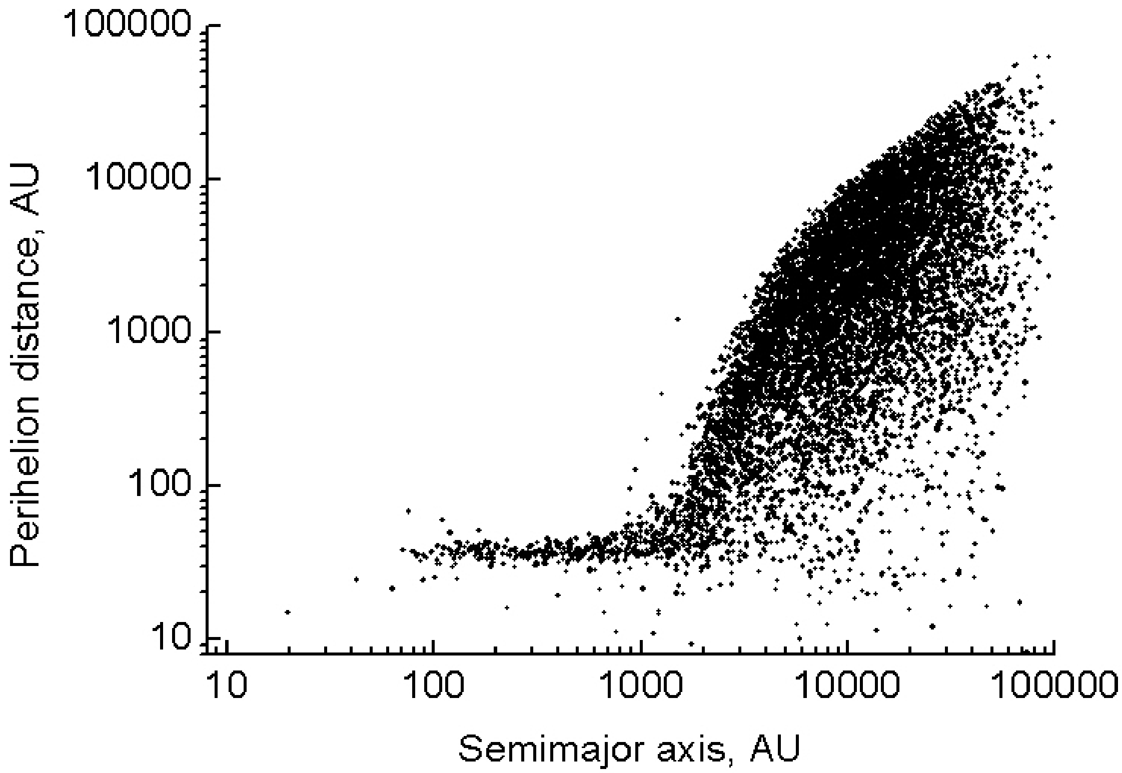
The Oort cloud (a>1000 AU)

There are various models of the Oort cloud formation (e.g., Duncan et al. 1987, Dones et al. 2004, Emel'yanenko, Asher and Bailey 2007, Rickman et al. 2008, Brasser et al. 2010, Kaib et al. 2011, Brasser and Mobidelli 2013, Fouchard et al. 2014). In these models, cometary planetesimals, formed in the proto-planetary disc, have been scattered outwards by the planets to become subject to stellar and Galactic perturbing forces.

Distribution of *a* and *i* for objects surviving after 4.5 Gyr (Emel’yanenko, Asher, Bailey 2007, 2013)



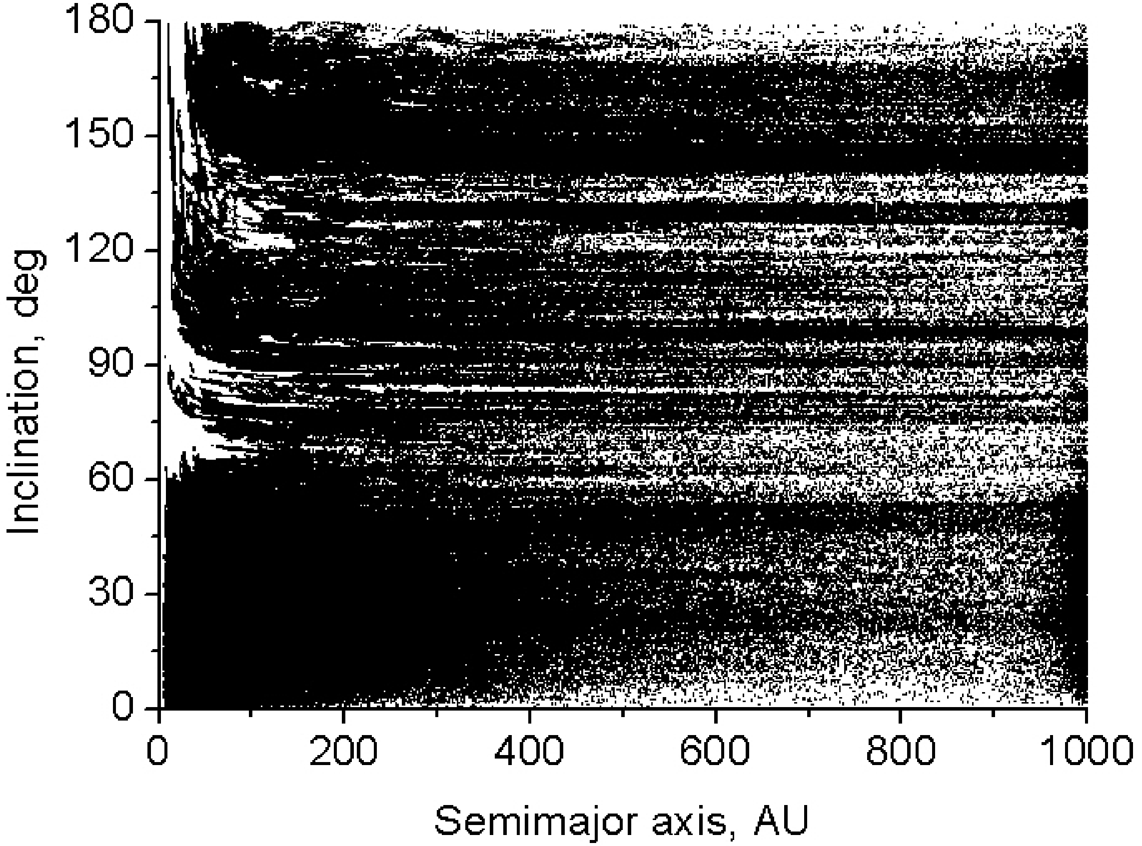
Distribution of *a* and *q* for objects surviving after 4.5 Gyr (Emel'yanenko, Asher, Bailey 2007, 2013)



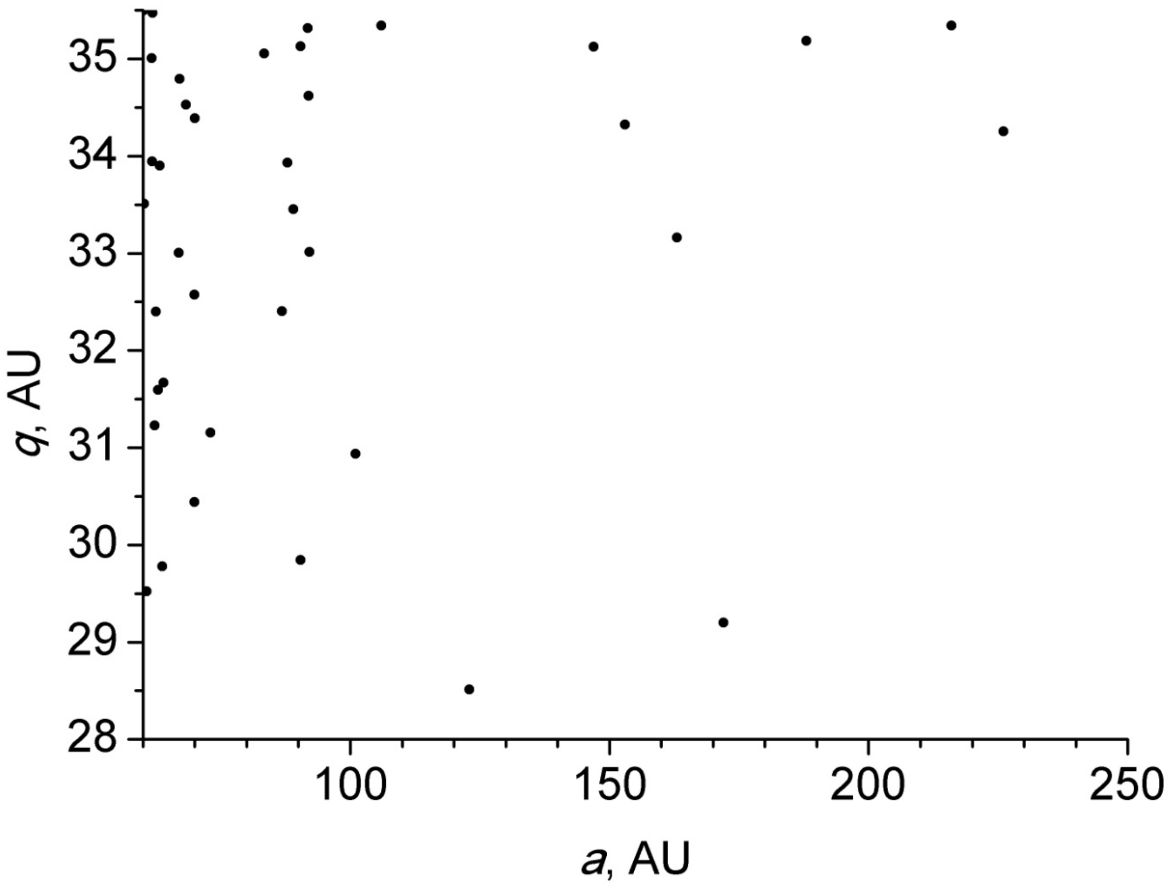
The Oort cloud

The flux of comets with a>10000 AU and $H_{10} < 11$ is $\nu_n \approx 2.5$ comets per AU in q per year (Bailey & Stagg 1988; Fernandez & Gallardo 1999; Francis 2005).

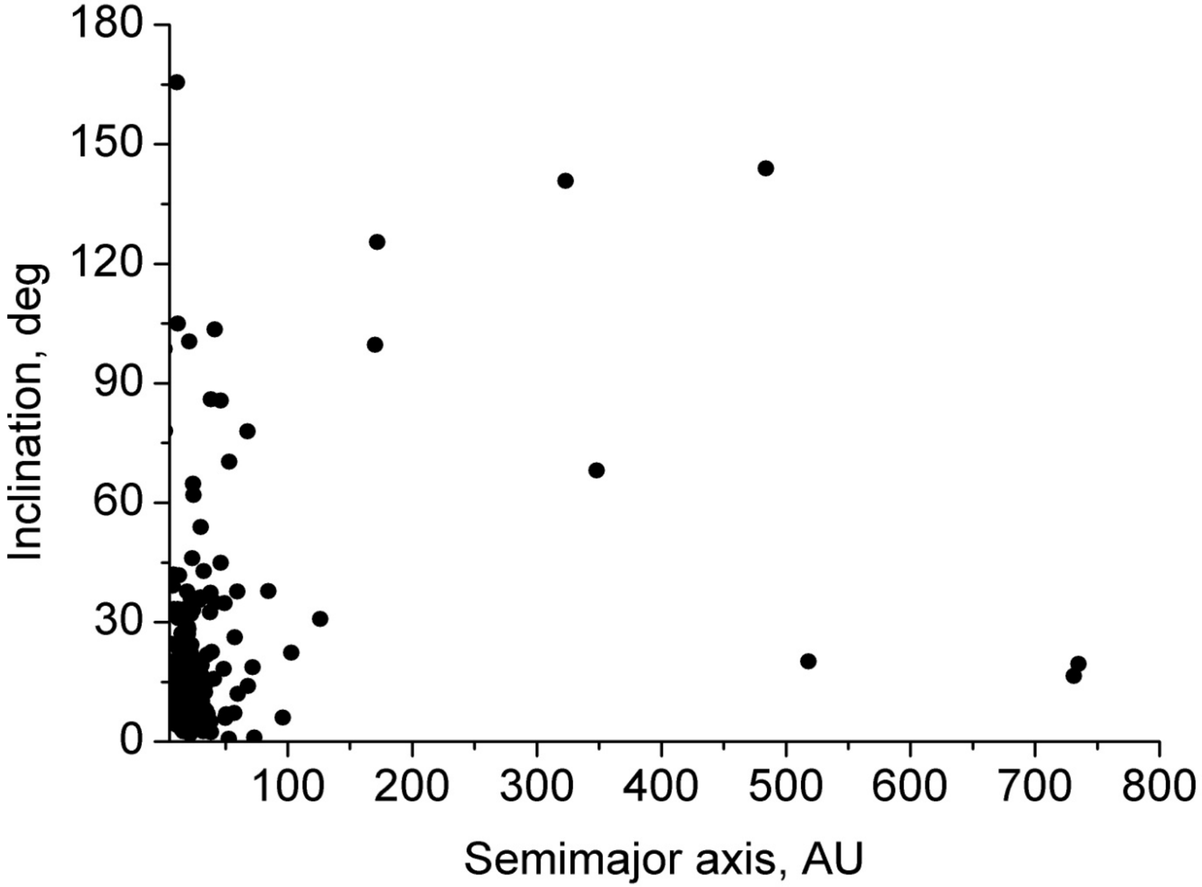
Distribution of *a* and *i* for perihelion passages of objects captured from the Oort cloud to the Centaur region



Distribution of the multiple opposition NNHE objects (MPC, 28<*q*<35.5 AU, 60<*a*<1000 AU). All the objects have *i*<40 deg.



Distribution of the multiple opposition Centaurs (MPC, $5<q<28$ AU, $a<1000$ AU)



The scattered disc

Near-Neptune high-eccentricity (NNHE) region: 28<q<35.5 AU, 60<a<1000 AU

$$N_C^{\ obs} = 0.13 N_N^{\ obs}$$ (Emel'yanenko, Asher, Bailey, 2005)

if we assume the same size distribution for Centaurs and SD objects

But from numerical studies (Emel'yanenko, Asher, Bailey, 2004)

$$N^{SD}{}_C = 0.008 N_N$$

This fact alone implies that the majority of Centaurs, particularly the majority of those with a>60 AU, must have another source, i.e. a source other than that represented by the observed NNHE region.

From our numerical simulations:

$$N^{SD}{}_{C}(a < 60) = 0.005 N_N,$$
$$N^{SD}{}_{C}(a > 60) = 0.003 N_N.$$

From the debiased observed distribution of distant objects:

$$N^{obs}{}_{C}(a < 60) = 0.013 N_N,$$
$$N^{obs}{}_{C}(a > 60) = 0.117 N_N.$$

Then

$$N^{OC}{}_{C}(a < 60) = 0.008 N_N,$$
$$N^{OC}{}_{C}(a > 60) = 0.114 N_N.$$

This ratio of 0.008/0.114≈0.07 is exactly what our model of the Oort cloud gives for $N^{OC}{}_{C}(a < 60) / N^{OC}{}_{C}(a > 60)$.

The number of initial objects is proportional to q_0^{α} where q_0 is the initial perihelion distance

$$(q_0 < 36\,AU)$$

	$\alpha = 1$	$\alpha = 0$
N_{OC}	6.1×10^{11}	5.8×10^{11}
N_{IC}	3.0×10^{11}	2.6×10^{11}
N_N	8.3×10^{9}	6.5×10^{9}
N_C	1.1×10^{9}	0.9×10^{9}
$N_C(a < 60)$	1.1×10^{8}	0.9×10^{8}
${\nu^{OC}}_{JF}$	0.13	0.10
${\nu^{SD}}_{JF}$	0.15	0.12

Model

$$N_0 \sim {q_0}^{\alpha}$$

$$\boldsymbol{\alpha > 0 \quad !}$$

$$L \sim {q_0}^{\beta}$$

$$L(q_0 > 25) = L_0$$

The number of cometary objects coming from various initial ranges of q_0 to different dynamical classes at

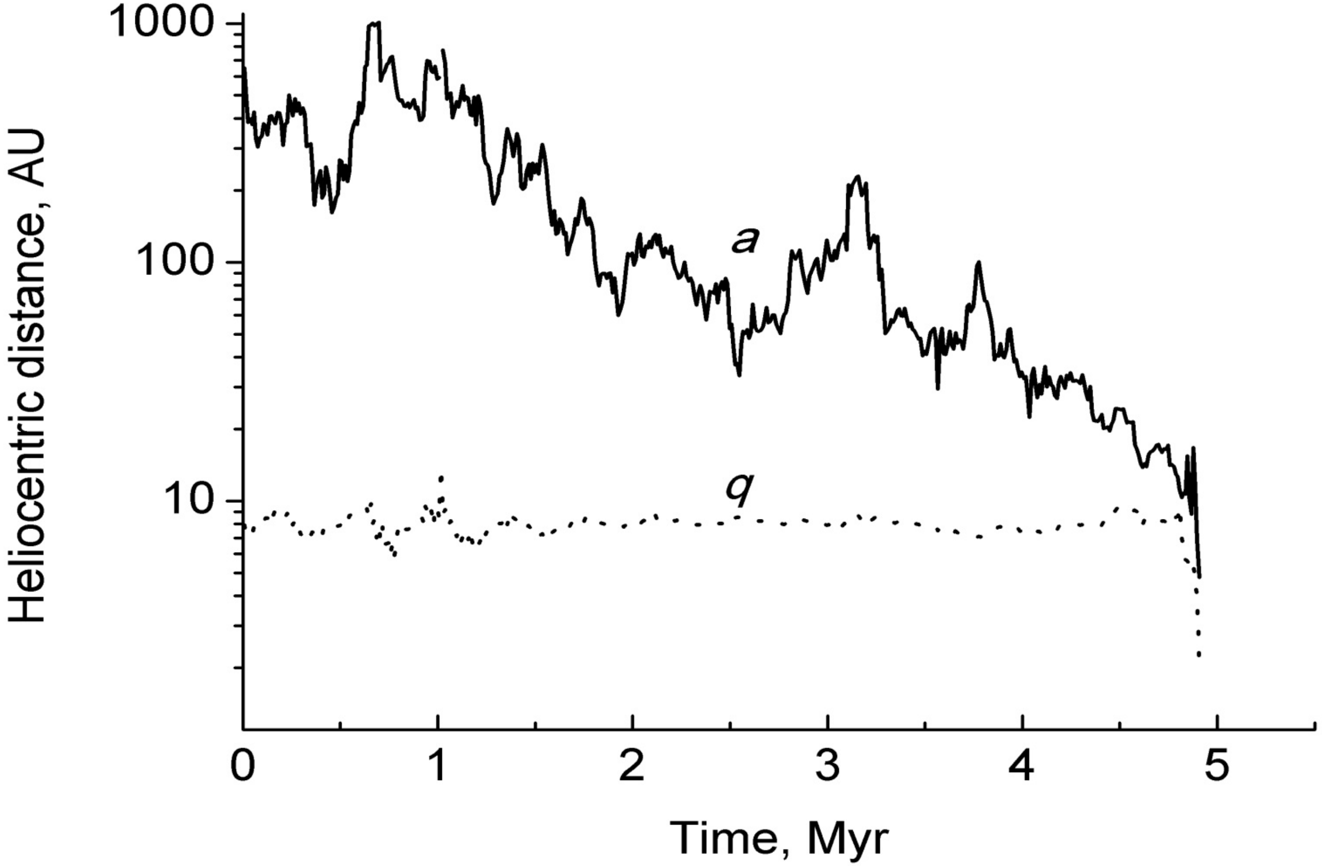
$$\alpha = 1, \beta = 2, L_0(q < 1.5\,AU) = 150,\ L_0(q < 2.5\,AU) = 420$$

Region (q_0)	5-10	10-25	25-36	SD
N_I	0.8×10^8	0.5×10^{11}	2.5×10^{11}	
N_O	0.1×10^{10}	1.3×10^{11}	1.8×10^{11}	
N_N	0	0.3×10^9	7.9×10^9	8.3×10^9
N_{JF}	0	1	41	51
N_{HT}	0	7	101	0

The number of NNHE objects in our simulations of the Oort cloud dynamics (8.2×10^9) is almost equal to the number of these objects estimated on the basis of observational data (8.3×10^9) .

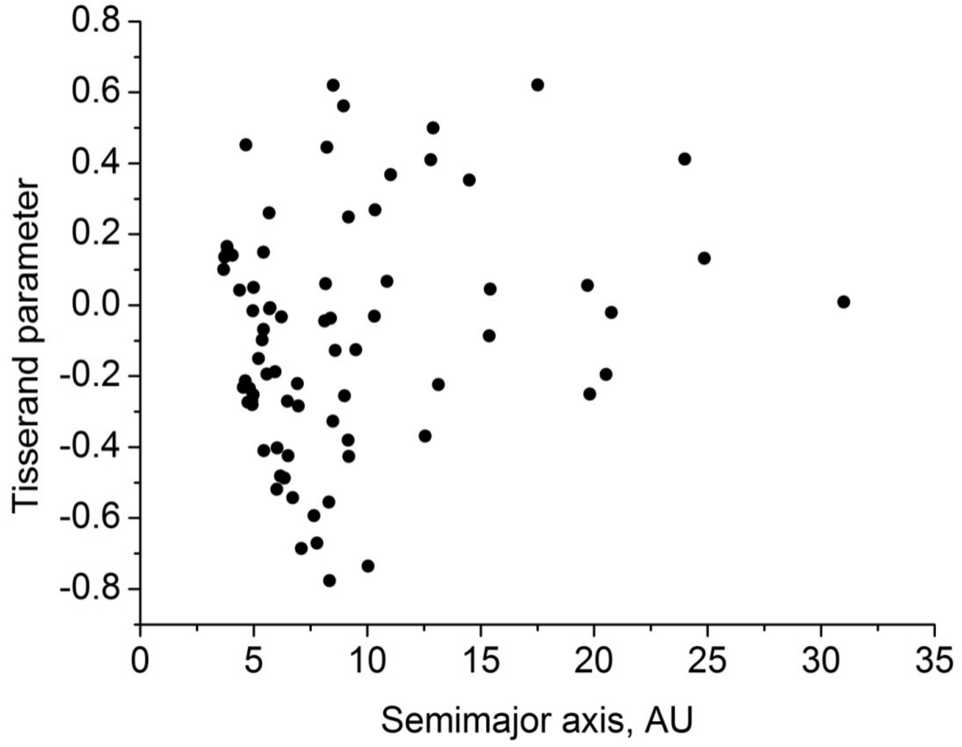
Then almost all objects observed in the NNHE region have already visited the Oort cloud region (a>1000 AU). This picture is consistent with the model (Brasser and Morbidelli 2013) on the common origin of the scattered disc and the Oort cloud.

Object 2013 AZ60 (*a*=651 AU, *q*=7.9 AU, *i*=16.5 deg)



Object 342842 (a=11.6 AU, q=6.5 AU, i=105 deg)

The probability of capture to SP orbits with q<1.5 AU is about 0.4

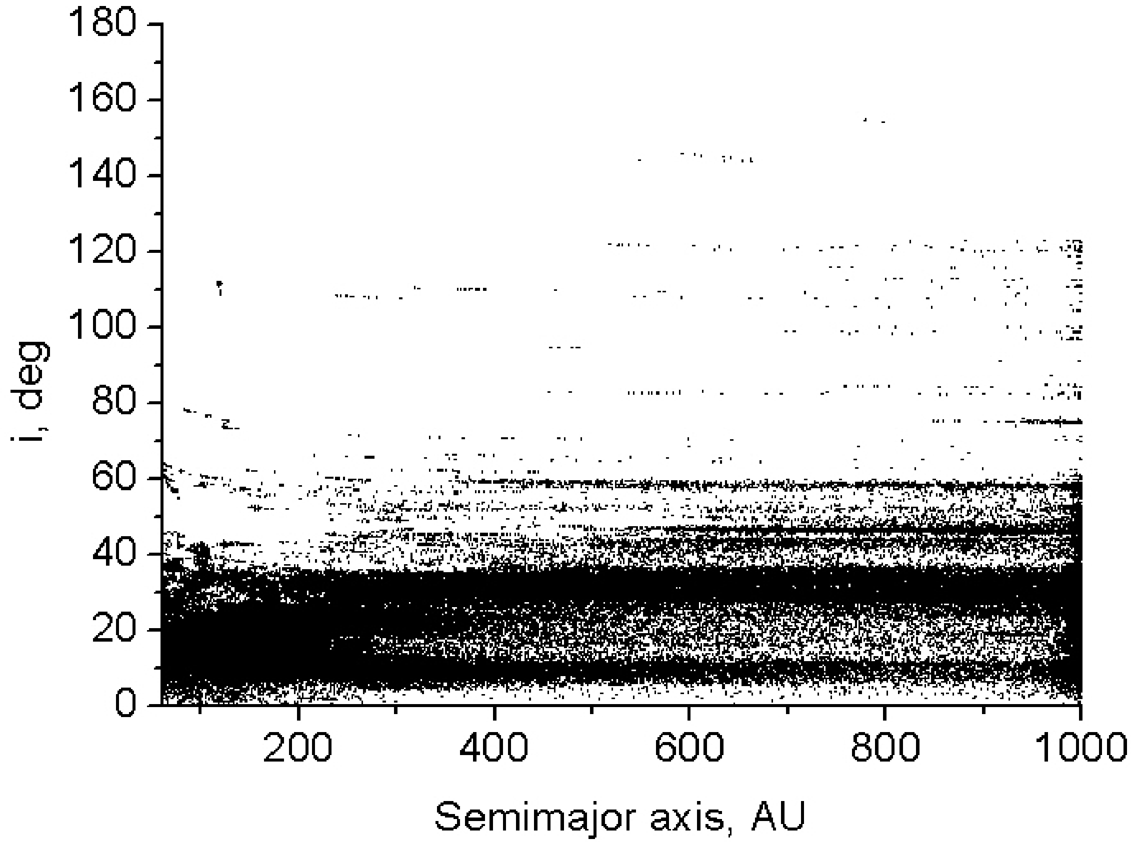


The observed example: 333P/LINEAR (a=4.2 AU, q=1.1 AU, i=132 deg)

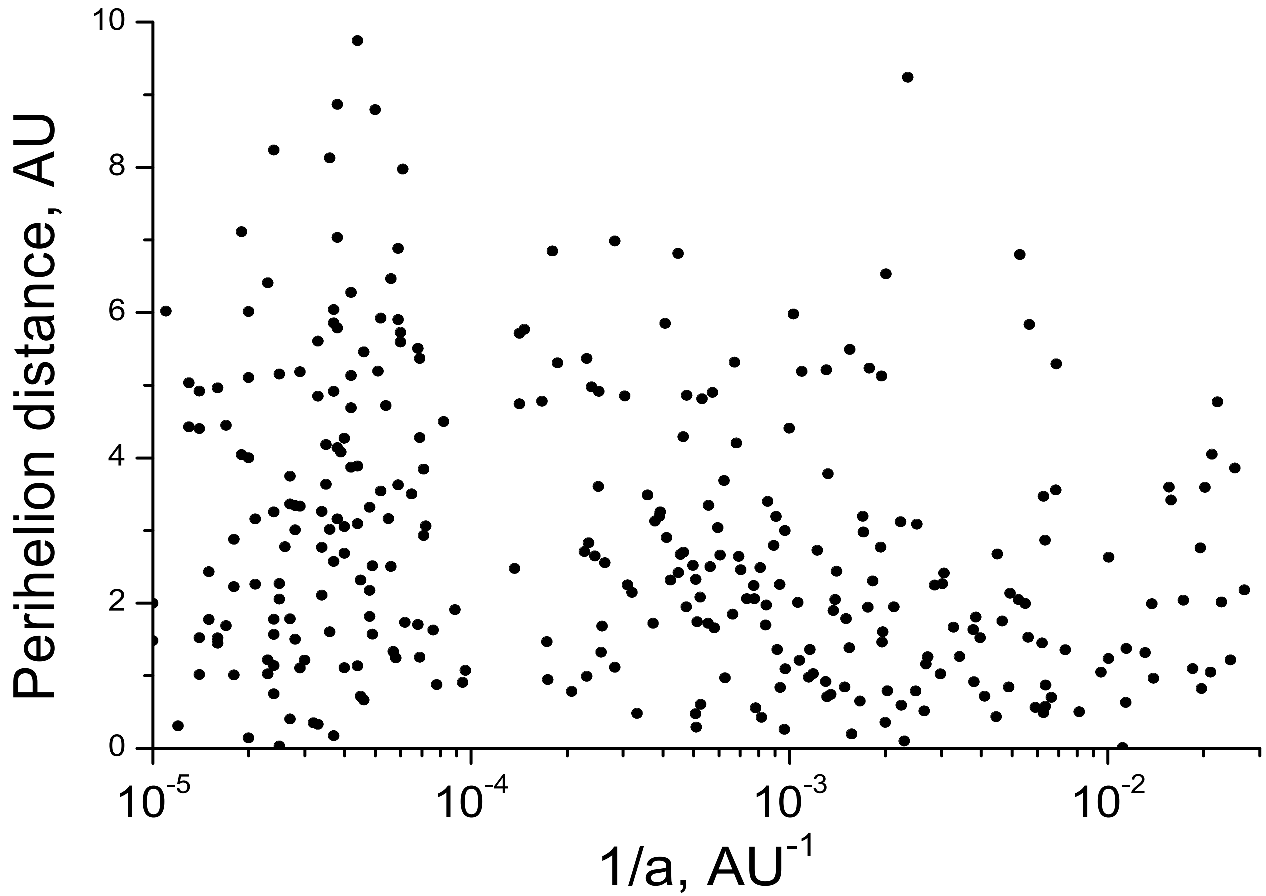
CONCLUSIONS

About half of the observed JF comets come from an Oort cloud source. The remaining ~50% of the JF comets come from the observed near-Neptune high-eccentricity population. It is quite possible that all the observed SP comets have experienced orbits with a >1000 AU.

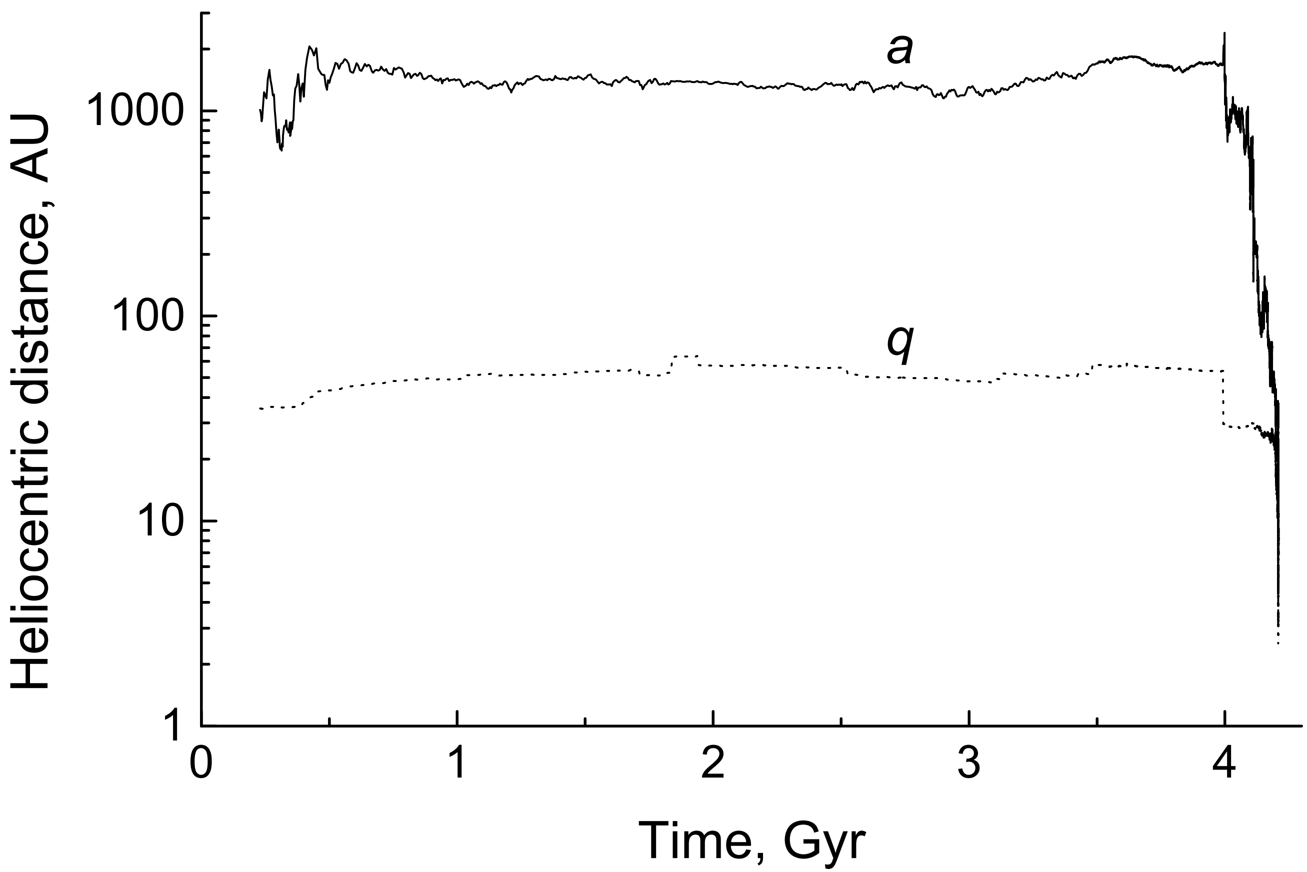
Distribution of *a* and *i* for perihelion passages of objects captured from the Oort cloud to the NNHE region



The distribution of *q* and *1/a* for long-period comets (Class 1, Marsden & Williams 2008)



Evolution of *a* and *q* for an object captured from the Oort cloud to the Jupiter family through the intermediate phase of Centaurs



Halley-type comets

HT comets: *T*<2, *q*<2.5 AU

	$\nu_{HT}(q>5)$
Only 25<*q*<36	0.069
$f(q)=const$	0.036
$f(q)\sim 1/q$	0.024
$f(q)\sim 1/q^2$	0.016

$$\nu_{HT}(q<2.5)\approx 0.1$$