Oort hypothesis

Piotr A. Dybczyński

425. seminarium astrofizyczne WFAIS UJ oraz Komisji Astrofizyki PAU,
Kraków, 30 marca 2022

Part one

How it all begins ...

In what follows I use excerpts from the book:

Jan Hendrik Oort: Master of the Galactic System

by Pieter C. van der Kruit, Springer 2020

BULLETIN OF THE ASTRONOMICAL INSTITUTES OF THE NETHERLANDS

1941 June 6 Volume IX No. 338

COMMUNICATIONS FROM THE OBSERVATORY AT LEIDEN

The attractive force of the galactic system as determined from the distribution of RR Lyrae variables, by *J. H. Oort* and *A. J. J. van Woerkom.*

Oort in 1941

Authors: Jan Hendrik Oort (1900 – 1992) and Adrianus Jan Jasper van Woerkom (1915 – 1991) . In 1941 van Woerkom, aged 26, was a student at Leiden.

Fig. 9.8 Participants in the second Netherlands Astronomers Conference in 1942. In the second row on the steps, we see from the left Blaauw, van Herk and Oort. In the back the second sitting person from the left is Adriaan Wesselink, next to him Johannes van Tulder and two persons further to the right Adriaan van Woerkom. The person sitting in the front in short sleeves is Henk van de Hulst and the one with sunglasses Jaap Houtgast. From the Netherlands Astronomers Club [230]

BULLETIN OF THE ASTRONOMICAL INSTITUTES OF THE NETHERLANDS

1948 December 8 | Volume X | No. 399

COMMUNICATION FROM THE OBSERVATORY AT LEIDEN

On the origin of comets, by *A. J. J. van Woerkom.*

In the first section a critical review is given of the more important previous investigations concerning the origin of comets. Already here it appears that small perturbations of the orbits, mainly caused by Jupiter, must be of paramount importance for the distribution of the major axes *a* of the long-period comets.

The one was Adriaan van Woerkom, who had already collaborated with Oort on the vertical force field in the Galaxy, resulting in a joint paper (Oort and van Woerkom 1941b; see Sect. 9.4). His thesis was the result of a suggestion by Hertzsprung concerning the origin of comets and the dynamics of their orbits. Since this was also the competence of Jan Woltjer, it is not inconceivable that Woltjer had been involved intimately with van Woerkom's work; he was thanked profusely in the preface to the thesis. Since Hertzsprung had left Leiden after the end of the War, and Woltjer had died as a result of the sufferings in the 'hunger winter', it was natural that Oort would act as van Woerkom's 'promotor', which resulted in a Ph.D. thesis defended in 1948

Adrianus Jan Jasper van Woerkom

Born October 3, 1915 in Werkendam, the Netherlands, van Woerkom began his professional life as an astronomer specializing in Celestial Mechanics after completing his Ph.D. in 1948 under the guidance of the well known Dutch astronomer, J.H. Oort. His extensive monograph, “On the Origin of Comets”, remains a seminal reference in the field today. He was then hired by Dirk Brouwer, Director of the Yale University Observatory, as a Research Associate and served as director of the computing laboratory which the Observatory established at that time.

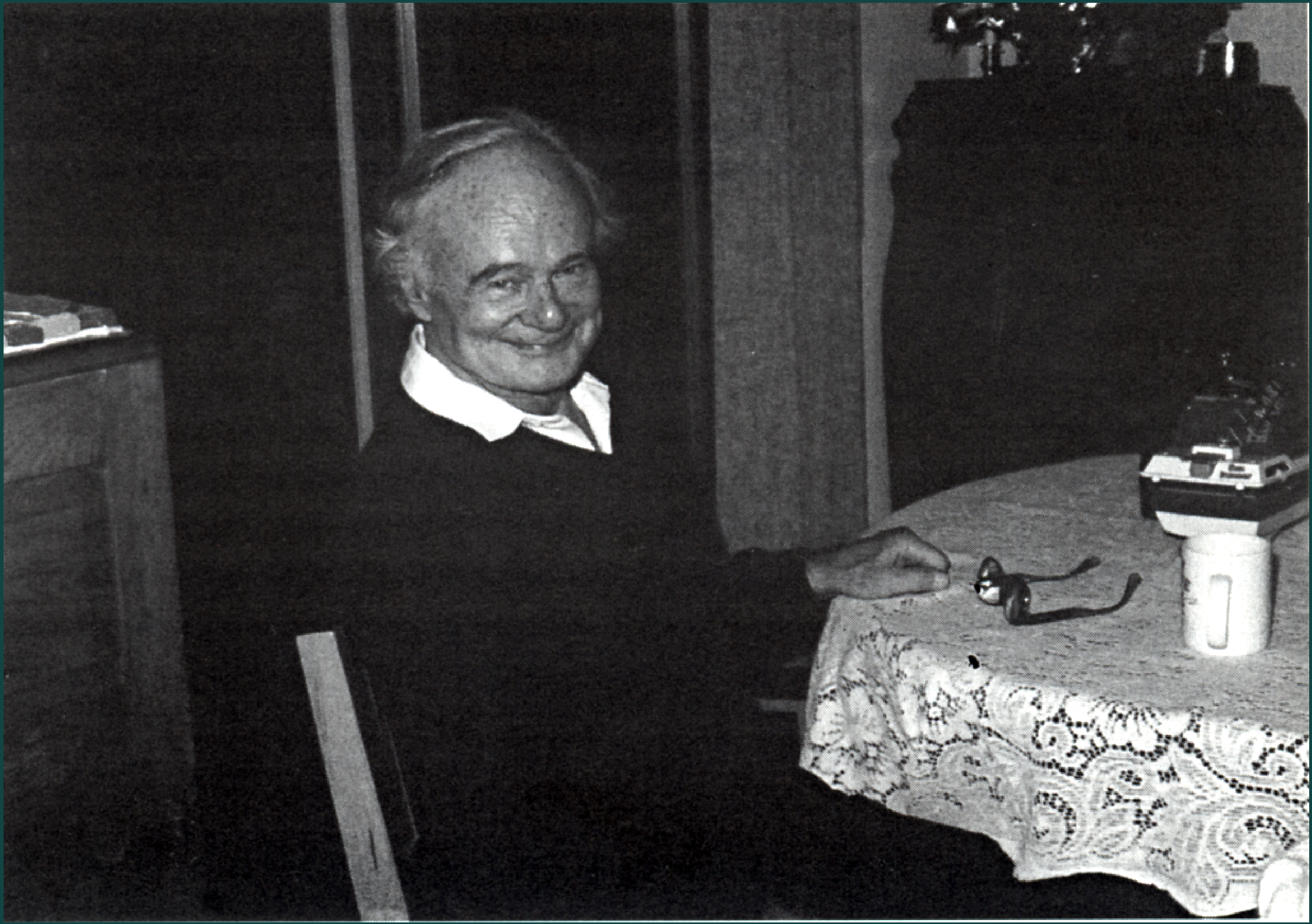
During his eight years at Yale, van Woerkom applied his creative mind to a large array of problems in Celestial Mechanics and Astrometry, including the secular perturbations of asteroids, numerical integrations of the orbits of Mars, Ceres, Pallas, Vesta, Juno, the motions of Uranus, Neptune and Pluto, and a repetition of the well-known numerical integrations of the five outermost planets, originally carried out on the SSEC and now executed on the Naval Weapons Laboratory computer known as NORC, to determine better mass coefficients. This period includes the still often-cited work, done jointly with Brouwer, on the secular variations of the orbital elements of the principal planets published in 1950 in the *Astronomical Papers of the US Naval Observatory Nautical Almanac*.

From the Obituary written by R. L. Duncombe and M. S. Davis,
Celestial Mechanics and Dynamical Astronomy, vol.53, no.1, 1992

Adrianus Jan Jasper van Woerkom

A.J.J. van Woerkom, known to his friends as “Jos”, died on July 8, 1991, at the age of 75 in Yale-New Haven Hospital after a brief illness. From 1972 to 1990 he was Chief Scientist in the Office of the Technical Director of the Naval Underwater System Center in New London, Connecticut. Prior to that he served for 16 years at the Electric Boat Company as technical director and later program manager of primary research efforts which underlie present submarine integrated combat systems. While there in the late 50’s, he introduced computers into engineering, scientific and business systems, and applications to the development of tactical weapons systems for submarines.

From the Obituary written by R. L. Duncombe and M. S. Davis,
Celestial Mechanics and Dynamical Astronomy, vol.53, no.1, 1992



Van Woerkom in his thesis clearly demonstrated that all proposed theories of cometary origin, both for short period comets and long period population are completely inconsistent with observations.

Comets can not originate from the Solar System but also do not come from the interstellar space.

Oort (1950) picked up the problem where van Woerkom had left it ...

PASP, 1993, vol.105, p. 681-685

Part two

What did Oort postulate ?

BULLETIN OF THE ASTRONOMICAL INSTITUTES OF THE NETHERLANDS

1950 JANUARY 13 VOLUME XI NUMBER 408

COMMUNICATION FROM THE OBSERVATORY AT LEIDEN

THE STRUCTURE OF THE CLOUD OF COMETS SURROUNDING THE SOLAR SYSTEM, AND A HYPOTHESIS CONCERNING ITS ORIGIN,

BY J. H. OORT

The combined effects of the stars and of Jupiter appear to determine the main statistical features of the orbits of comets.

From a score of well-observed original orbits it is shown that the "new" long-period comets generally come from regions between about 50000 and 150000 A.U. distance. The sun must be surrounded by a general cloud of comets with a radius of this order, containing about 10^{11} comets of observable size; the total mass of the cloud is estimated to be of the order of 1/10 to 1/100 of that of the earth. Through the action of the stars fresh comets are continually being carried from this cloud into the vicinity of the sun.

The article indicates how three facts concerning the long-period comets, which hitherto were not well understood, namely the random distribution of orbital planes and of perihelia, and the preponderance of nearly-parabolic orbits, may be considered as necessary consequences of the perturbations acting on the comets.

The theoretical distribution curve of $1/a$ following from the conception of the large cloud of comets (Table 8) is shown to agree with the observed distribution (Table 6), except for an excess of observed "new" comets. The latter is taken to indicate that comets coming for the first time near the sun develop more extensive luminous envelopes than older comets. The average probability of disintegration during a perihelion passage must be about 0·014. The preponderance of direct over retrograde orbits in the range from *a* 25 to 250 A.U. can be well accounted for.

The existence of the huge cloud of comets finds a natural explanation if comets (and meteorites) are considered as minor planets escaped, at an early stage of the planetary system, from the ring of asteroids, and brought into large, stable orbits through the perturbing actions of Jupiter and the stars.

The investigation was instigated by a recent study by VAN WOERKOM on the statistical effect of Jupiter's perturbations on comet orbits. Action of stars on a cloud of meteors has been considered by ÖPIK in 1932.

1. *Sketch of the Problem.*

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BULLETIN OF THE ASTRONOMICAL INSTITUTES OF THE NETHERLANDS

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TABLE 1

Oort paper can be roughly divided into four parts:

- an evidence that the Solar System is surrounded by a huge cloud of comets,
- a discussion on the importance of stellar perturbations in the inference on the cloud structure, velocity distribution and its long term evolution,
- a comparison of the 1/a distribution resulting from the proposed model with observations including the comet fading problem,
- and finally a hypothesis on the origin of the cometary cloud assuming that it formed together with the rest of the Solar System.

Table I

Distribution of original semi-major axes (*a* in Astronomical Units)

1/*a*		*n*
	< ·000 05	10
·000 05	— 10	4
10	15	1
15	20	1
20	25	1
25	50	1
·000 50	75	1
	> ·000 75	0

Oort wrote: among the so-called long-period comets there are 22 for which, largely by the work of Elis Strömgren, accurate calculations have been made of the orbits followed when they were still far outside the orbits of the major planets (1). For the present limiting ourselves to the comets for which the perturbations were rigorously determined, and excluding 3 for which the mean error of the reciprocal major axis, 1/a, is larger than 0.000100, the values of 1/a for the remaining 19 comets are distributed as shown in Table I.

In a footnote he specified:

1. A list of these is given by Sinding, Danske Vidensk. Selsk., Mat.-Fys. Medd. 24, Nr 16, 1948, or Publ. o. Mindre Medd. Köbenhavns Obs. Nr 146. Van Biesbroeck's orbit for comet 1908 III has been added to this list.

From: Geelmuyden-Strömgren, Lærebog i Astronomi, published at Oslo in 1945., page 285.

Nr.	Komet	Oskulerende e	Oskulerende $\frac{1}{a}$	Middelfejl	Oprindeligt $\frac{1}{a}$	
1	1853 III ..	1.000 2514	— 0.000 8193	± 0.000 0228	+ 0.000 0829	
2	1863 VI ..	1.000 6499	— 0.000 4949	0495	+ 0.000 0166	
~~3~~	~~1882 II ...~~	~~0.999 9078~~	~~+ 0.011 8963~~	~~2710~~	~~+ 0.012 1488~~	
4	1886 I ...	1.000 4461	— 0.000 6944	0220	— 0.000 0071	
5	1886 II ...	1.000 2286	— 0.000 4770	0091	+ 0.000 3166	
6	1886 IX ..	1.000 3824	— 0.000 5765	0276	+ 0.000 0630	
7	1889 I ...	1.001 255	— 0.000 6915	0606	+ 0.000 042	
8	1890 II ...	1.000 4103	— 0.000 2151	0101	+ 0.000 0718	
9	1897 I ...	1.000 9270	— 0.000 8722	0476	+ 0.000 0396	
10	1898 VII..	1.001 0336	— 0.000 6074	0096	— 0.000 0157	
11	1902 III ..	0.999 9675	+ 0.000 0810	0184	+ 0.000 0054	*
12	1904 I ...	1.001 3646	— 0.000 5040	0079	+ 0.000 2165	
13	1905 VI ..	1.000 1846	— 0.000 1424	0501	+ 0.000 6210	
14	1907 I ...	1.001 024	— 0.000 4991	0400	+ 0.000 0252	
~~15~~	~~1910 I ...~~	~~0.999 9723~~	~~+ 0.000 2143~~	~~1479~~	~~+ 0.003 3021~~	
16	1914 V ...	1.000 1618	— 0.000 1465	0031	+ 0.000 0119	
17	1922 II ...	1.000 8596	— 0.000 3806	0174	+ 0.000 0038	**
18	1925 I ...	1.000 6286	— 0.000 5665	0310	+ 0.000 0540	
19	1925 VII..	1.000 4276	— 0.000 2730	0226	+ 0.000 1150	
20	1932 VI ..	1.001 3760	— 0.000 5948	0010	+ 0.000 0441	
~~21~~	~~1936 I ...~~	~~1.001 97~~	~~— 0.000 487~~	~~22~~	~~+ 0.000 205~~	

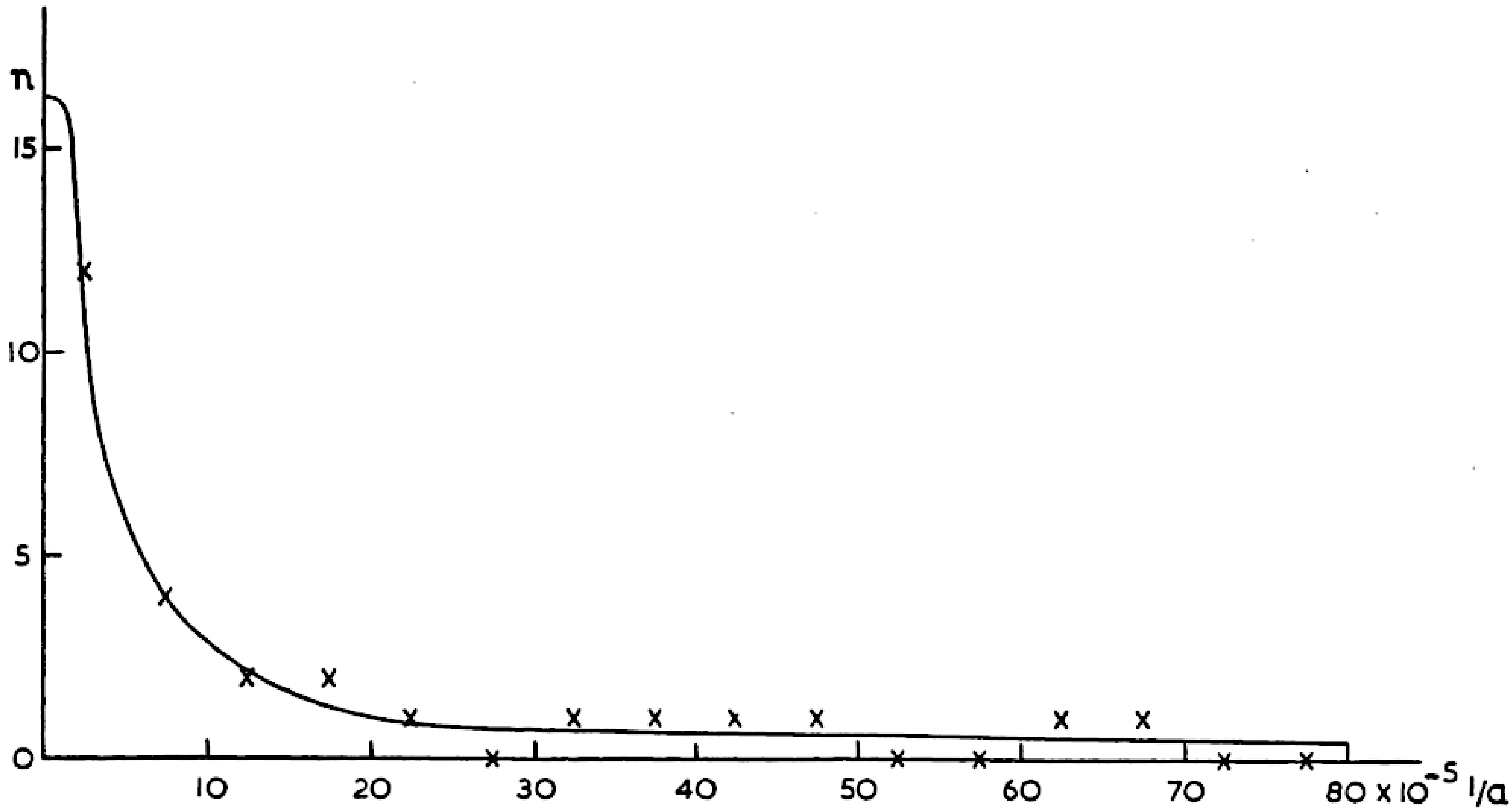
More: https://apollo.astro.amu.edu.pl/PAD/pmwiki.php?n=WikicometPub.OortTable

* 1902 III → $1/a = 0.0000054$ → $a \cong$ 185000 au

** 1922 II → $1/a = 0.0000038$ → $a \cong$ 263000 au

and the aphelion distance $Q = 2 * a$!

FIGURE I



Distribution of reciprocal semi-major axes. Crosses indicate numbers of comets in intervals of ·00005 in 1/*a*.

Oort & Schmidt, 1951, BAN vol.11, p. 259

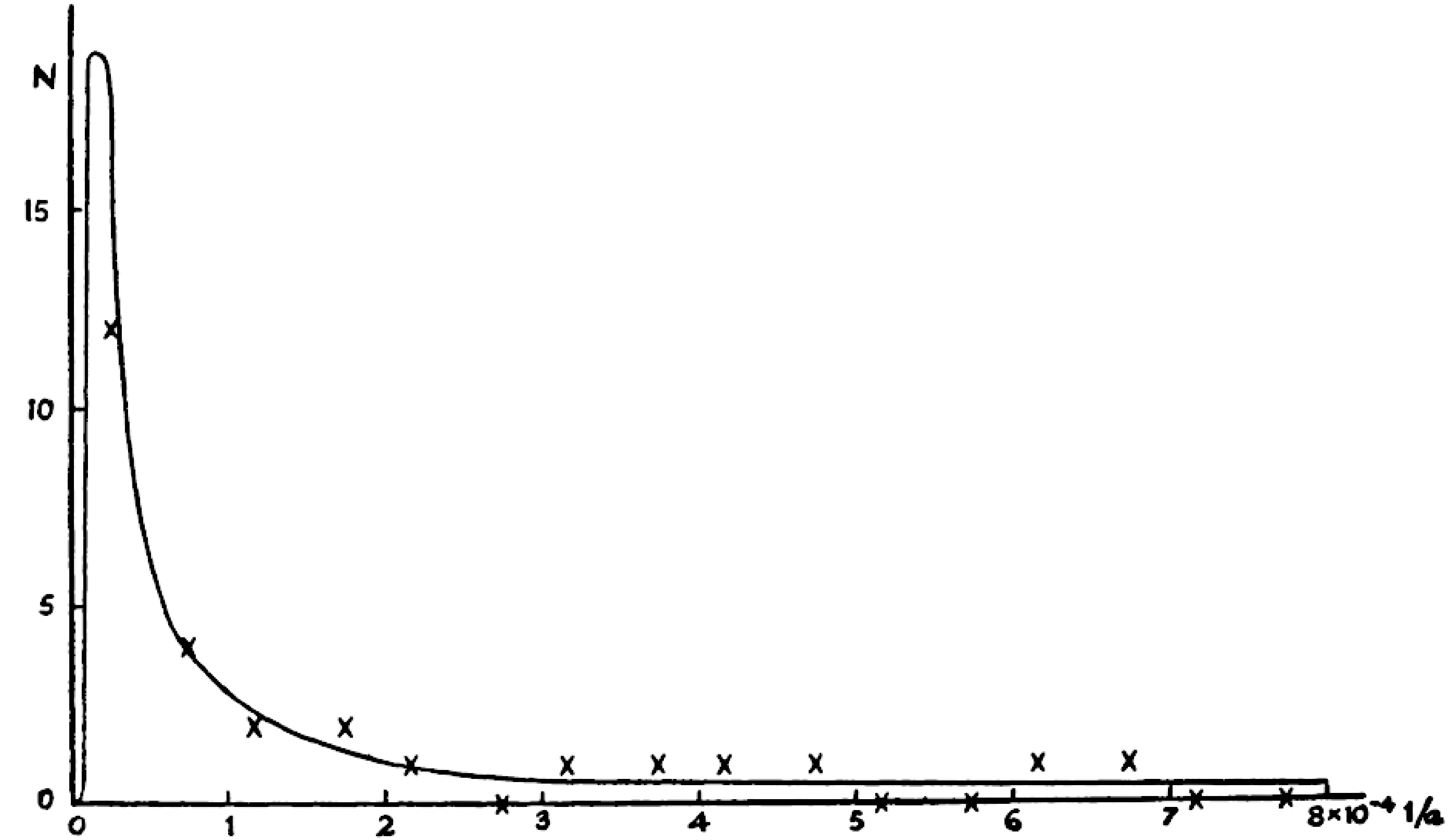


Fig. 5.
Distribution of reciprocal semi-major axes of comet orbits.

The semi-major axes are expressed in astronomical units; one division of the horizontal scale corresponds to 10^{-4} A.U.$^{-1}$, ordinates are numbers of orbits per interval of 5×10^{-5}. (From *B.A.N.* **11**, 259, 1951).

Oort, 1951, Origin and development of comets,
Halley Lecture for 1951, delivered at Oxford on May 1.

Part three

In next years ...

THE UNIVERSITY OF ARIZONA

TUCSON

STEWARD OBSERVATORY

January 13, 1961

Dr. J. H. Oort, Director
Sterrewacht
Leiden, Holland

Dear Dr. Oort:

On his return to Tucson Dr. Kuiper told me that you are agreeable to collaborating with Dr. van Woerkom on the chapter, COMETS: STATISTICS AND DYNAMICS OF ORBITS. He also mentioned that Mrs. Groeneveld-van Houten may be associated with you in this chapter. We are very happy that you are willing to do this.

...

Sincerely yours,

Barbara Middlehurst

Barbara Middlehurst
Associate Editor

cc: Dr. van Woerkom

ELECTRIC BOAT

DIVISION OF GENERAL DYNAMICS CORPORATION

GROTON, CONNECTICUT

IN REPLY REFER
TO FILE NO.

11/29/61

Dear Dr. Oort.

THE UNIVERSITY OF ARIZONA

TUCSON

LUNAR AND PLANETARY LABORATORY

December 5, 1961

Dr. A. J. J. van Woerkom
Post Office Box 82
Niantic, Connecticut

Dear Dr. van Woerkom:

Many thanks for your letter of November 29. I am very sorry that you find that you can not participate in the chapter on comets for Volume IV of "The Solar System."

With best personal wishes,

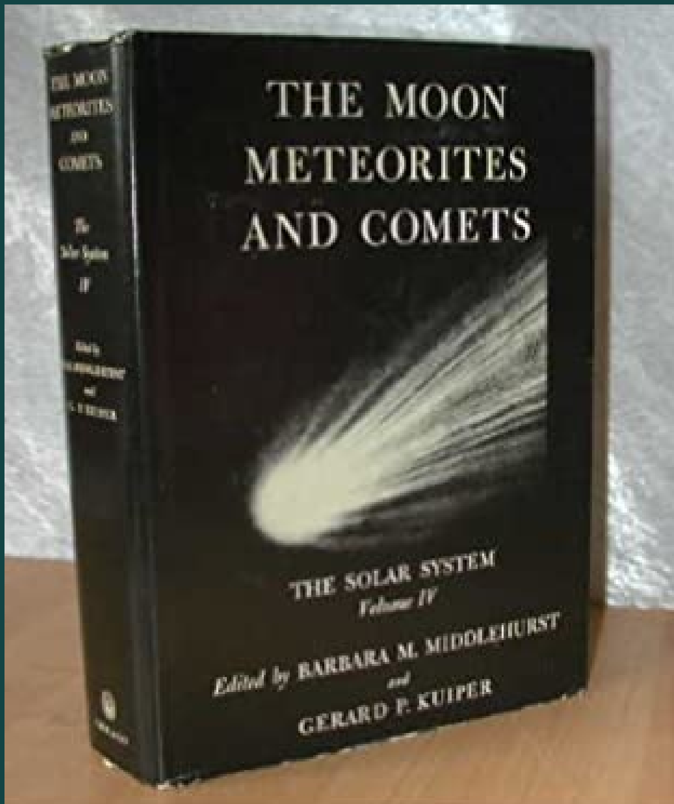
Sincerely yours,

Gerard P. Kuiper

GPK/dh

cc: Dr. Oort
Miss Middlehurst

COPY



CHAPTER 20

Empirical Data on the Origin of Comets

By J. H. OORT
Leiden Observatory

The Solar System. vol. 4, The Moon, Meteorites, and Comets.
Barbara M. Middlehurst and Gerard P. Kuiper, Eds.
University of Chicago Press, Chicago, 1963. xxii + 810 pp.

TABLE 1

Distribution of $1/a$

Interval $1/a$	n	n_{corr}
−0.00015 to −0.00011	1	0
− .00010 − .00006	1	0
− .00005 − .00001	4	0
.00000 + .00004	15	26
+ .00005 + .00009	8	5
+ .00010 + .00014	3	1
+ .00015 + .00019	1	1
+ .00020 + .00024	1	1
+ .00025 + .00049	1.0 (5)	1.0
+ .00050 + .00074	0.8 (4)	0.8
+ .00075 + .00099	0.6 (3)	0.6
+ .00100 + .00199	0.25 (5)	0.17 (10)
+ .00200 + .00499	0.05 (3)	0.08 (14)
+ .00500 + .00999	0.05 (5)	0.043 (13)
+ .01000 + .01999	0.015 (3)	0.017 (10)
+0.02000 +0.03999	0.002 (1)	0.004 (5)

The Moon Meteorites and Comets, Edited by Gerard P. Kuiper, and Barbarra Middlehurts. Chicago: The University of Chicago Press, 1963, p.666

Once again Oort persists with his shell idea, steadfastly repeating the patent errors on which it proceeds. For reasons still unexplained, Oort plots the number of comets against $1/a$, the reciprocal of the semi-major axis, and regards it as significant that a large number appear for small values of $1/a$. But this property of a reciprocal plot holds for any distribution that extends to large values, as, for example, the positive integers. It may be mentioned that the distribution of number of comets against a itself has recently been plotted independently (by Dr. B. G. Marsden at my own suggestion) and is found to show no special group at large values of a.

Lyttleton, R. A., Nature, Volume 202, Issue 4932, pp. 526-527 (1964).

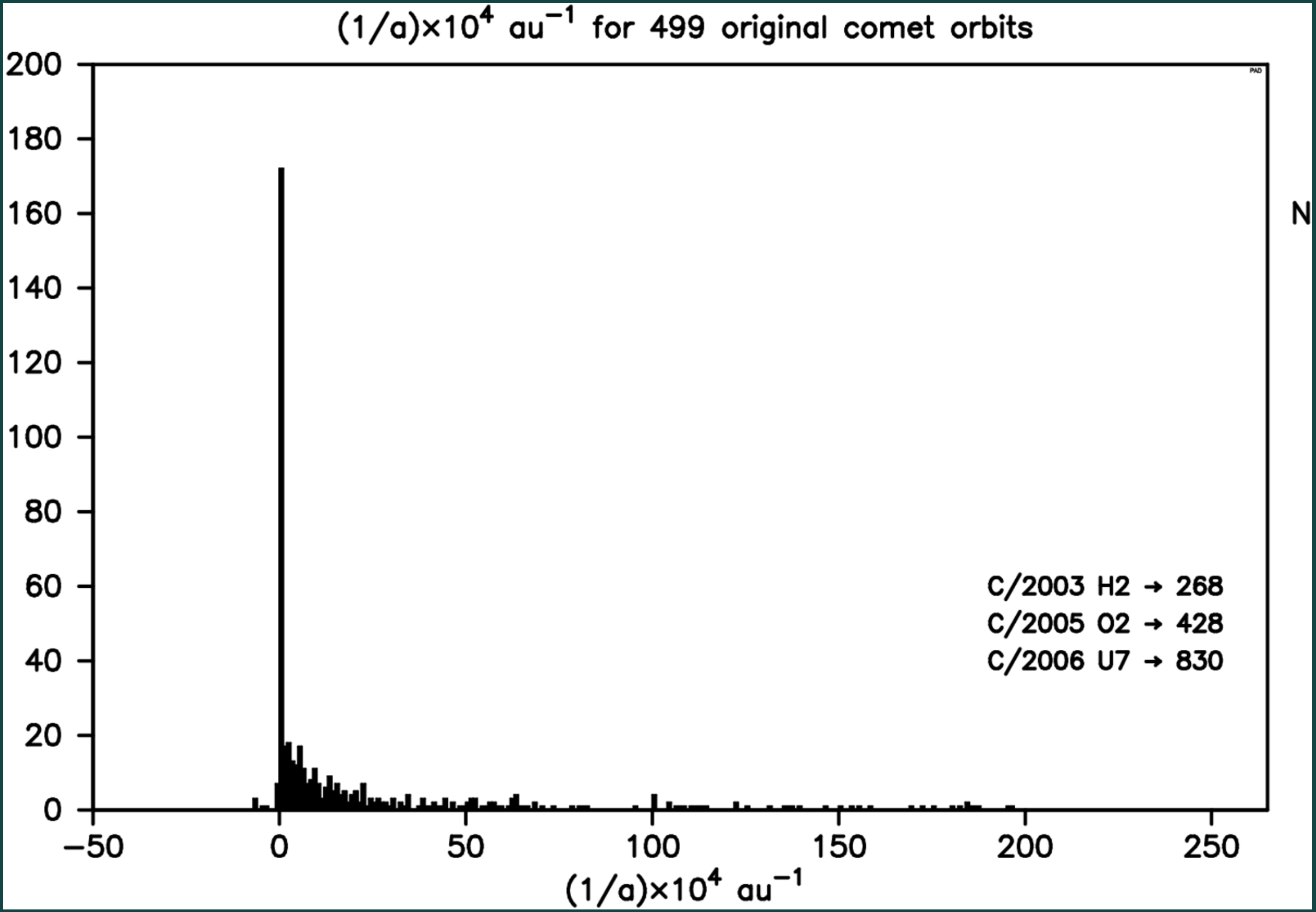
Dr. Lyttleton wonders why, in exposing this picture I have tabulated reciprocal values of the semi-major axes (1/_a_) instead of, as he appears to prefer, the semi-major axes, _a_, themselves. It is evident that this is irrelevant. It is only more _convenient_, as well as more natural, to present the results in a table showing values of 1/_a_, as 1/_a_ represents the orbital energy per unit of mass. Perturbations by the planets cause a certain change in this energy, and therefore in 1/_a_, which is independent of the orbital energy. On the other hand the corresponding changes in _a_ itself depend, of course, strongly on _a_.

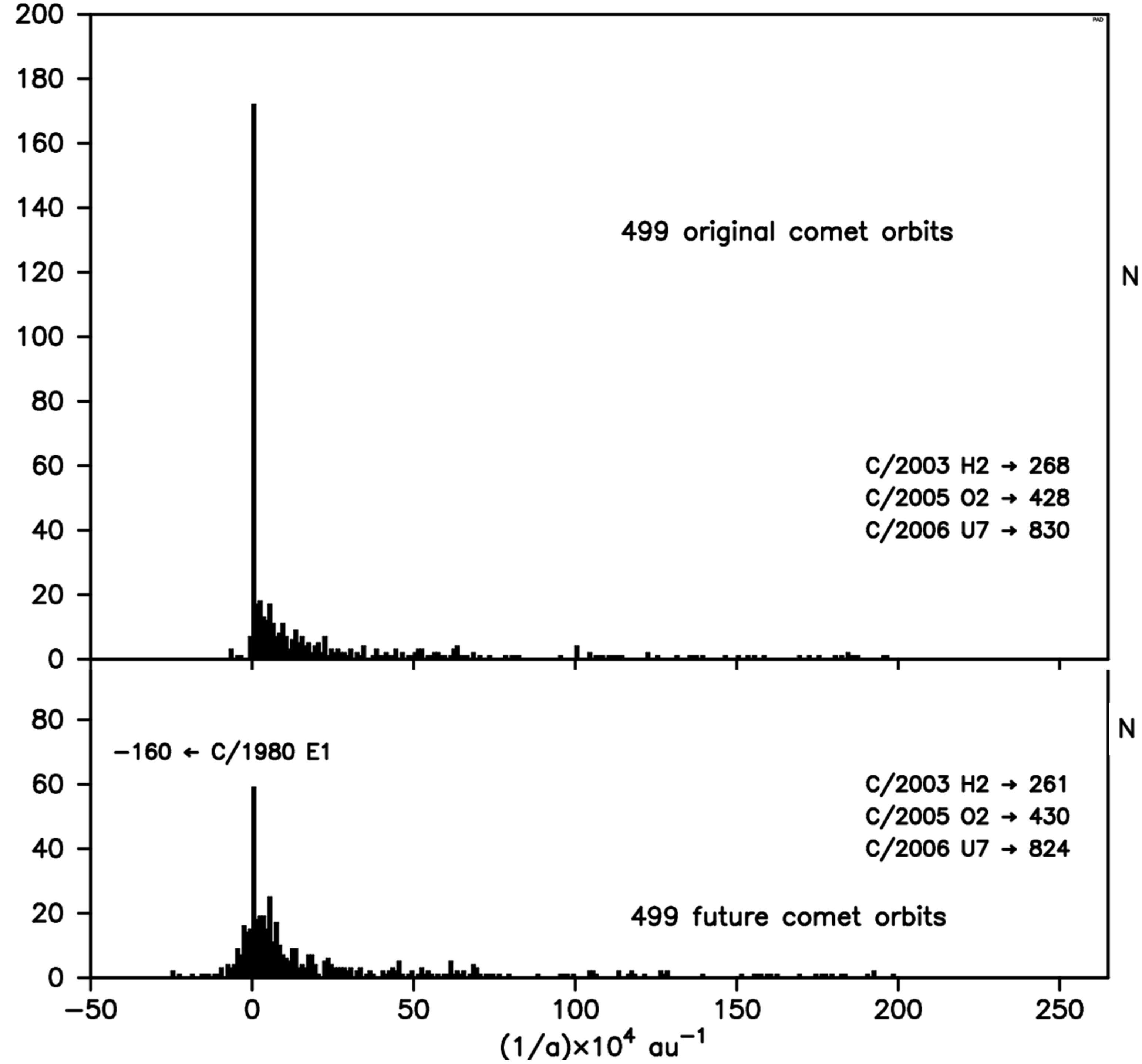
A small piece of the letter from Oort to the Nature editors as a response to the Lyttleton's review of the book.

Part four:

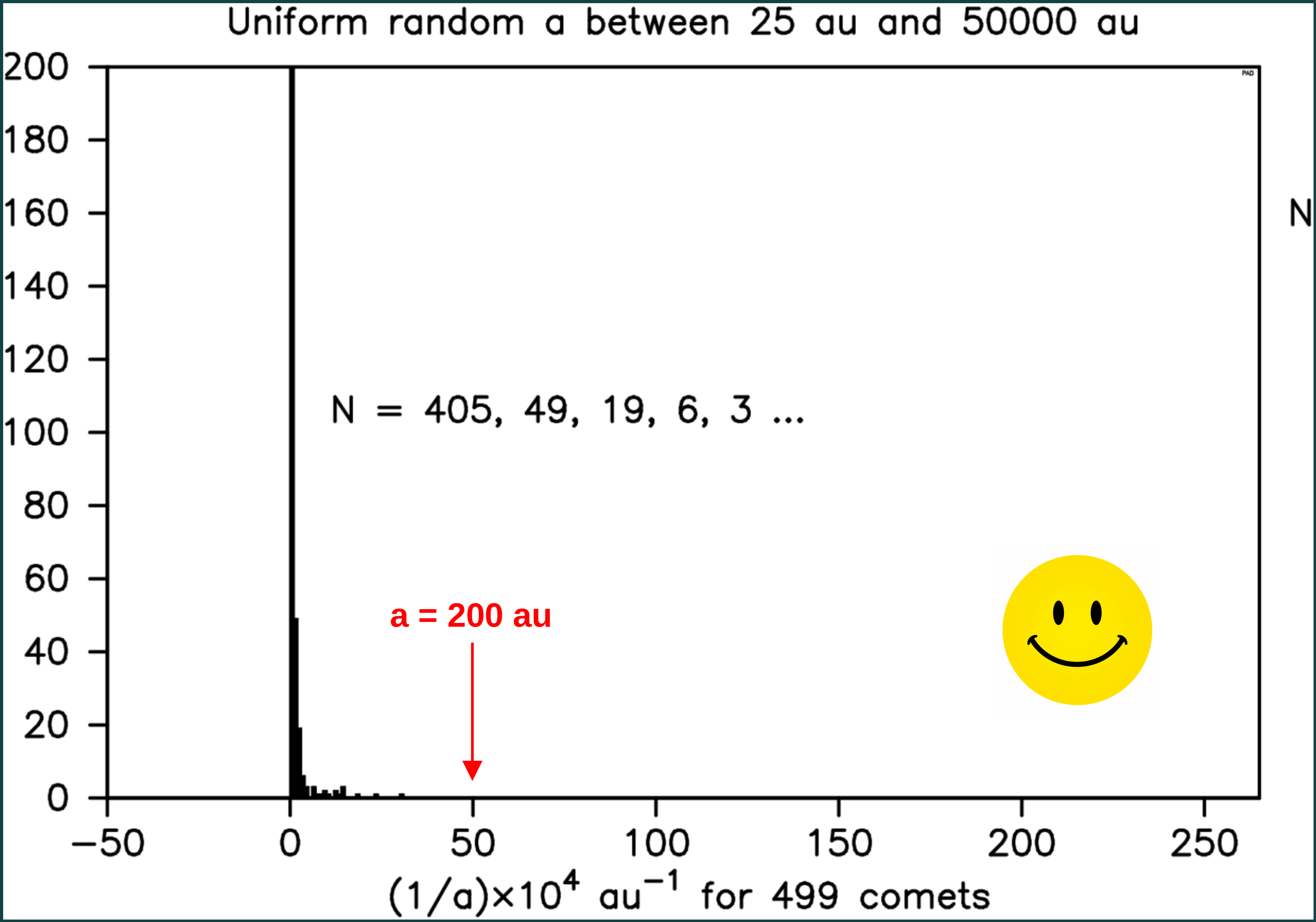
What remains intact after 70 years ?

Overall $1/a_{orig}$ distribution



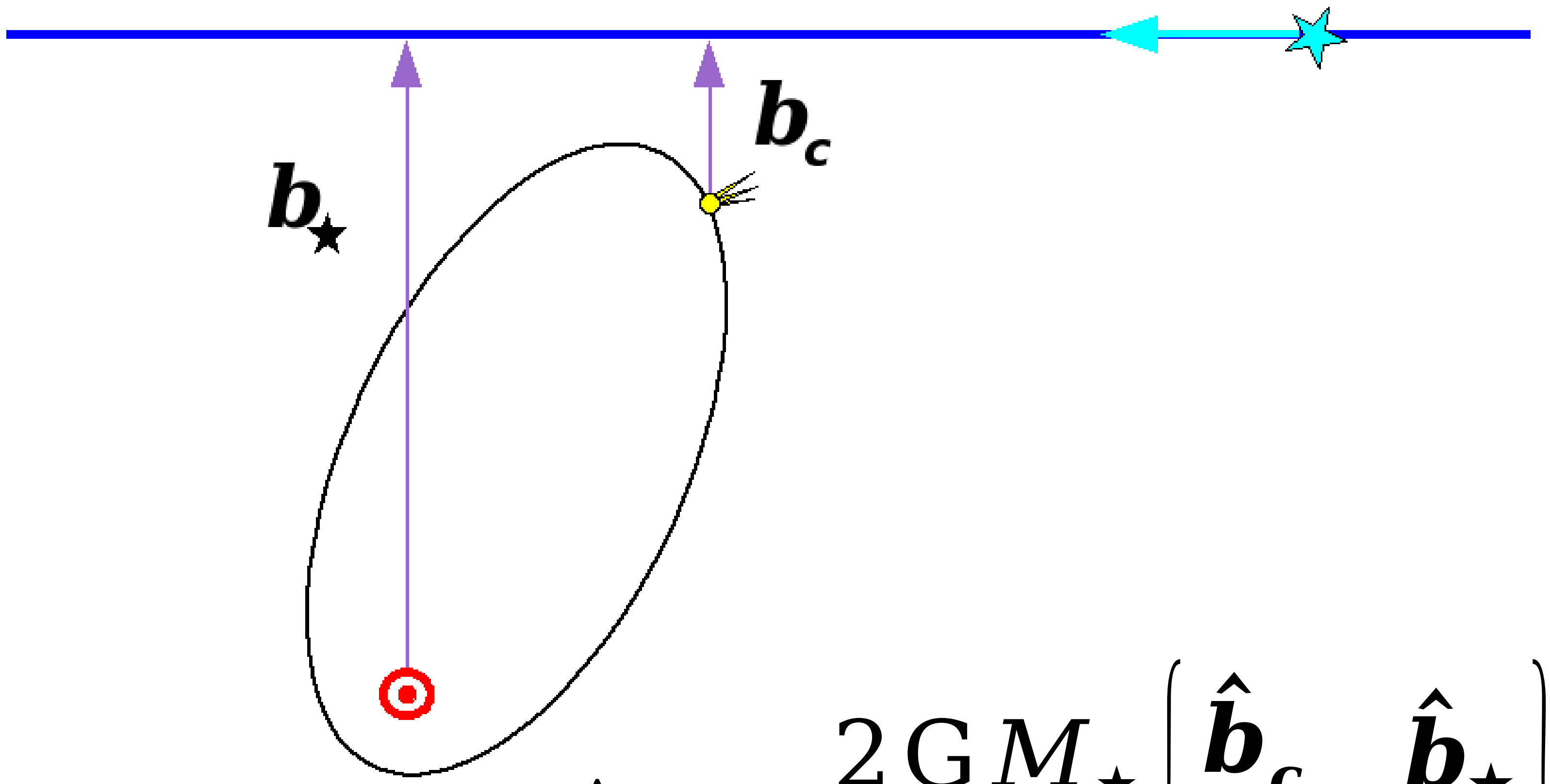

499 original comet orbits
C/2003 H2 → 268
C/2005 O2 → 428
C/2006 U7 → 830
N
−160 ← C/1980 E1
C/2003 H2 → 261
C/2005 O2 → 430
C/2006 U7 → 824
499 future comet orbits
N
(1/a)×10^4 au^−1

But ...

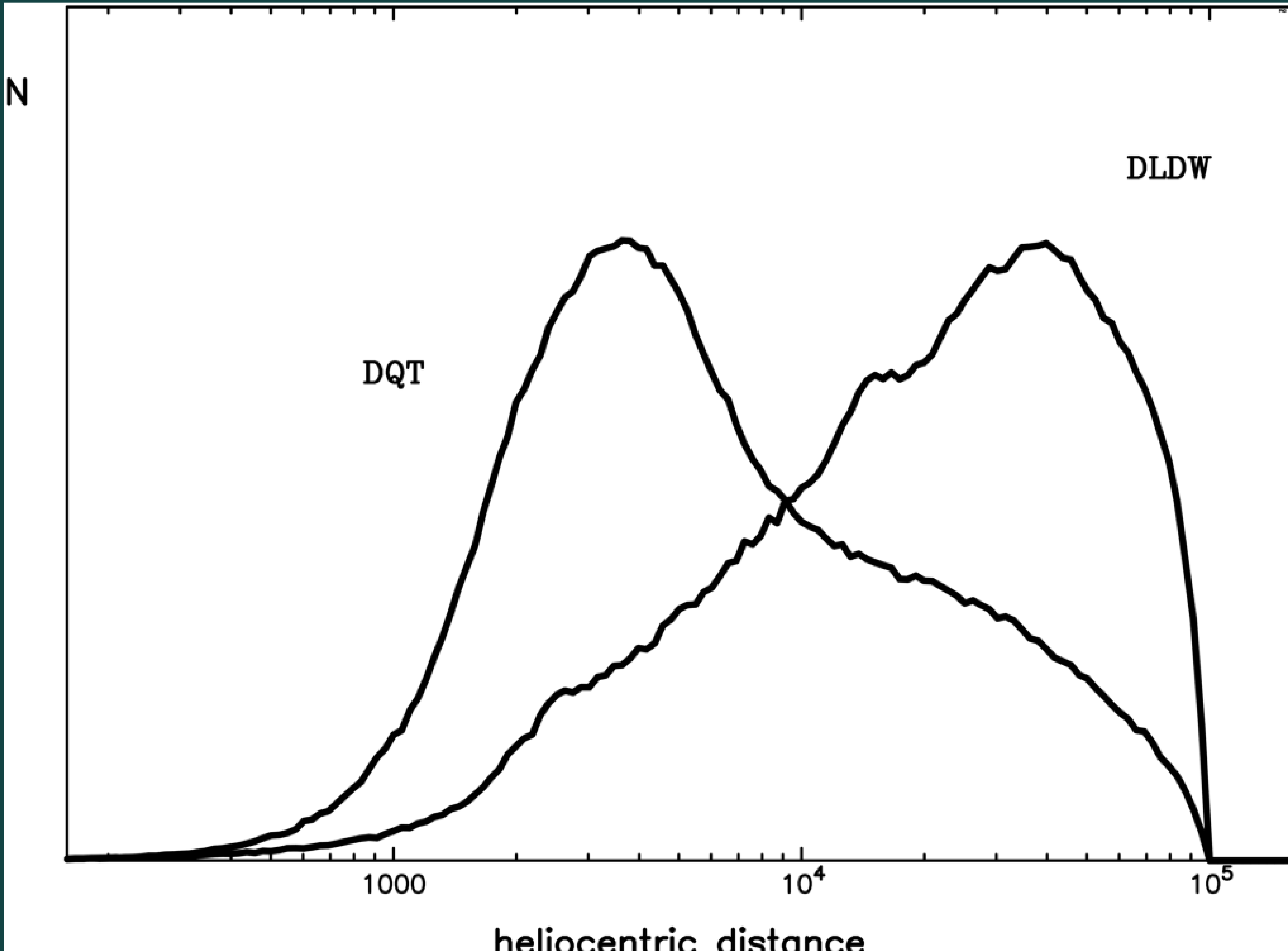


Uniform random a between 25 au and 50000 au
200
180
160
140
120
100
80
60
40
20
0
N
N = 405, 49, 19, 6, 3 ...
a = 200 au
−50
0
50
100
150
200
250
(1/a)×10⁴ au⁻¹ for 499 comets

Classical impulse approximation

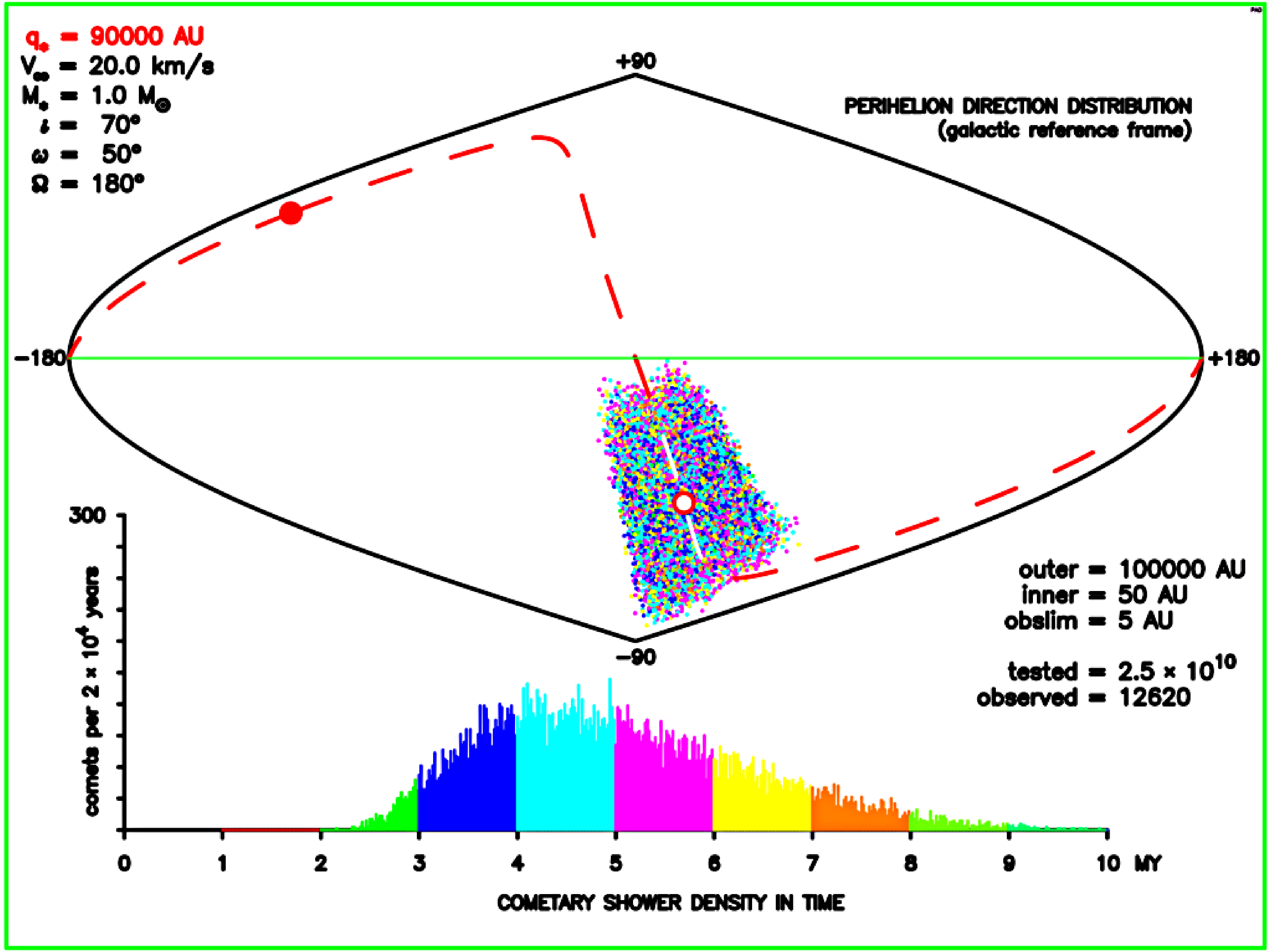


$$\Delta \boldsymbol{v}_c = \frac{2GM_\star}{V_\star}\left\{\frac{\hat{\boldsymbol{b}}_c}{b_c} - \frac{\hat{\boldsymbol{b}}_\star}{b_\star}\right\}$$



Duncan, Quinn, Tremaine, 1987   Dones, Levison, Duncan, Weissman, 1998 - 2004

Single stellar passage effects



Part five

Galactic perturbations

- It is important to realize that Oort based his hypothesis on the assumption that outside the planetary zone comets move on Keplerian orbits, with only sporadic impulse perturbations from passing stars.

- This is very surprising taking into account his great knowledge on the Galaxy, its rotation and the kinematics of stars.

- It is even more astonishing if we recall that in 1943 van Woerkom published a paper on the precession of planetary orbits as a result of the Galactic gravitational action. This subject was suggested to van Woerkom by Oort ! (see BAN, vol. 357, page 427, 1943)

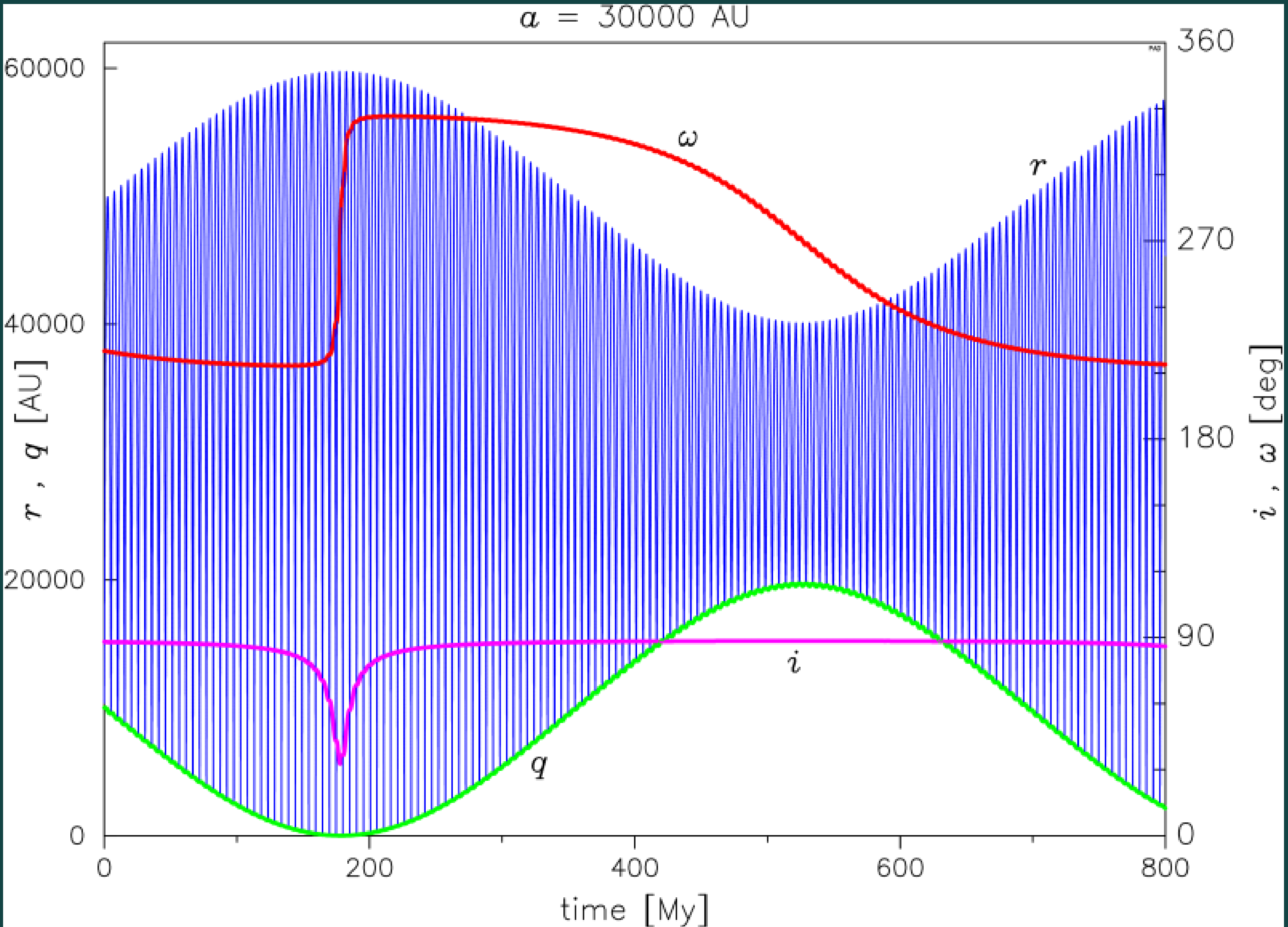
$$\ddot{x} = -\frac{\mu x}{r^3}$$

$$\ddot{y} = -\frac{\mu y}{r^3}$$

$$\ddot{z} = -\frac{\mu z}{r^3} - 4\pi G\rho z$$

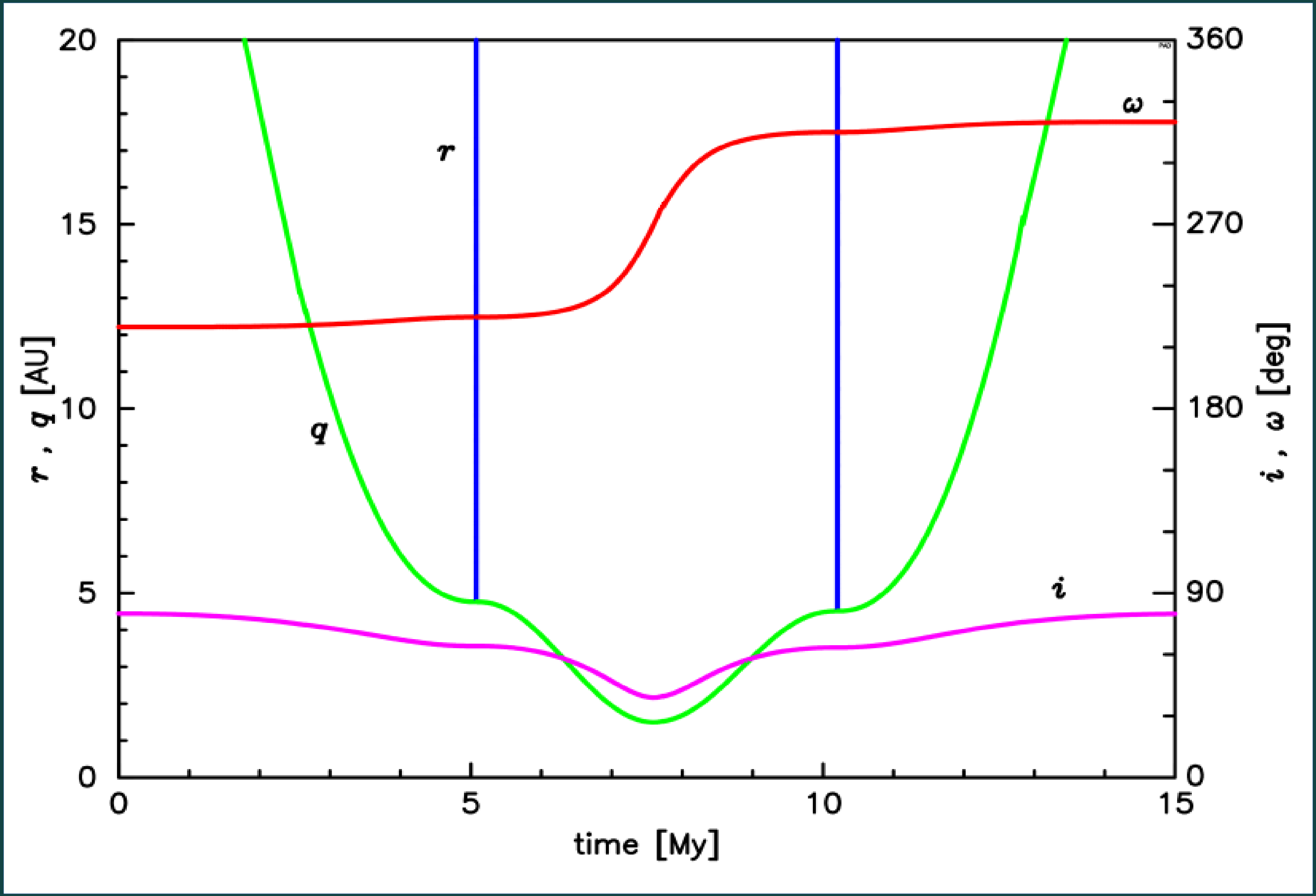
$$\mu = k^2 \cdot (1 + \sum m_p) \qquad \rho = 0.1 \ M_\odot pc^{-3}$$

Simplified model of Galactic tide, Heisler & Tremaine, 1986, Icarus 65, 13

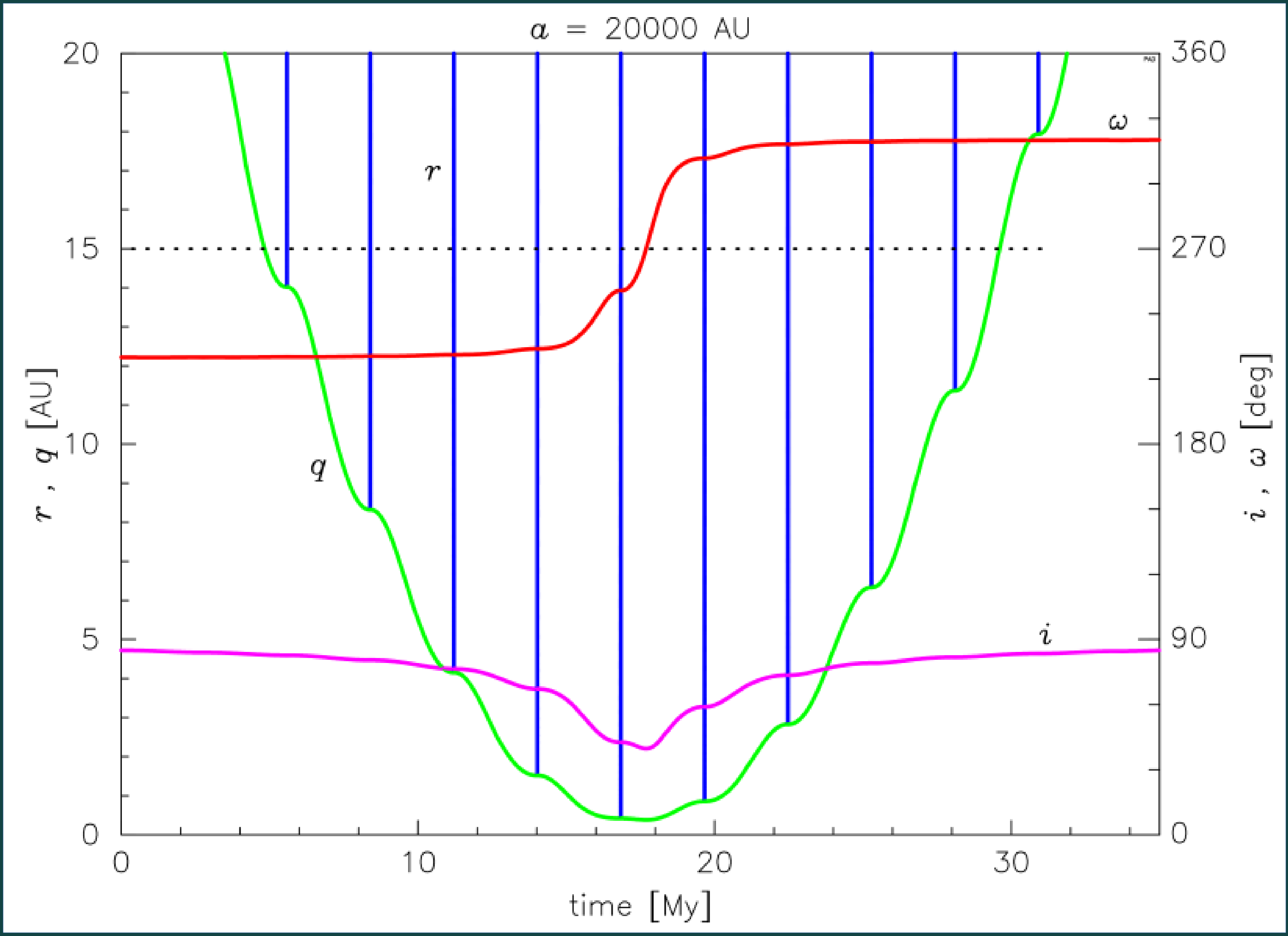


a = 30000 AU
60000
40000
20000
0
r , q [AU]
360
270
180
90
0
i , ω [deg]
0
200
400
600
800
time [My]
ω
r
i
q

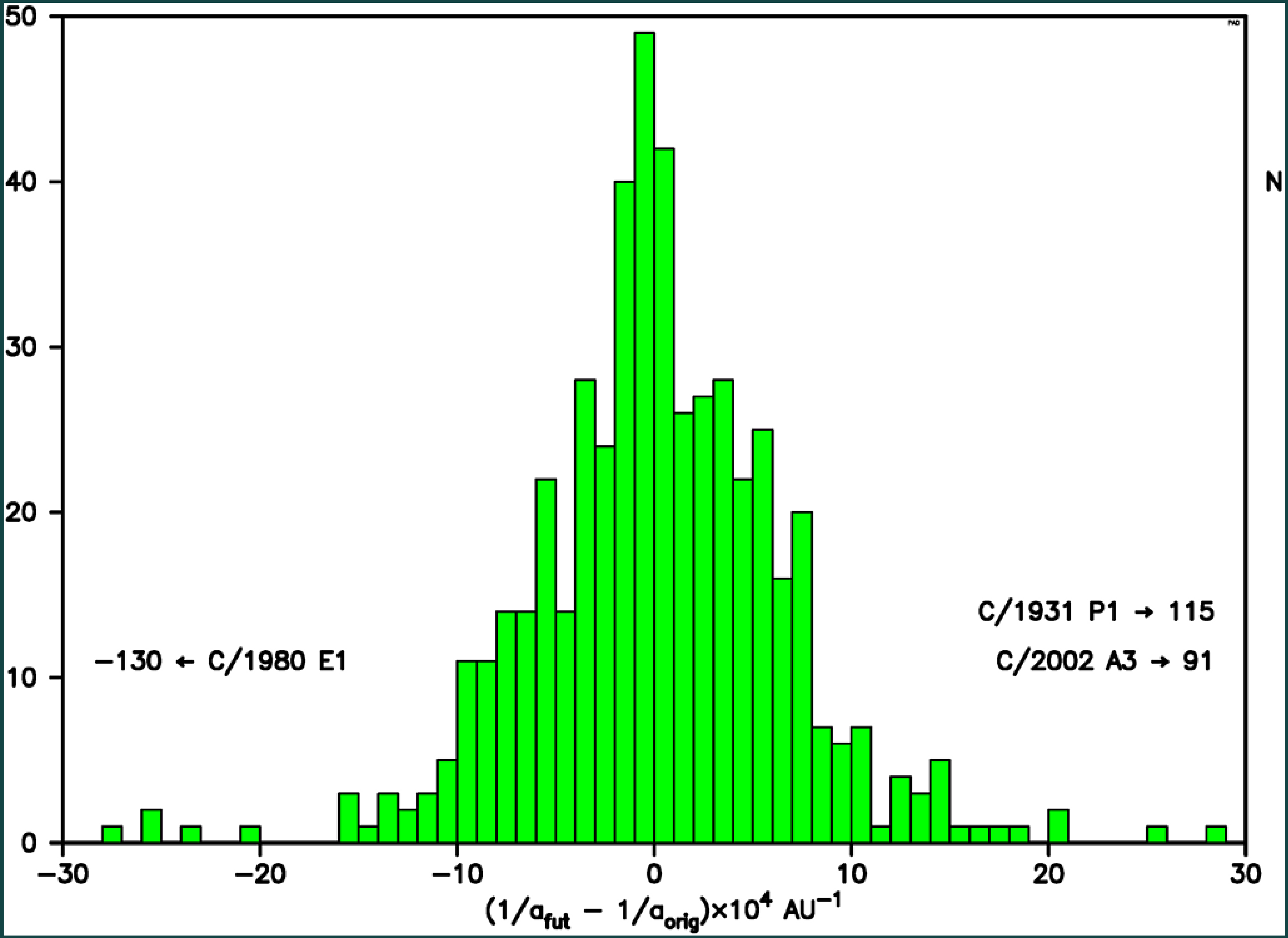
Numerical integration is necessary ...



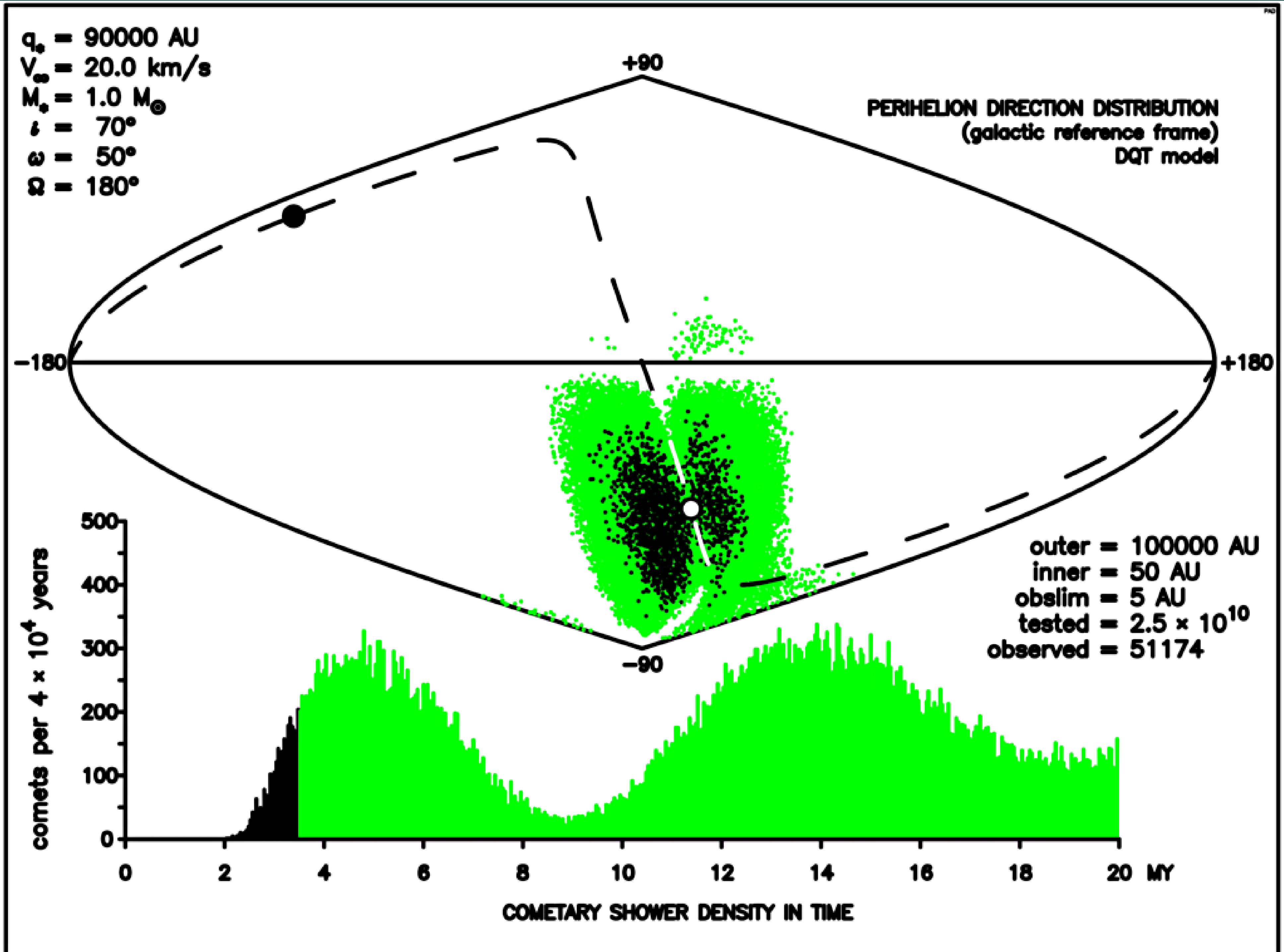
Which perihelion passage ?



Planetary perturbations for 499 comets



Detailed calculations show that only 50% of comets are removed from the Oort cloud during a single passage through the planetary zone.



$q_* = 90000$ AU
$V_\infty = 20.0$ km/s
$M_* = 1.0\ M_\odot$
$i = 70°$
$\omega = 50°$
$\Omega = 180°$
+90
-180
+180
-90
PERIHELION DIRECTION DISTRIBUTION
(galactic reference frame)
DQT model
outer = 100000 AU
inner = 50 AU
obslim = 5 AU
tested = 2.5×10^{10}
observed = 51174
comets per 4×10^4 years
0
100
200
300
400
500
0 2 4 6 8 10 12 14 16 18 20 MY
COMETARY SHOWER DENSITY IN TIME

Galactic potential

(ρ, φ, Z) are Galactocentric cylindrical coordinates, $\rho = \sqrt{X^2 + Y^2}$, and $R = \sqrt{\rho^2 + Z^2}$

$$\Phi(\rho, Z) = \Phi_b(R) + \Phi_d(\rho, Z) + \Phi_h(R)$$

$$\Phi_b(R) = \frac{-GM_b}{\sqrt{R^2 + b_b^2}}$$

$$\Phi_d(\rho, Z) = \frac{-GM_d}{\sqrt{\rho^2 + \left(a_d + \sqrt{Z^2 + b_d^2}\right)^2}}$$

$$\Phi_h(R) = \frac{GM_h}{a_h}\left(\ln\left(\frac{a_h + R}{a_h + \Lambda}\right) - \frac{\Lambda}{a_h + \Lambda}\right)$$

Equation of comet motion

The heliocentric motion of a comet results from

$$\ddot{\boldsymbol{r}} = \ddot{\boldsymbol{R}} - \ddot{\boldsymbol{R}}_\odot = -\frac{GM_\odot}{r^3}\boldsymbol{r} + \boldsymbol{f}(\boldsymbol{R}_\odot, \boldsymbol{r}),$$

where

$$\boldsymbol{R} = \boldsymbol{R}_\odot + \boldsymbol{r}$$

$$\begin{aligned} \boldsymbol{f}(\boldsymbol{R}_\odot, \boldsymbol{r}) = \quad & [\boldsymbol{F}_b(\boldsymbol{R}_\odot + \boldsymbol{r}) - \boldsymbol{F}_b(\boldsymbol{R}_\odot)] \\ & + [\boldsymbol{F}_d(\boldsymbol{R}_\odot + \boldsymbol{r}) - \boldsymbol{F}_d(\boldsymbol{R}_\odot)] \\ & + [\boldsymbol{F}_h(\boldsymbol{R}_\odot + \boldsymbol{r}) - \boldsymbol{F}_h(\boldsymbol{R}_\odot)] = \boldsymbol{f}_b + \boldsymbol{f}_d + \boldsymbol{f}_h \end{aligned}$$

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Astronomy & Astrophysics

Galactic and stellar perturbations of long-period comet motion

Practical considerations

Piotr A. Dybczyński and Sławomir Breiter

Astronomical Observatory Institute, Faculty of Physics, Adam Mickiewicz University, Słoneczna 36, Poznań, Poland
e-mail: dybol@amu.edu.pl; breiter@amu.edu.pl

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Part six

Stellar data

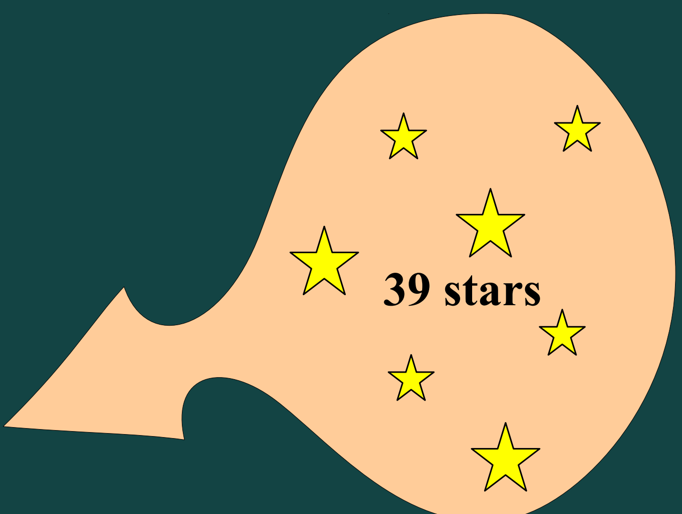
Before *Gaia*

Algol, 5.8 $M_\odot$, **-7.4 Myr**

HD 15117, 1.2 $M_\odot$, **-6.4 Myr**

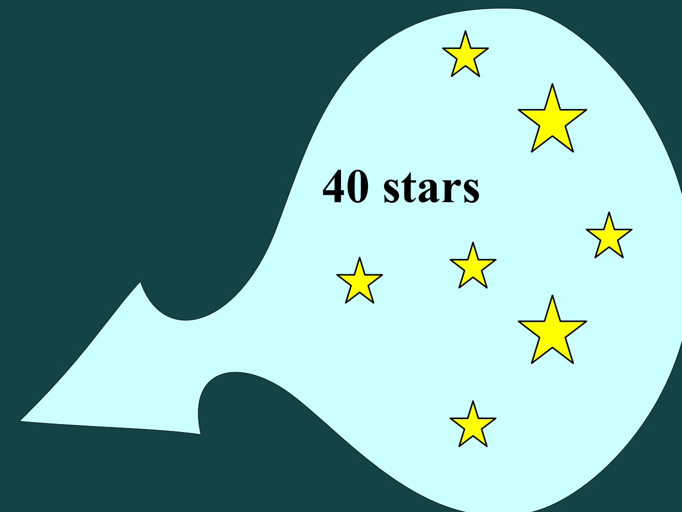
Θ Col, 4 $M_\odot$, **-4.8 Myr**

GJ 217.1, 2.4 $M_\odot$, **-0.9 Myr**



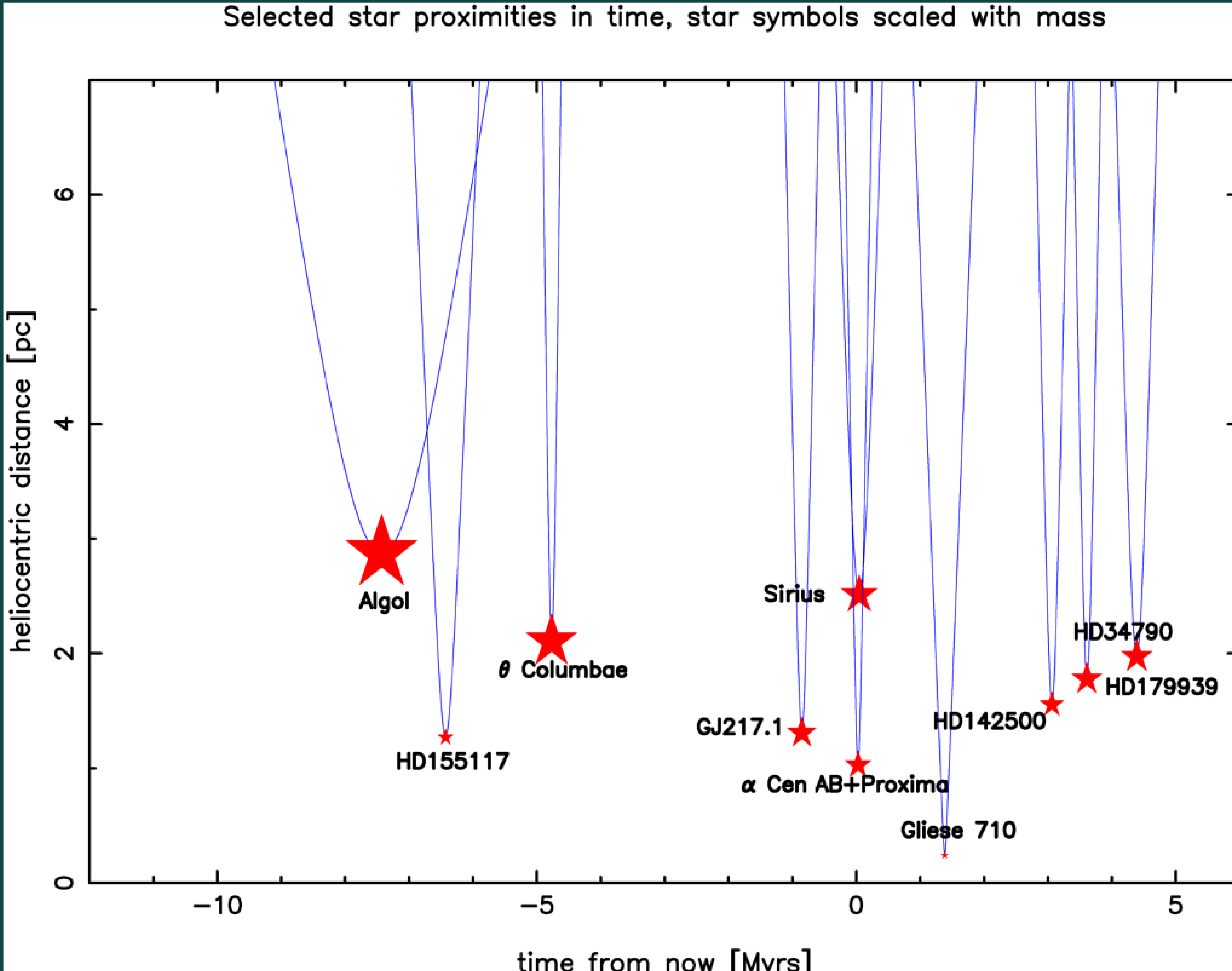
α CenAB+Proxima, 2.2 $M_\odot$

SiriusAB, 3 $M_\odot$



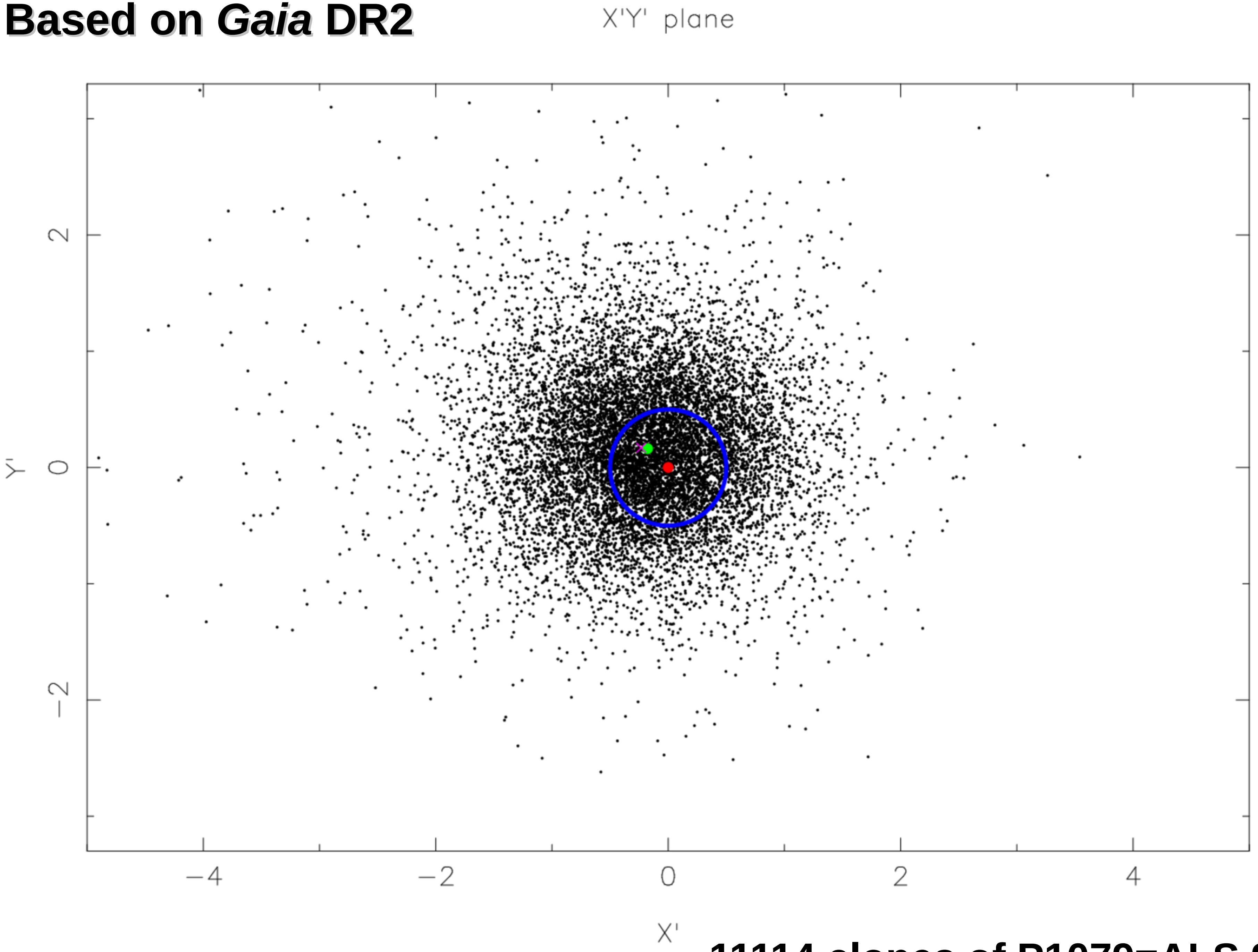
GJ 710, 0.6 $M_\odot$, **+1.4 Myr**

HD 142500, 2 $M_\odot$, **+3 Myr**



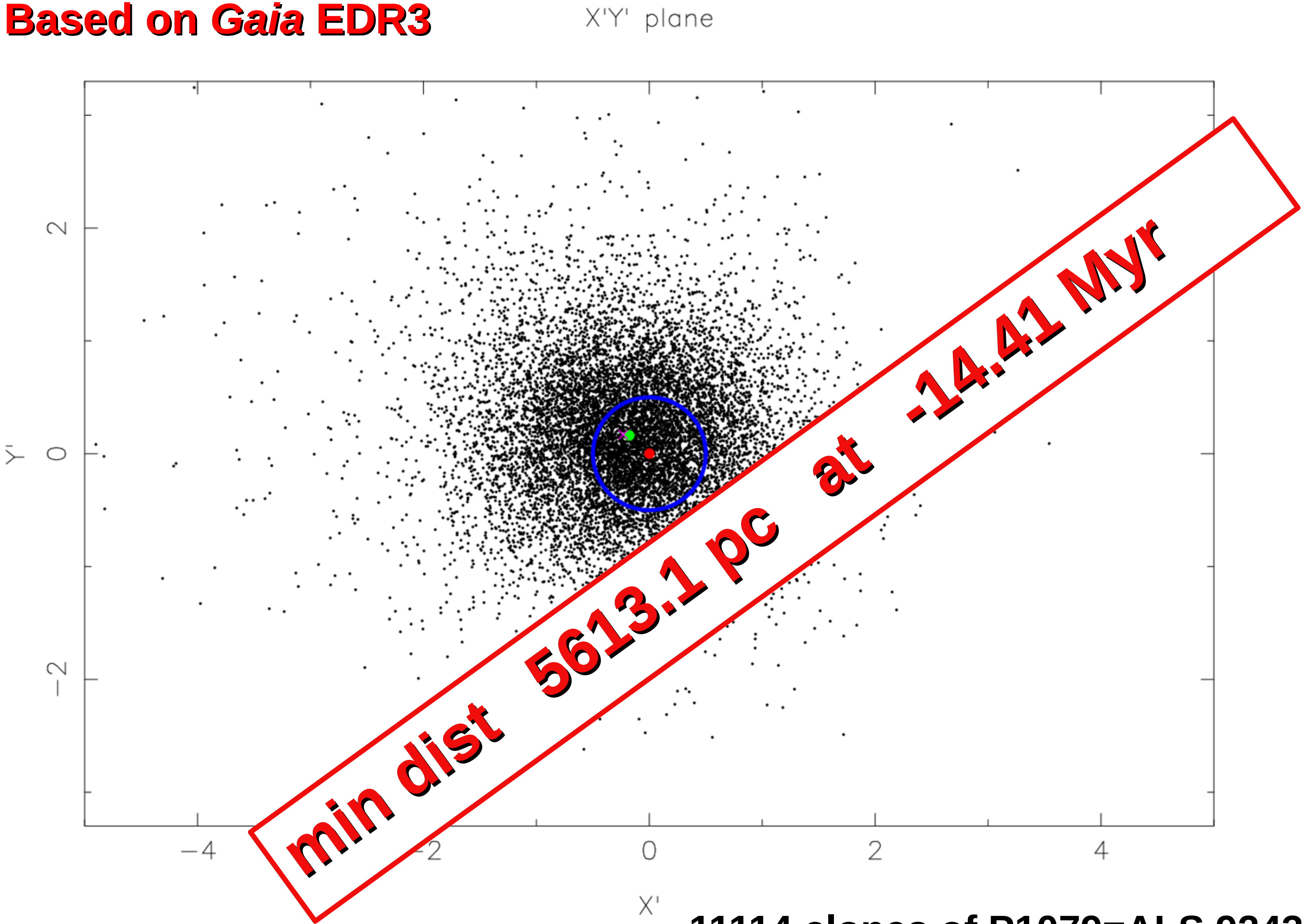
Selected star proximities in time, star symbols scaled with mass
heliocentric distance [pc]
time from now [Myrs]
0
2
4
6
−10
−5
0
5
Algol
HD155117
θ Columbae
Sirius
GJ217.1
α Cen AB+Proxima
Gliese 710
HD142500
HD34790
HD179939

Based on *Gaia* DR2



11114 clones of P1079=ALS 9243

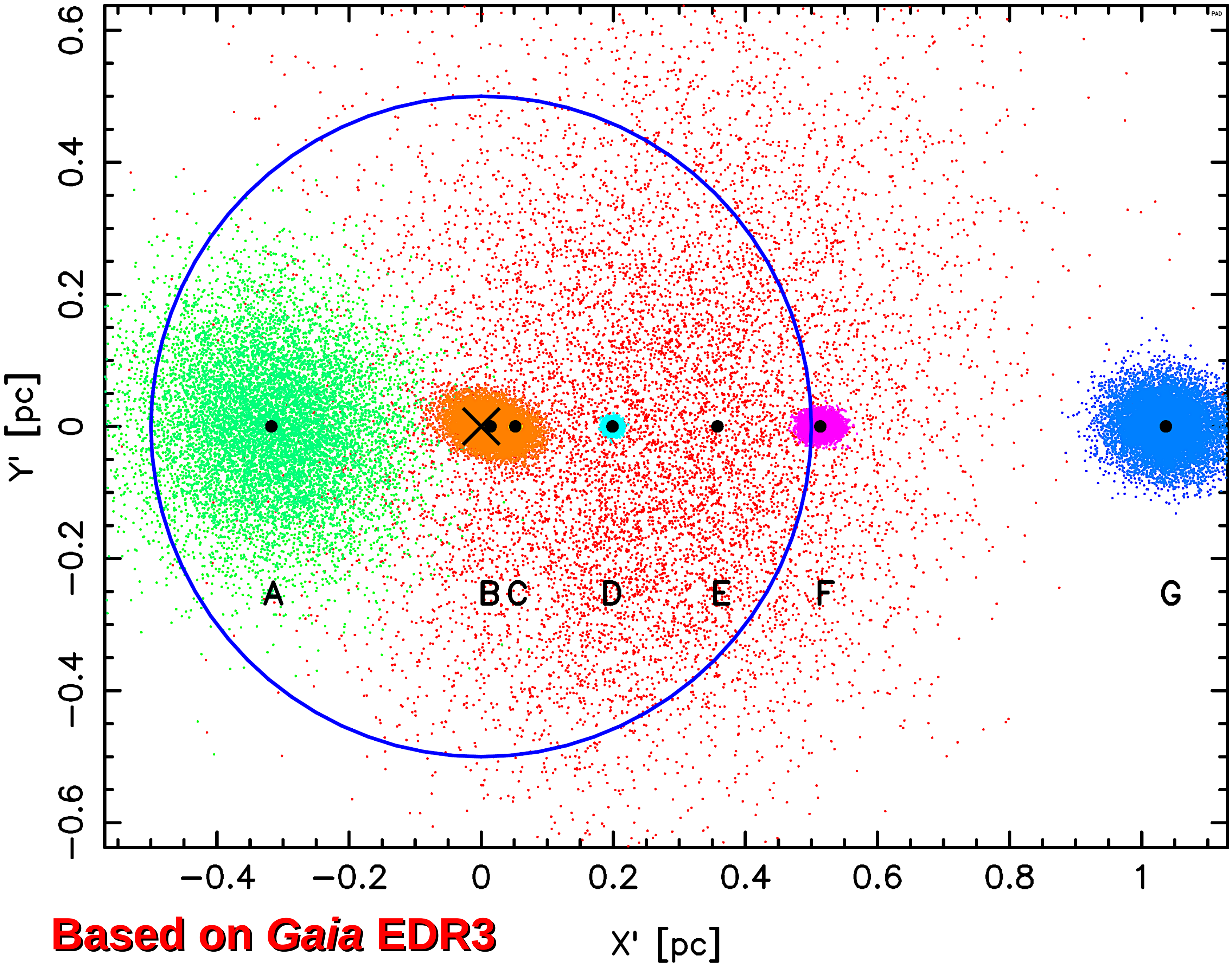
Based on *Gaia* EDR3



11114 clones of P1079=ALS 9243

DR2 versus EDR3 (777 stars)

- diff. in plx > 100% :…………………………………….... 180
- diff. in plx > 50% :………………………………………..... 8
- diff. in plx > 10% :………………………………………..... 28
- diff. in plx > 1% :..………………………………………... 182
- diff. in plx below 1% :…………………………………..... 370
- diff. in pm > 100% :..…………………………………….... 222
- diff. in pm > 50% :………………………………………..... 88
- diff. in pm > 10% :……………………………………….... 199
- diff. in pm > 1% :..……………………………………….... 142
- diff. in pm below 1% :……………...……………………….. 126



Based on *Gaia* EDR3

Fig. 1. The seven stars mentioned in this paper – the spread of star clones due to their data uncertainties and a distance of each clone cloud from the Sun. Black dots in the center of each clone cloud mark the nominal star position at the closest Sun–star approach; they have been artificially aligned along the horizontal axis. All 10 000 clones of star C are hidden under its black dot since the stellar data are extremely precise in this case. Label meanings: A: P0509, B: P0230 (HD 7977), C: P0107 (Gliese 710), D: P0506, E: P0508, F: P0417 (Ton 214), G: P0111 (HIP 94512). See Table 2 for details on each star.

From: Dybczyński & Królikowska, 2022, arXiv:2112.15353

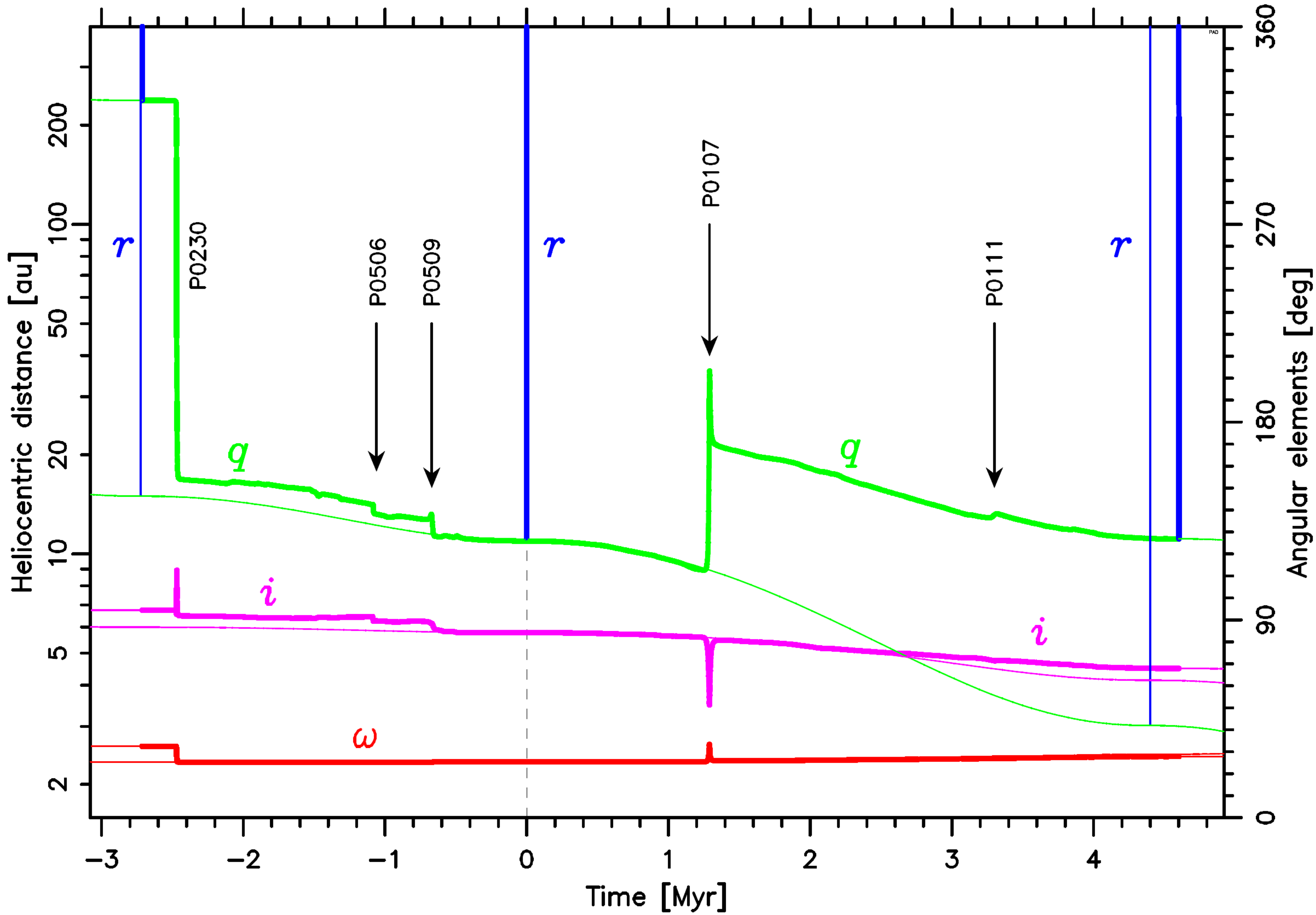


Fig. 2. Past and future dynamical evolution of the nominal orbit of C/2014 UN_{271} (b8 solution). Changes in a perihelion distance (green), an inclination (fuchsia) and an argument of perihelion (red) are shown. The thick lines depict the result of the full dynamical model while thin lines show the evolution of elements in the absence of any stellar perturbations, i.e. only the Galactic perturbations are taken into account. Angular elements are expressed in a Galactic frame. Shown are also names of stars that make significant impart on this dynamical evolution.

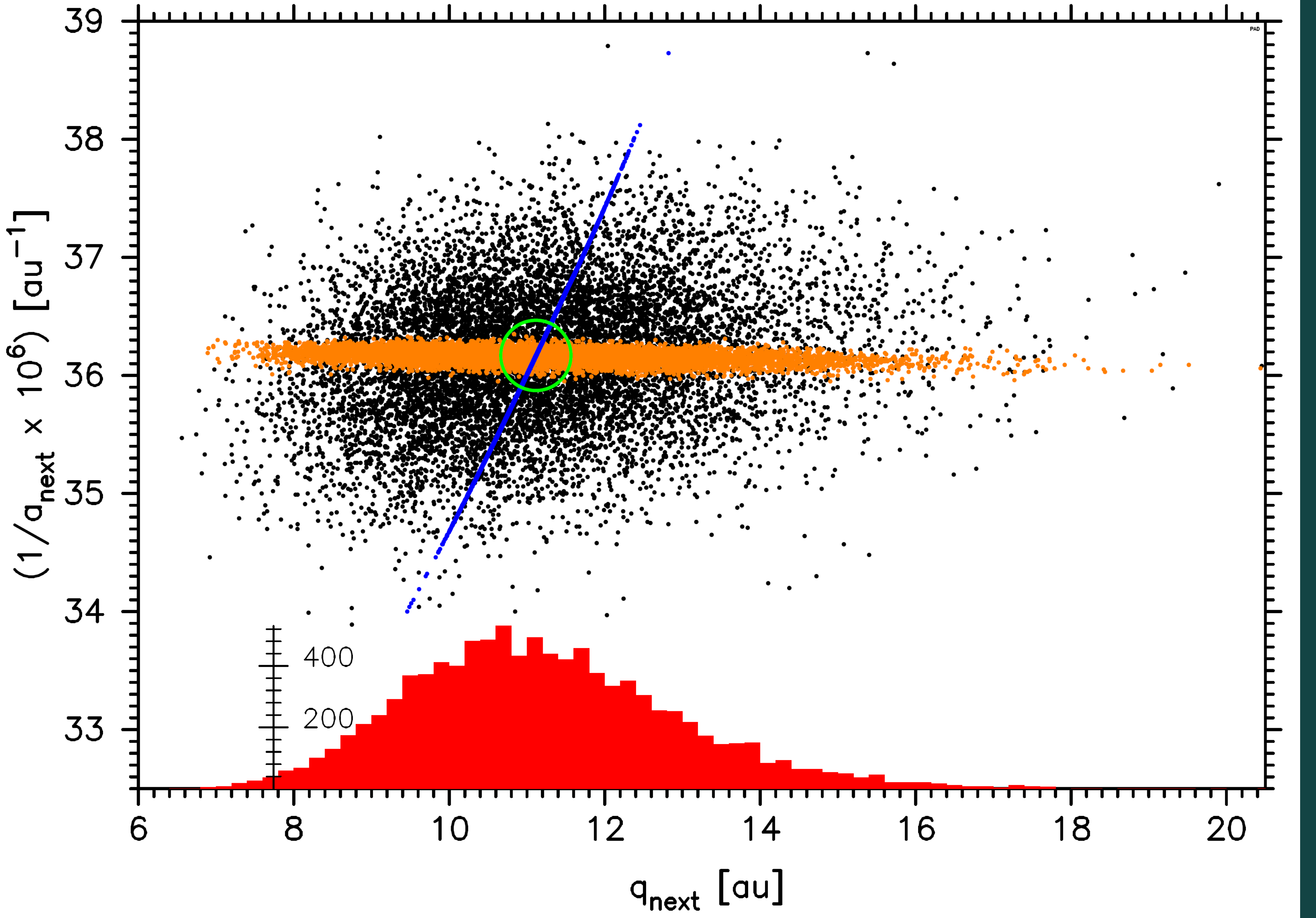
From: Dybczyński & Królikowska, 2022, arXiv:2112.15353

Previous perihelion distances of these 19 comets.

C/1853 L1	1B	+0.000013	5741.
C/1863 T1	2A	+0.000014	3239.
C/1885 X1		–0.000423	
C/1885 X2	1B	+0.000331	0.476
C/1886 T1	1B	+0.000045	0.499
C/1888 R1	1A	+0.000048	3.281
C/1890 F1	1B	+0.000089	2.162
C/1896 V1	1B	+0.000005	112.100
C/1898 L1	1A	+0.000068	2.189
C/1902 R1	1B	+0.000027	19.940
C/1906 B1	2B	+0.000630	1.296
C/1907 E1	1B	+0.000025	38.940
C/1908 R1	1B	+0.000174	0.945
C/1913 Y1	1A	+0.000028	41.070
C/1922 U1	1A	+0.000021	107.8
C/1925 G1	1A	+0.000039	0.324
C/1925 W1	1B	+0.000024	82.59
C/1932 M2	1A	+0.000045	3.984
C/1935 Q1	1A	+0.000018	124.8

~1.5

~2.3



From: Dybczyński & Królikowska, 2022, arXiv:2112.15353

Part seven

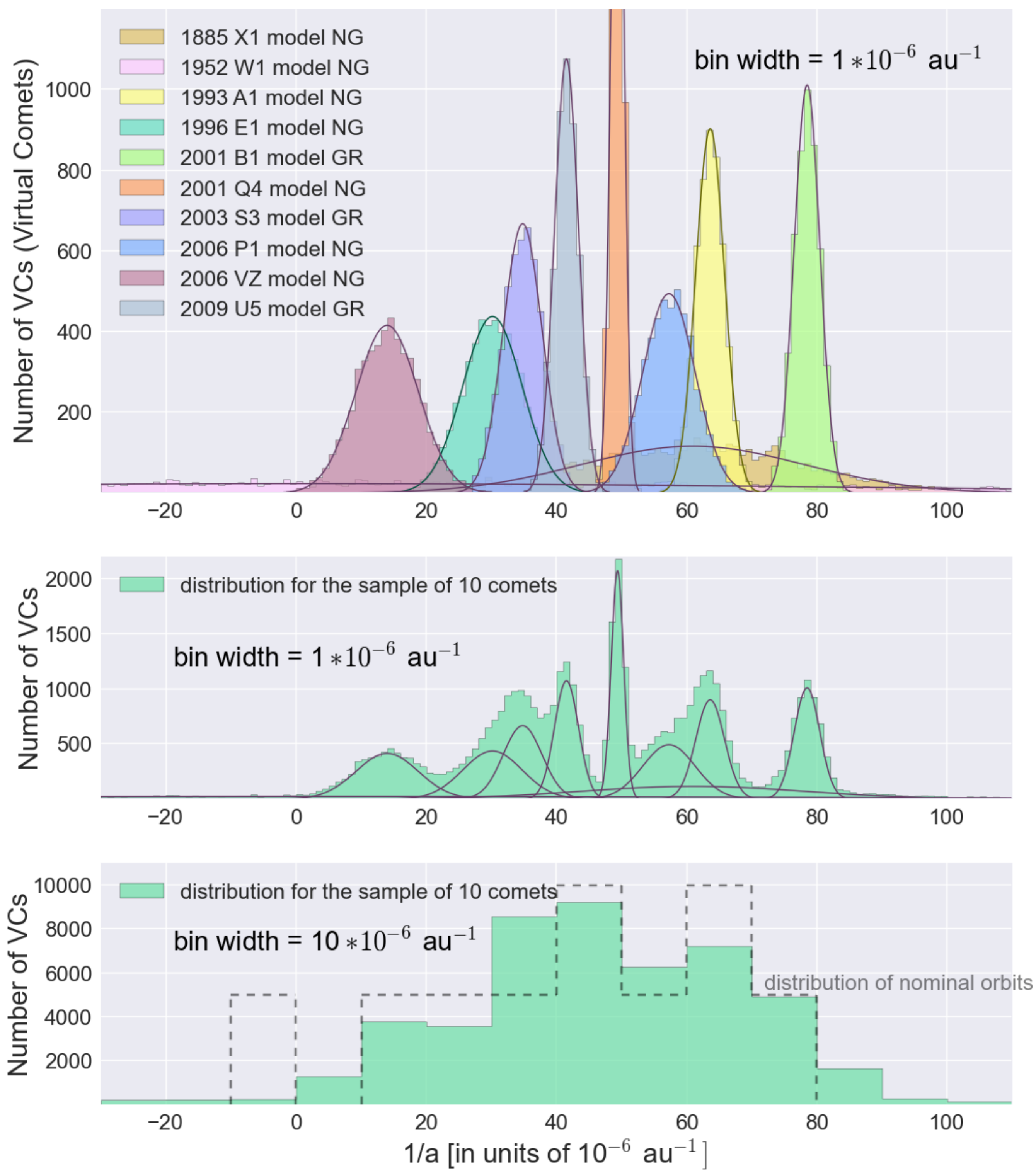
$1/a_{orig}$ distribution details

A&A 640, A97 (2020)
https://doi.org/10.1051/0004-6361/202038451

Astronomy & Astrophysics

The catalogue of cometary orbits and their dynamical evolution★

Małgorzata Królikowska[1] and Piotr A. Dybczyński[2]



From: Dybczyński & Królikowska, 2015,
Planetary and Space Science, Volume 123, p. 77-86

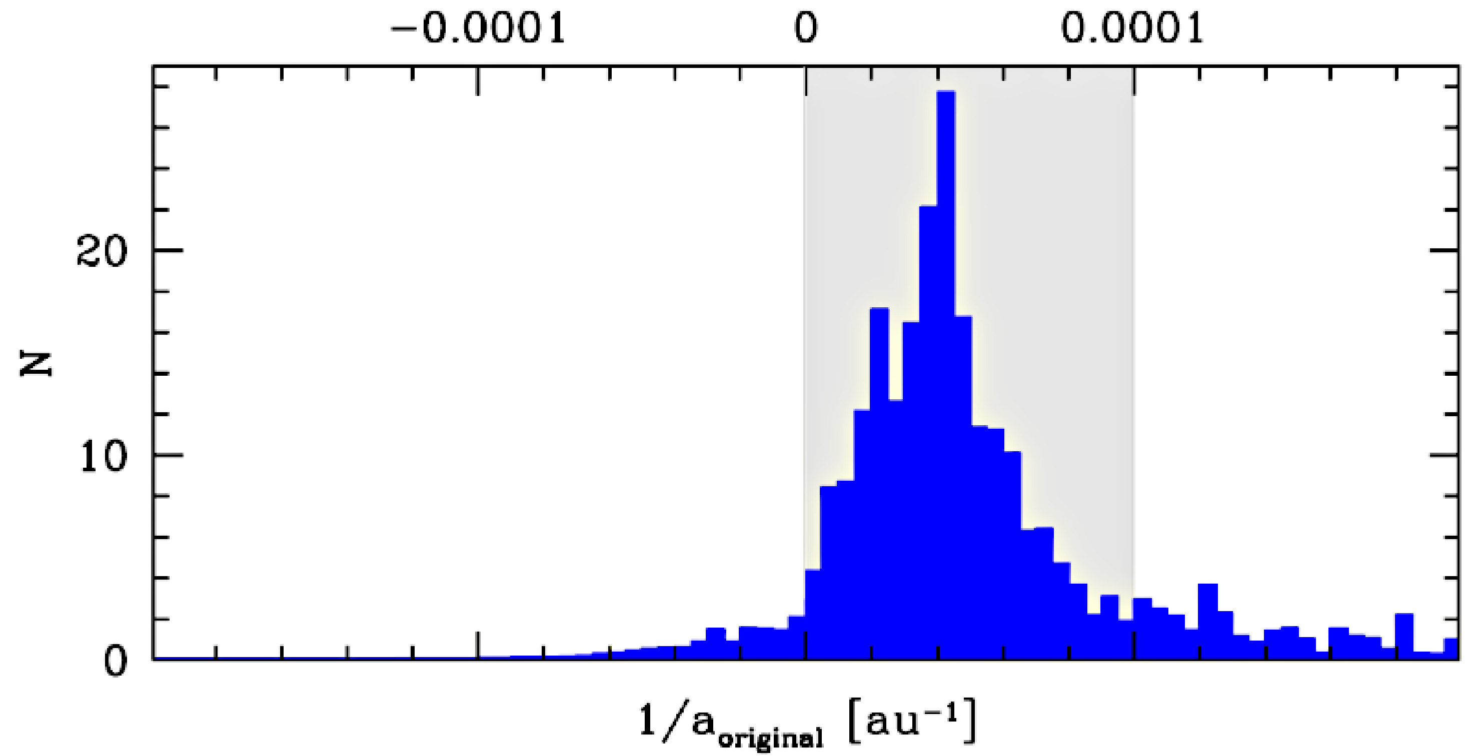


Fig. 3. Distribution of $1/a_{\rm ori}$ based on the preferred orbits for the whole sample of LPCs available in the CODE catalogue; about one-third have NG solutions. The light grey vertical band indicates the region occupied by Oort spike comets.

From: Królikowska & Dybczyński (2020)

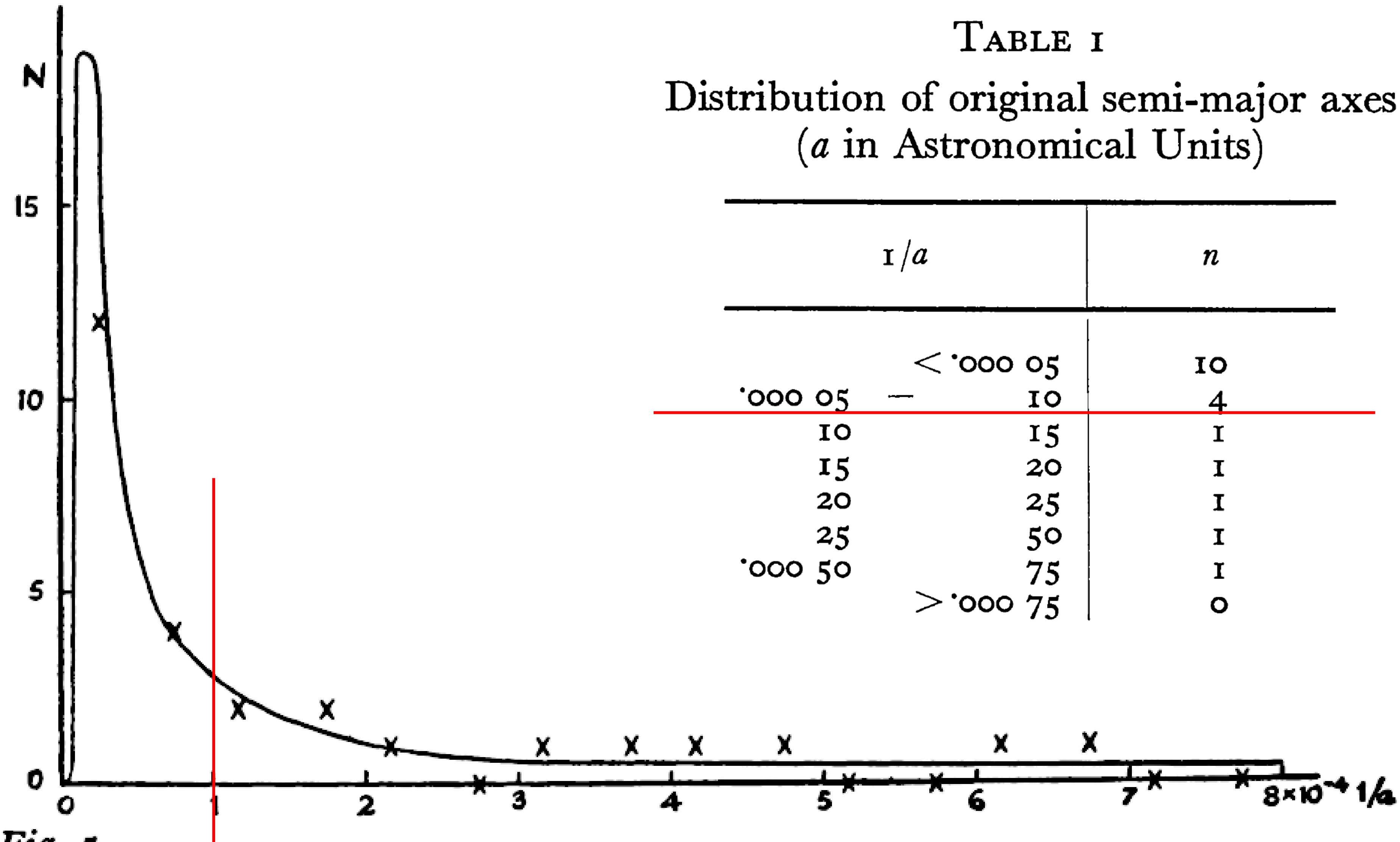


TABLE I

Distribution of original semi-major axes
(*a* in Astronomical Units)

1/*a*		*n*
	< ·000 05	10
·000 05	— 10	4
10	15	1
15	20	1
20	25	1
25	50	1
·000 50	75	1
	> ·000 75	0

Fig. 5.
Distribution of reciprocal semi-major axes of comet orbits.
The semi-major axes are expressed in astronomical units; one division of the horizontal scale corresponds to 10^{-4} A.U.$^{-1}$, ordinates are numbers of orbits per interval of 5×10^{-5}. (From *B.A.N.* **11**, 259, 1951).

Supplement

A new mechanism was proposed in 2009 by Kaib & Quinn

(Science 325, 1234, Reassessing the Source of Long-Period Comets)

but without any significant reaction or discussion

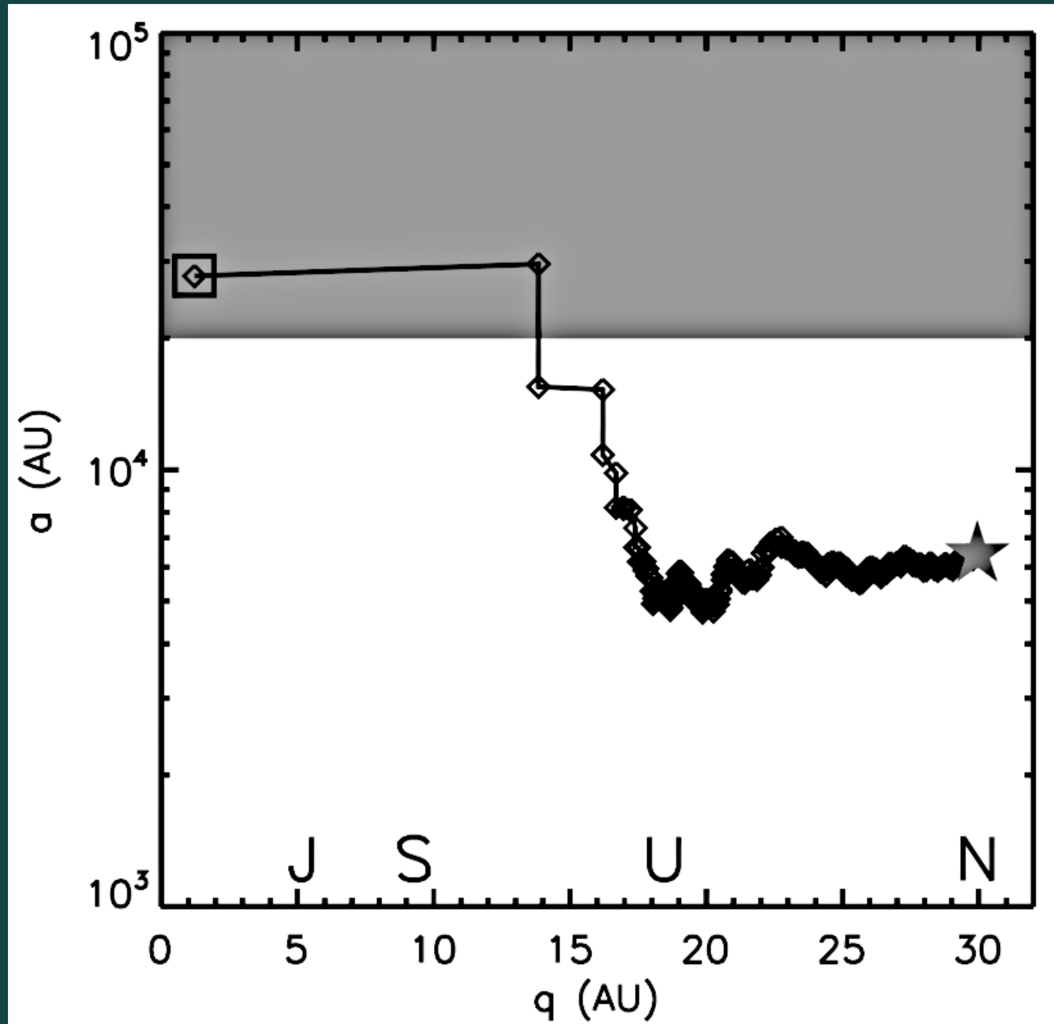


Figure 1: An example of the typical evolution from an inner Oort Cloud object into an observable LPC. Orbital elements are sampled each time the object crosses the $r = 35$ AU boundary (twice per orbit). The star data point marks the start of the evolution and the square marks the end. The shaded area indicates the a-range of the outer Oort Cloud, and the perihelia of the giant planets are noted using their initials.

The End