On the existence of comet families in extrasolar planetary systems

R.Dvorak, Ch. Lhotka, B.Loibnegger, M. Cuntz
University of Vienna, IWF Graz, University of Texas

Contents

Reassessing the formation of the inner Oort cloud in an embedded star cluster
R. Brasser, M. J. Duncan, H. F. Levison, M. E. Schwamb, M. E. Brown, Icarus, 2012

- The comets of the Oort cloud may have formed in a cluster of about a thousand of other stars, all packed together.

- Each young star then creates a huge number of small icy bodies around it in a disk from which planets gradually form.

- In our galaxy's early times, many of these icy objects got "ejected" from the planetary systems and eventually became comets.

- A few stayed near the Sun and formed the Oort cloud, about a light-year from the Sun.

Reassessing the formation of the inner Oort cloud in an embedded star cluster

R. Brasser, M. J. Duncan, H. F. Levison, M. E. Schwamb, M. E. Brown

The theory proposes that many comets may have formed in other Solar Systems: when our Sun was still a young star in its birth cluster, it may have gravitationally captured the Oort cloud comets formed in this big cluster.

This contradicts the earlier theory that most comets were born in the Sun's protoplanetary disk.

Two families of exocomets in the β Pictoris system

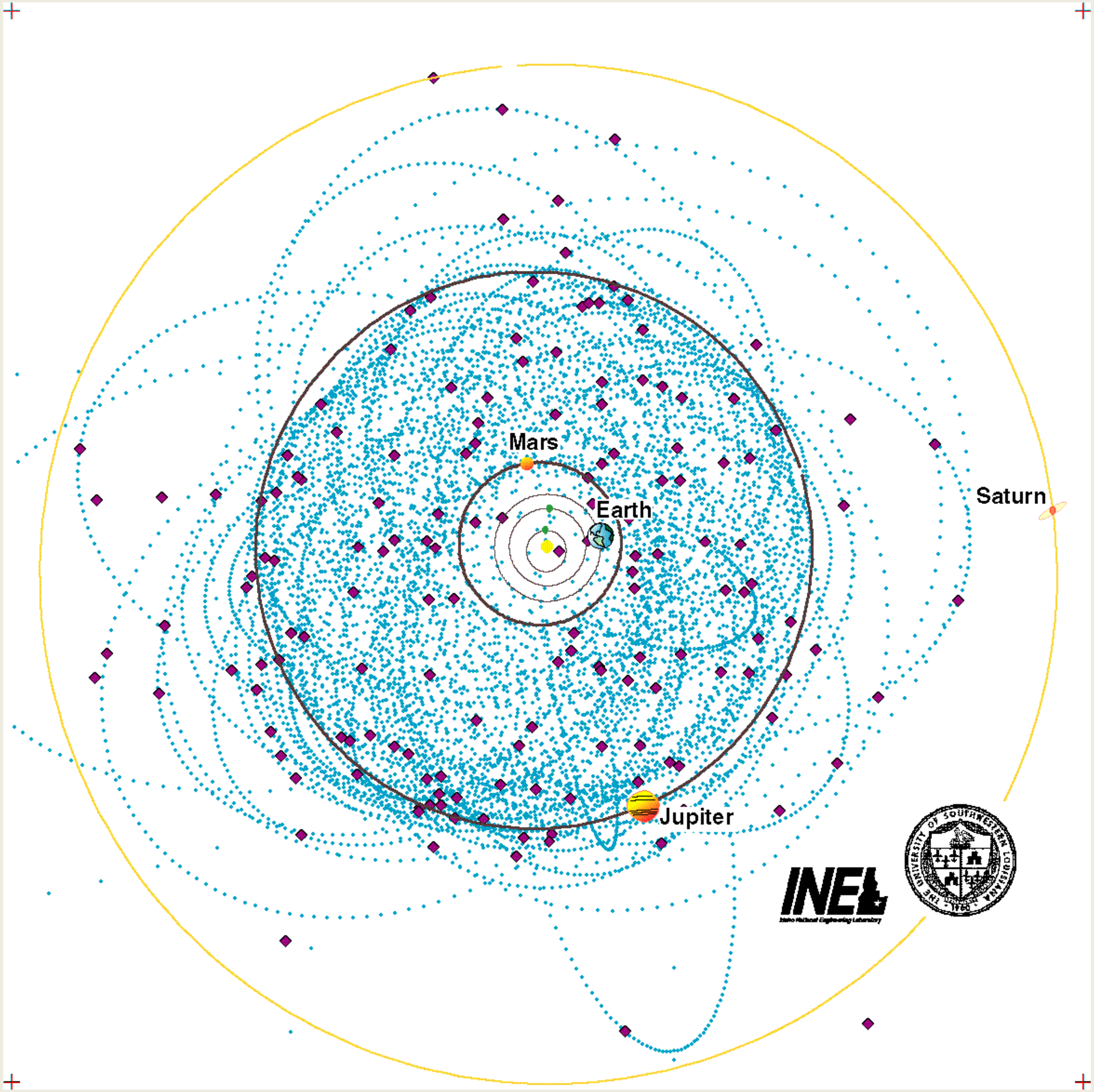
- F. Kiefer et al, Nature 514, 462 – 464, October 2014

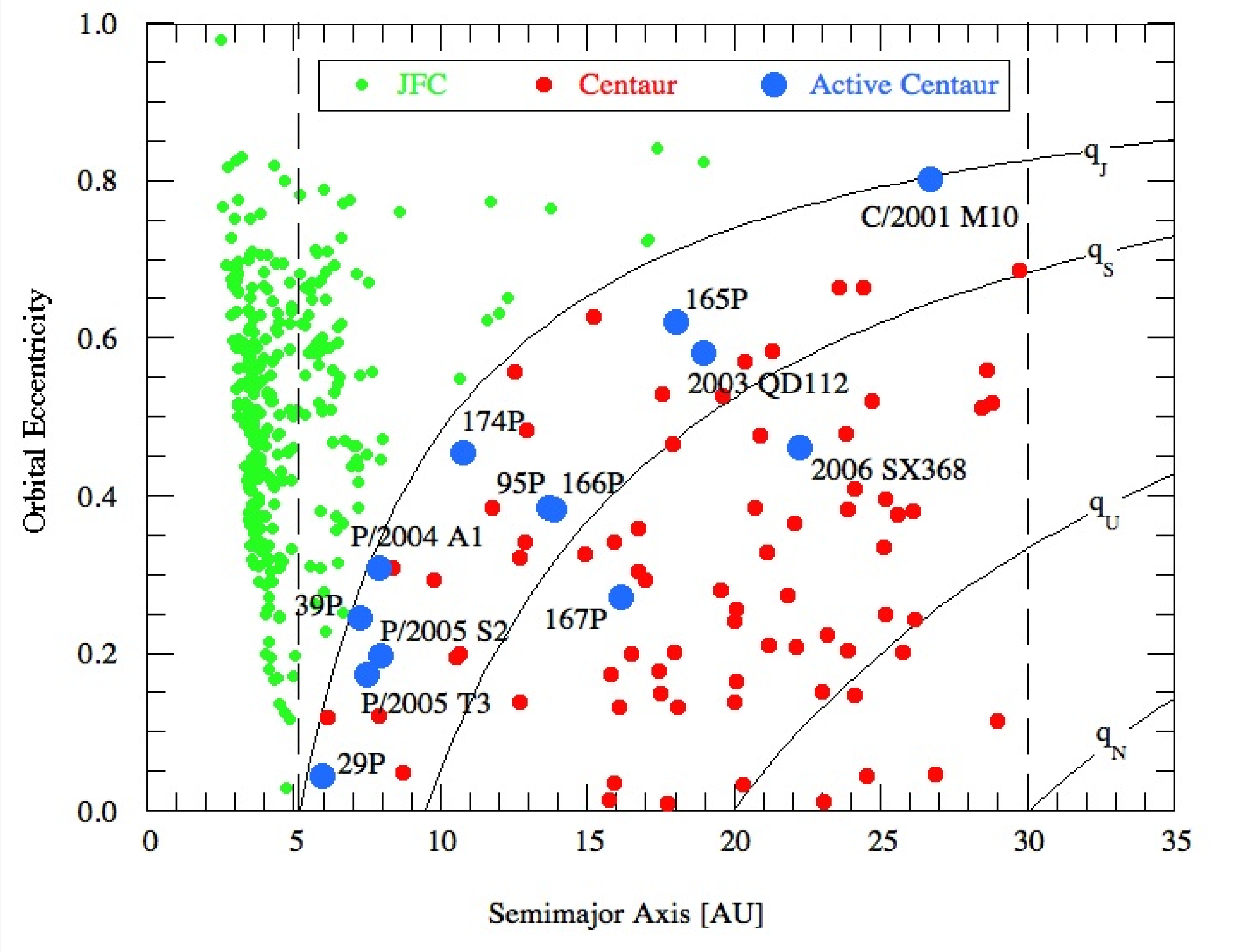
β Pictoris harbours active minor bodies

Spectroscopic observations of β Pictoris
-> a high rate of transits of small evaporating bodies
->exocomets.

They produce a large amount of dust and gas through collisions and evaporation

Evaporating bodies observed in the β Pictoris system are analogous to the comets in our own Solar System.


Mars
Earth
Saturn
Jupiter


JFC
Centaur
Active Centaur
C/2001 M10
165P
2003 QD112
174P
2006 SX368
95P
166P
P/2004 A1
39P
P/2005 S2
167P
P/2005 T3
29P
q_J
q_S
q_U
q_N
Orbital Eccentricity
Semimajor Axis [AU]
0.0
0.2
0.4
0.6
0.8
1.0
0
5
10
15
20
25
30
35

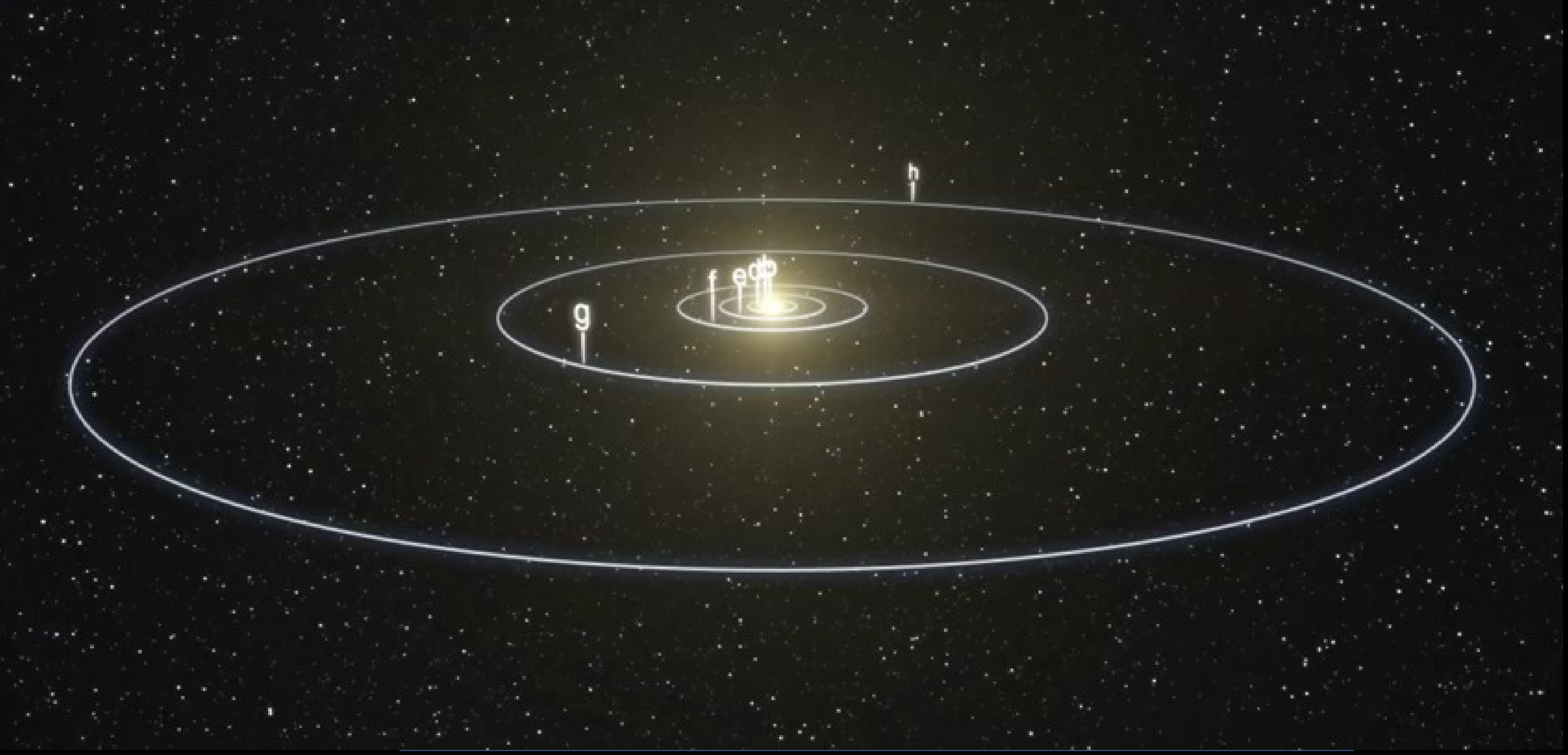
Spectral type	G1V	
Apparent magnitude V	7,33	
Mass	1.06 (± 0.05) M_{Sun}	
Age	4.3 (± 0.5) Gyr	
Effective temperature	5911.0 (± 19.0) K	
Radius	—	
Metallicity [Fe/H]	0.08 (± 0.01)	

The 4 outer planets of HD 10180; there are more planets moving inside HD 10180 e, see http://www.exoplanets.eu

Name	a[AU]	e	i	omega	Omega	M
10180 h	3.40	0.080	0.60	1.0	1.0	1.0
10180 g	1.4220	0.00010	0.80	1.0	1.0	181.0
10180 f	0.49220	0.1350	0.70	1.0	1.0	90.0
10180 e	0.270	0.0260	0.70	1.0	1.0	50.0

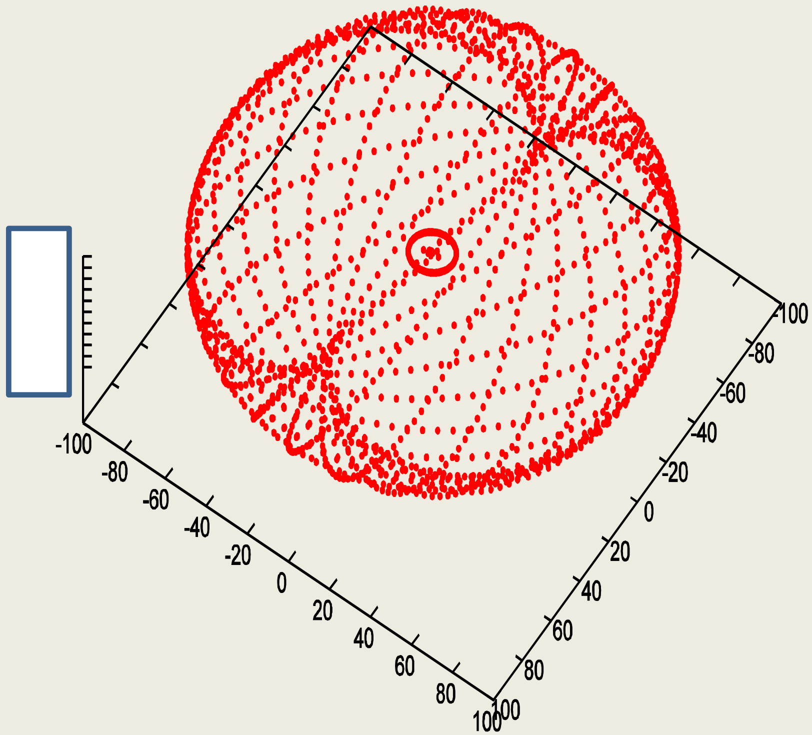
Name	mass $[M_{\mathrm{Jupiter}}]$	R_{Hill} [AU]	r_{ρ_1} [AU]	r_{ρ_2} [AU]
10180 h	0.2095	0.1379	3.05E-04	2.42E-04
10180 g	0.0702	0.0400	2.12E-04	1.68E-04
10180 f	0.0786	0.0144	2.20E-04	1.75E-04
10180 e	0.0827	0.0080	2.24E-04	1.78E-04

The extrasolar system HD 10180

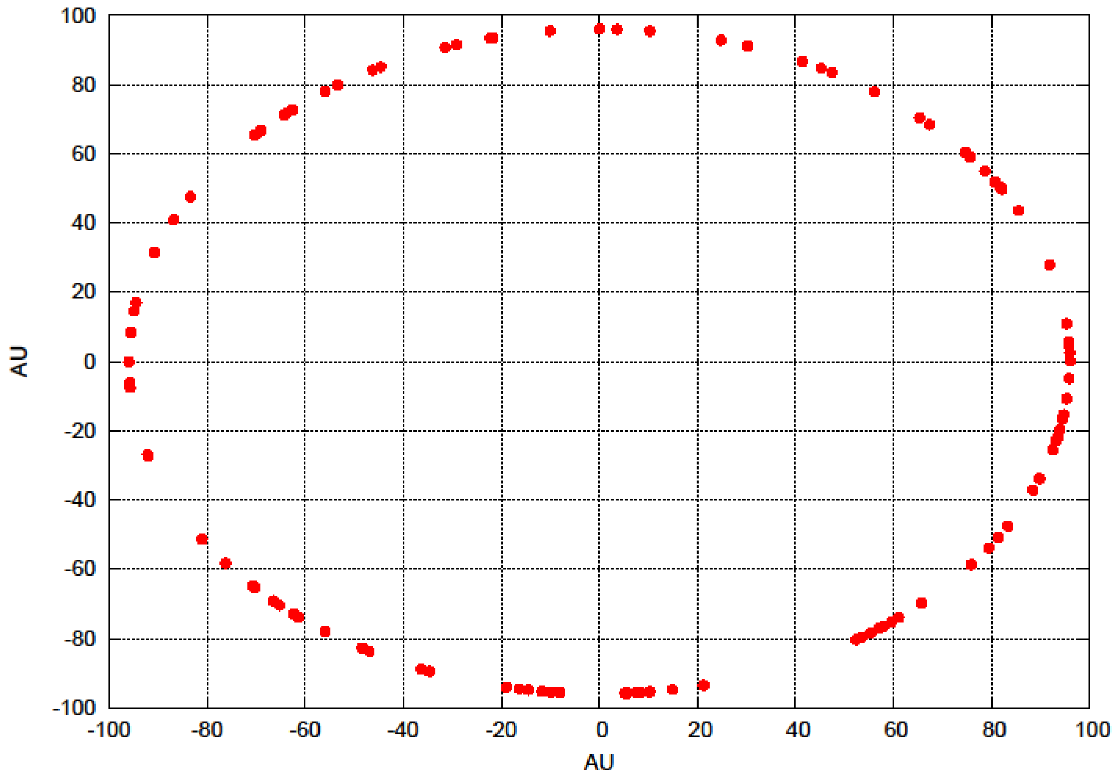


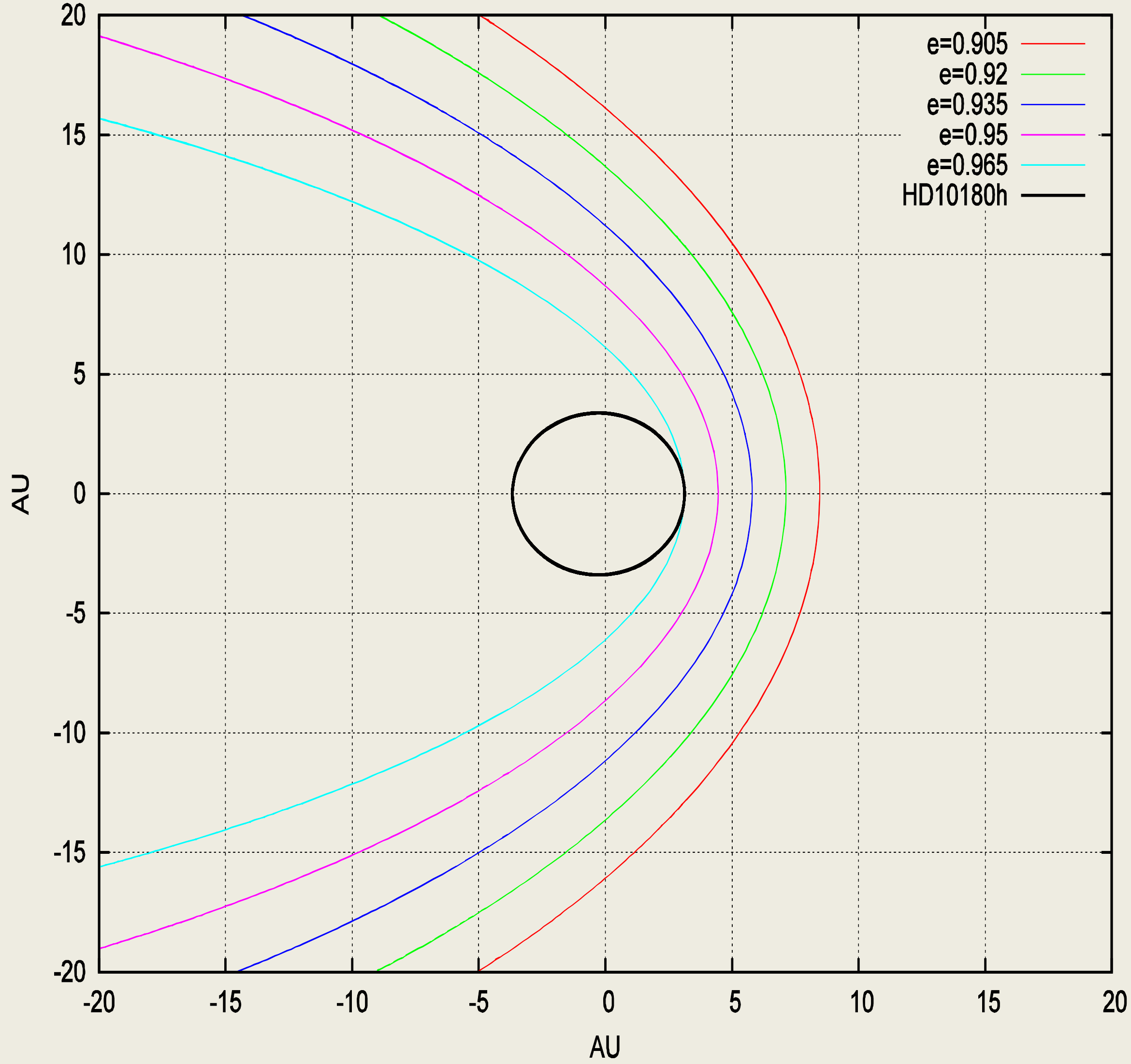
INITIAL CONDITIONS:
100 comets from ~100 AU
0.9 < e < 0.99
0 < omega < 360 deg
0 < inclinations < 180 deg

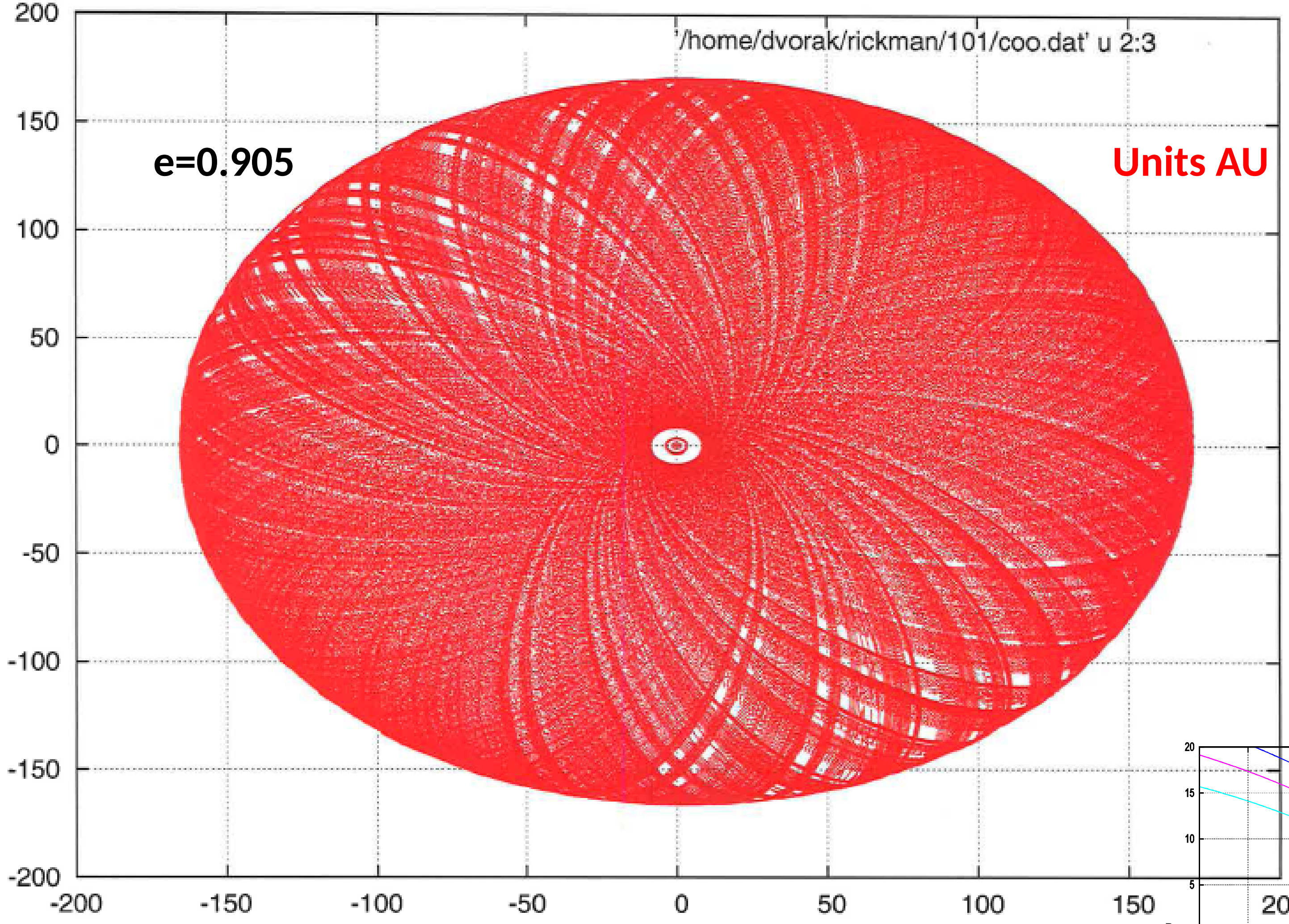
Star + 4 outer planets
Integration for 1 Myrs – to 10 Myrs
escapes to infinity by close encounters ->
replaced by another ‘new’ comet

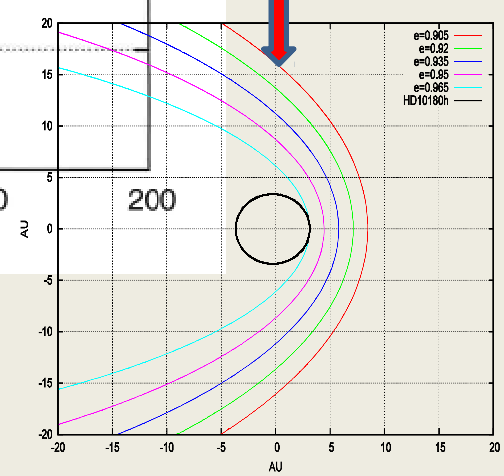


Initial conditions for the comet cloud in HD10180
Inclination = 0 deg, 100 different perihelion

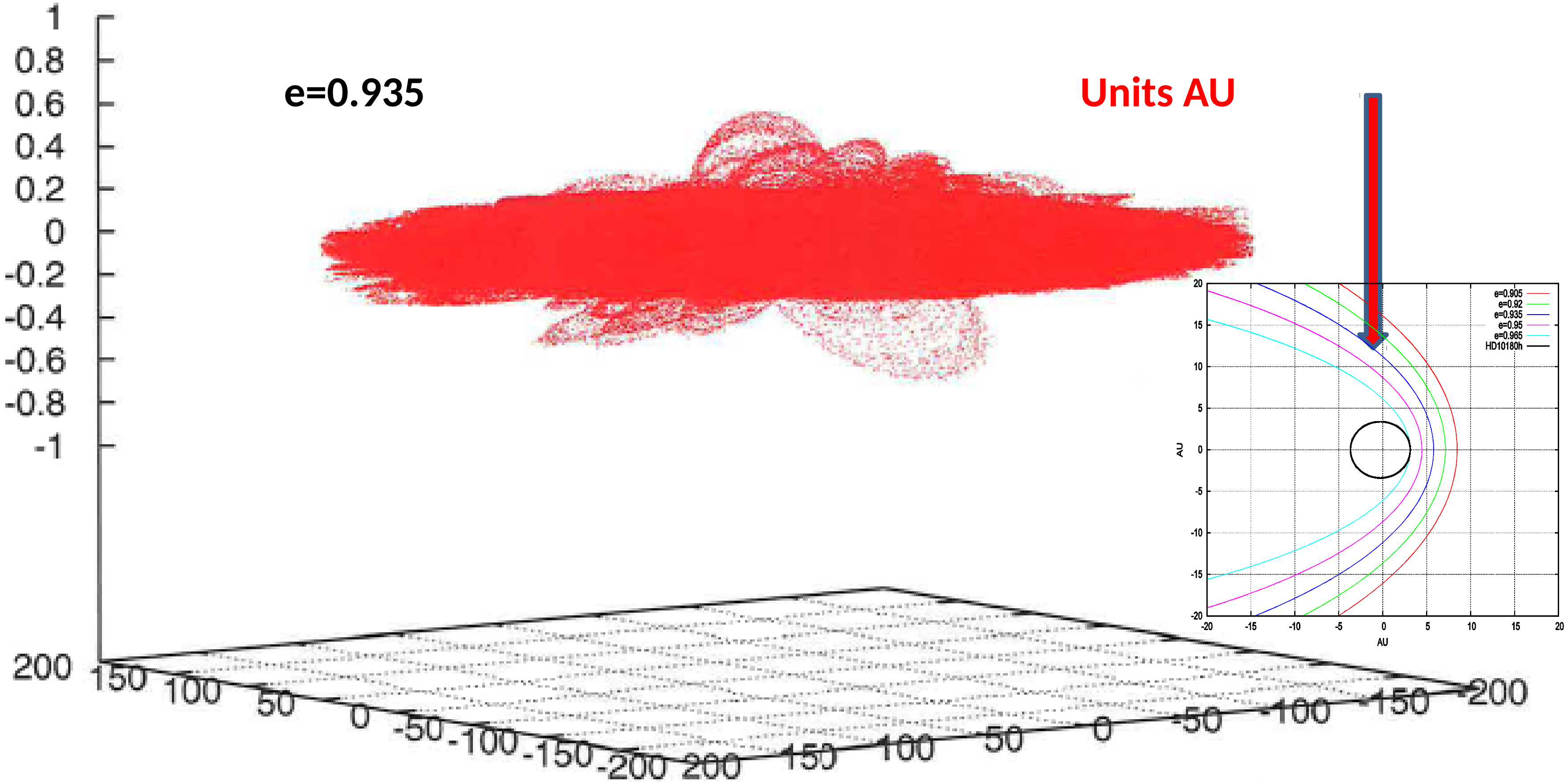



e=0.905
e=0.92
e=0.935
e=0.95
e=0.965
HD10180h
AU
AU
20
15
10
5
0
-5
-10
-15
-20
-20
-15
-10
-5
0
5
10
15
20

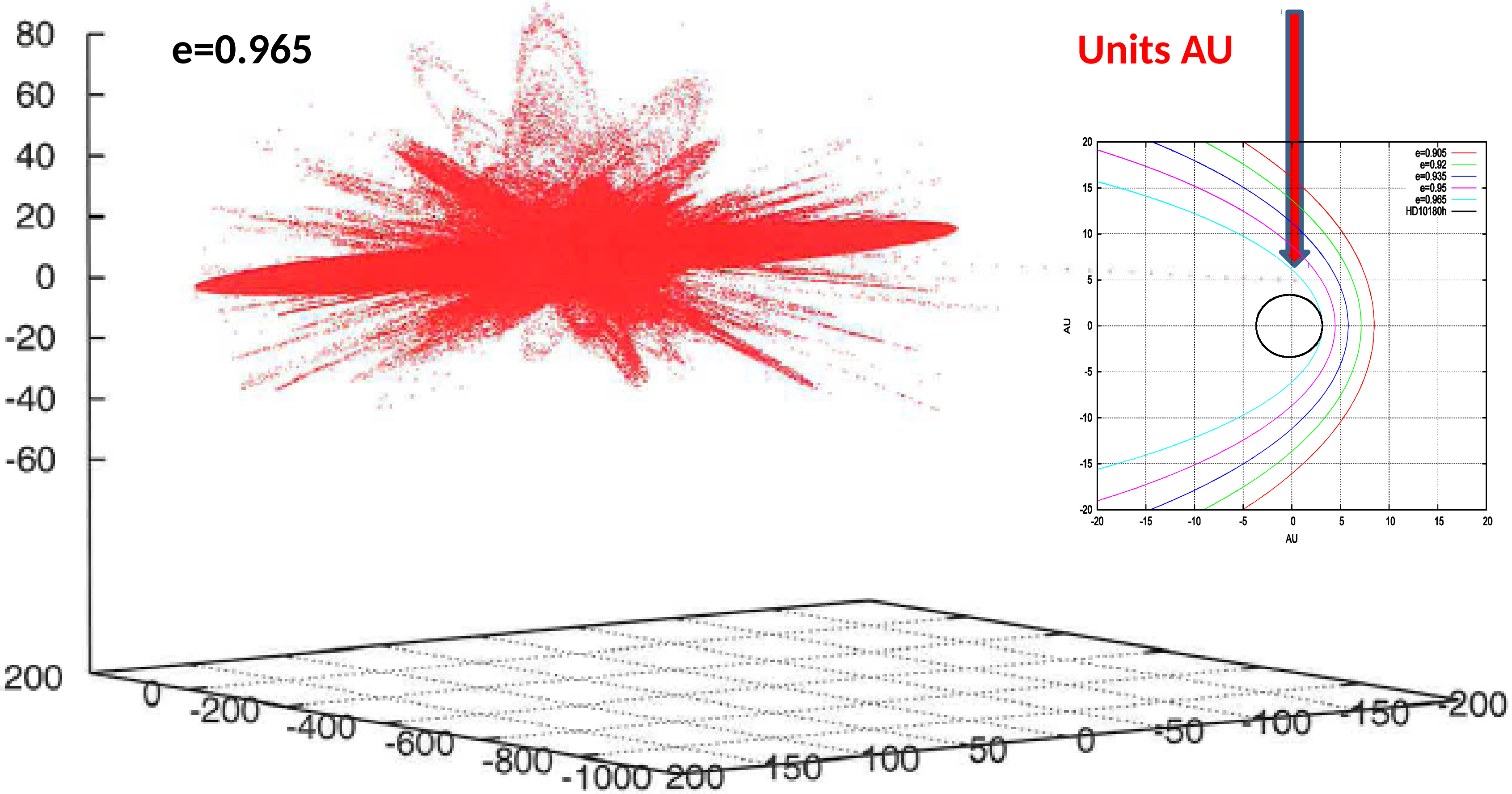




Orbits for 100 initial conditions for 1 Myr

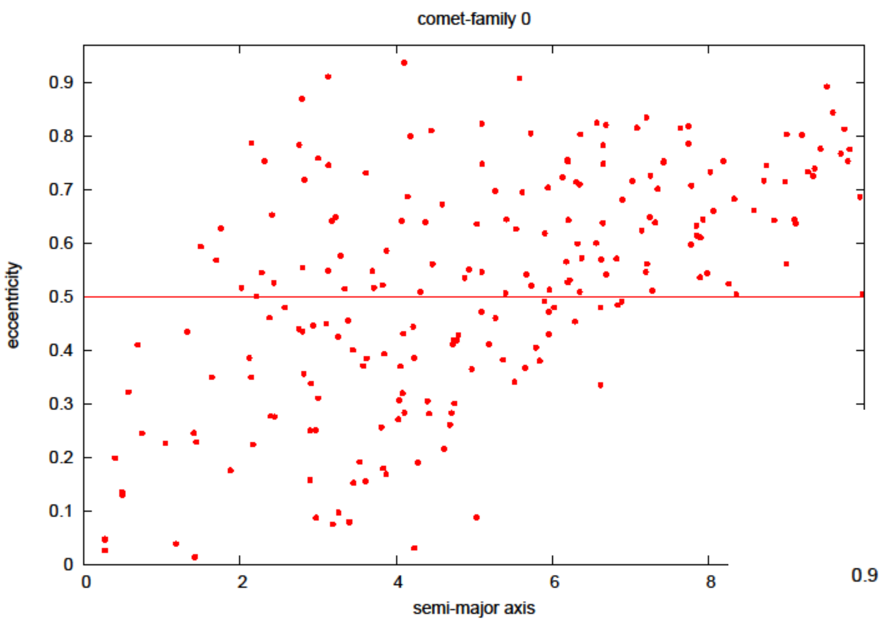


Orbits for 100 initial conditions
ca 1000 new comets



Orbits for 100 initial conditions for ca 5000 new comets

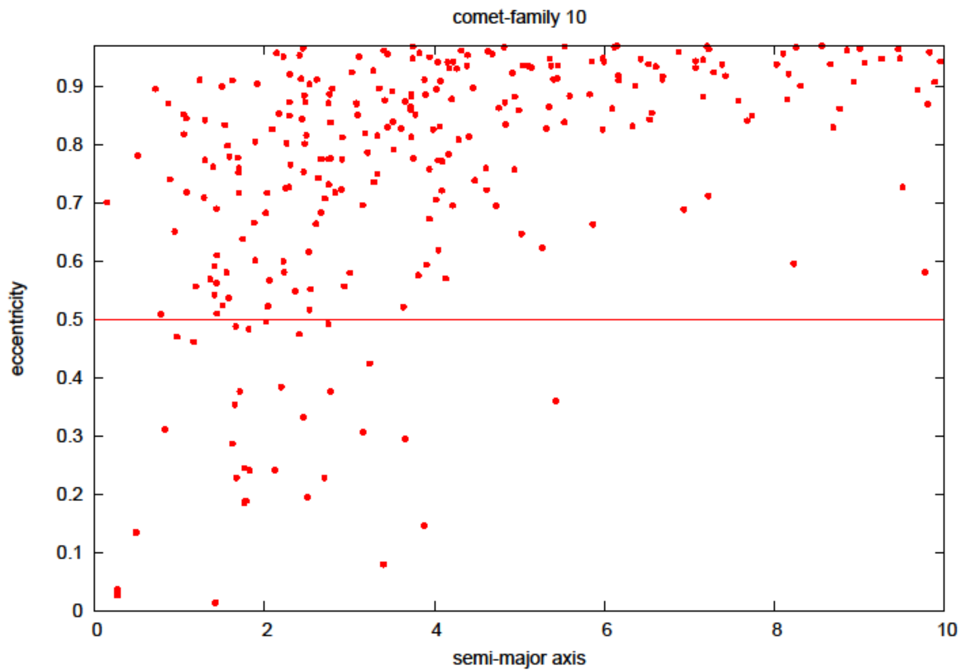
Temporary captures in the system HD 10180



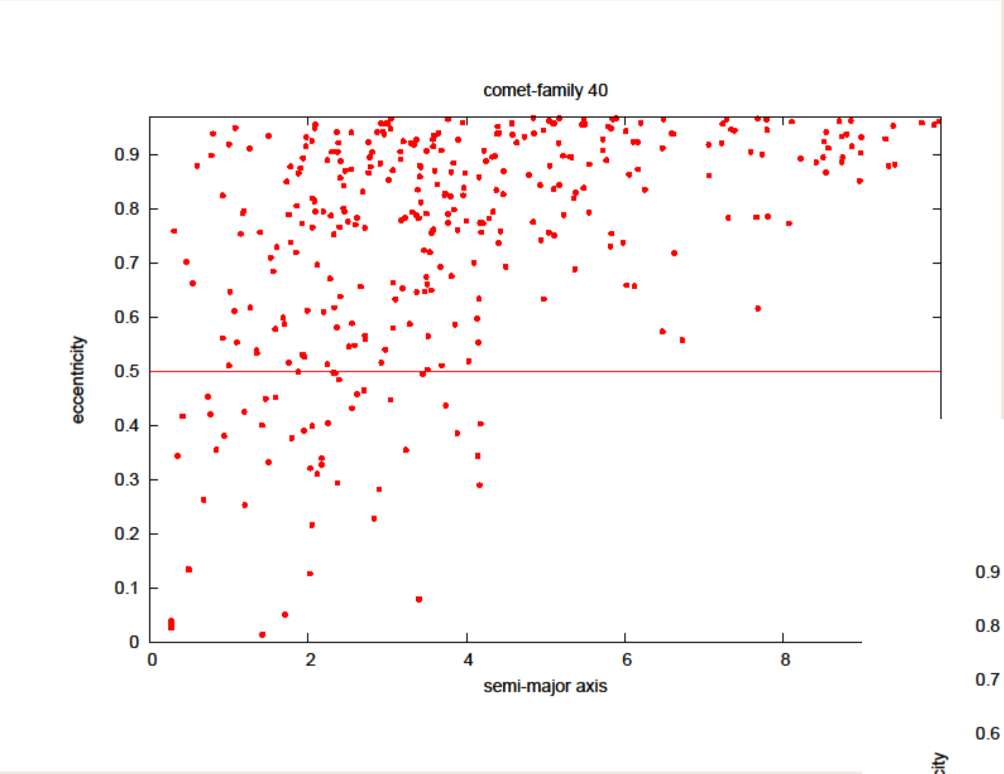
Captured comets for i=0 deg

semimajor axis

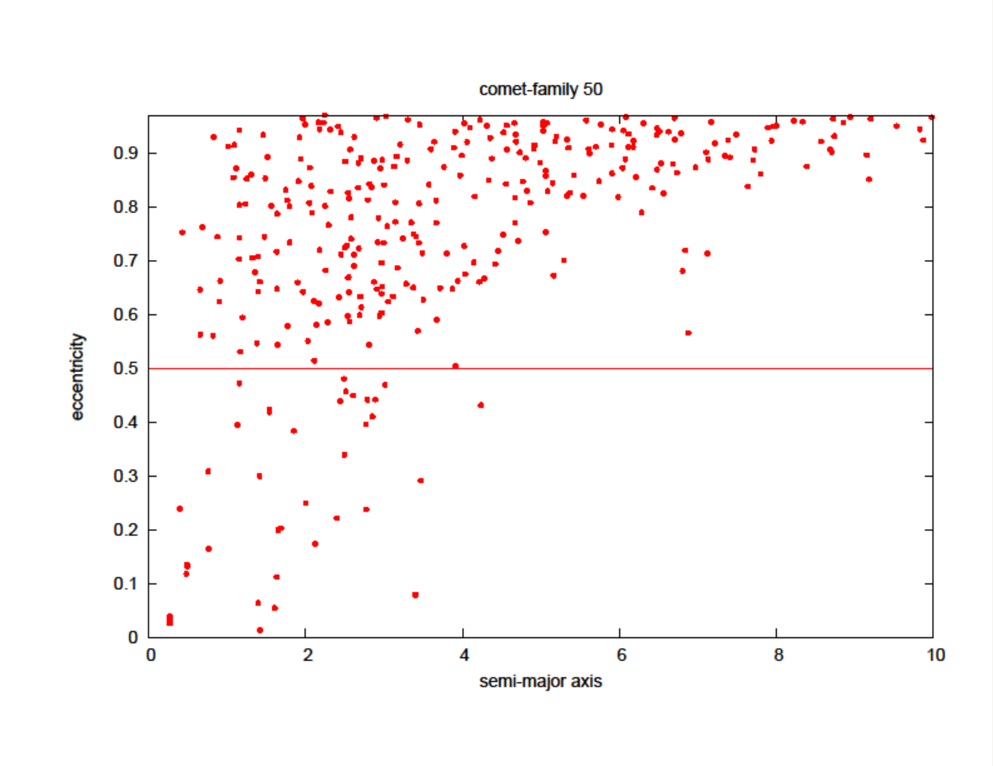
Captured comets for i=10 deg



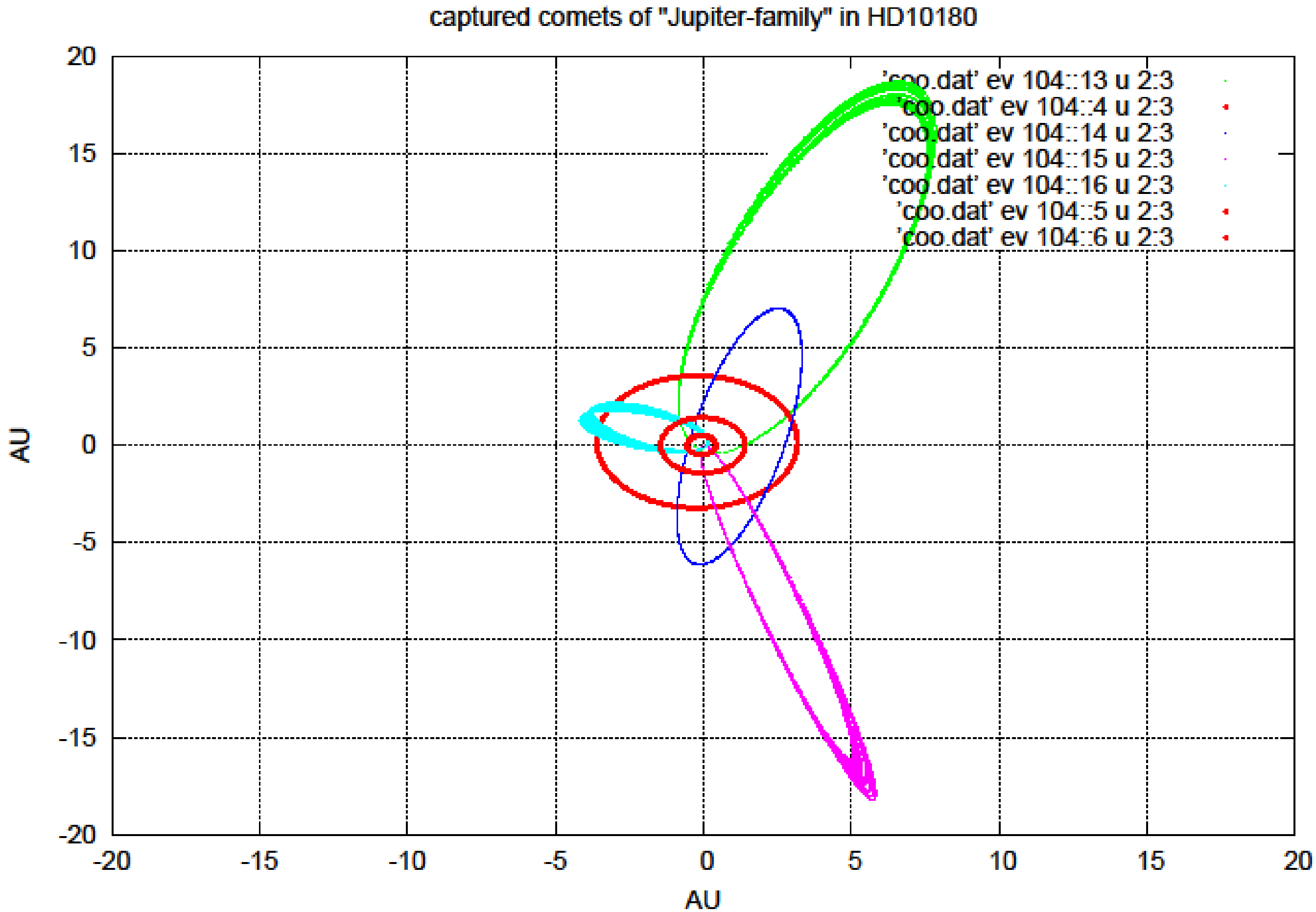
Temporary captures in the system HD 10180



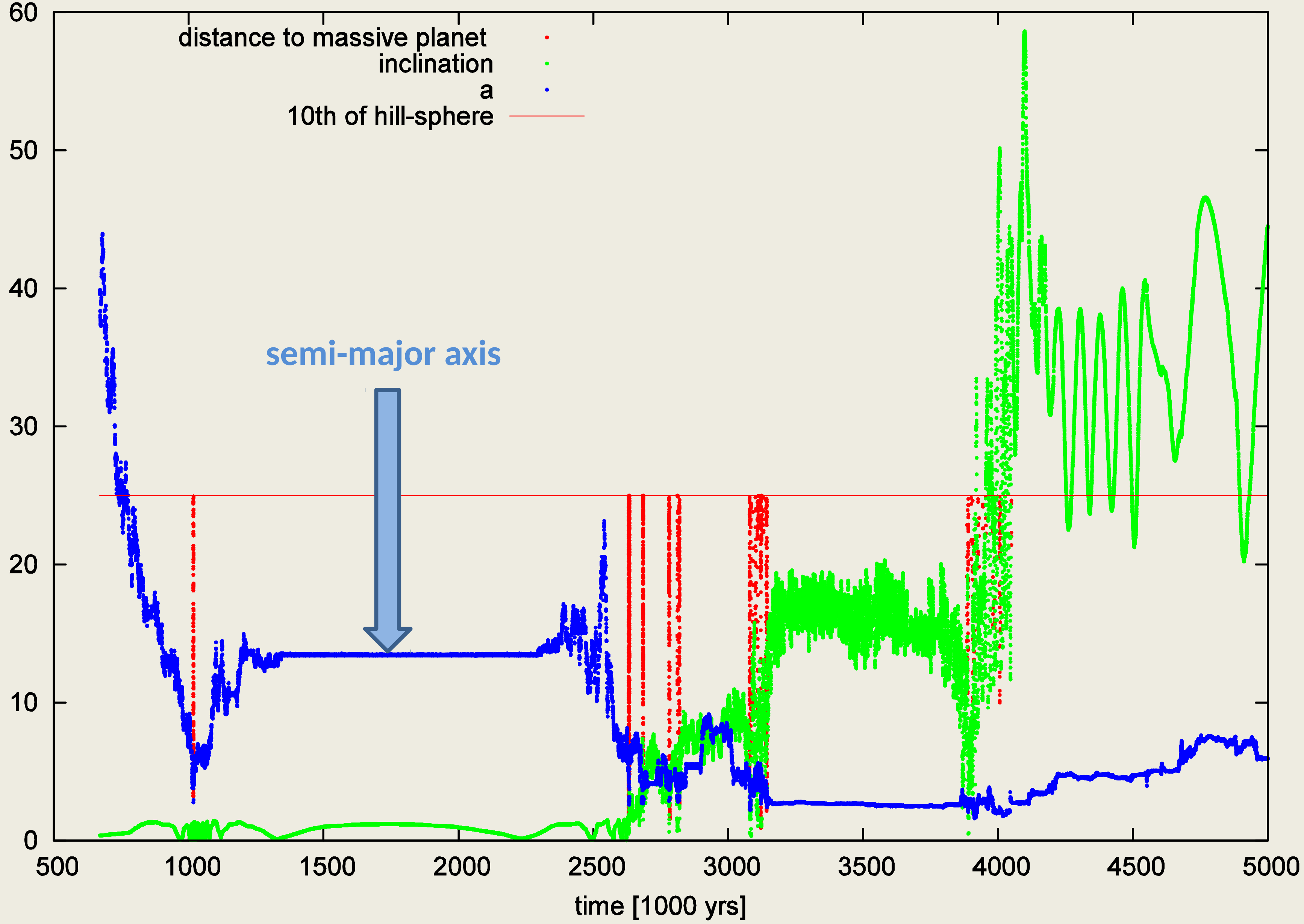
Captured comets for i=40 deg



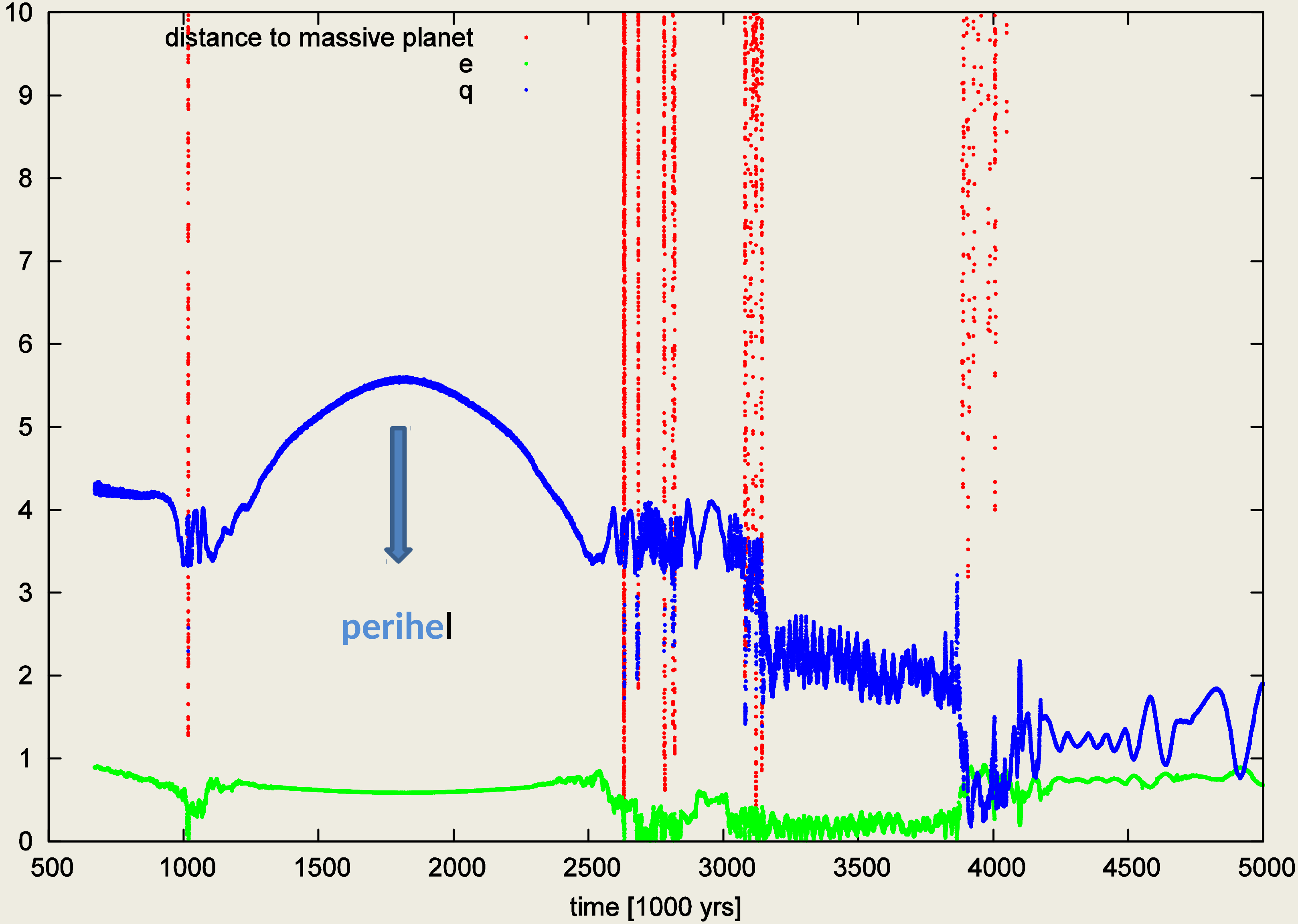
Captured comets for i=50 deg


captured comets of "Jupiter-family" in HD10180
'coo.dat' ev 104::13 u 2:3
'coo.dat' ev 104::4 u 2:3
'coo.dat' ev 104::14 u 2:3
'coo.dat' ev 104::15 u 2:3
'coo.dat' ev 104::16 u 2:3
'coo.dat' ev 104::5 u 2:3
'coo.dat' ev 104::6 u 2:3
AU
AU
20
15
10
5
0
-5
-10
-15
-20
-20
-15
-10
-5
0
5
10
15
20

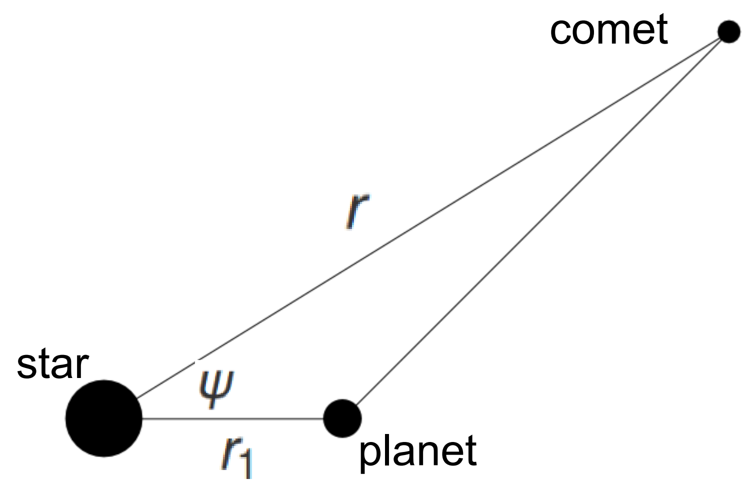
EXAMPLE OF A CAPTURED COMET



EXAMPLE OF A CAPTURED COMET



Statement of the problem



The exact perturbing function:

$$R = \mu_1 \left(\frac{1}{\Delta} - \frac{r \cdot \cos\psi}{r_1^{\,2}} \right)$$

The approximate perturbing function for inner perturber:

$$R = \frac{\mu_1}{r} \sum_{n=2}^{\infty} \left(\frac{r_1}{r} \right)^n P_n(\cos\psi) + \left(\frac{r_1}{r^2} - \frac{r}{r_1^{\,2}} \right) \cos\psi$$

Series developments of products of the form:

$$r^a \, r_1^{\,b} \cos^c \psi \quad \text{with } a, b, c \in \mathbb{Z}$$

Cometary expansions require low order n but high eccentricity e !

Most expensive (computational) part:

$$\cos\psi = A(i, i_1, \omega, \omega_1, \Omega, \Omega_1)\cdot\cos f\cdot\cos f_1 + B(i, i_1, \omega, \omega_1, \Omega, \Omega_1)\cdot\cos f\cdot\sin f_1 + C(i, i_1, \omega, \omega_1, \Omega, \Omega_1)\cdot\cos f_1\cdot\sin f + D(i, i_1, \omega, \omega_1, \Omega, \Omega_1)\cdot\sin f\cdot\sin f_1$$

Classical expansions (around e=0) do not work, we start with Fourier series representation:

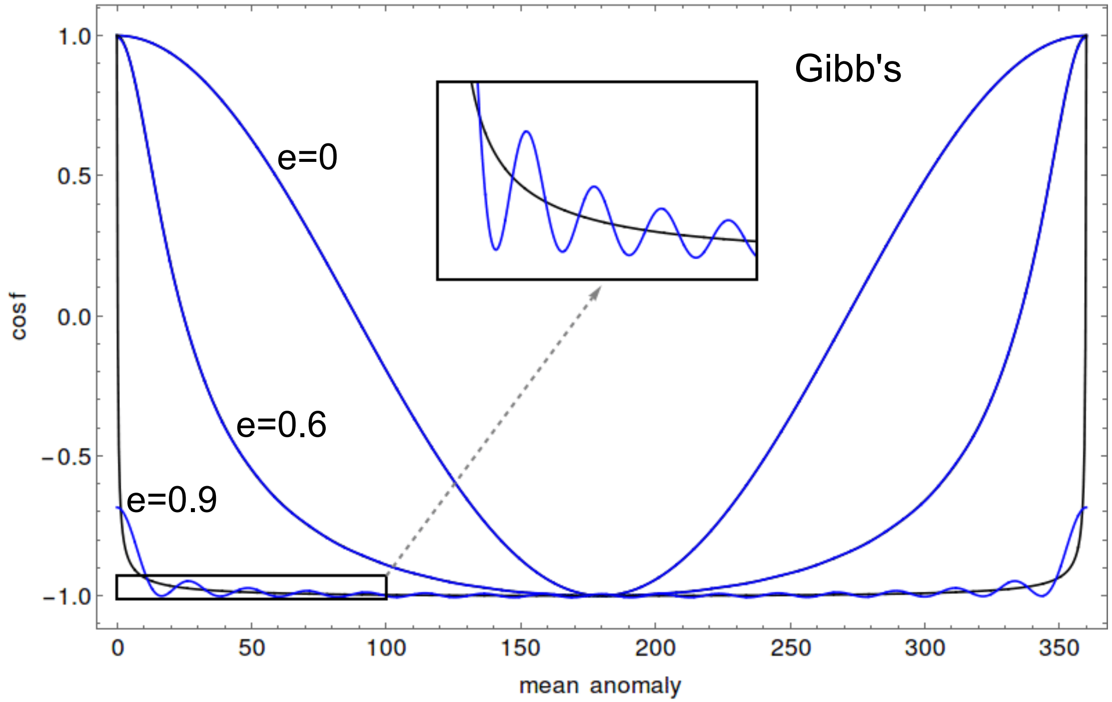
$$r = a\left(1 + \frac{1}{2}e^2 - 2e\sum_{v=1}^{\infty}\frac{dJ_v(e)}{de}\frac{\cos(vM)}{v^2}\right)$$

$$r^{-1} = \frac{1}{a}\left(1 + 2\sum_{v=1}^{\infty}J_v(e)\cos(vM)\right)$$

$$\cos f = 2\frac{1-e^2}{e}\sum_{v=1}^{\infty}J_v(e)\cos(vM) - e$$

$$\sin f = 2\sqrt{1-e^2}\sum_{v=1}^{\infty}\frac{dJ_v(e)}{de}\frac{\sin(vM)}{v}$$

Bessel functions



Inclinations, arguments of pericenter, ascending node longitudes, true anomalies:

$$i,\ i_1,\ \omega,\ \omega_1,\ \Omega,\ \Omega_1,\ f,\ f_1$$

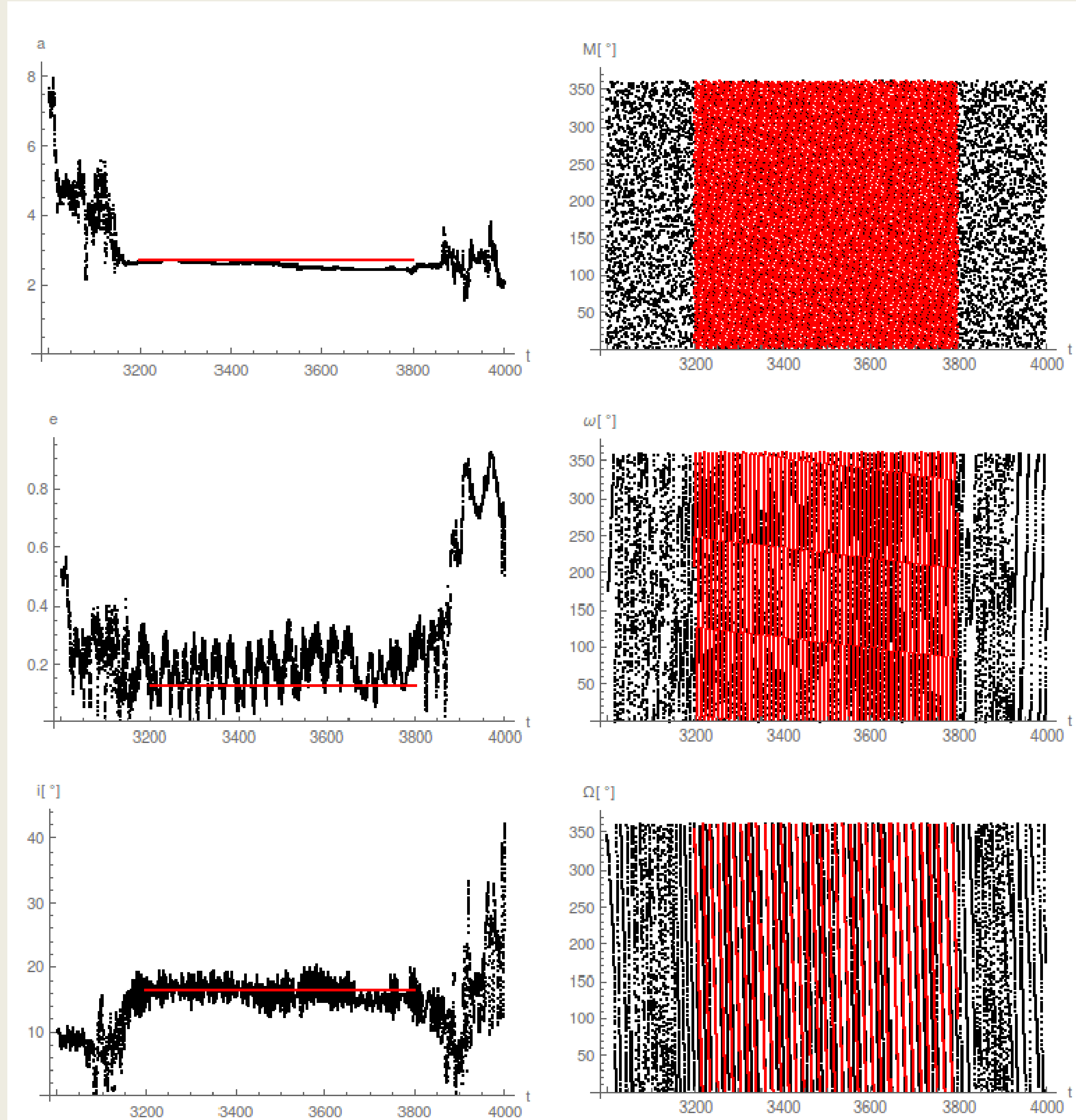
Preliminary results

$$H = \underline{H_s} + H_r + H_p$$

Separate dynamics:
- secular evolution
- resonant evolution
- close encounters

Emel'yanenko 1991:
Expansion of the secular and resonance parts of the perturbing function in the theory of motion of long-periodic comets.

Petrosky, Broucke 1988:
Area preserving mappings and deterministic chaos for nearly parabolic motions



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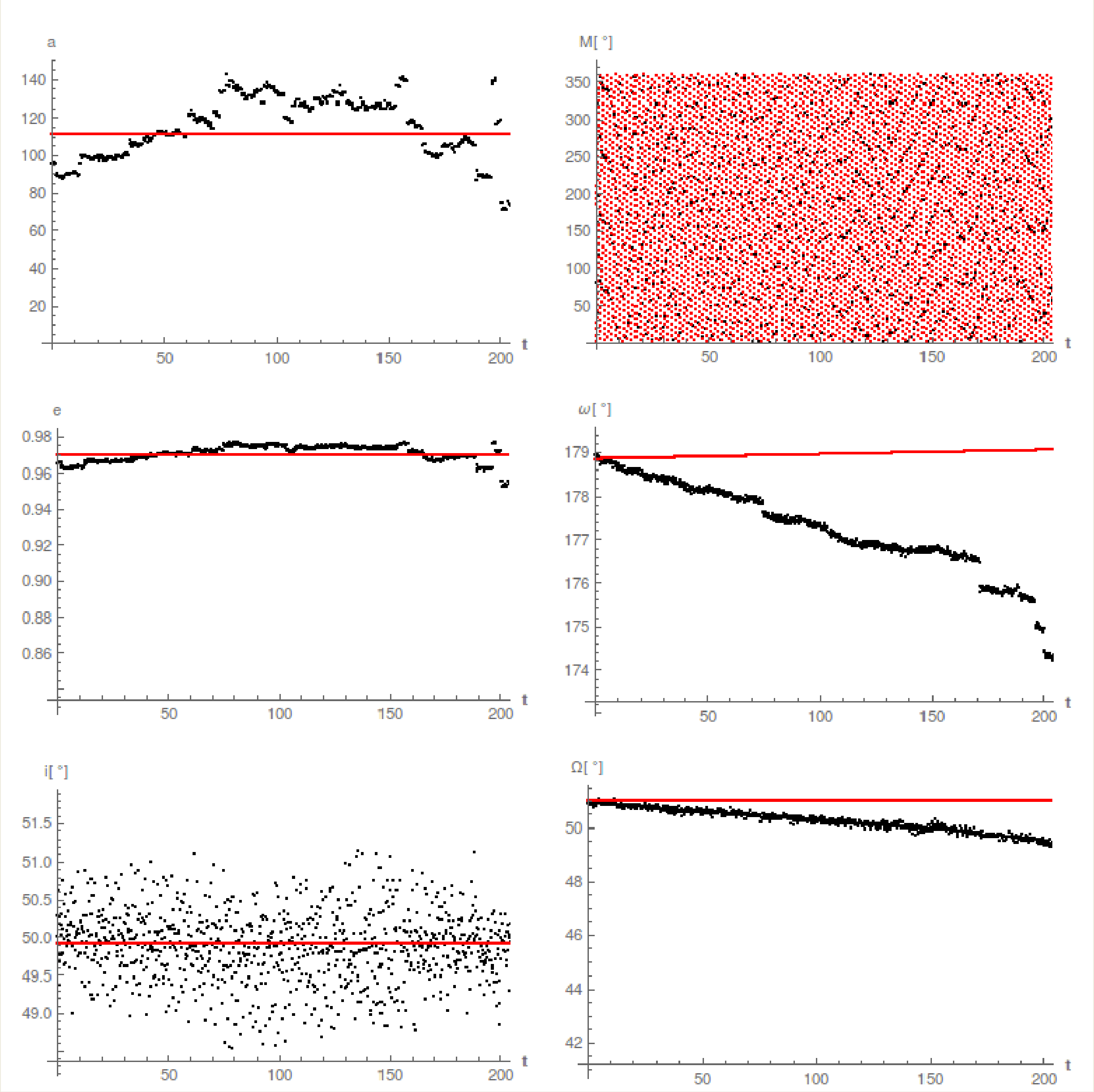
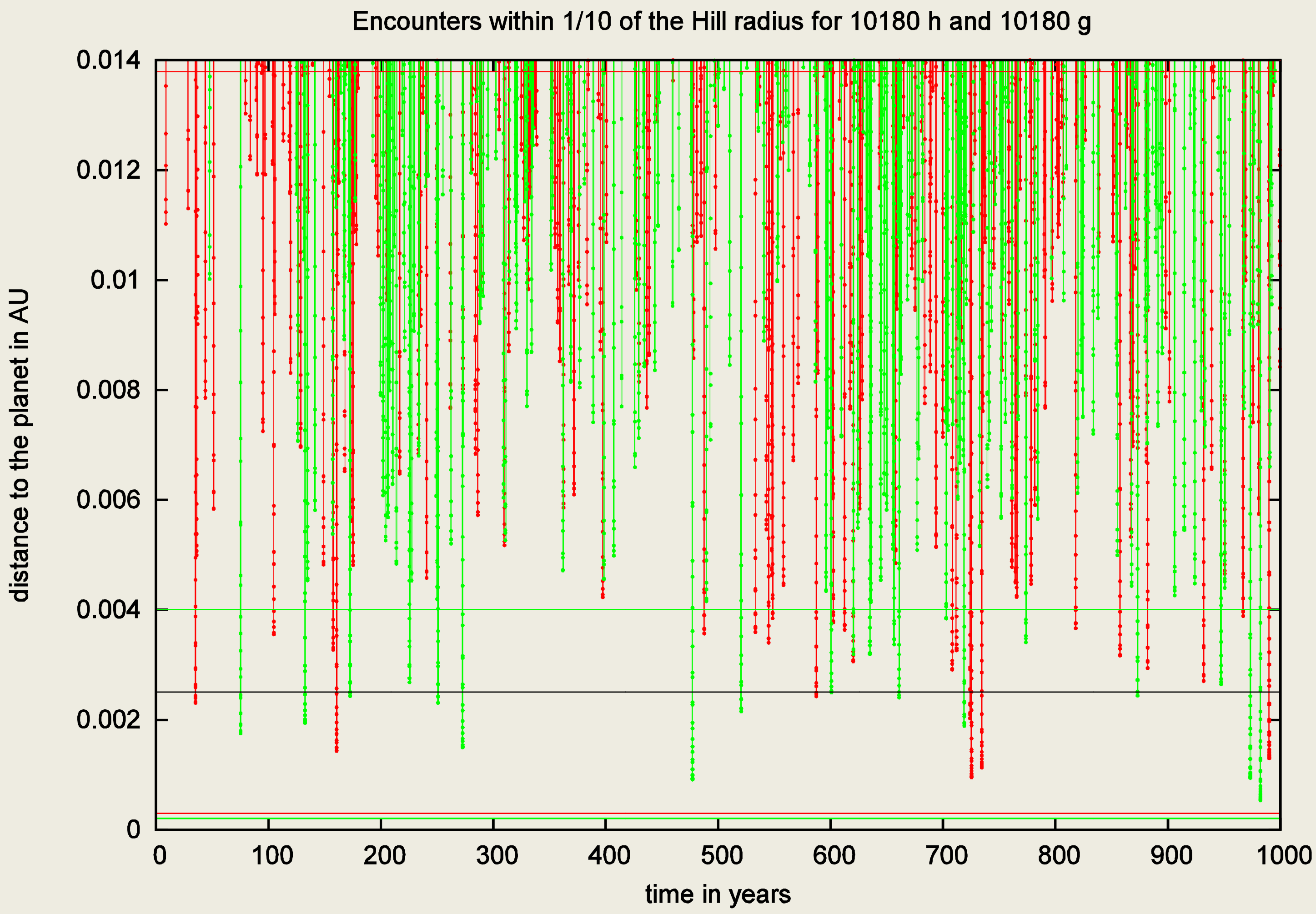
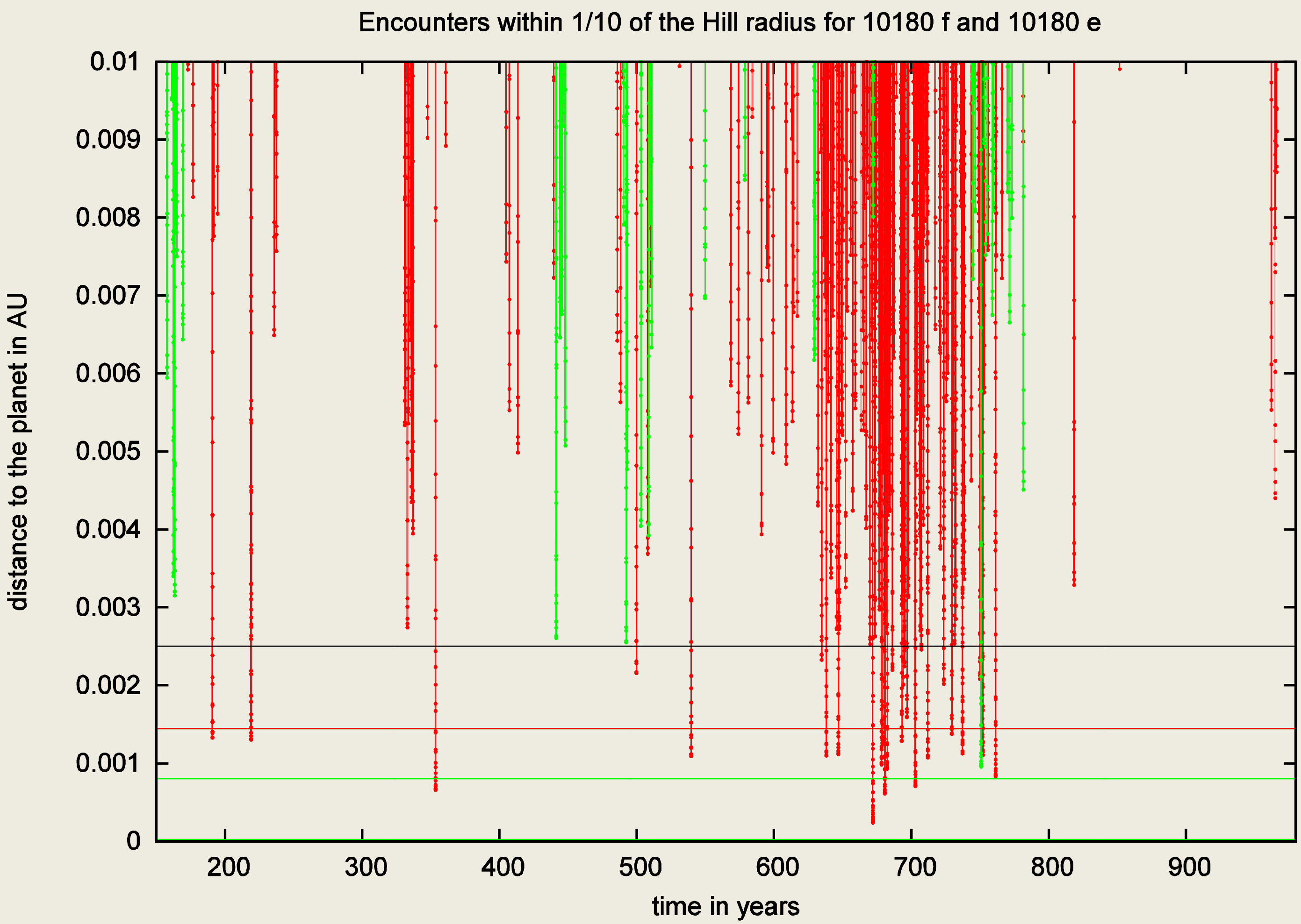
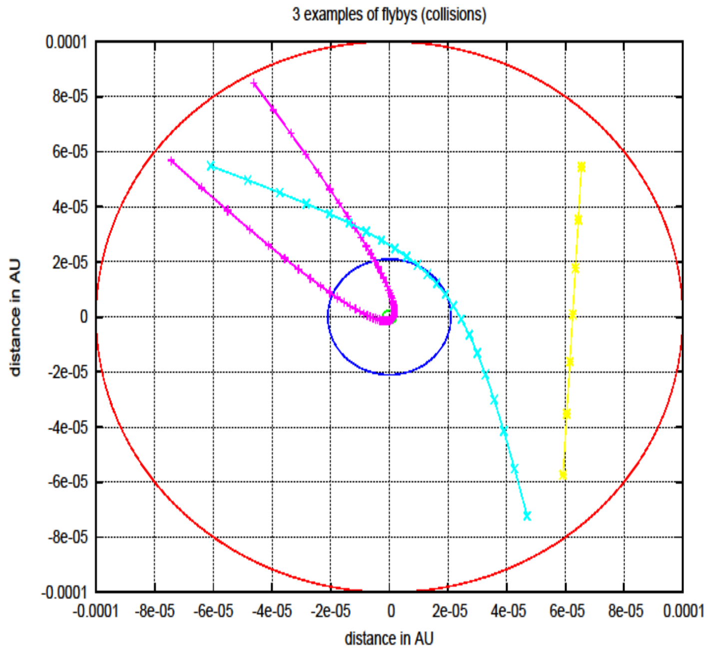
Aim: understand capture process on the basis of restricted three-body problem

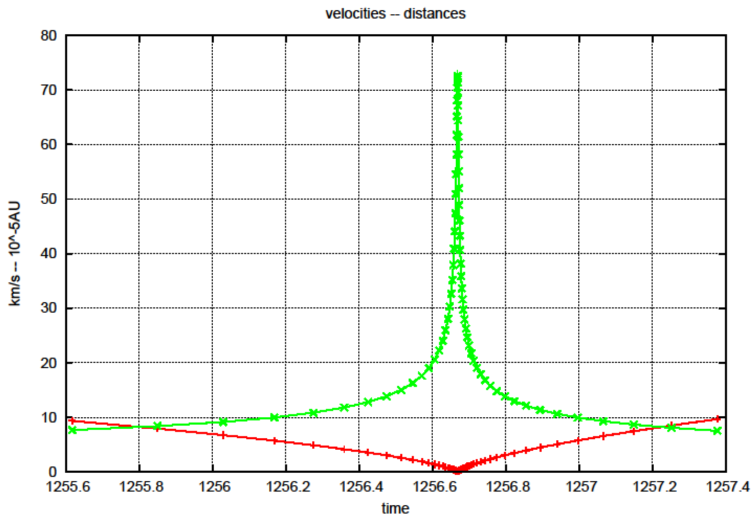


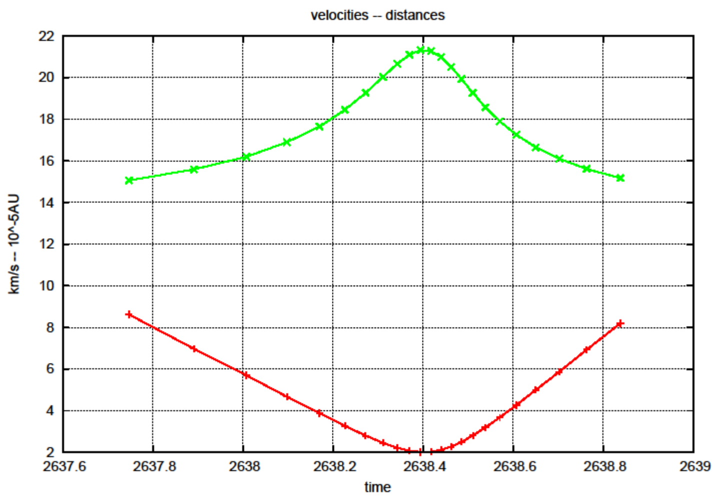

Encounters within 1/10 of the Hill radius for 10180 h and 10180 g
distance to the planet in AU
time in years
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0
100
200
300
400
500
600
700
800
900
1000



Encounters within 1/10 of the Hill radius for 10180 f and 10180 e
distance to the planet in AU
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
200
300
400
500
600
700
800
900
time in years

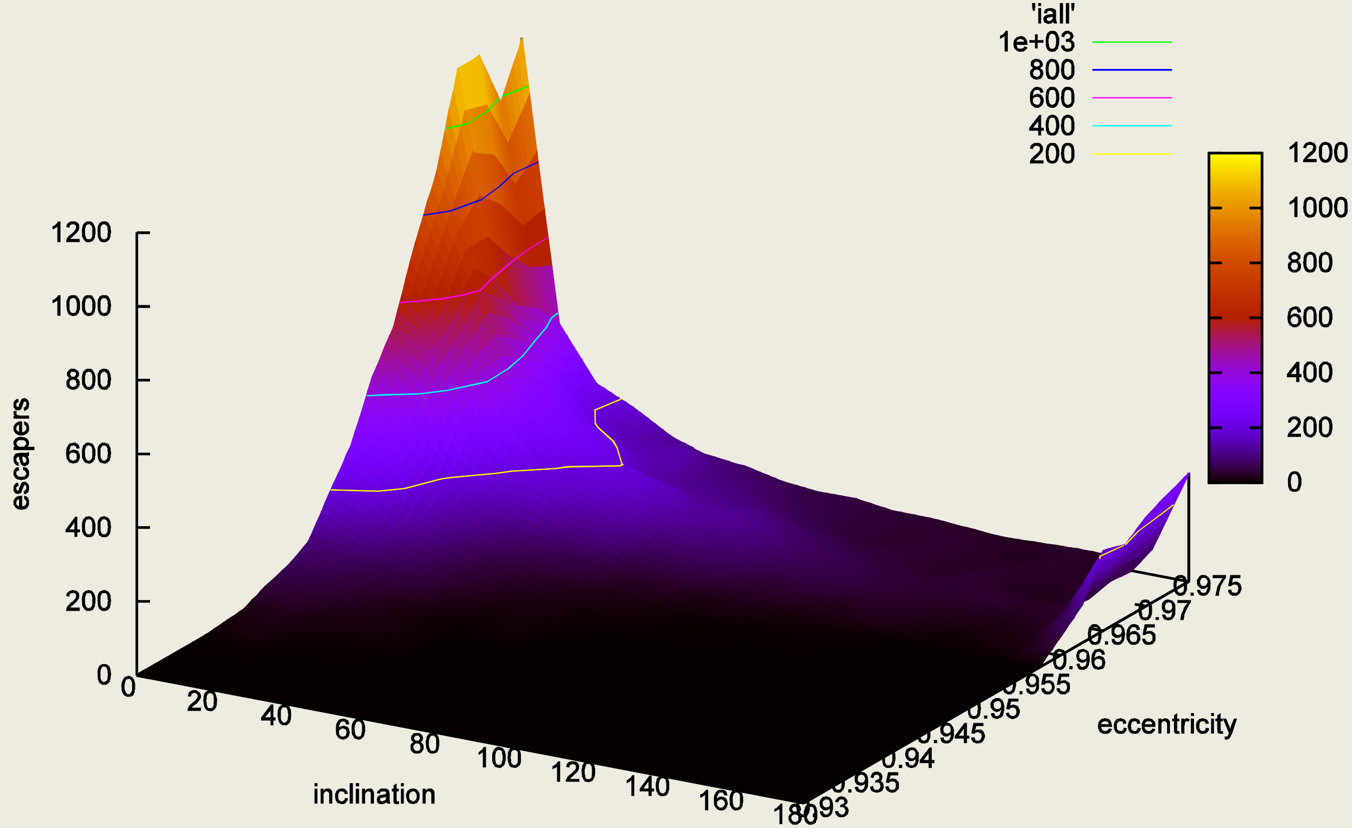




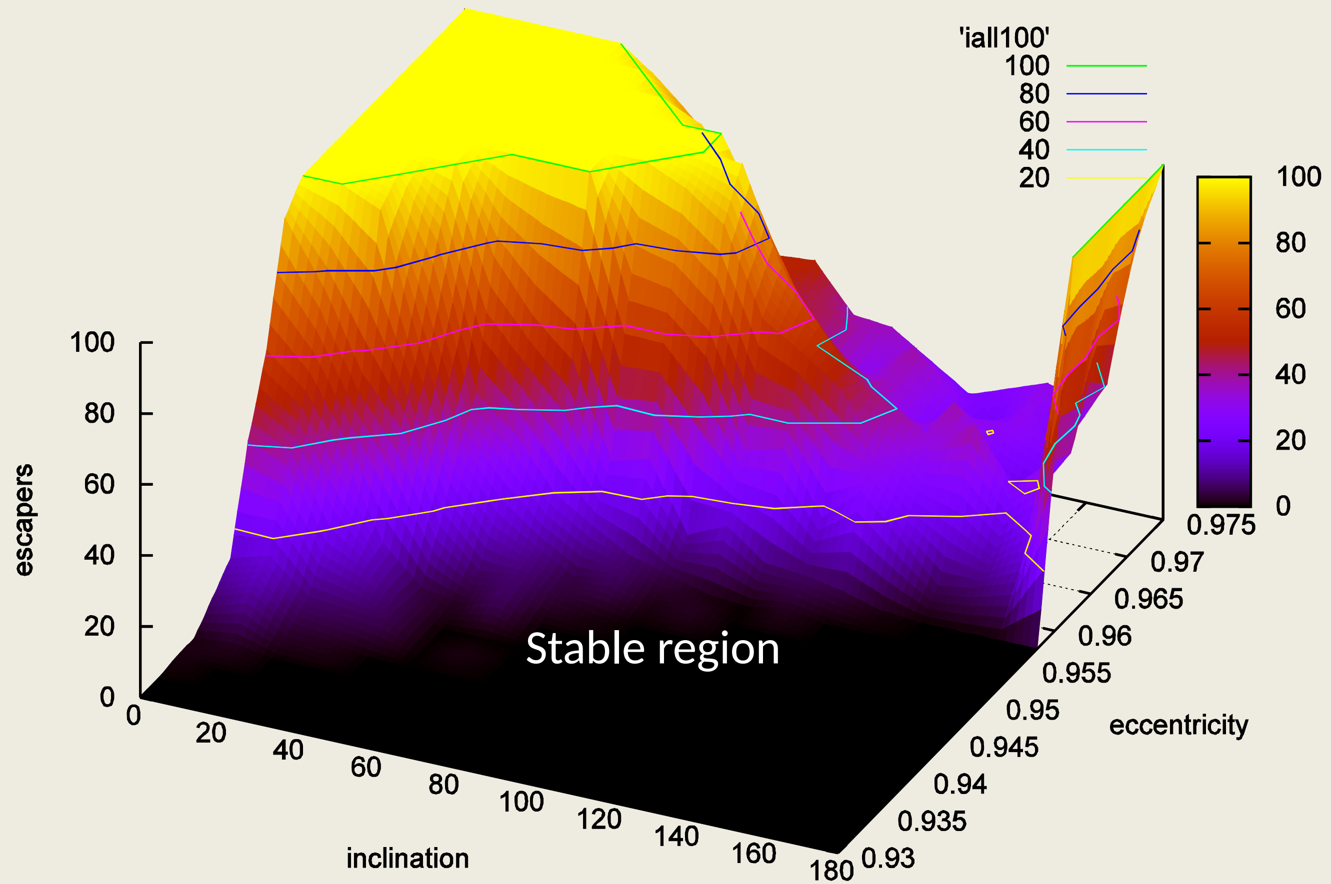


3 different scanaria of encounter

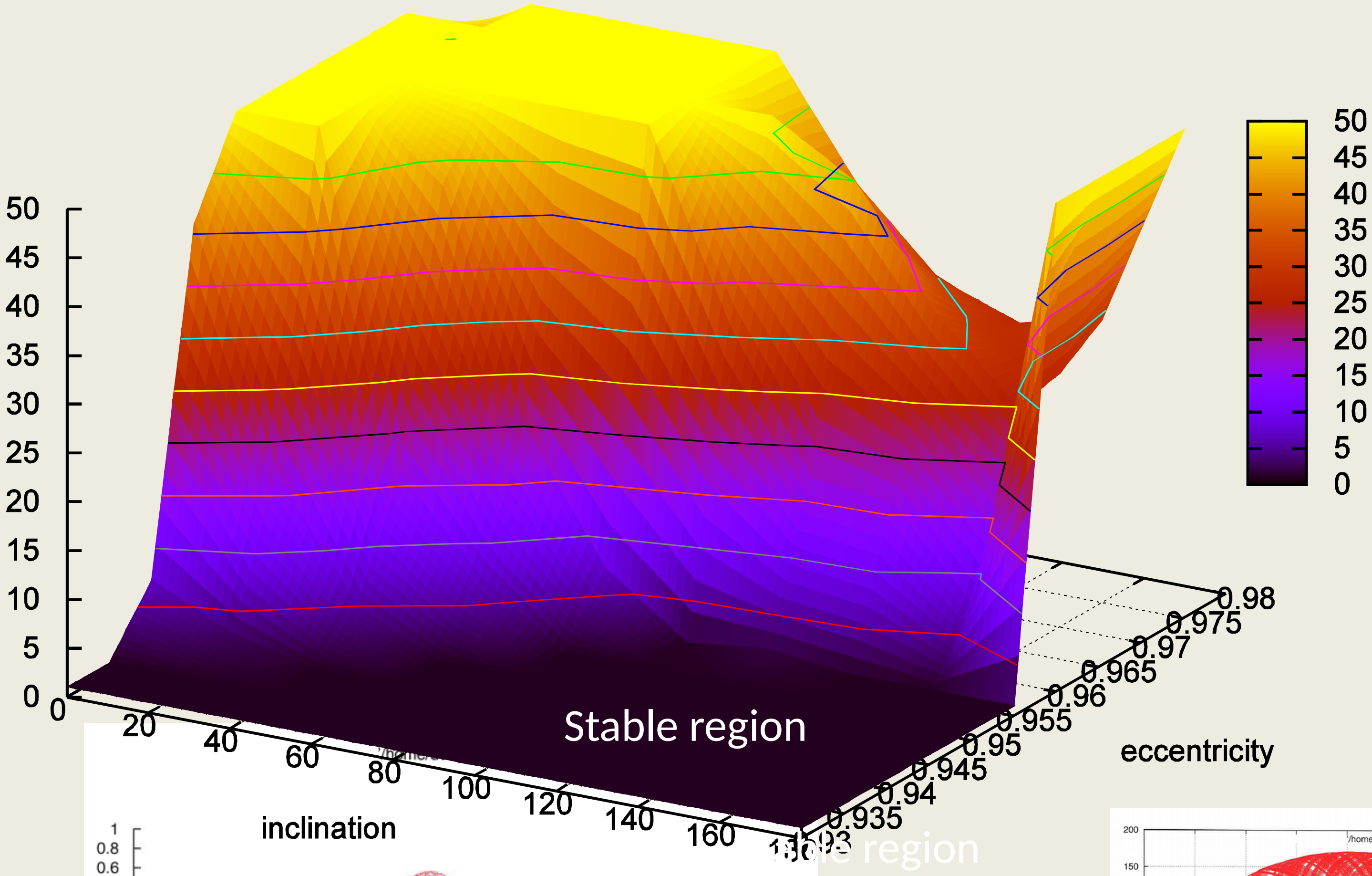
NEW (UNSTABLE) COMETS IN HD 10180

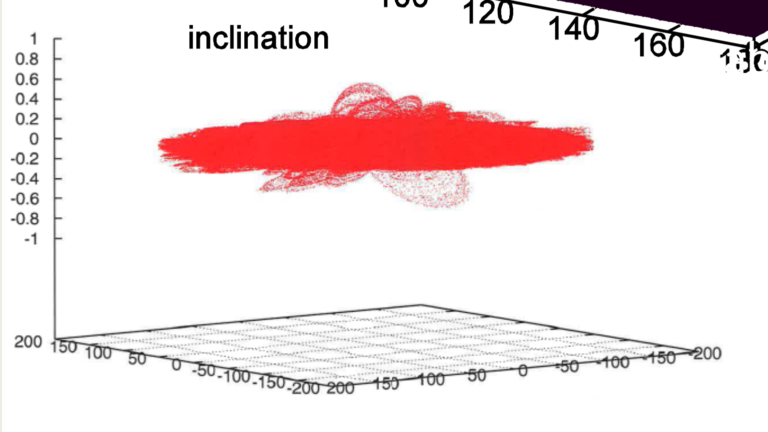


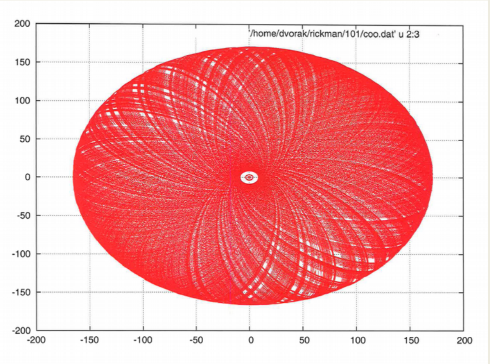
NEW (UNSTABLE) COMETS IN HD 10180 -- DETAIL

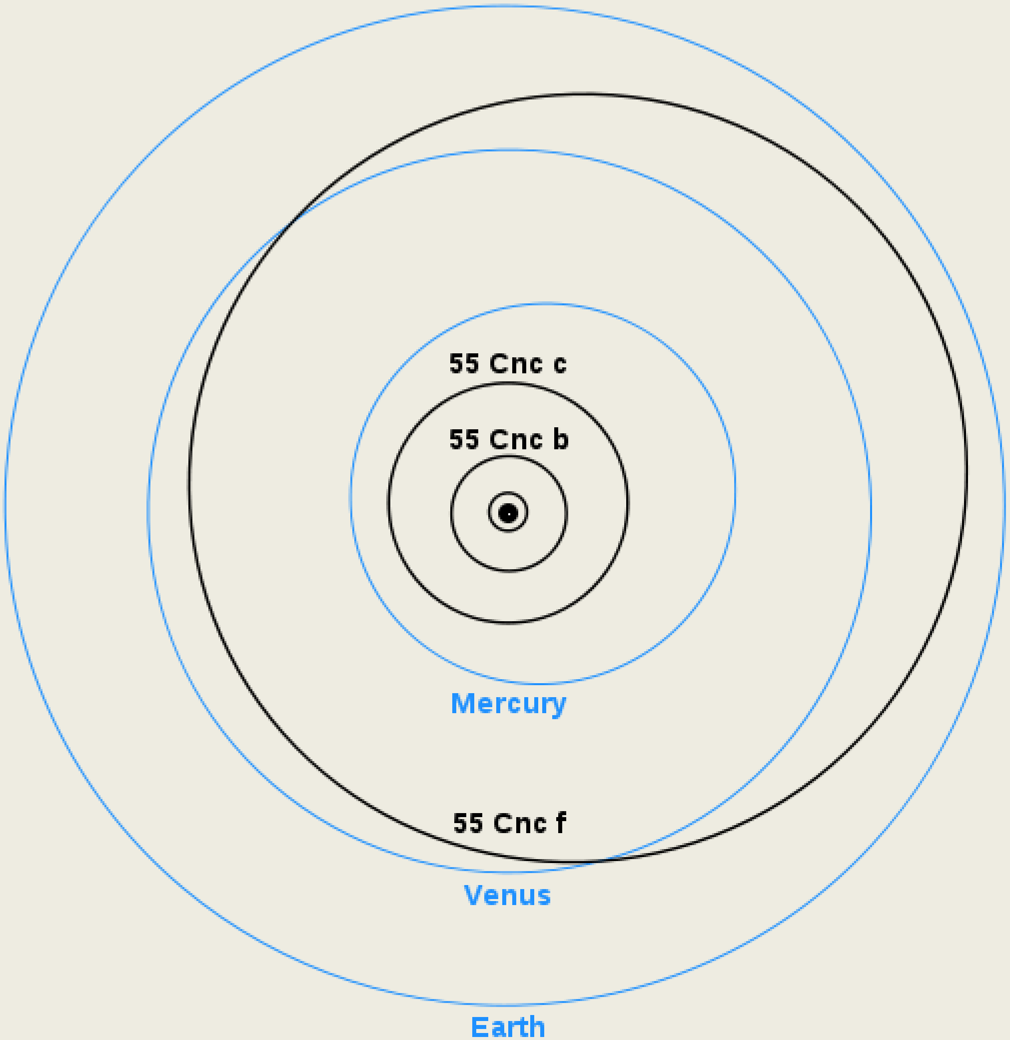


NEW (UNSTABLE) COMETS IN HD 10180 -- DETAIL



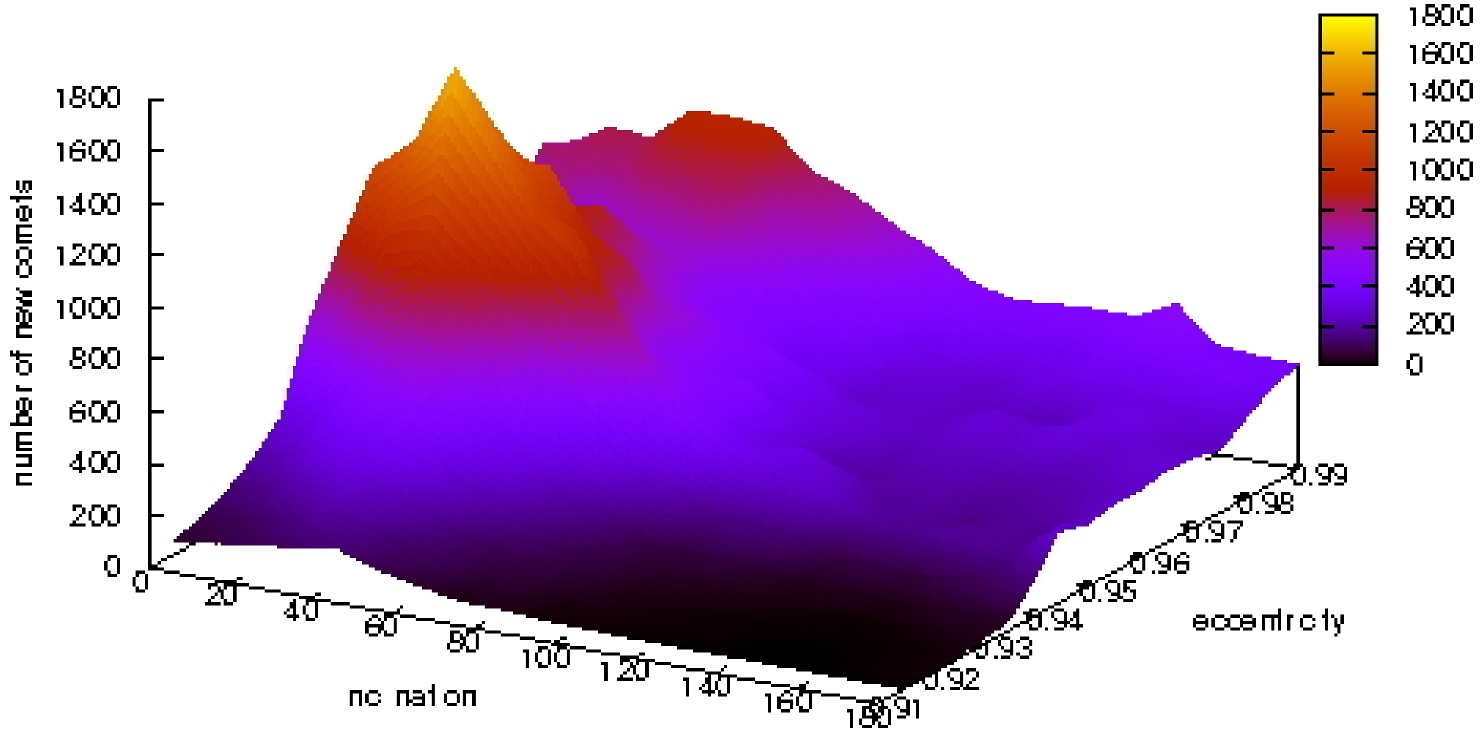





55 Cnc c
55 Cnc b
Mercury
55 Cnc f
Venus
Earth

The 55 Cancri A planetary system[20][31]

Companion (in order from star)	Mass	Semimajor axis (AU)	Orbital period (days)	Eccentricity	Inclination	Radius
e (Janssen)	8.63 ± 0.35 $M_{\oplus}$	0.01560 ± 0.00011	0.736537 ± 0.000013	0.17 ± 0.04	83.4 ± 1.7°	2.00 ± 0.14 $R_{\oplus}$
b (Galileo)	0.825 ± 0.003 M_J	0.1148 ± 0.0008	14.6507 ± 0.0004	0.010 ± 0.003	~85°	—
c (Brahe)	≥0.171 ± 0.004 M_J	0.2403 ± 0.0017	44.364 ± 0.007	0.005 ± 0.003	—	—
f (Harriot)	≥0.155 ± 0.008 M_J	0.781 ± 0.006	259.8 ± 0.5	0.30 ± 0.05	—	—
d (Lipperhey)	≥3.82 ± 0.04 M_J	5.74 ± 0.04	5169 ± 53	0.014 ± 0.009	—	—



number of new comets
0
200
400
600
800
1000
1200
1400
1600
1800
0
20
40
60
80
100
120
140
160
180
0.91
0.92
0.93
0.94
0.95
0.96
0.97
0.98
0.99
eccentricity

- Goal was to find comet families like in our SS
- (Halley-types - Jupiter family comets)
- (with C. Lhotka from IWF-secular perturbation theory for e~0.9)

- With M. Cuntz
- Transport of water to habitable zones by comets
- why comets (see first slide!)
- HD 10108, interesting also other systems
- Statistical approach (~10^6 comets) will show the probability of
- Captures and impacts with planets
- 'LIFE of families '

Idea to look for early exosystems
When a comet collides with a planet in the habitable zone
(SPH collision computations Water? C-molecules?

All collisions are with respect to velocity of impact and impact angle available – but many additional computations necessary and an appropriate analysis of the huge amount of data during

CHECK OF ALL EXOPLANETS WITH OUTER GAS GIANT + PLANETS INSIDE

END