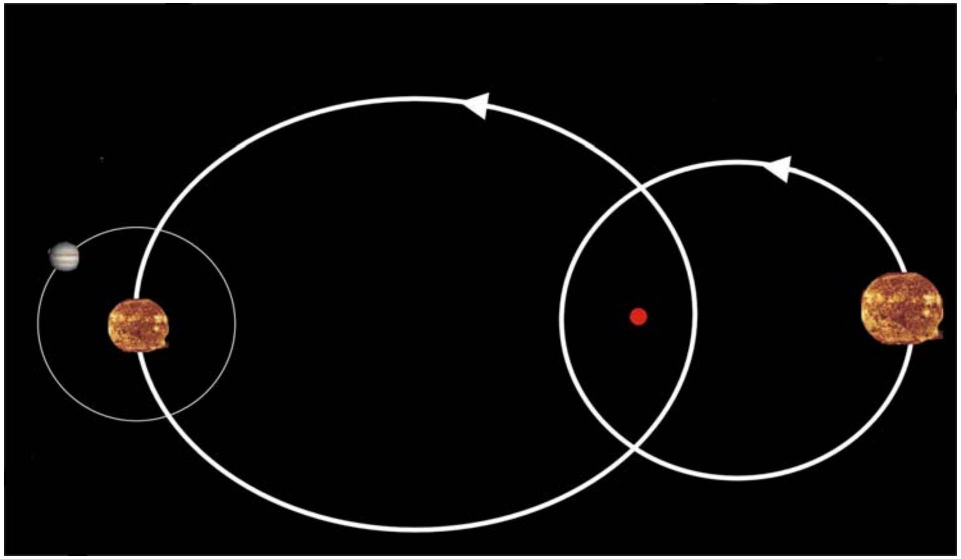
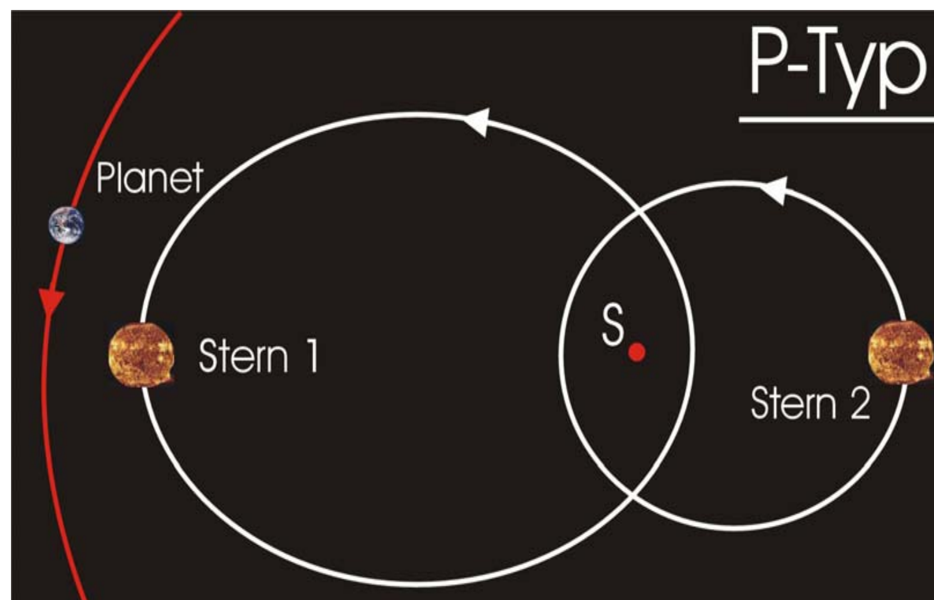
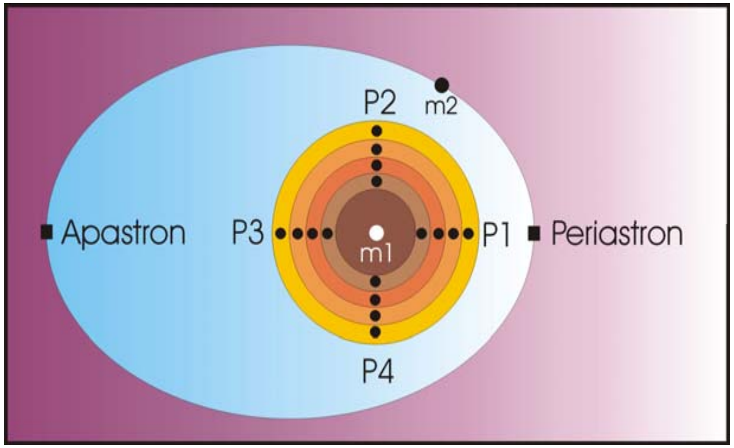


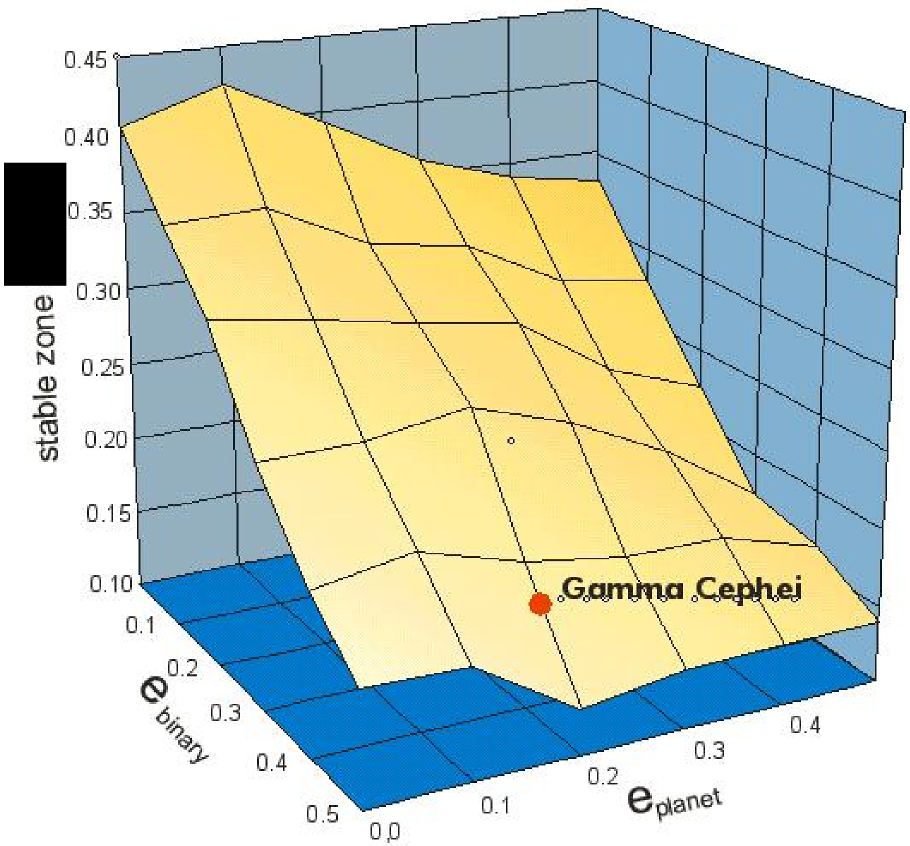
Planetary motion in binaries:



Stability analysis



mass-ratio = 0.2



Initial Conditions:

a_{binary} =1 AU

e_{binary}=[0, ….0.9]

a_{planet}=[0.1, …0.9]

e_{planet}=[0,… 0.9]

i, 'Ω,ω, = 0°

M= 0°,90°,180°,270°

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:

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

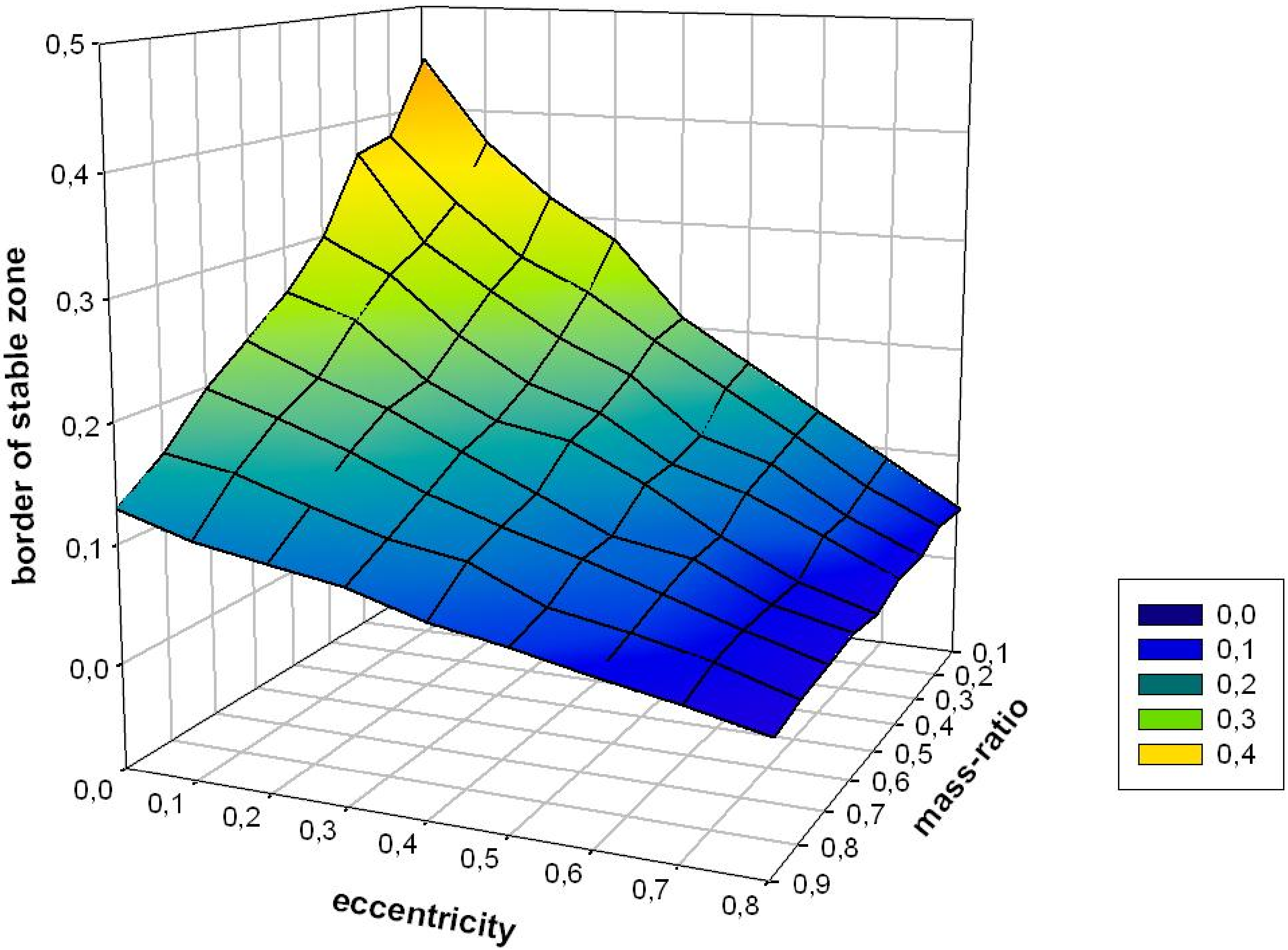
(n denotes the dimension of the phase space)

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.

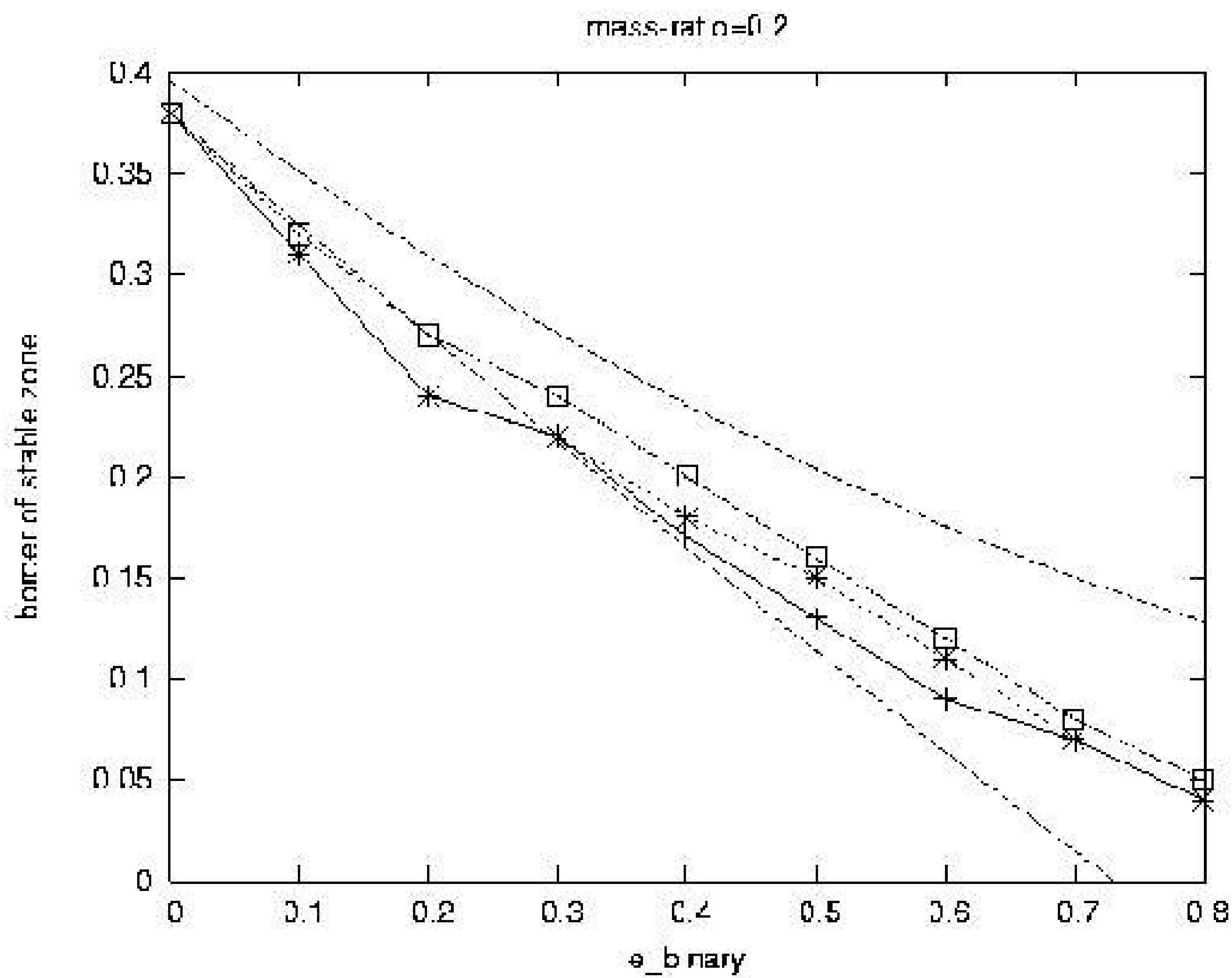
S-type motion

e_binary \ mass-ratio	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.0	0.45	0.38	0.37	0.30	0.26	0.23	0.20	0.16	0.13
0.1	0.37	0.32	0.29	0.27	0.24	0.20	0.18	0.15	0.11
0.2	0.32	0.27	0.25	0.22	0.19	0.18	0.16	0.13	0.10
0.3	0.28	0.24	0.21	0.18	0.16	0.15	0.13	0.11	0.09
0.4	0.21	0.20	0.18	0.16	0.15	0.12	0.11	0.10	0.07
0.5	0.17	0.16	0.13	0.12	0.12	0.09	0.09	0.07	0.06
0.6	0.13	0.12	0.11	0.10	0.08	0.08	0.07	0.06	0.045
0.7	0.09	0.08	0.07	0.07	0.05	0.05	0.05	0.045	0.035
0.8	0.05	0.05	0.04	0.04	0.03	0.035	0.03	0.025	0.02

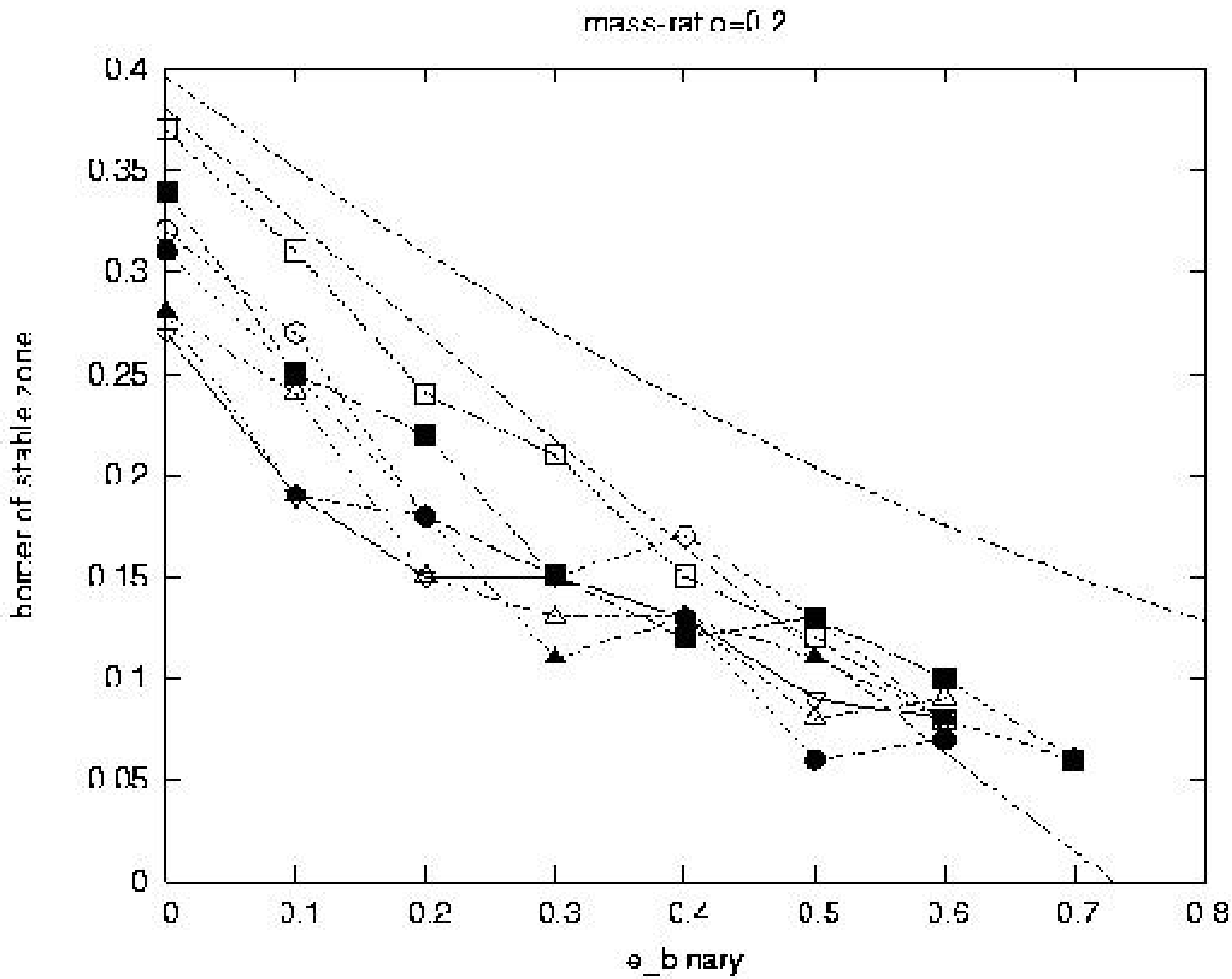
Stable zone (in units of length) of S-type motion for all computed mass-ratios and eccentricities of the binary. The given size for each (mu,e_binary) pair is the lower value of the studies by Holman &Wiegert (AJ,1999) and Pilat-Lohinger &Dvorak (CMDA, 2002)



border of stable zone
0,5
0,4
0,3
0,2
0,1
0,0
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
eccentricity
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
mass-ratio
0,0
0,1
0,2
0,3
0,4



mass-ratio=0.2
border of stable zone
e_binary
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8



mass-ratio=0.2
border of stable zone
e_binary
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

real binary system gamma Cephei which hosts a giant planet of about 1.6 Jupiter-masses.
The **mass-ratio** of the binary is **0.2** and the binary's eccentricity is about 0.4. Even if the observed eccentricity of *gamma Cep b* is only 0.11 we show the reduction for eccentricities up to 0.5.
Using **20 AU** as separation for the two stars the following result was found:

Planet's eccentricity	border of stable region [AU]
0.0	4.0
0.1	3.8
0.2	3.6
0.3	3.4
04	3.2
0.5	3.0

planets in binaries

Star	a_{bin} [AU]	a_{pl} [AU]	M_{pl} *sin* i [M_{Jup}]
HD 40979	~6400	0.88	3.16
Gl 777 A	~3000	3.65	1.15
HD 80606	~1200	0.469	3.90
55 Cnc B	~1065	0.11	0.84
		0.24	0.21
		5.9	4.05
Ups And	~750	0.059	0.69
		0.83	1.96
		2.56	3.98
16 Cyg B	~700	1.66	1.64
HD 178911	~640	0.32	6.29
Tau Boo	~240	0.05	4.09
HD 195019	~150	0.14	3.55
HD 114762	~130	0.35	11.0
HD 19994	~100	1.30	2.00
Gamma Cep	~22	2.1	1.76
Gl 86	~19	0.11	4.00
HD 41004	~21	1.31	2.3

Gamma Cephei

Primary and Secondary:

$m_1 = 1.6\ M_S$

$m_2 = 0.4\ M_S$

a = 21.36 AU

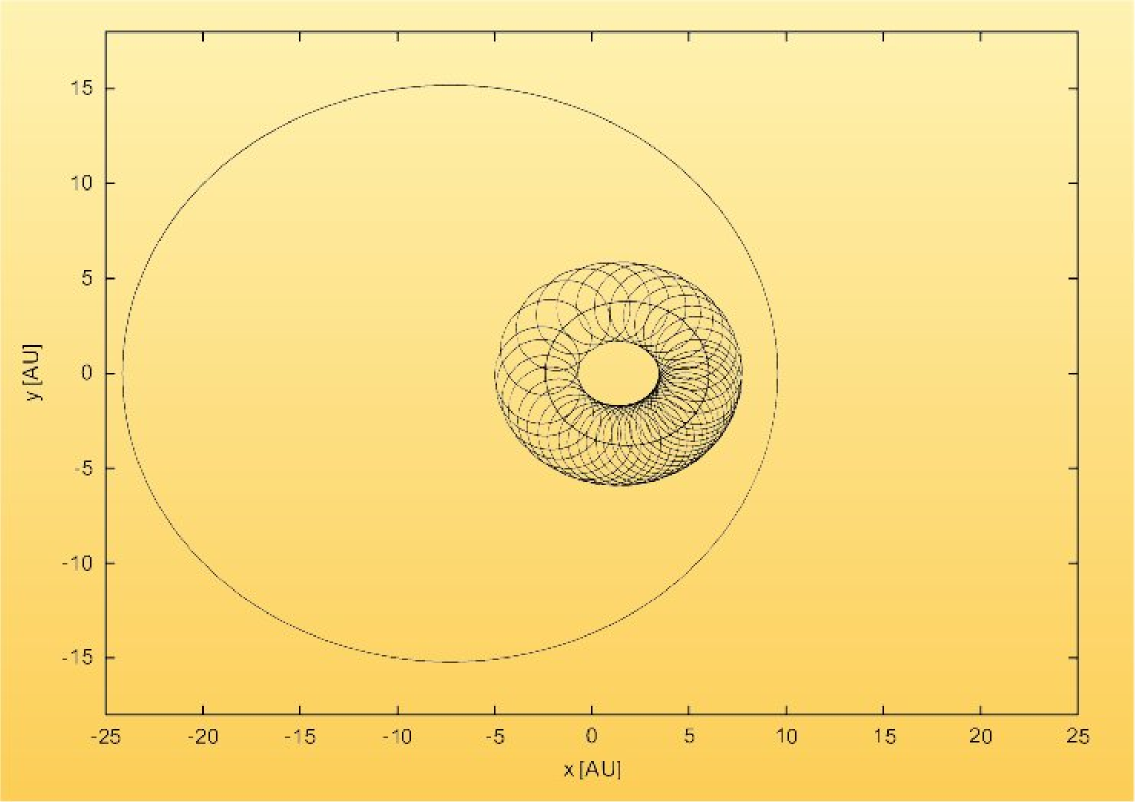
e = 0.44

Planet:

$m_P = 1.7\ M_{jup}$

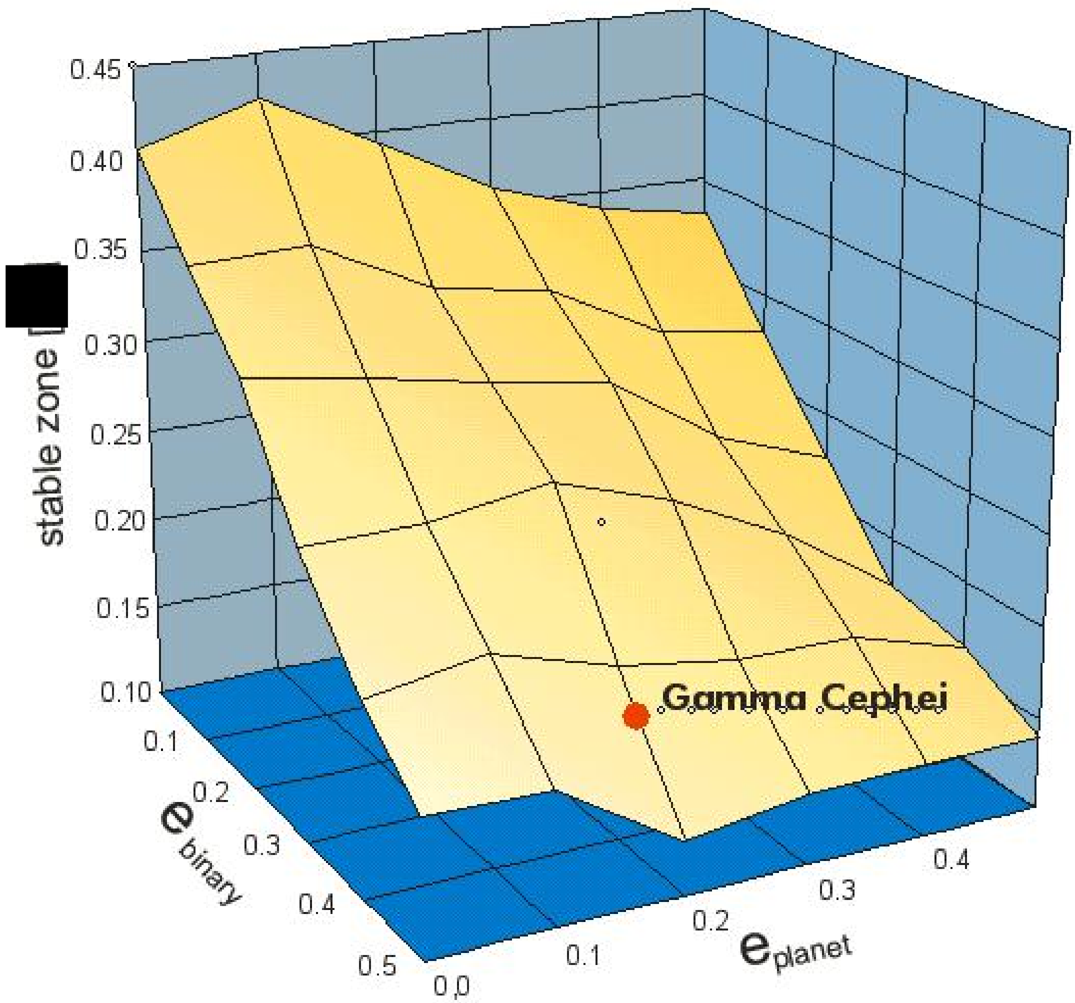
a = 2.15 AU

e = 0.2

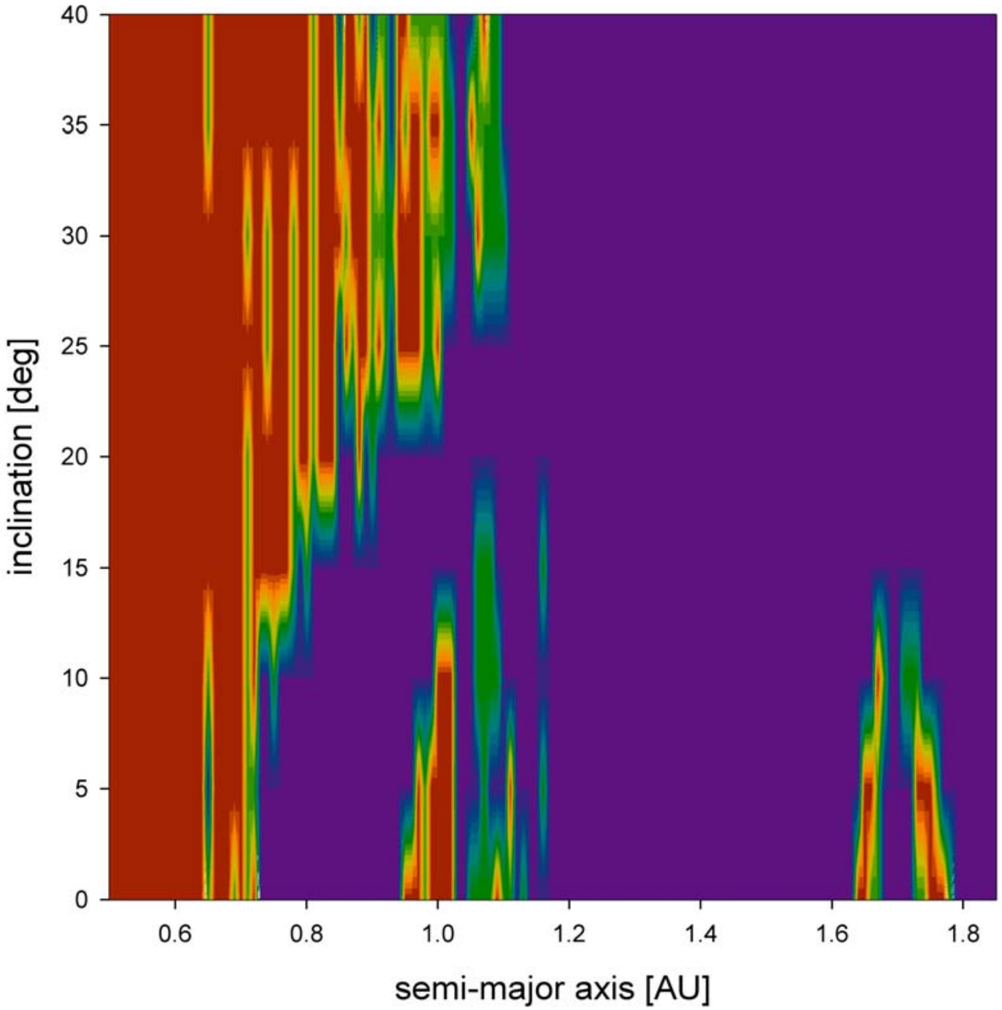


Stability analysis

mass-ratio = 0.2



gamma Cephei



Primary and Secondary:

m1 = 1.6 MS

m2 = 0.4 MS

a = 21.36 AU

e = 0.44

Planet:

mP = 1.7 Mjup

a = 2.15 AU

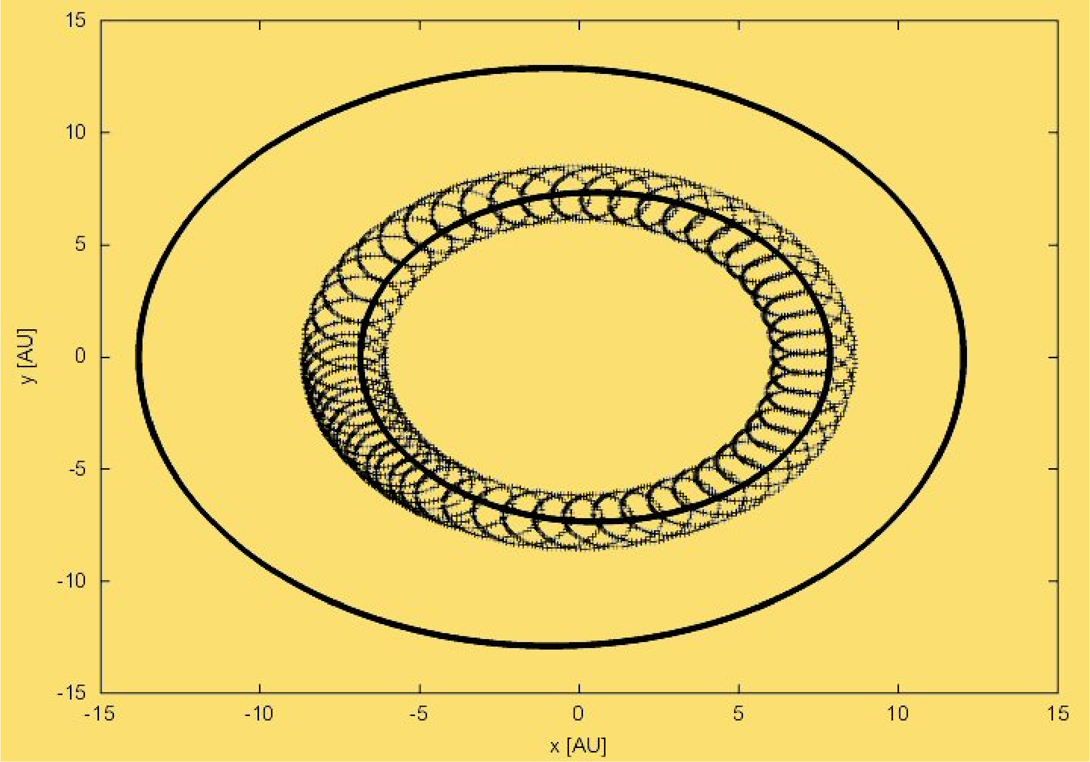
e = 0.2

HD 41004 A

$M_{star1} = 0.7\ M_{Sun}$

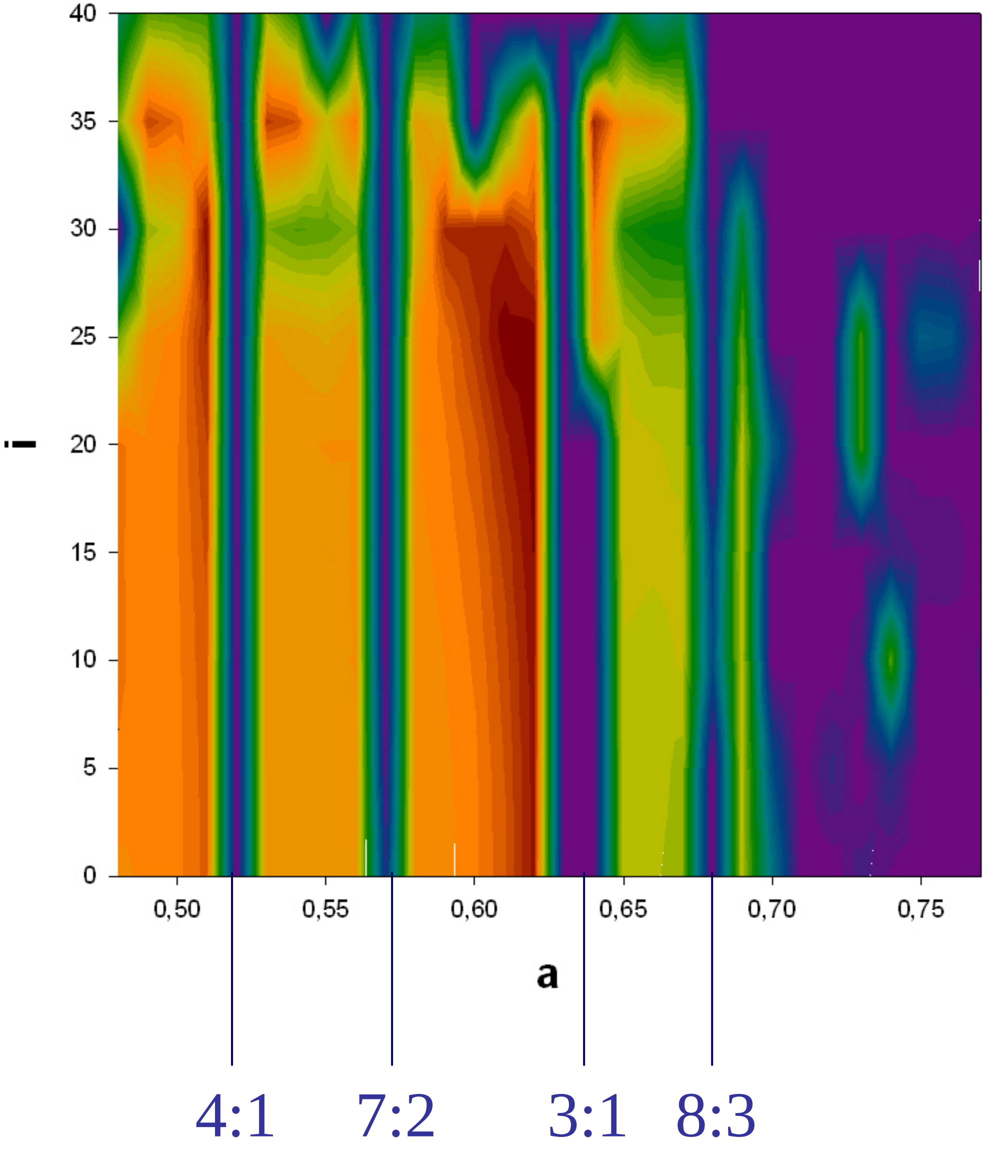
- *The orbital parameters were taken from the Geneva planetary search group*
- *Masses are Minimum Masses*

Planet
$m \sin i = 2.3\ M_{jup}$
$a = 1.31$ AU
$e = 0.39 \pm 0.17$
$\omega \approx 114^o$

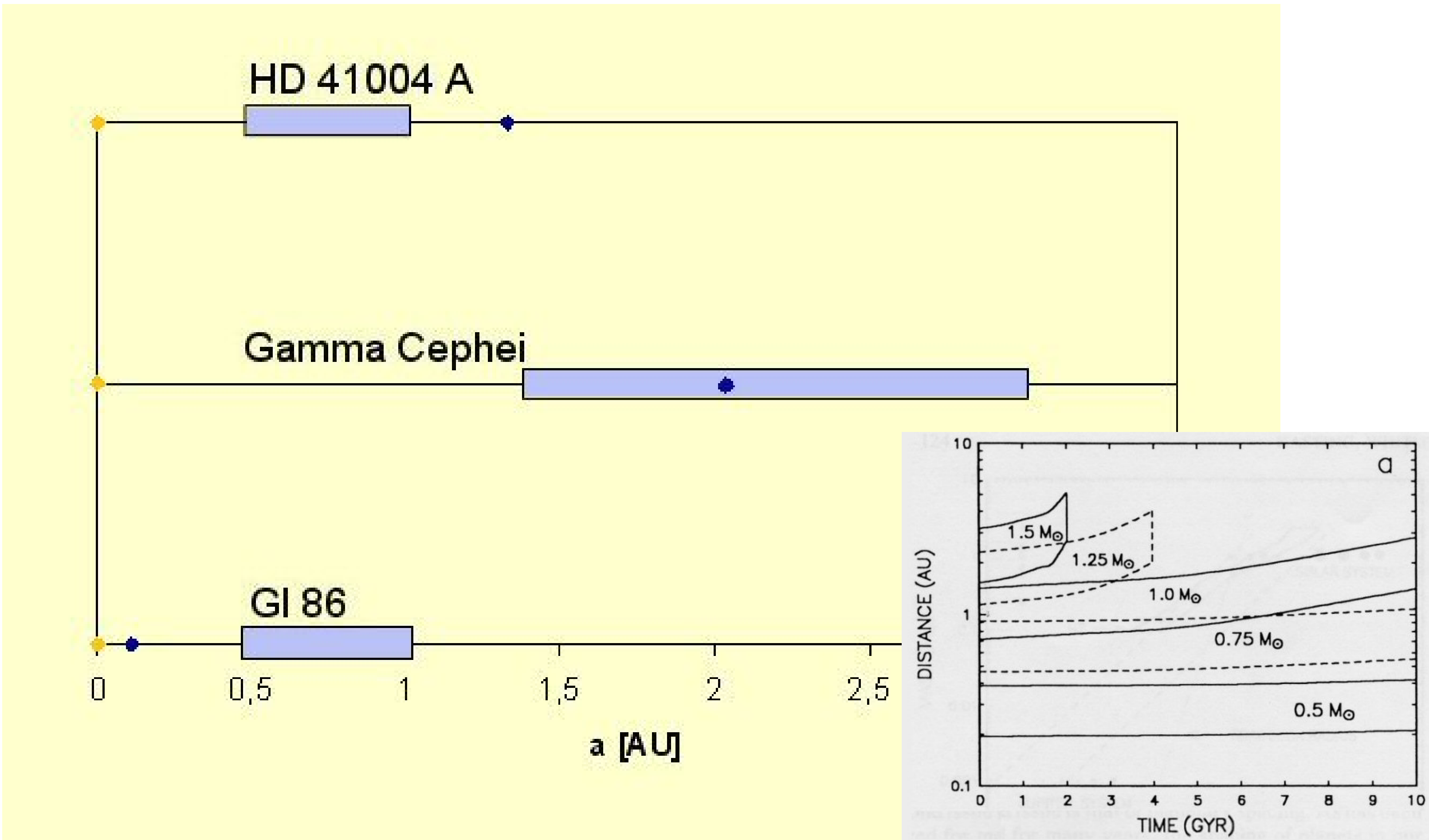


Star 2
$m = 0.4\ M_{Sun}$
$a = 21$ AU
$e = 0.1$

Resonances with the discovered Planet



Habitable Zones in the three close binaries



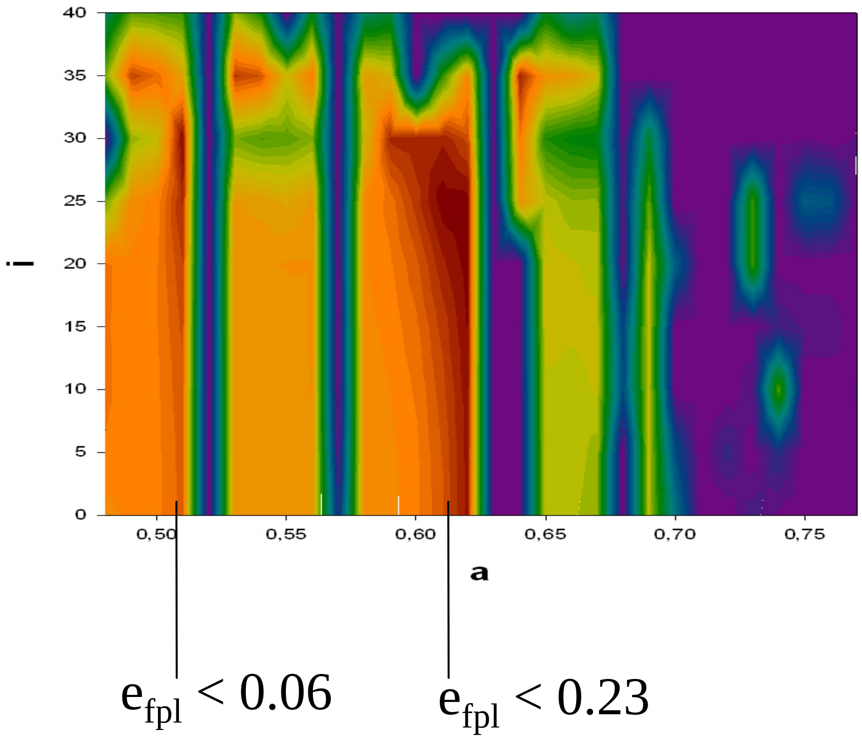
Ref: Kasting, J.F., Whitmire, D.P., Reynolds, R.T.: Habitable Zones around Main Sequence Stars, Icarus, 101, p. 108, 1993

Results for HD41004A

- stable motion in the HZ only for a ≤ 0.7 AU
- the eccentricity of the binary

  ebin ≤ 0.7

- we have found two zones for habitable planets:
  - for nearly circular planetary motion around 0.5 AU the
  - eccentricity of the detected planet has to be ≤ 0.36
  - for higher eccentric planetary motion around 0.6 AU the
  - eccentricity of the detected planet has to be < 0.3



maximum eccentricity

HD 41004 A

$M_{star1} = 0.7\ M_{Sun}$

Planet

$m \sin i = 2.3\ M_{jup}$

$a = 1.31$ AU → 1.64 – 1.7 AU

$e = 0.39 \pm 0.17$ → 0.5 – 0.74

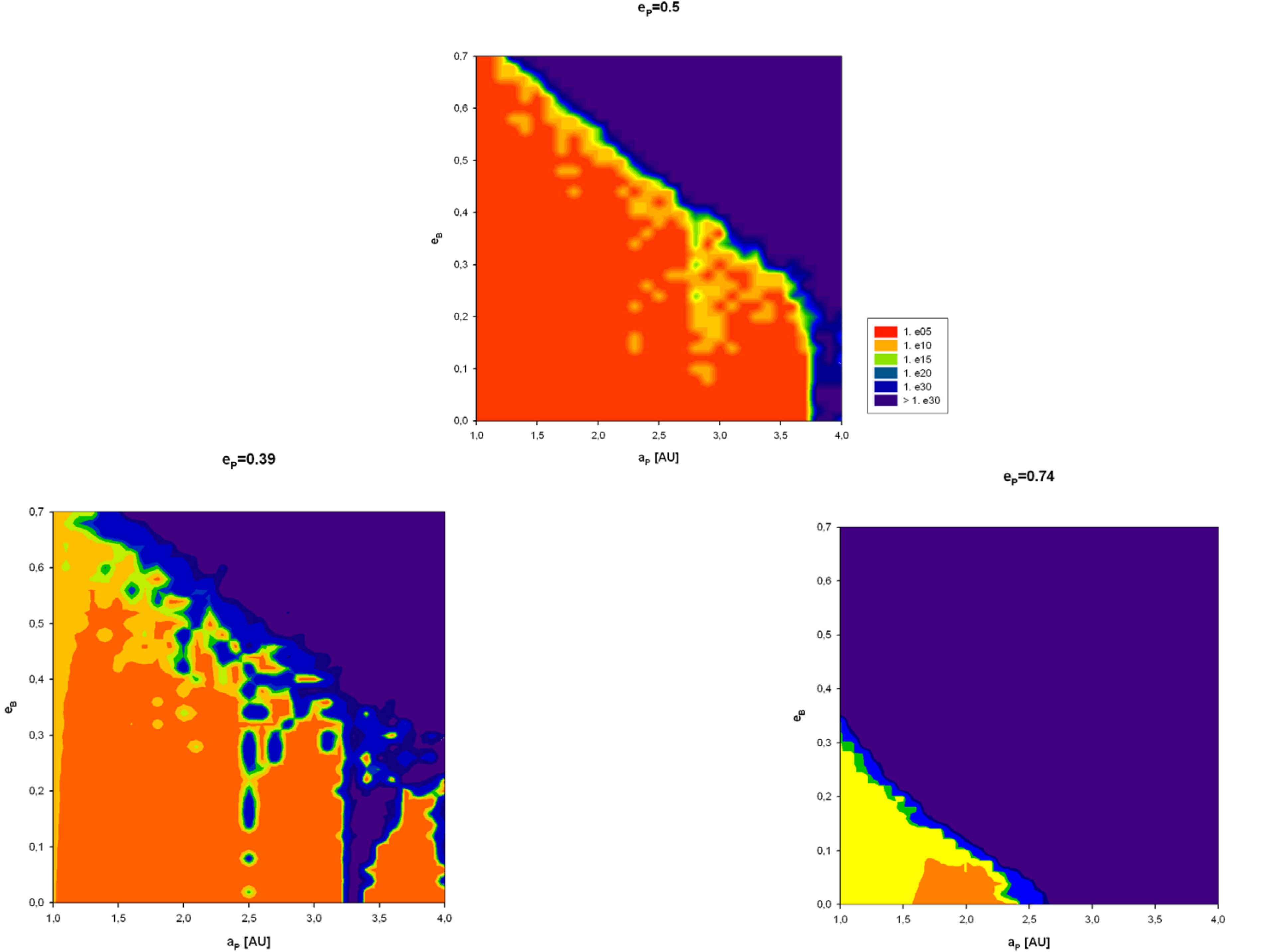
$\omega \approx 114^o$

Star 2

$m = 0.4\ M_{Sun}$

$a = 21$ AU -→ 23 AU

$e = ?$

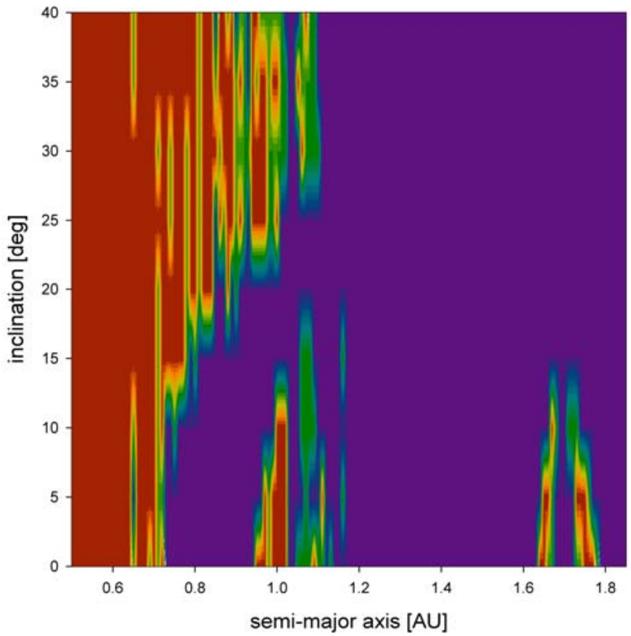


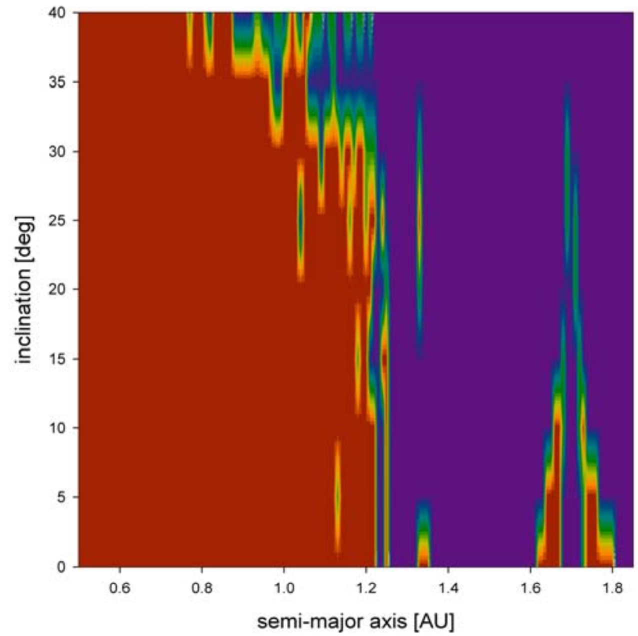
e_P=0.5
e_B
a_P [AU]
1. e05
1. e10
1. e15
1. e20
1. e30
> 1. e30
e_P=0.39
e_B
a_P [AU]
e_P=0.74
e_B
a_P [AU]

with secondary

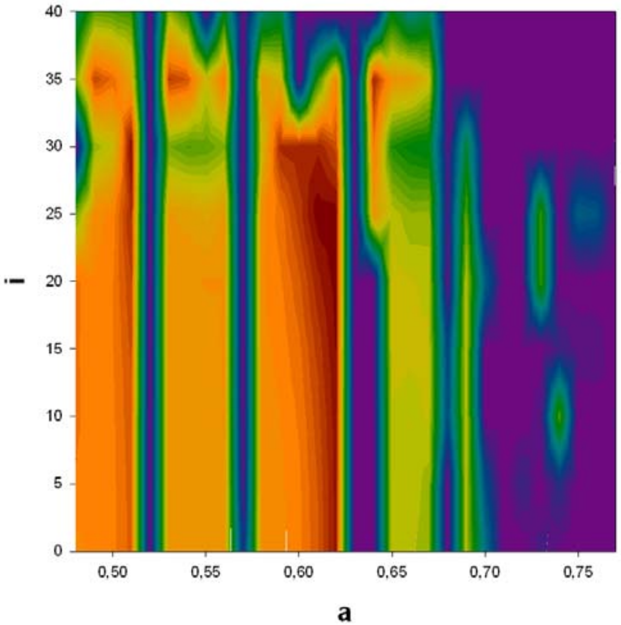
without secondary

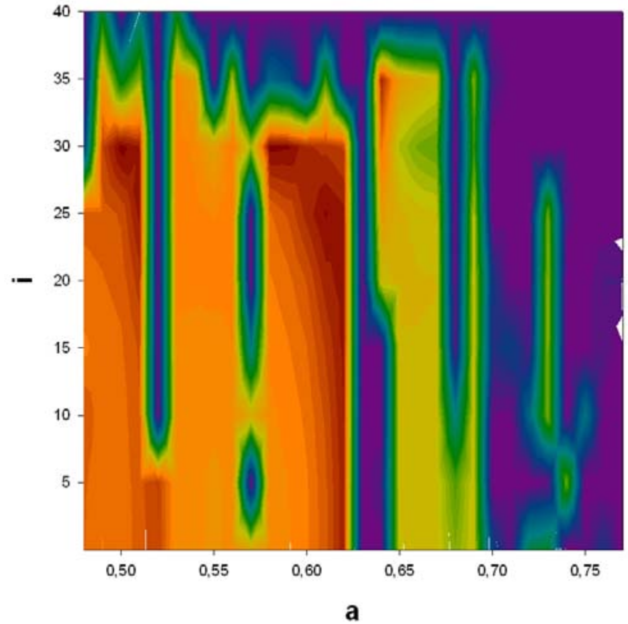
<u>gammaCep</u>
e_b=0.44
e_pl=0.209





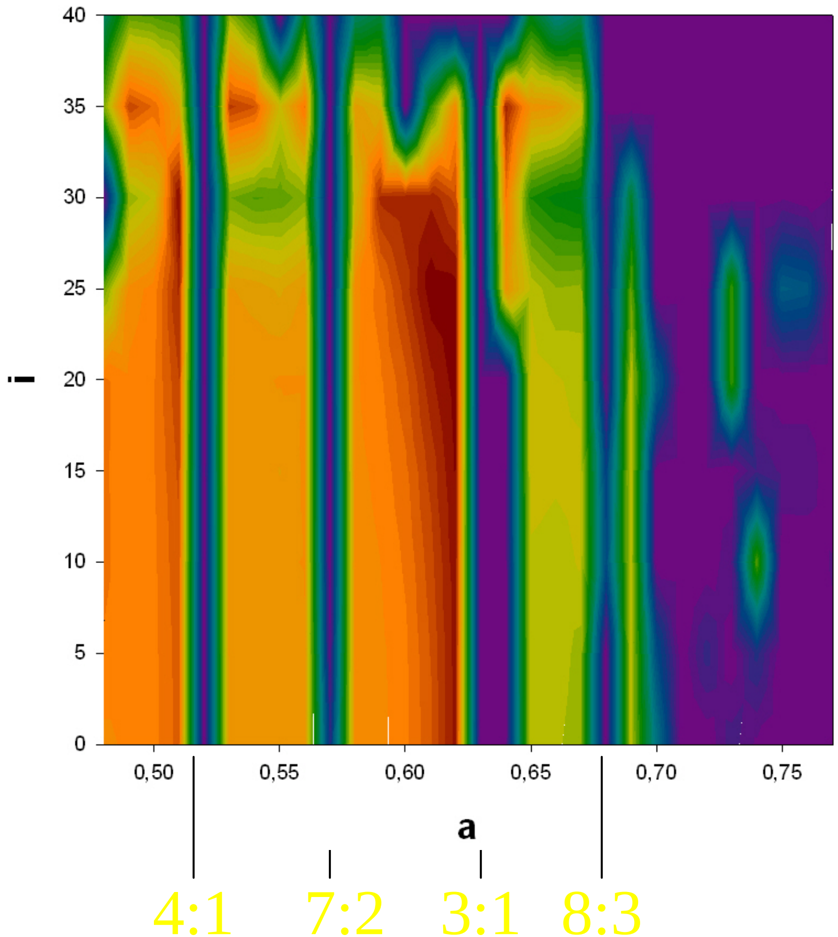
<u>HD41004</u>
e_b=0.2
e_pl=0.22



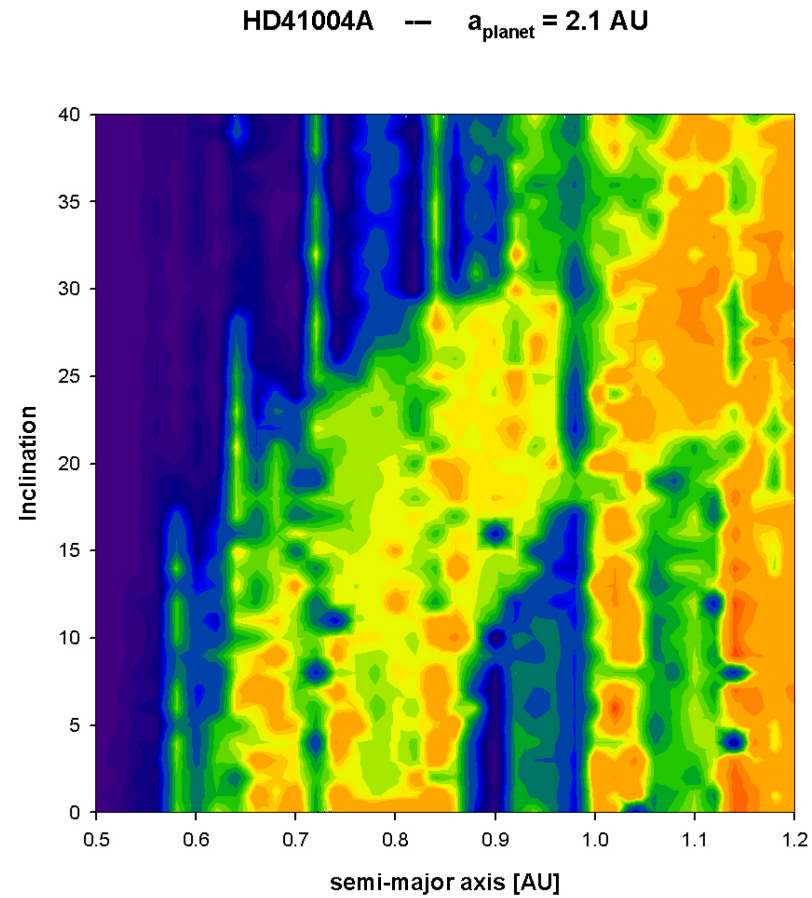


Differences of the two planetary systems:

- **semi-major axis of the planet**
- **eccentricity of the binary**
- **mass-ratio of the binary**
- **mass of the giant planet**

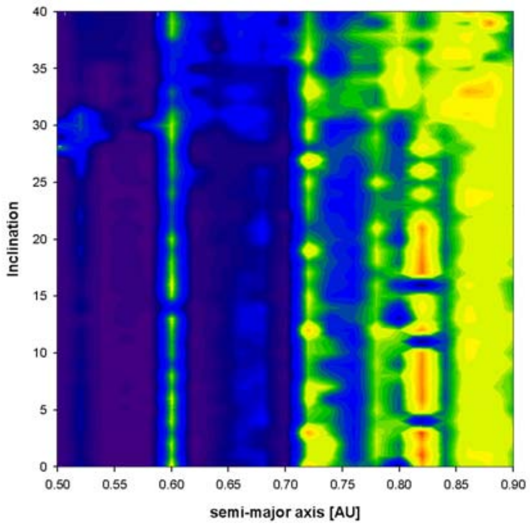


40
35
30
25
20
15
10
5
0
i
0,50
0,55
0,60
0,65
0,70
0,75
a
4:1
7:2
3:1
8:3

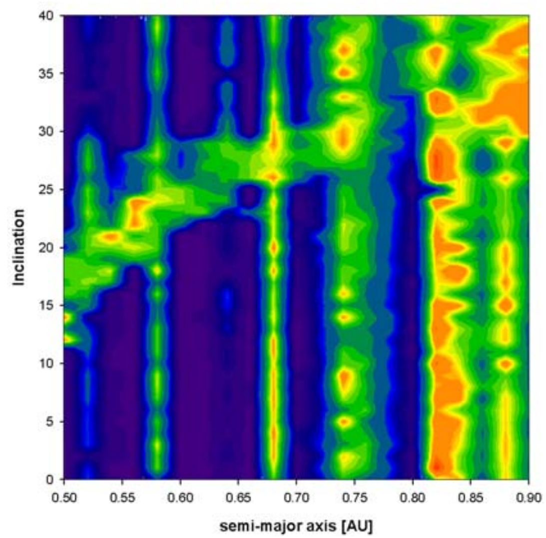


HD41004A -- a_{planet} = 2.1 AU
40
35
30
25
20
15
10
5
0
Inclination
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
semi-major axis [AU]

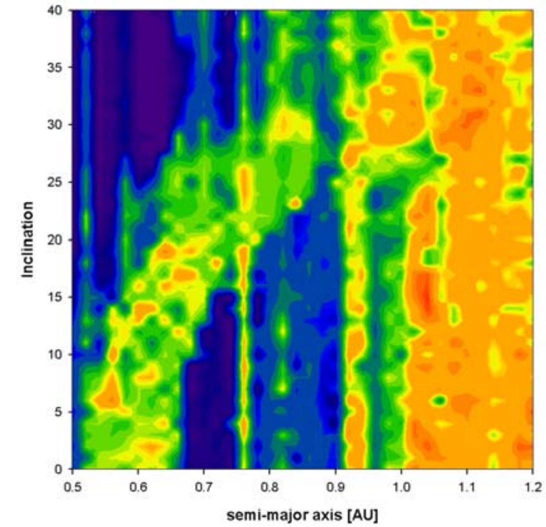
HD41004A — a_{planet} = 1.5 AU

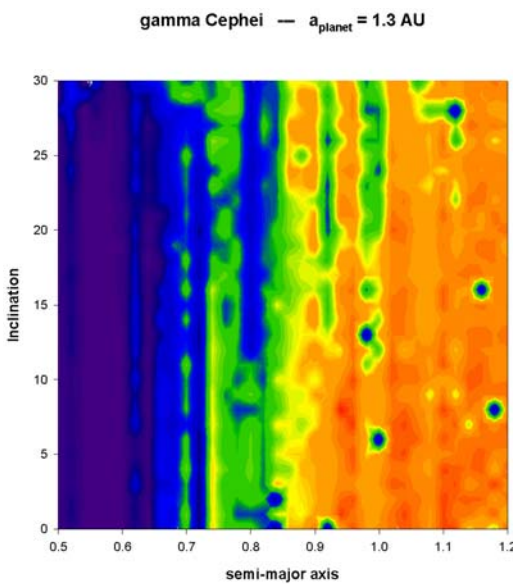


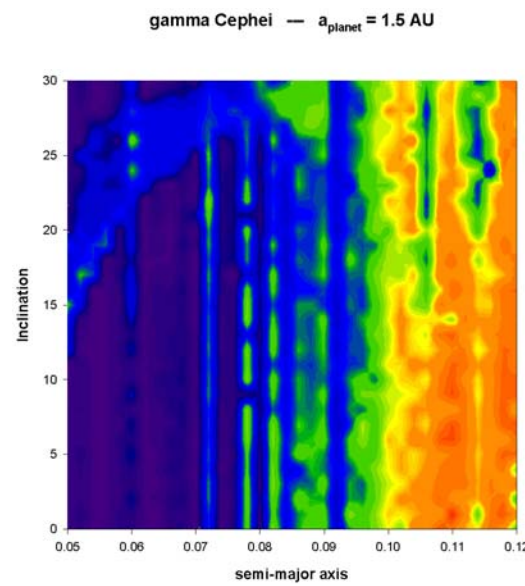
HD41004A — a_{planet} = 1.7 AU

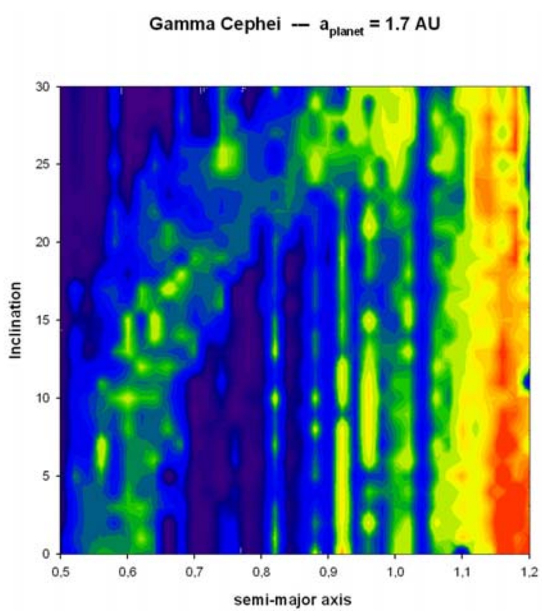


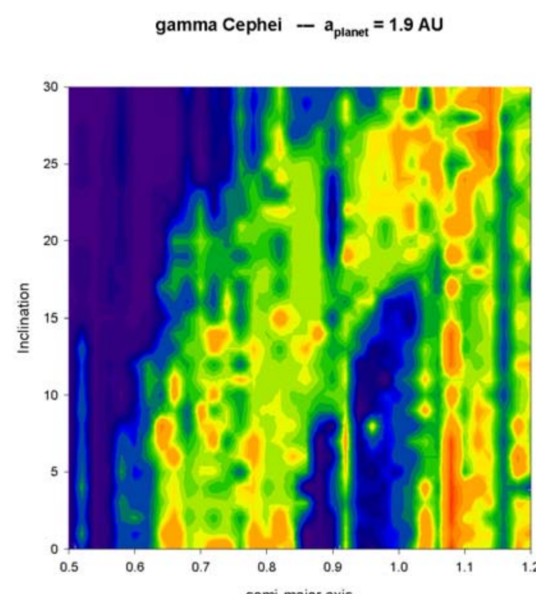
HD41004A — a_{planet} = 1.9 AU




gamma Cephei — a_{planet} = 1.3 AU
Inclination
semi-major axis
0
5
10
15
20
25
30
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2


gamma Cephei — a_{planet} = 1.5 AU
Inclination
semi-major axis
0
5
10
15
20
25
30
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12


Gamma Cephei — a_{planet} = 1.7 AU
Inclination
semi-major axis
0
5
10
15
20
25
30
0,5
0,6
0,7
0,8
0,9
1,0
1,1
1,2


gamma Cephei — a_{planet} = 1.9 AU
Inclination
semi-major axis
0
5
10
15
20
25
30
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2

- **Planet is close to the host-star: The region is mainly influenced by the mean motion resonances**

- **If the planet is closer to the secondary -> an arc-like structure appears which depends on: a_planet, e_binary, masses,**

Gliese 86

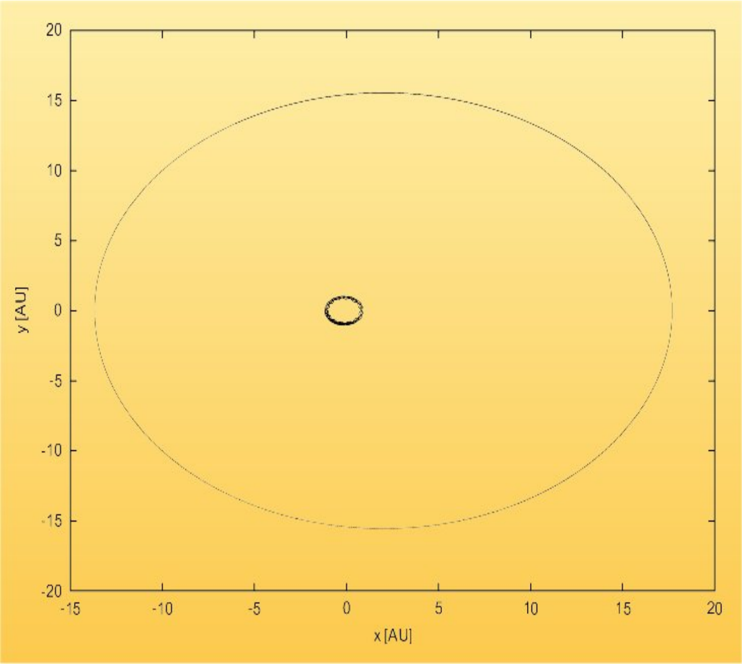
Primary and Secondary:

$m_1 = 0.79\ M_S$

$m_2 = 0.0477\ M_{Jup}$ → $0.5\ M_{Sun}$

$a = 18.75$ AU → 20 AU

$e = ?$

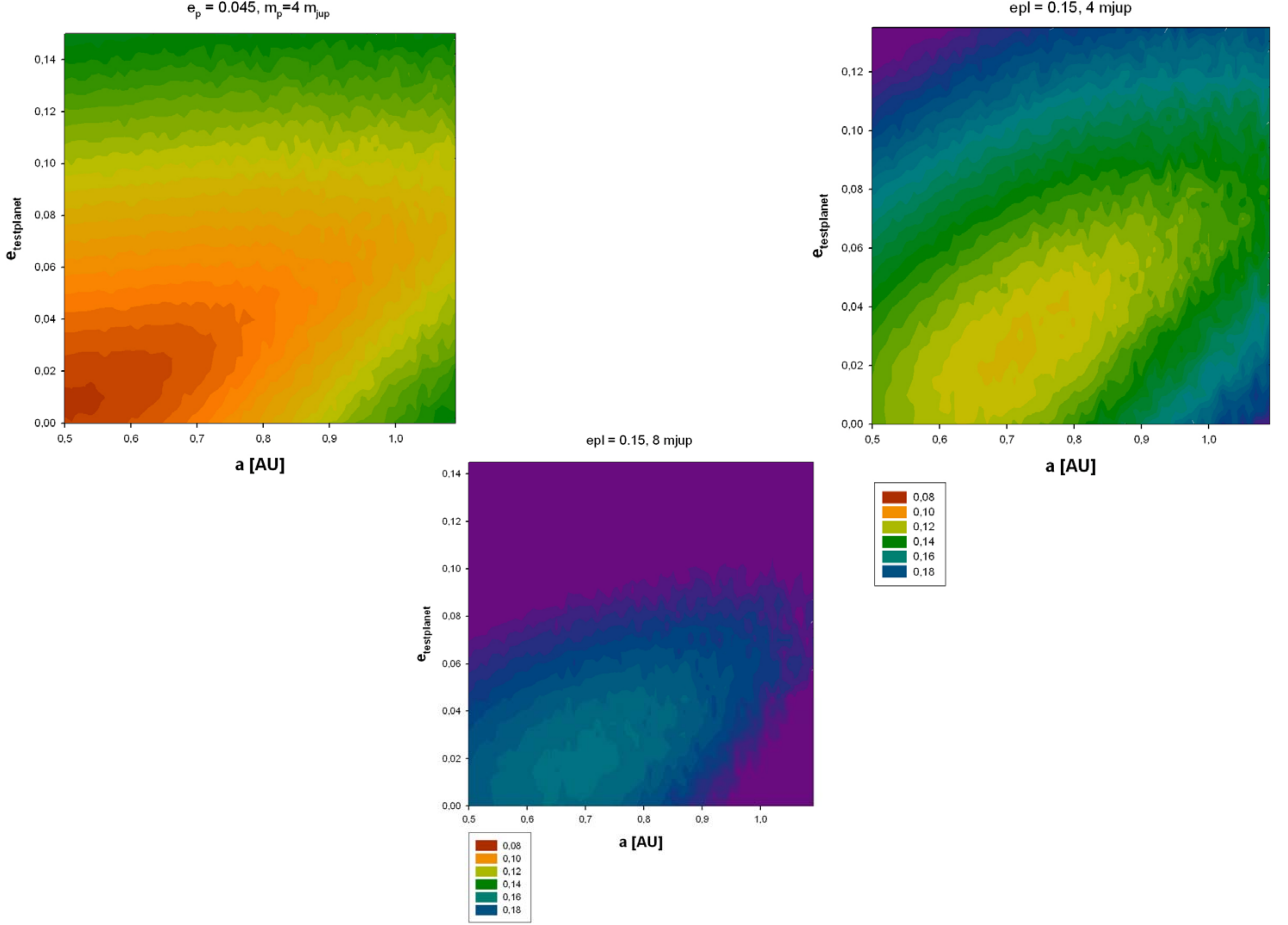


Planet:

$m_P = 4\ M_{jup}$

$a = 0.11$ AU

$e = 0.046$



e_p = 0.045, m_p=4 m_{jup}
$e_{testplanet}$
0,14
0,12
0,10
0,08
0,06
0,04
0,02
0,00
0,5
0,6
0,7
0,8
0,9
1,0
a [AU]
epl = 0.15, 4 mjup
$e_{testplanet}$
0,12
0,10
0,08
0,06
0,04
0,02
0,00
0,5
0,6
0,7
0,8
0,9
1,0
a [AU]
0,08
0,10
0,12
0,14
0,16
0,18
epl = 0.15, 8 mjup
$e_{testplanet}$
0,14
0,12
0,10
0,08
0,06
0,04
0,02
0,00
0,5
0,6
0,7
0,8
0,9
1,0
a [AU]
0,08
0,10
0,12
0,14
0,16
0,18