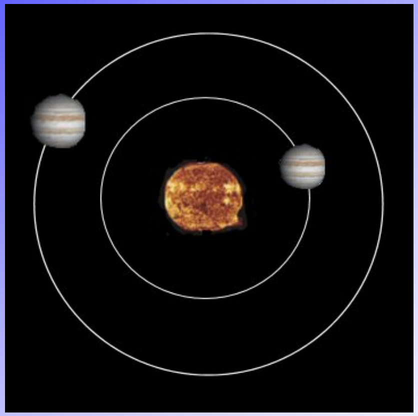
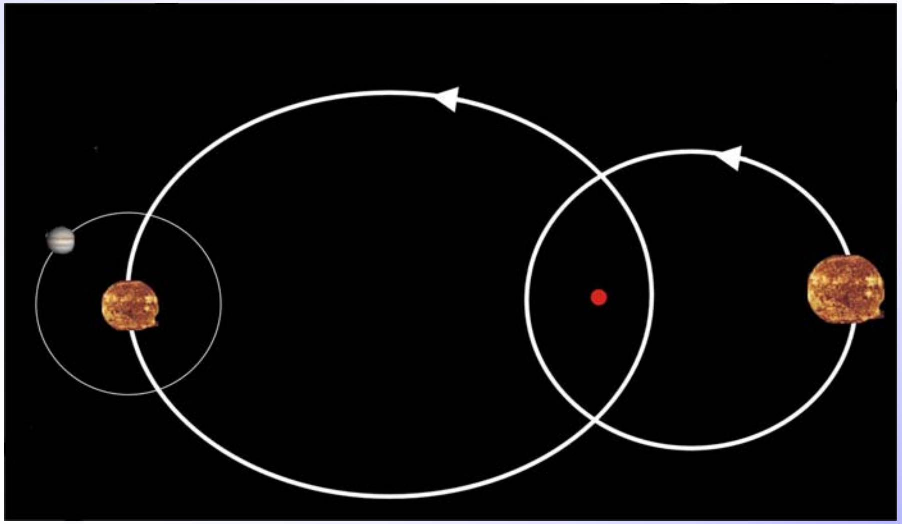
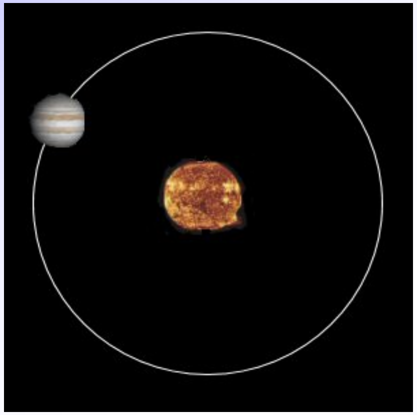


➢Multi-planetary systems



➢Binaries



➢ Single Star and Single Planetary Systems

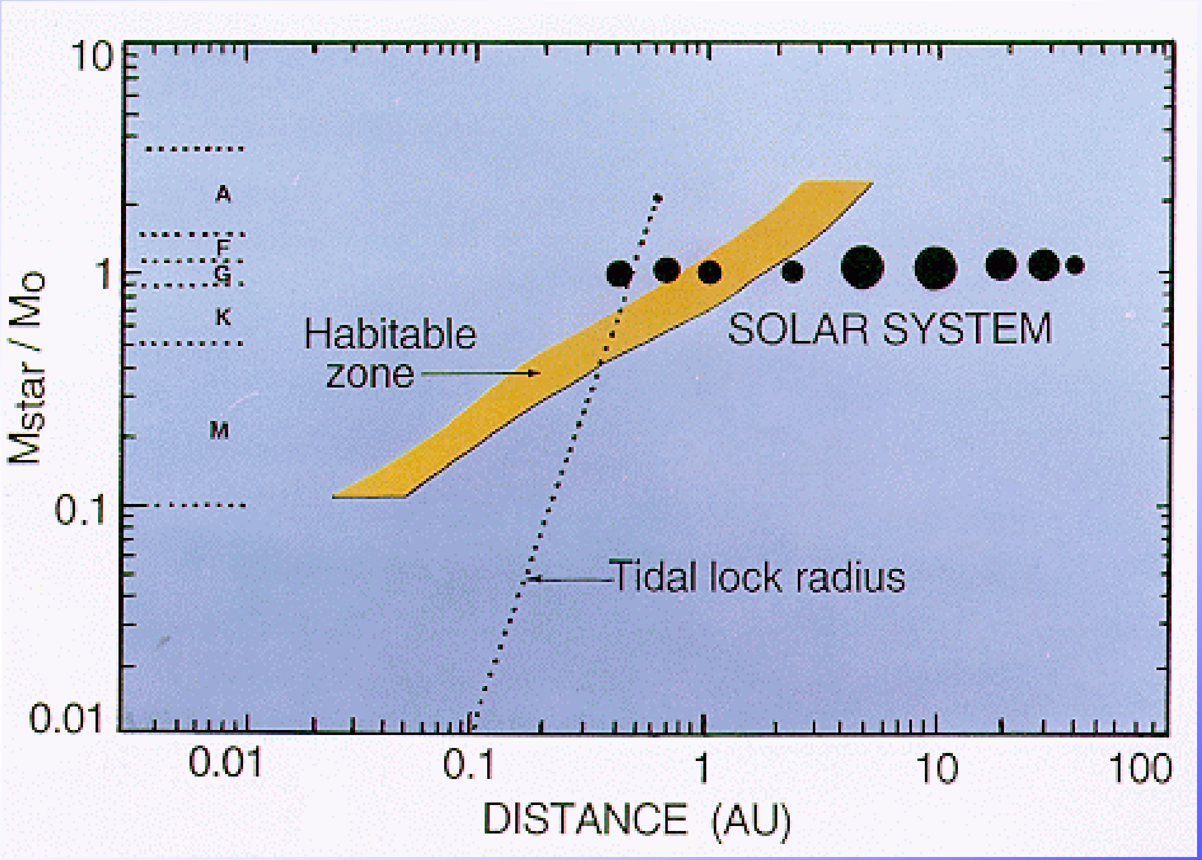
Terrestrial planets: Habitable Zone

- **Zone around a star where liquid water can exist on the surface of such a planet**

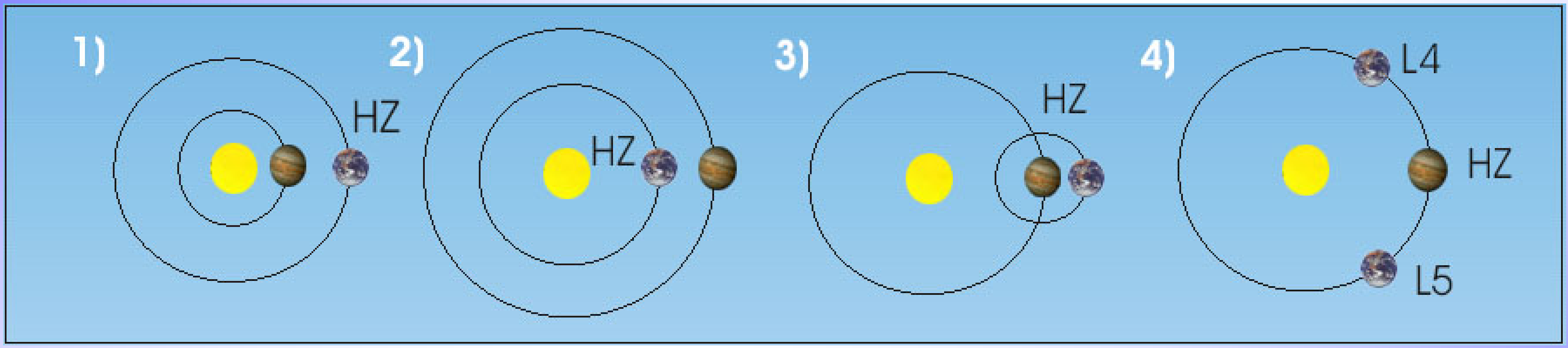
- **This zone depends on:**
  - **the spectraltype , the mass , the age, …. of the star**
  - **the orbit of the planet**
  - **the mass, the composition, the atmosphere , ……of the planet**
  - **the parameters of other planets in this system (mass, orbit, …)**

Size of the habitable zone of a planetary system

based on the definition given by Kasting et al. (1993).



Types of Habitable Zones:



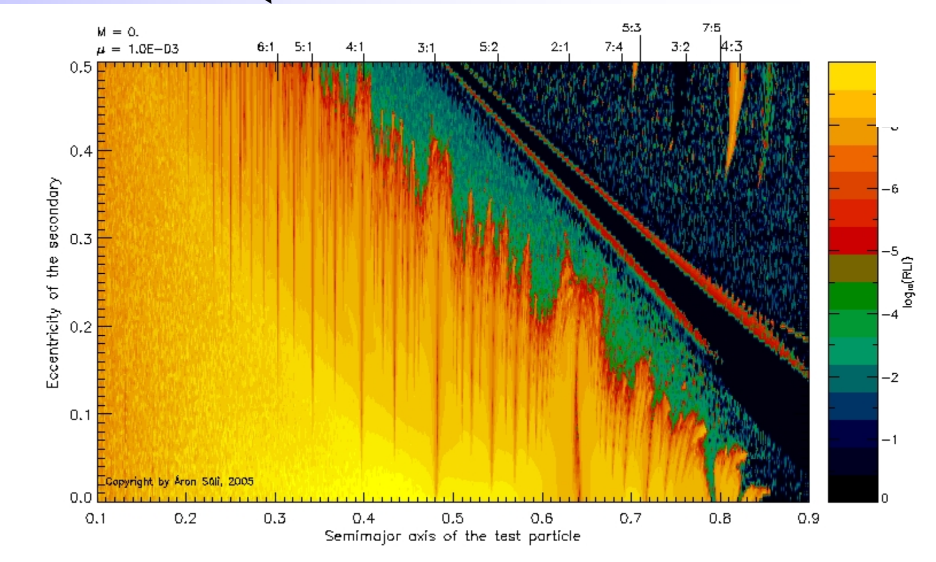
(1) Hot-Jupiter type

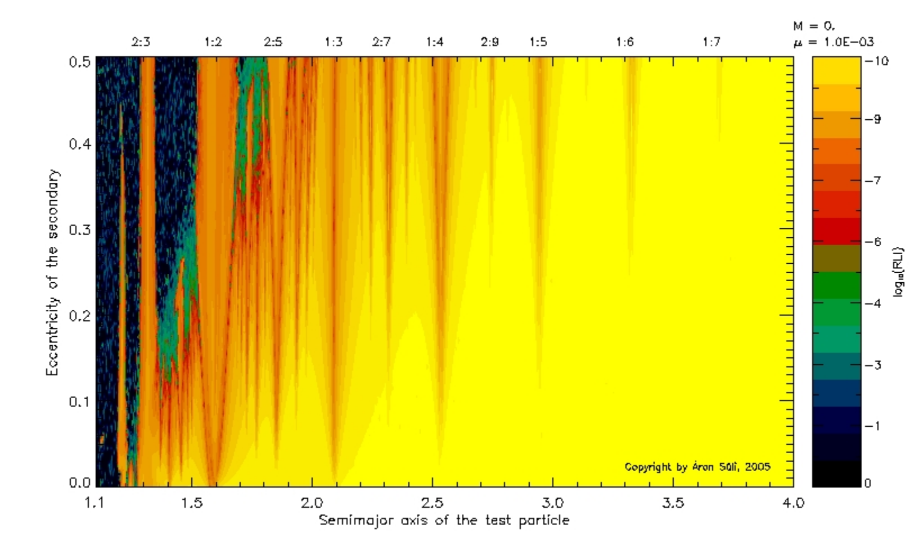
(2) Solar system type

(3)+(4) giant planet type: habitable moon
or trojan planet

Stability maps

Inner region **(Solar system type)**

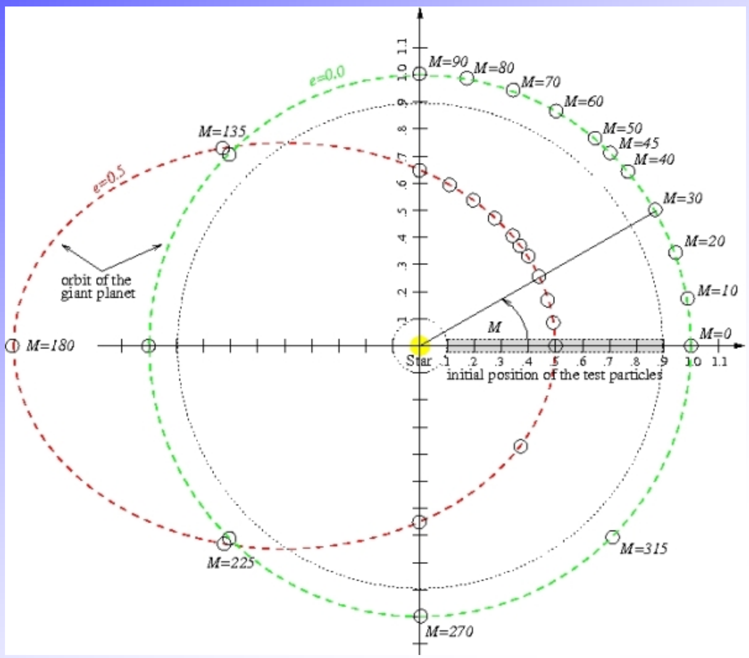




Outer region

(Hot-Jupiter-type)

Computations



distance star-planet: 1 AU

variation of

- **a_tp:**[0.1,0.9] [1.1,4] AU
- **e_gp:** 0 – 0.5
- **M_gp:** 0 and 180 deg
- **M_tp:** [0, 315] deg

Dynamical model:

restricted 3 body problem

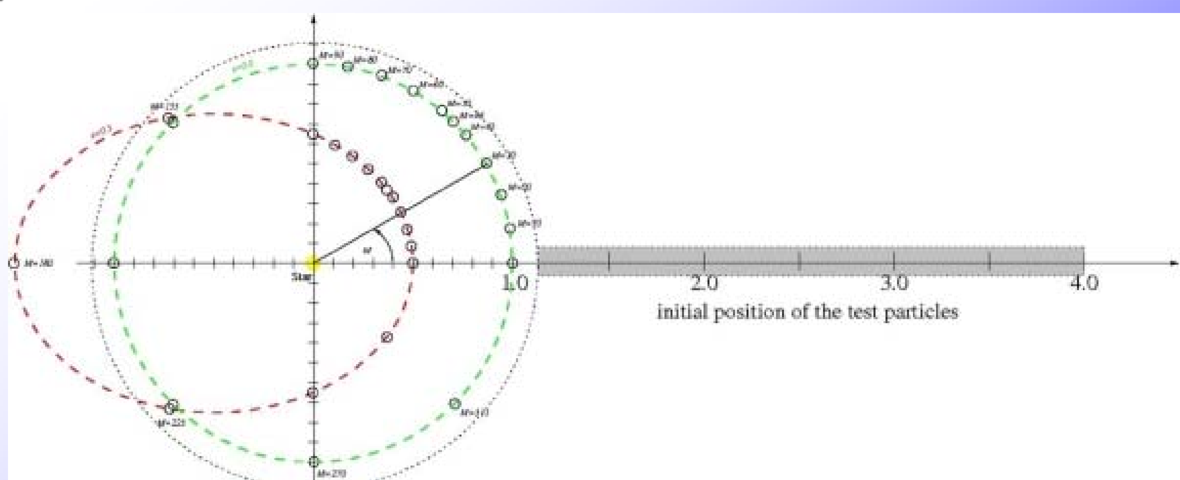
Methods:

(i) Chaos Indicator:

- FLI (Fast Lyapunov)
- RLI (Relative Lyapunov)

(ii) Long-term computations

- e-max



Chaos Indikatoren

Fast Lyapunov Indicator (FLI)
C. Froeschle, R.Gonczi, E. Lega (1996)

MEGNO
RLI
Helicity Angle

Lyapunov Characteristic Exponent (LCE)

The Fast Lyapunov Indicator (FLI)

(see Froeschle et al., CMDA 1997)

a fast tool to distinguish between regular and chaotic motion

length of the largest tangent vector:

$$FLI(t) = \sup_i |v_i(t)| \qquad i=1,\ldots,n$$

(n denotes the dimension of the phase space)

it is obvious that chaotic orbits can be found very quickly because of the exponential growth of this vector in the chaotic region.

For most chaotic orbits only a few number of primary revolutions is needed to determine the orbital behavior.

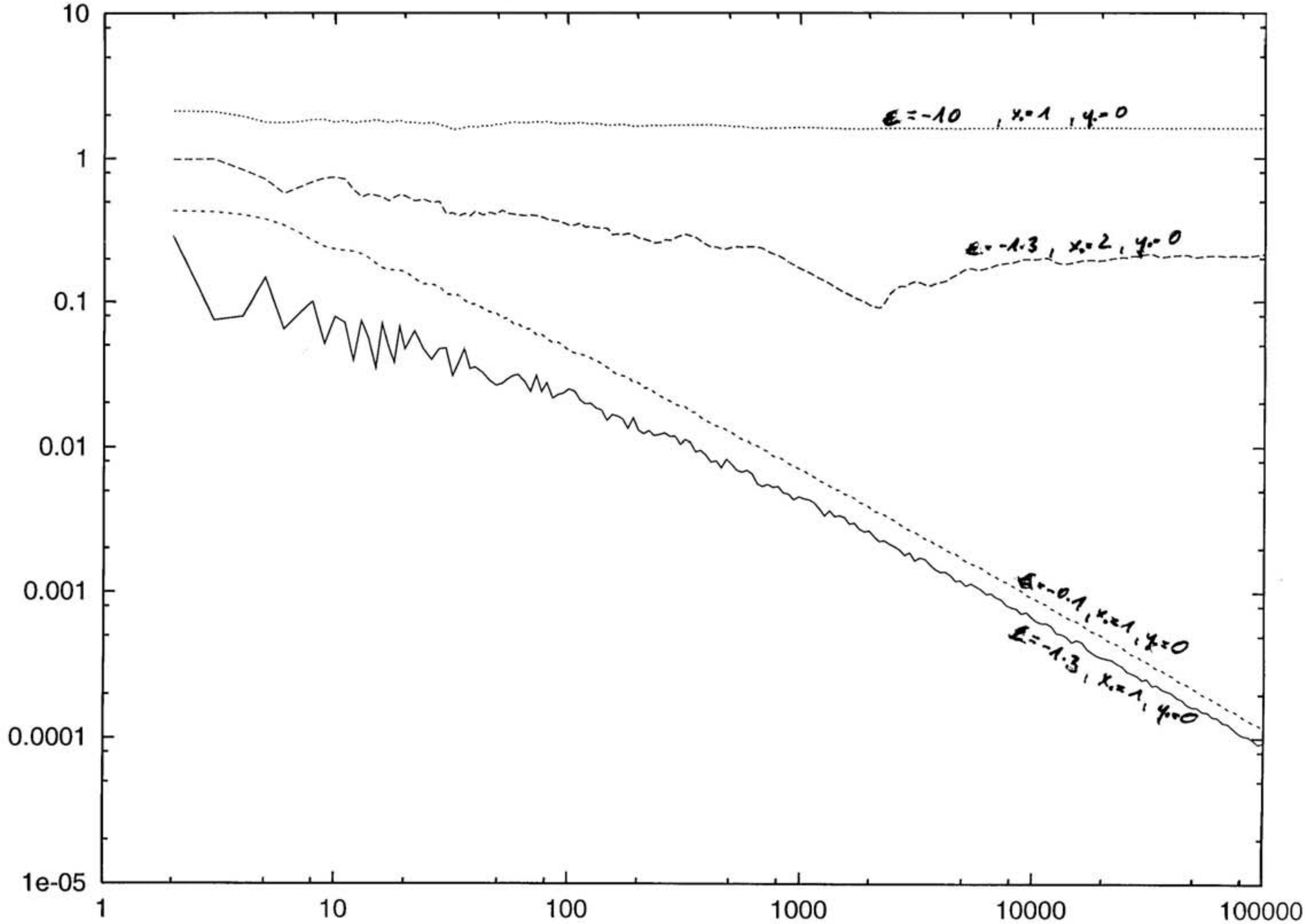
Long-term numerical integration:

Stability-Criterion:

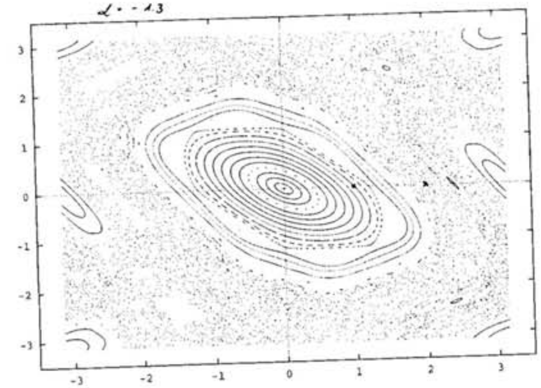
No close encounters within the Hill' sphere

(i)Escape time

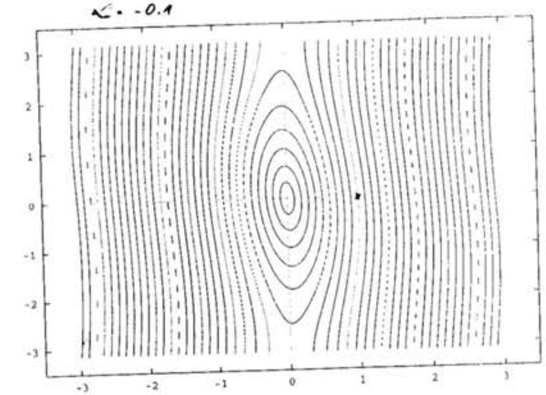
(ii) Study of the eccentricity: maximum eccentricity


10
1
0.1
0.01
0.001
0.0001
1e-05
1
10
100
1000
10000
100000

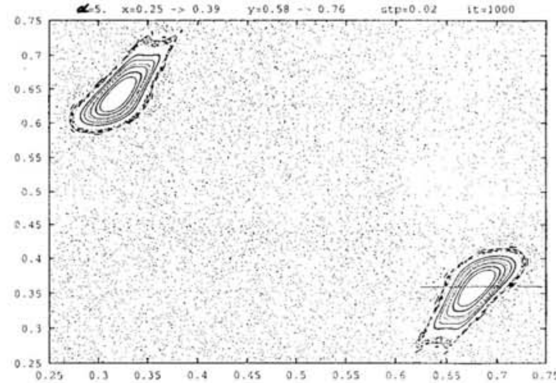
α = -1.3



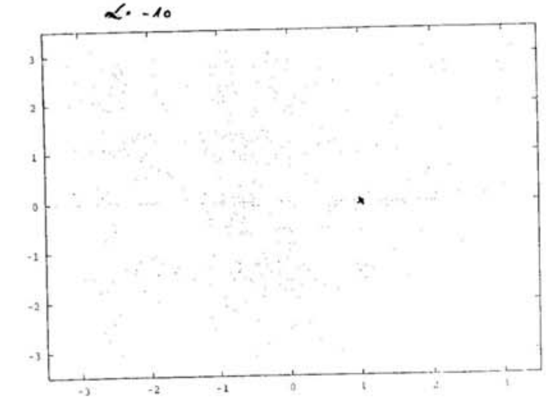
α = -0.1

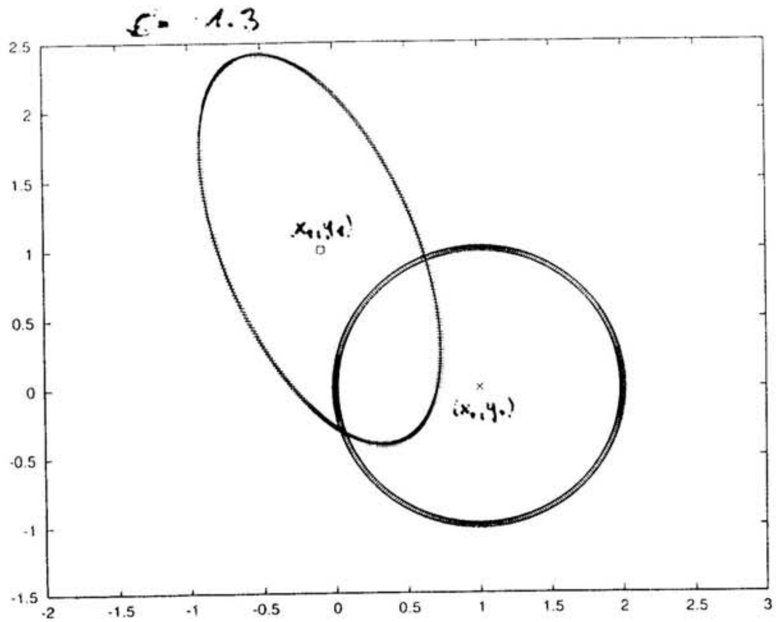


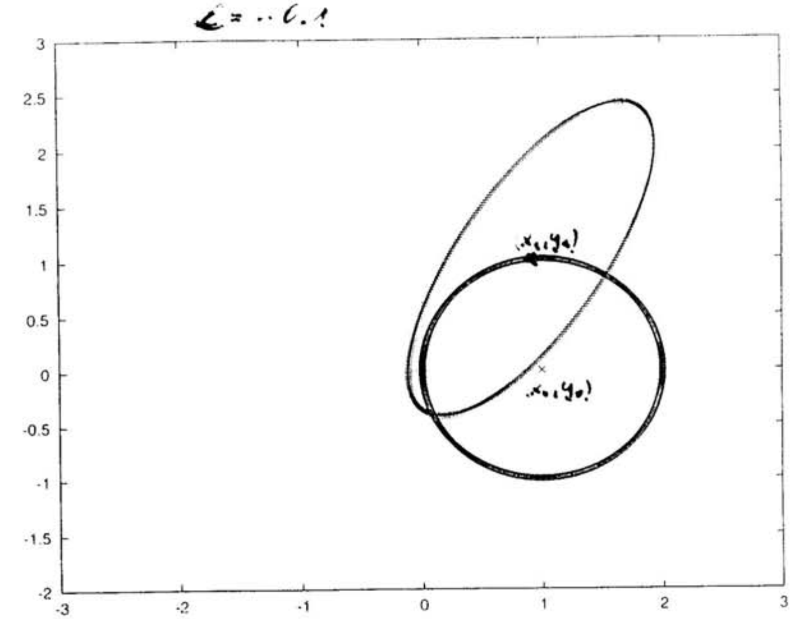
α=5.   x=0.25 -> 0.39   y=0.58 -- 0.76   stp=0.02   it=1000

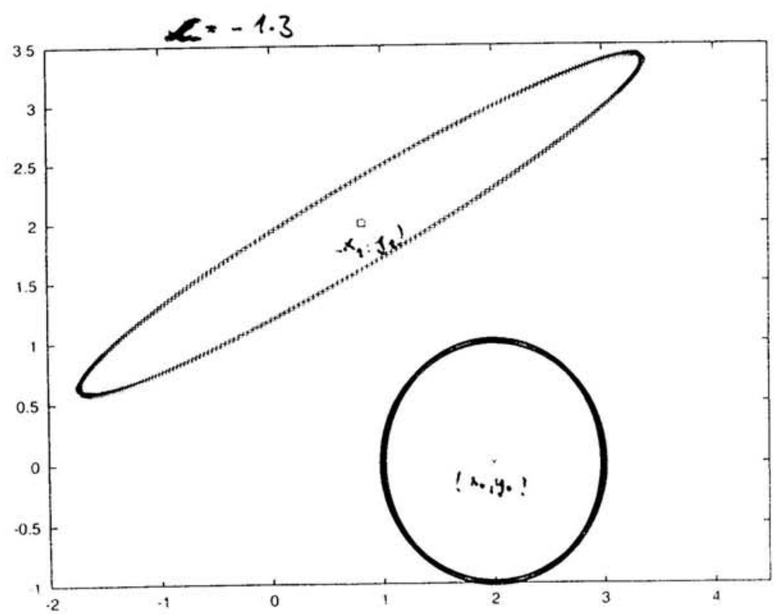


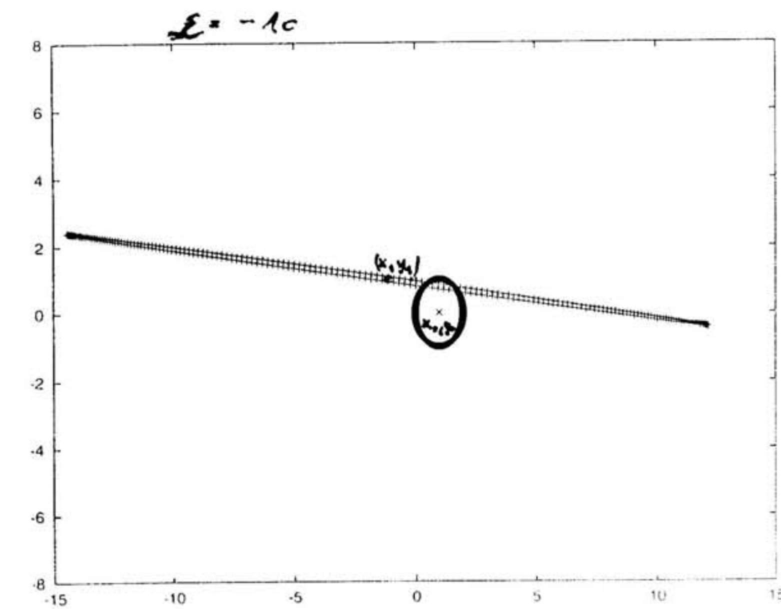
α = -10

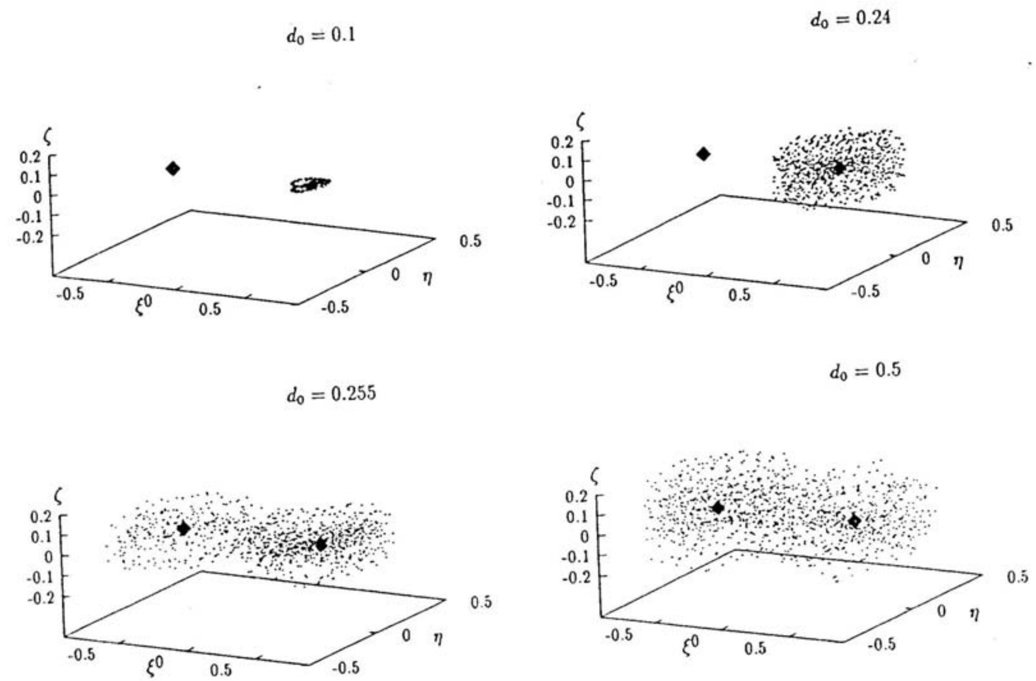


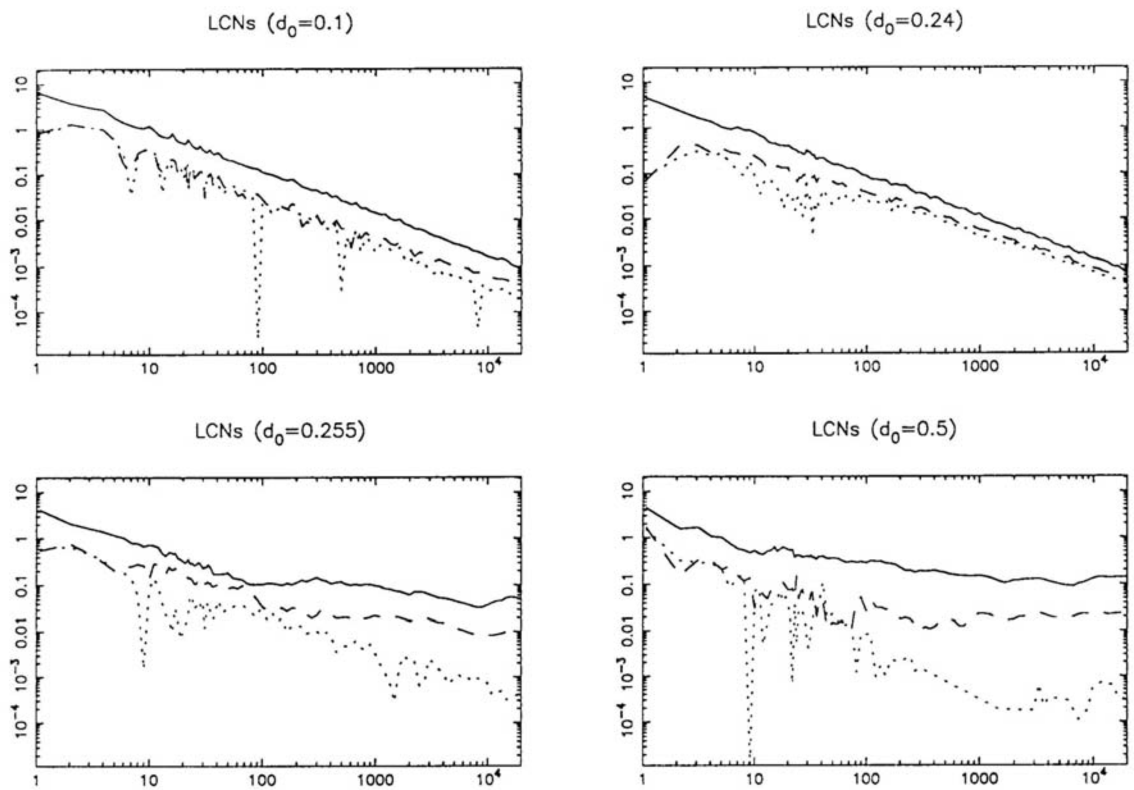

ℰ = -1.3
(x1,y1)
(x0,y0)


ℰ = -0.1
(x1,y1)
(x0,y0)


ℰ = -1.3
(x1,y1)
(x0,y0)


ℰ = -10
(x1,y1)


$d_0 = 0.1$
$d_0 = 0.24$
$d_0 = 0.255$
$d_0 = 0.5$
ζ
ξ^0
η



LCNs (d_0=0.1)
LCNs (d_0=0.24)
LCNs (d_0=0.255)
LCNs (d_0=0.5)
10
1
0.1
0.01
10^{-3}
10^{-4}
1
10
100
1000
10^4

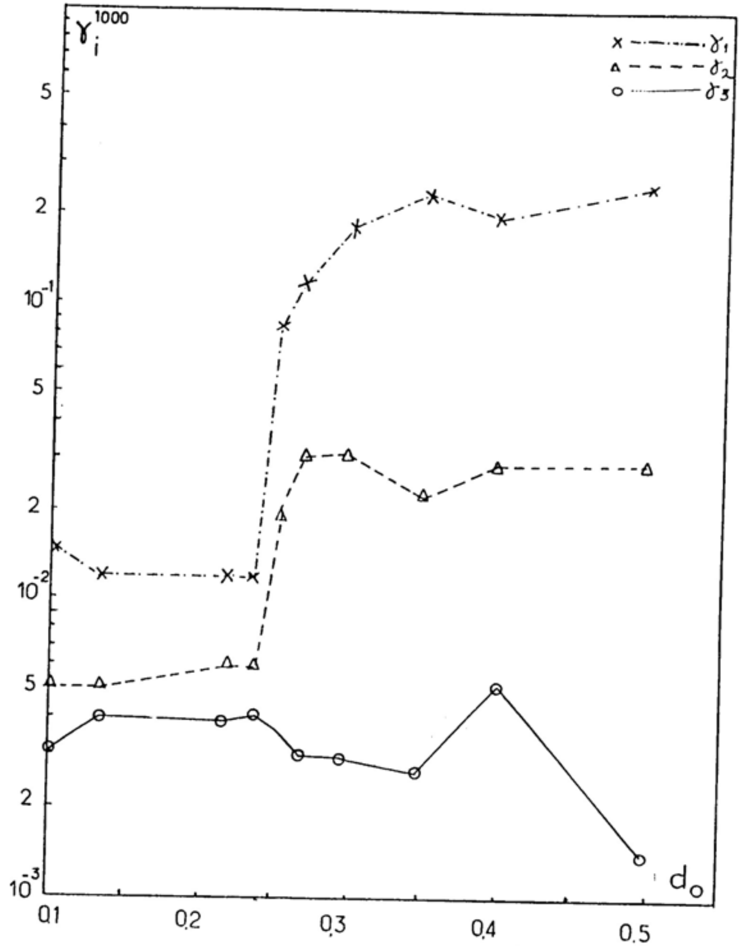
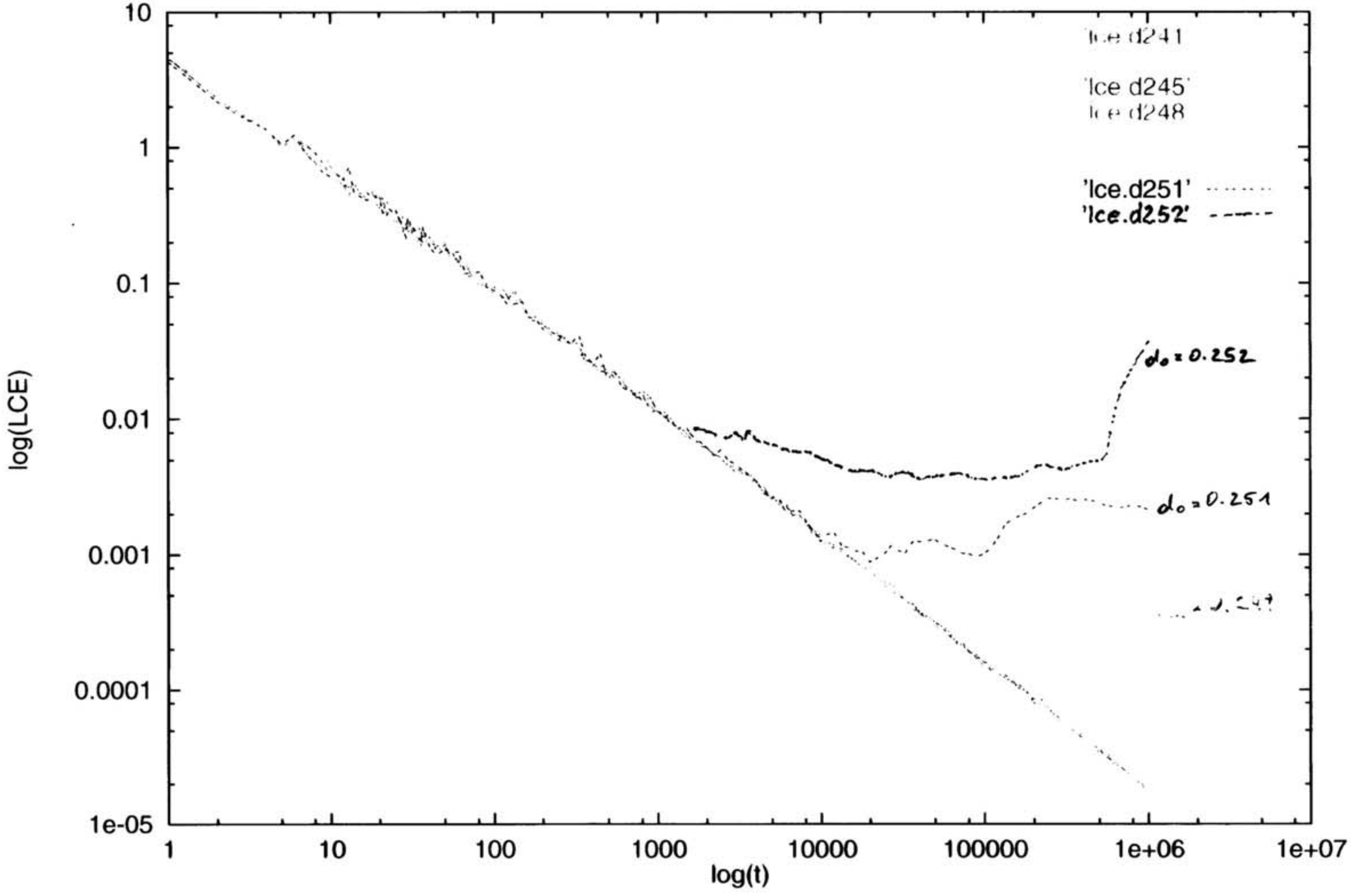
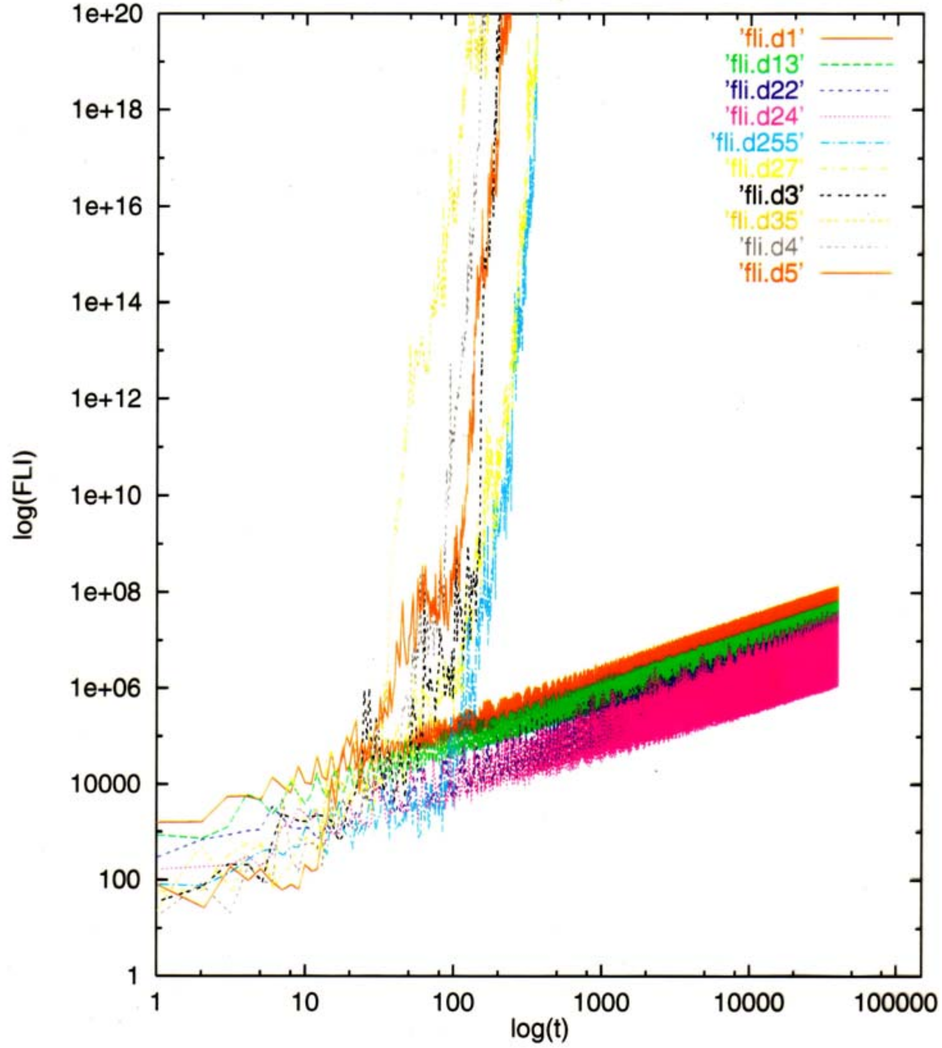


Fig. 5. Variation of $\gamma_i^{1000}(P)$ (whose values estimate the LCN's) as a function of d_0.



'lce.d241'
'lce.d245'
'lce.d248'
'lce.d251'
'lce.d252'
$d_0 = 0.252$
$d_0 = 0.251$
10
1
0.1
0.01
0.001
0.0001
1e-05
log(LCE)
1
10
100
1000
10000
100000
1e+06
1e+07
log(t)



'fli.d1'
'fli.d13'
'fli.d22'
'fli.d24'
'fli.d255'
'fli.d27'
'fli.d3'
'fli.d35'
'fli.d4'
'fli.d5'
log(FLI)
log(t)
1e+20
1e+18
1e+16
1e+14
1e+12
1e+10
1e+08
1e+06
10000
100
1
1
10
100
1000
10000
100000

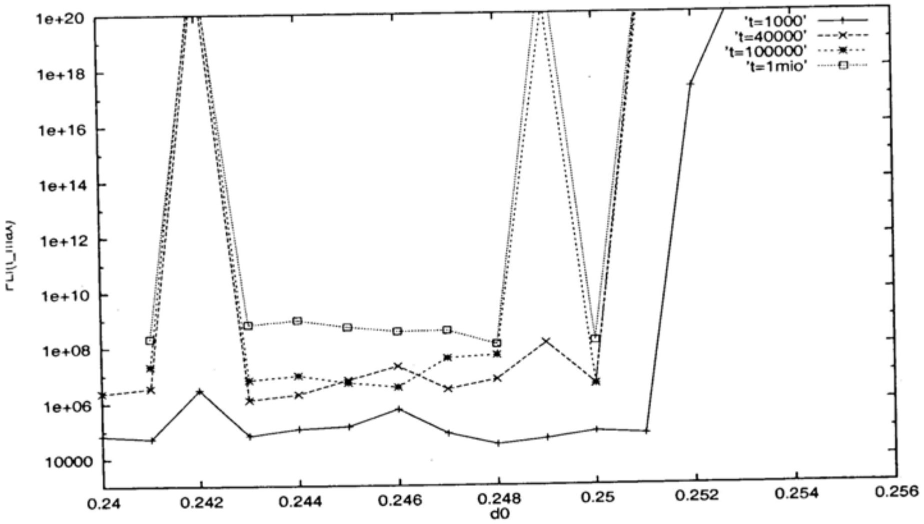
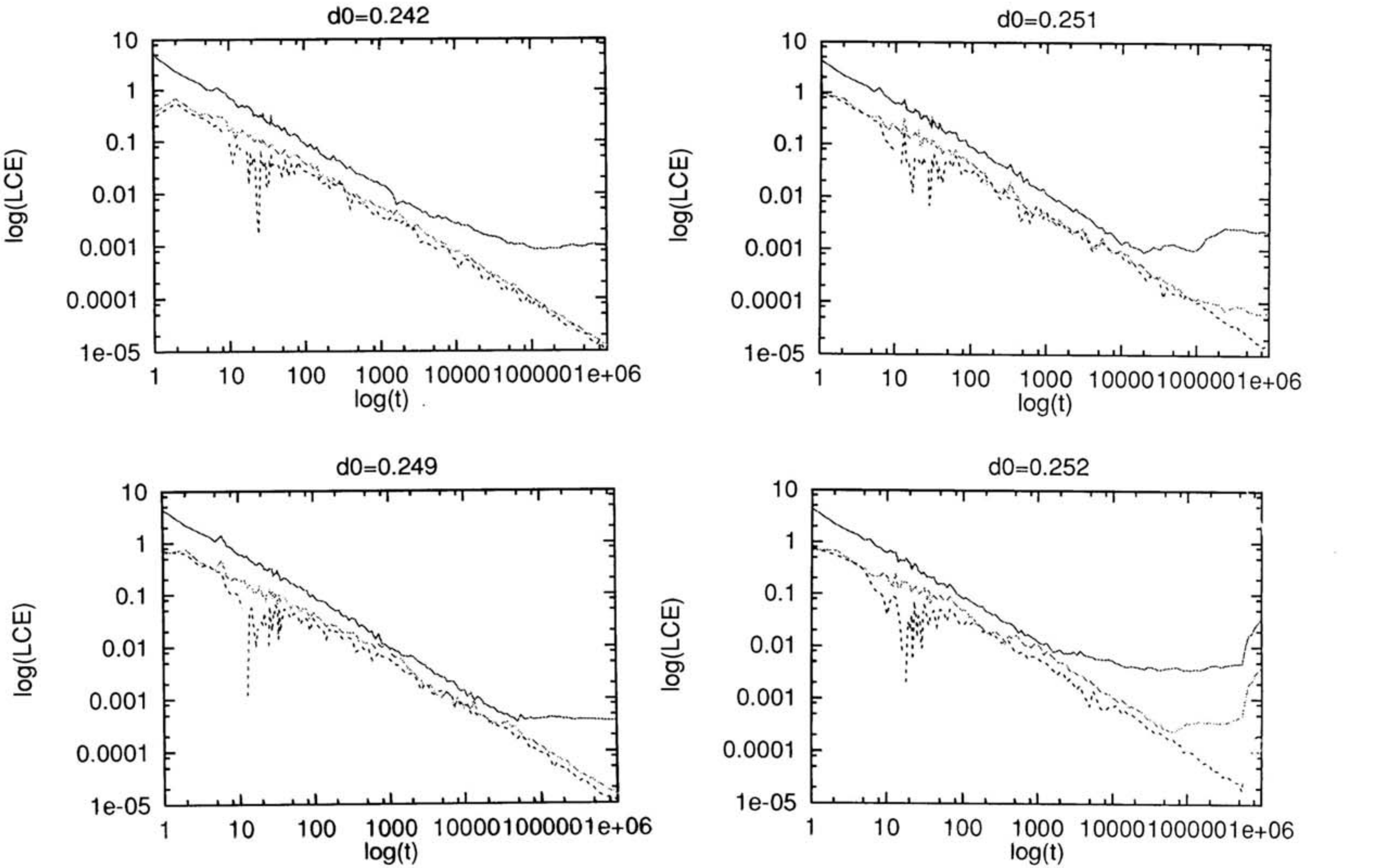
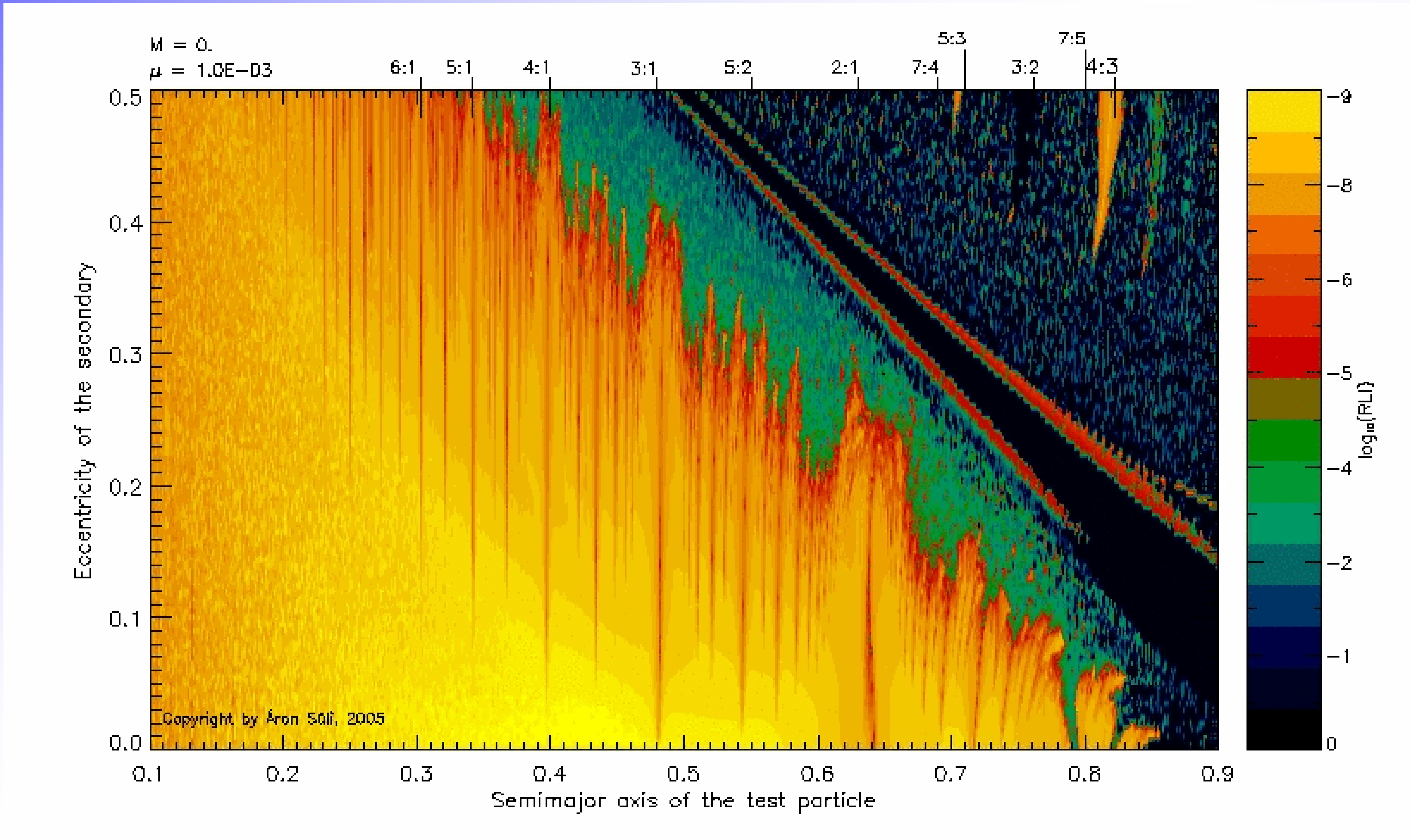


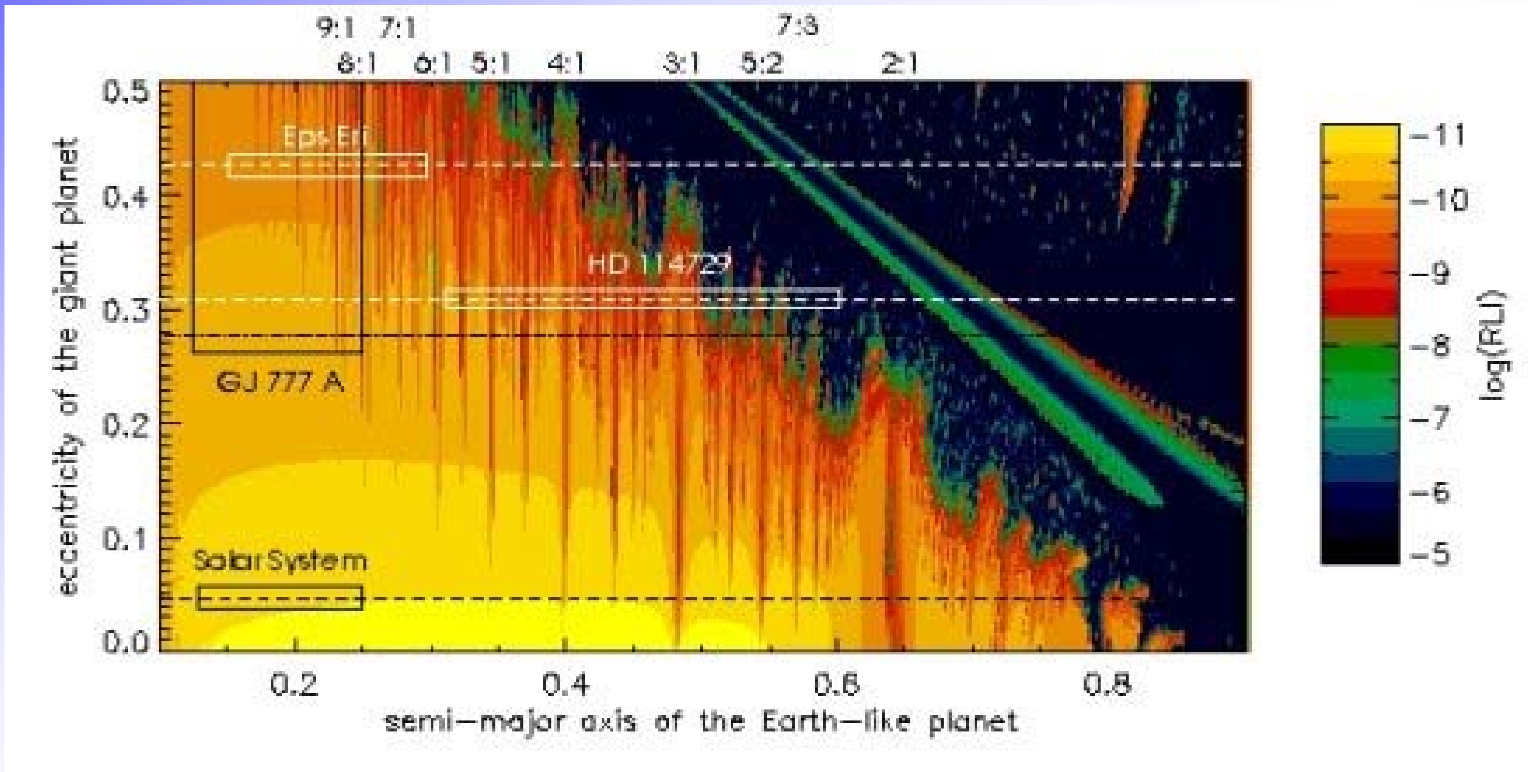
Figure 2: The FLIs for orbits started at d_0 between 0.24 and 0.256. The solid line shows the results after an integration time of 1000 units; the dashed line with crosses is for 40 000 time units; the dashed line with stars for t=100 000 units and the dotted line shows the results after 1 mio. periods of the binary.


d0=0.242
d0=0.251
d0=0.249
d0=0.252
log(LCE)
log(t)
10
1
0.1
0.01
0.001
0.0001
1e-05
1
10
100
1000
10000
100000
1e+06

ANIMATION


M = 0.
μ = 1.0E−03
6:1
5:1
4:1
3:1
5:2
2:1
7:4
5:3
3:2
7:5
4:3
0.5
0.4
0.3
0.2
0.1
0.0
Eccentricity of the secondary
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Semimajor axis of the test particle
Copyright by Áron Süli, 2005
−9
−8
−6
−5
−4
−2
−1
0
log₁₀(RLI)

How to use the catalogue



HD114729: m_p=0.82 [Mjup]

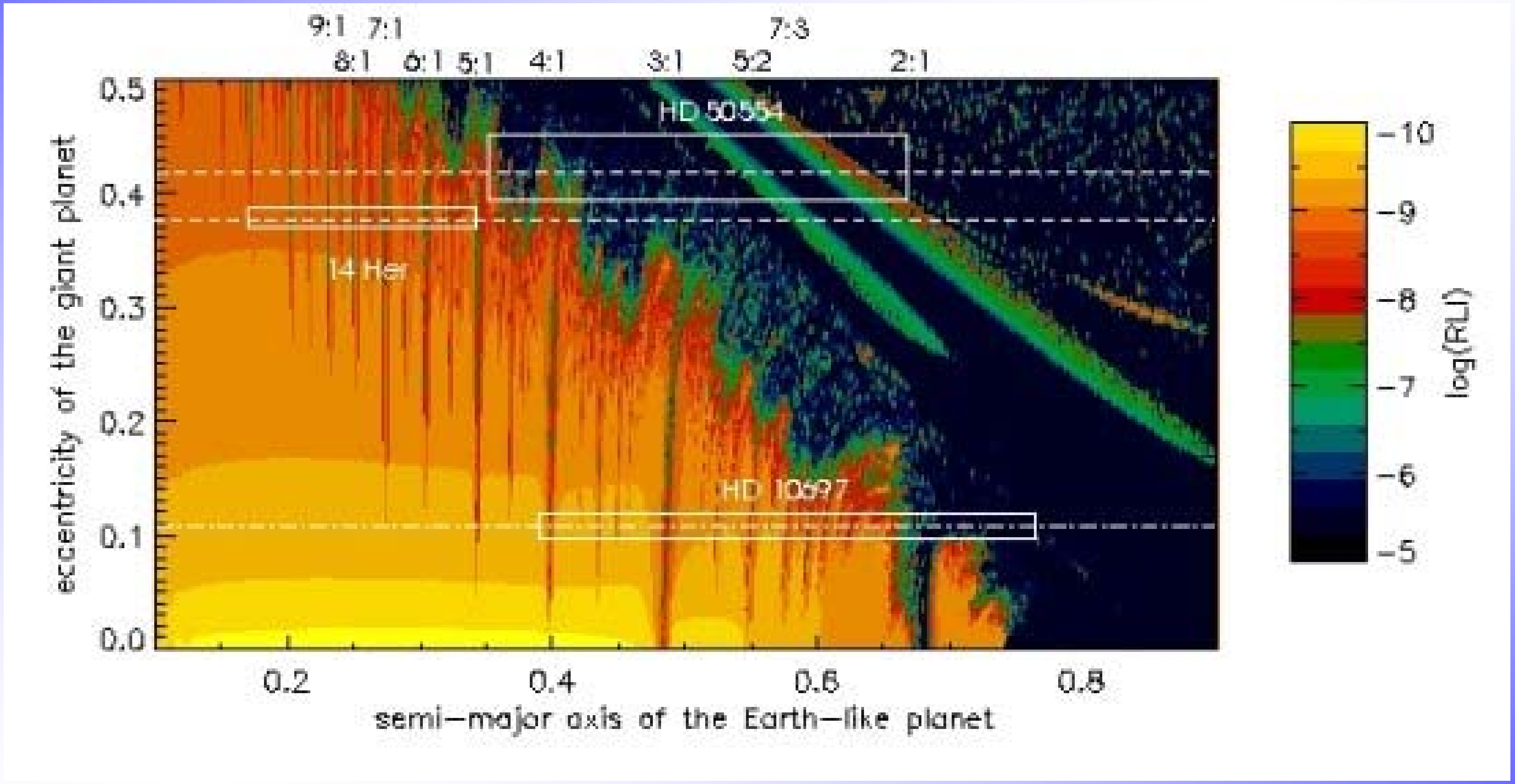
(0.93 [Msun]) a_p= 2.08 AU

e_p=0.31

❍=0.001

HZ: 0.7 – 1.3 AU

❍ = 0.005



HD10697: m_p= 6.12 [Mjup]

(1.15 Msun) a_p = 2.13 AU

e_p = 0.11

HZ: 0.85 – 1.65 AU

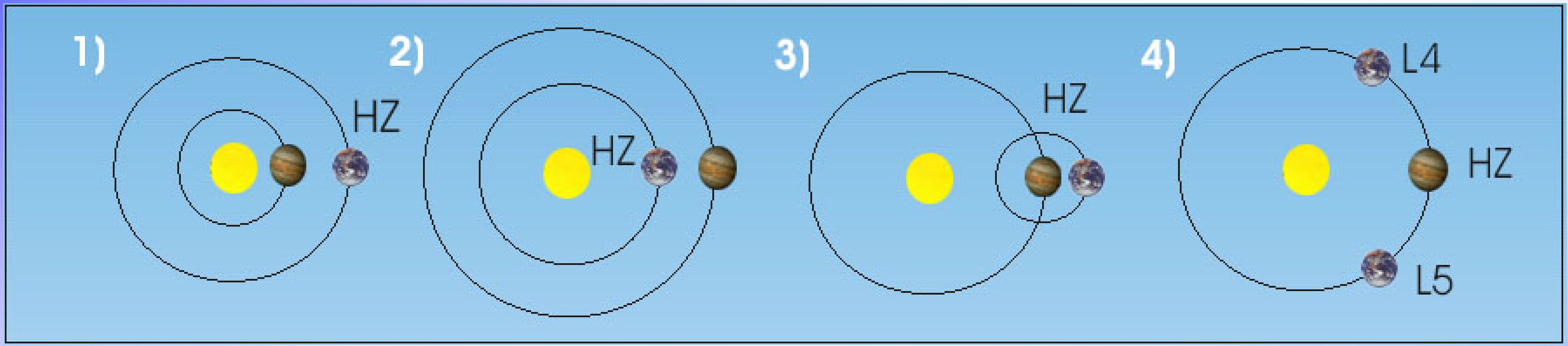
The EXOCATALOGUE:

http://www.univie.ac.at/adg/

Details:

Sándor, Zs., **Süli**, A., **Érdi**, B., **Pilat-Lohinger**, E. and **Dvorak**, R.: *"A Stability Catalogue of the Habitable zones in Extrasolar Planetary Systems"*, Monthly Notices of the Royal Astronomical Society (MNRAS), 2006

From the dynamical point of view there are four possible configurations for terrestrial like planets



1) The giant planet moves close to the central star.

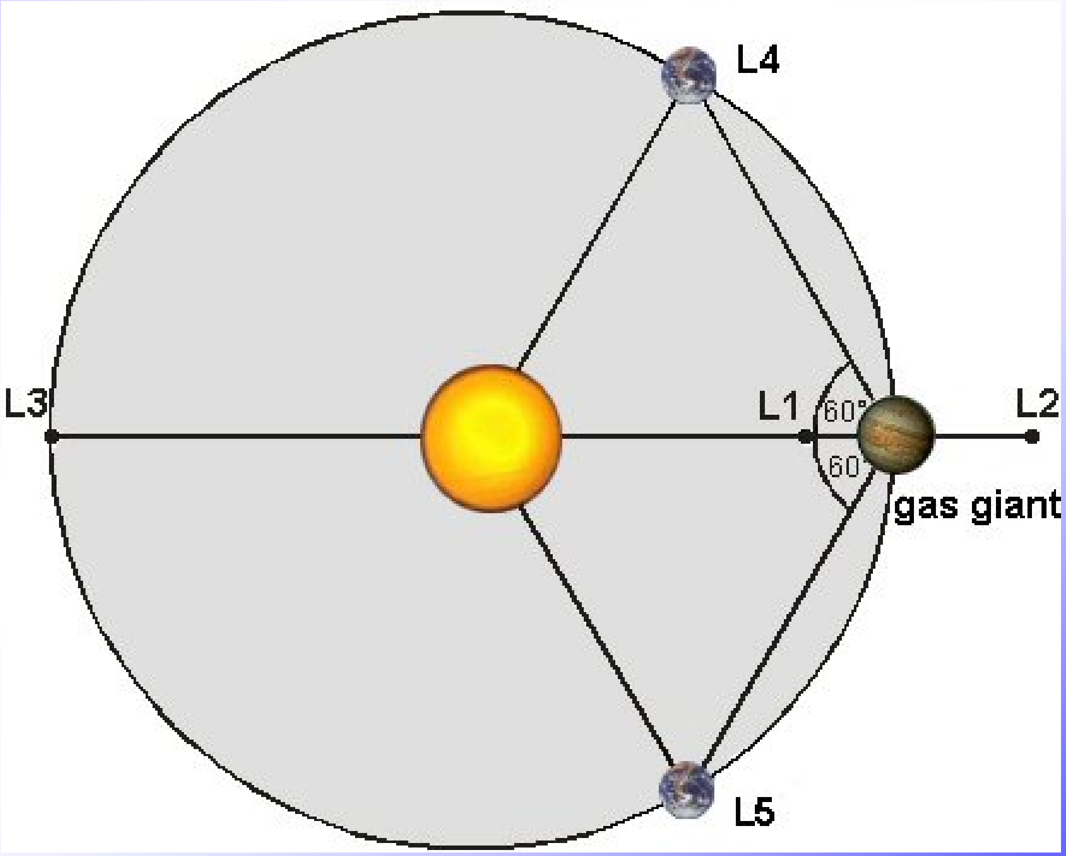
2) Solar configuration:

3) Satellite configuration (e.g. Europa):

4) Trojan configuration:

…Like the Jupiter-Trojans
Two groups of asteroids close to L4 and L5

1. L_1, L_2 and L_3 (not stable) lie on a straight line connecting the primaries
2. L_4 and L_5 (stable for μ < 1:25) are at the third vertex of an equilateral triangle (Sun-Jupiter-Asteroid)



List of extrasolar systems with one giant planet in the HZ (Single-planetary systems)

Name	Spec.	mass $[M_{sol}]$	mass $[M_{jup}]$	a [AU]	ecc	HZ [AU]	partly in HZ [%]
HD101930	K1V	0.74	0.30	0.30	0.11	0.30-0.64	53
HD93083	**K3V**	**0.70**	**0.37**	**0.48**	**0.14**	**0.28-0.60**	**100**
HD134987	G5V	1.05	1.58	0.78	0.24	0.75-1.40	58
HD17051	**G0V**	**1.03**	**1.94**	**0.91**	**0.24**	**0.70-1.30**	**100**
HD28185	**G5**	**0.99**	**5.70**	**1.03**	**0.07**	**0.70-1.30**	**100**
HD99109	**K0**	**0.93**	**0.50**	**1.11**	**0.09**	**0.65-1.25**	**100**
HD27442	**K2IVa**	**1.20**	**1.28**	**1.18**	**0.07**	**0.93-1.80**	**100**
HD188015	**G5IV**	**1.08**	**1.26**	**1.19**	**0.15**	**0.70-1.60**	**100**
HD114783	K0	0.92	0.99	1.20	0.10	0.65-1.25	50
HD221287	**F7V**	**1.25**	**3.09**	**1.25**	**0.08**	**1.10-2.30**	**100**
HD20367	G0	1.05	1.07	1.25	0.23	0.75-1.40	76
HD23079	(F8)/G0V	1.10	2.61	1.65	0.10	0.85-1.60	35

CATALOGUE

Modelparameters (initial conditions)

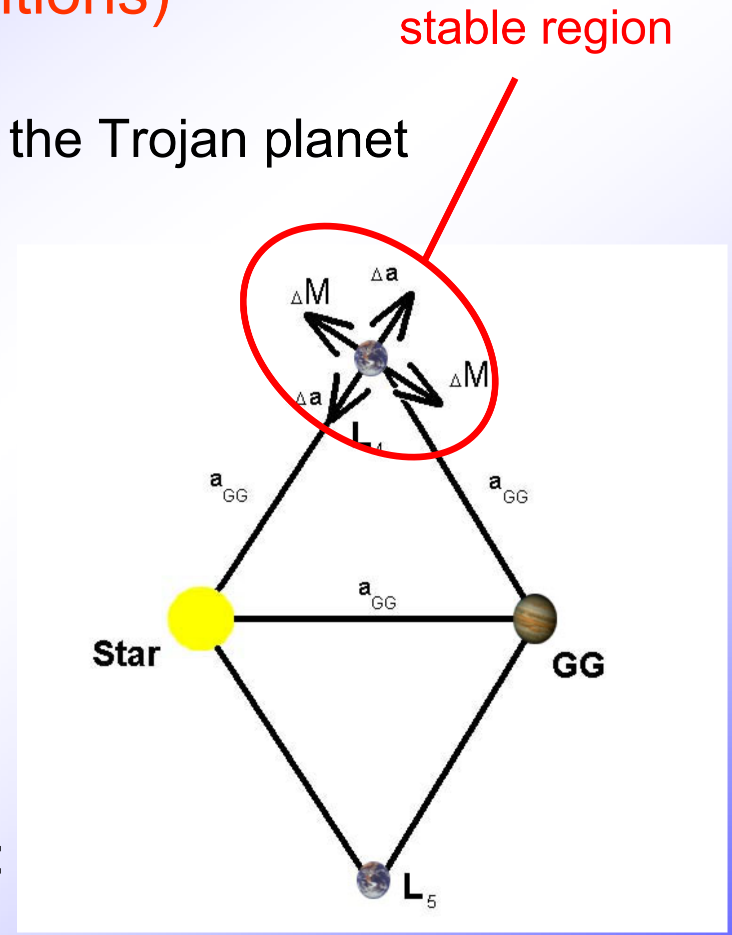
Eccentricity of the gas giant (GG) & the Trojan planet
$0{,}00 < e < 0{,}3$ $\Delta e = 0{,}05$

Mass ratio (μ)
$0{,}001 < \mu < 0{,}04$ $\Delta \mu = 0{,}001$

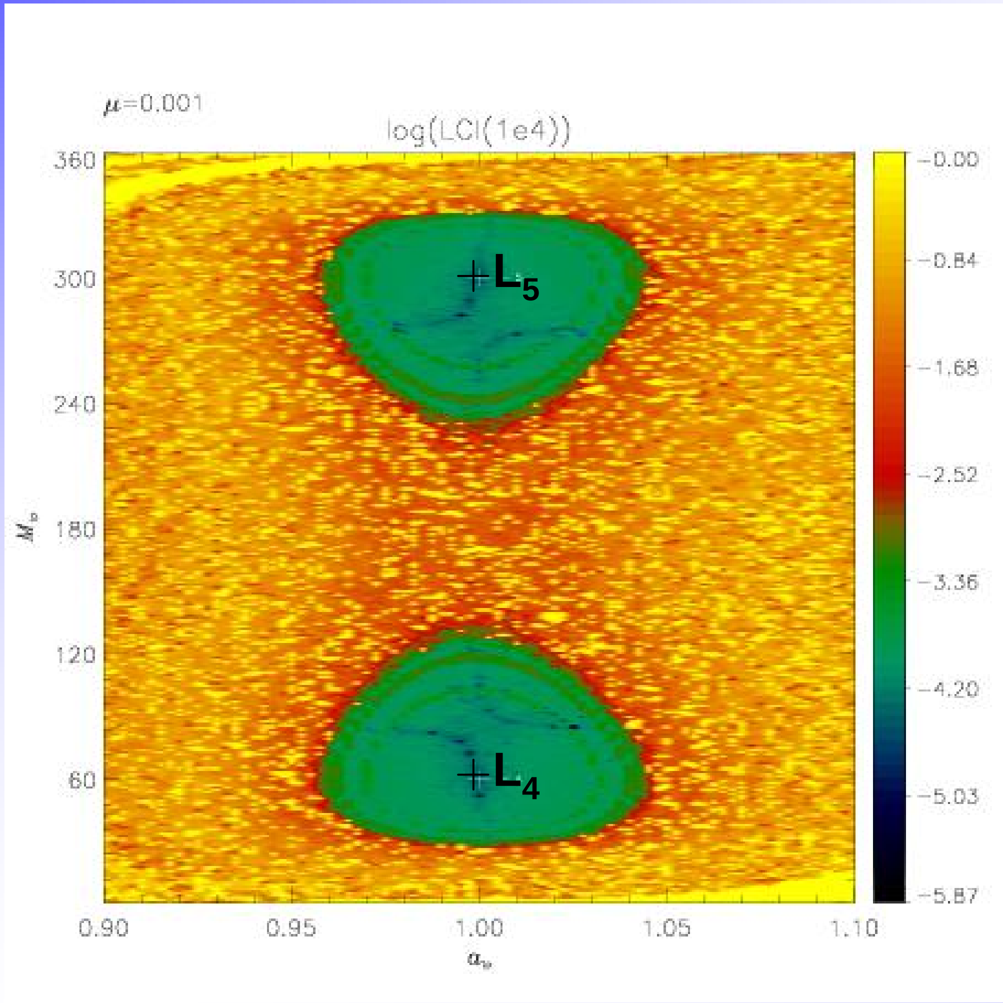
Stable region:

$0{,}9 \text{ AU} < a < 1{,}1 \text{ AU}$ $\Delta a = 0{,}0025$
a is normalized to 1AU

Angular distance to the primary (M):
$0° < M < 360°$ $\Delta M = 1°$



Catalogue



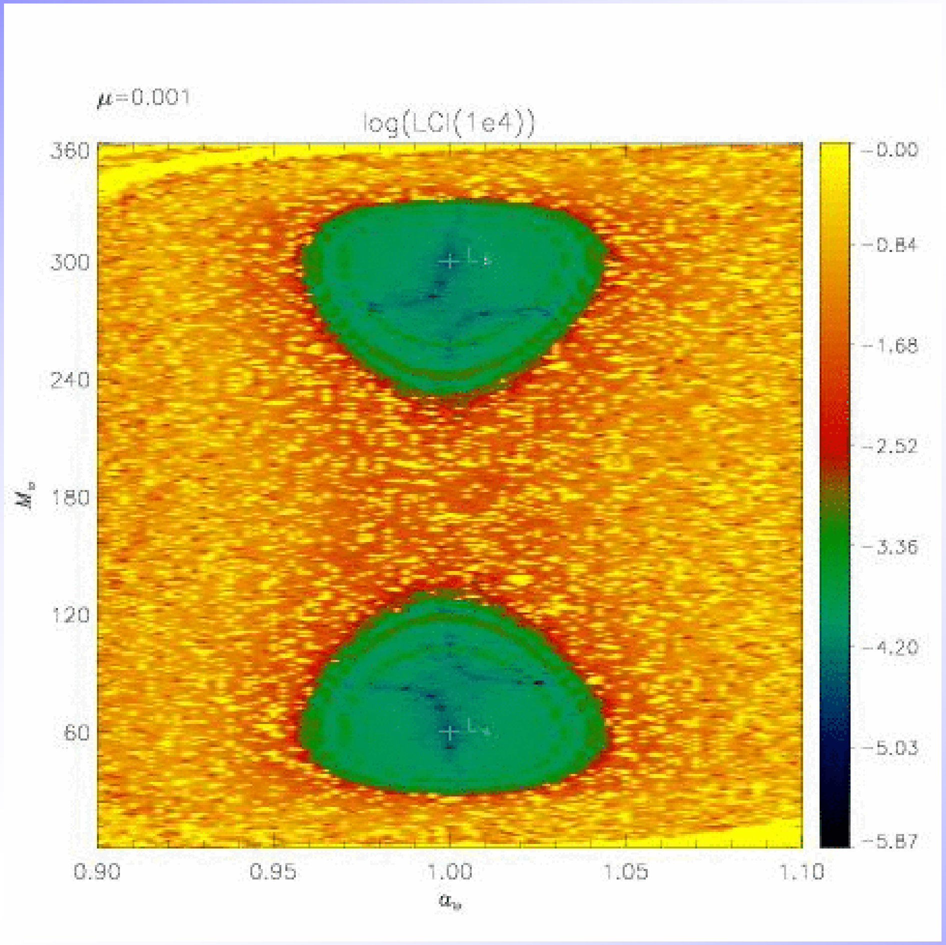
Variation of:
$0 < e < 0,3$
$0 < \mu < 0,04$

Grid:

$\Delta\mu=0,001$

Animation for ecc 0,05

Mass ratio →



Variation of

$0 < \mu < 0{,}21$

$\Delta\mu = 0{,}001$

Integration-time

10^4 revolutions