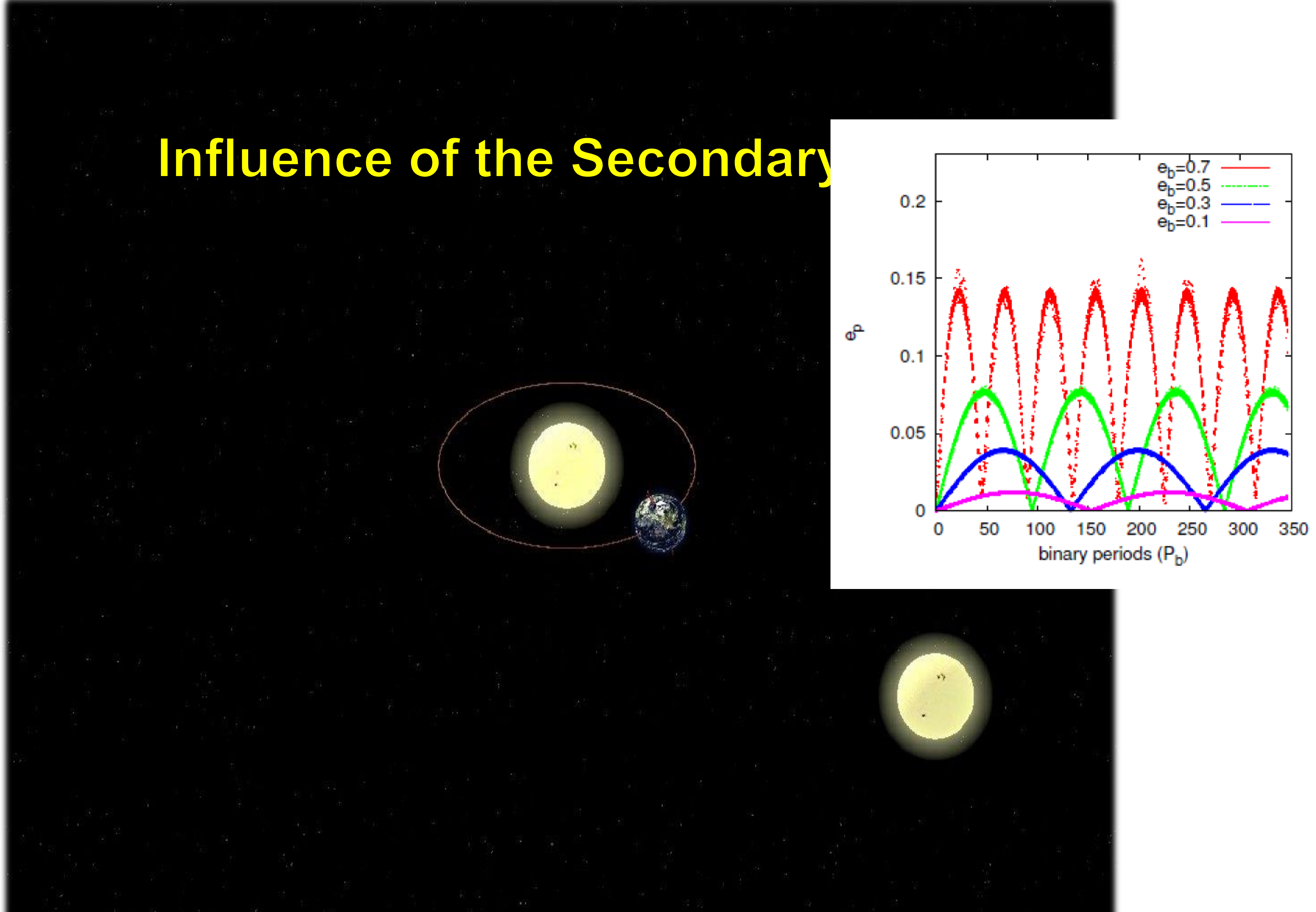
Influence of the Secondary Star

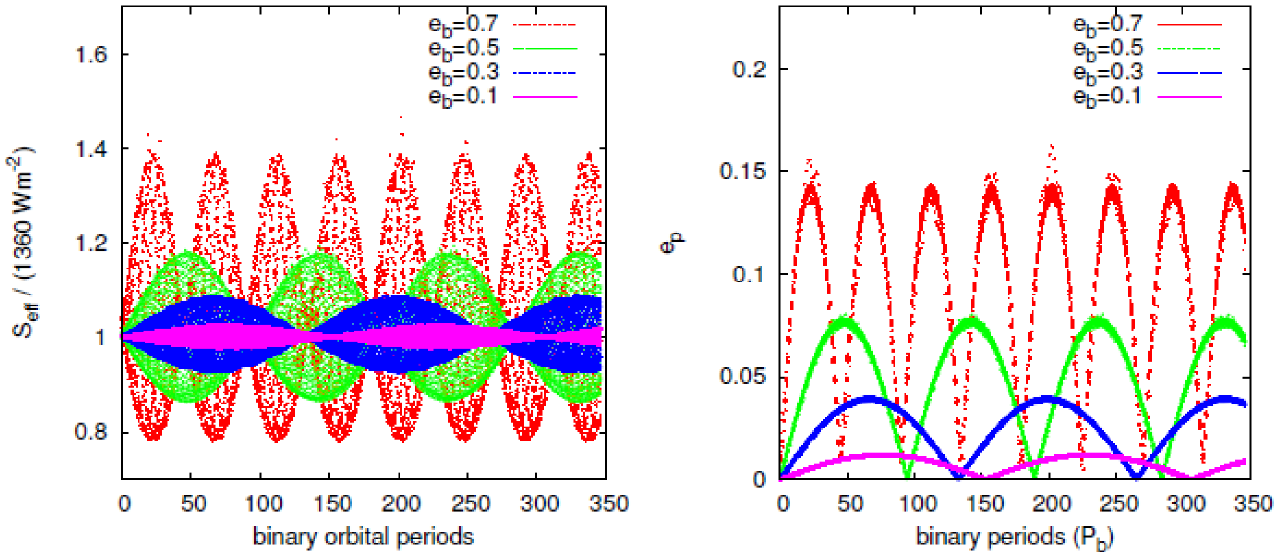
Influence of the Secondary



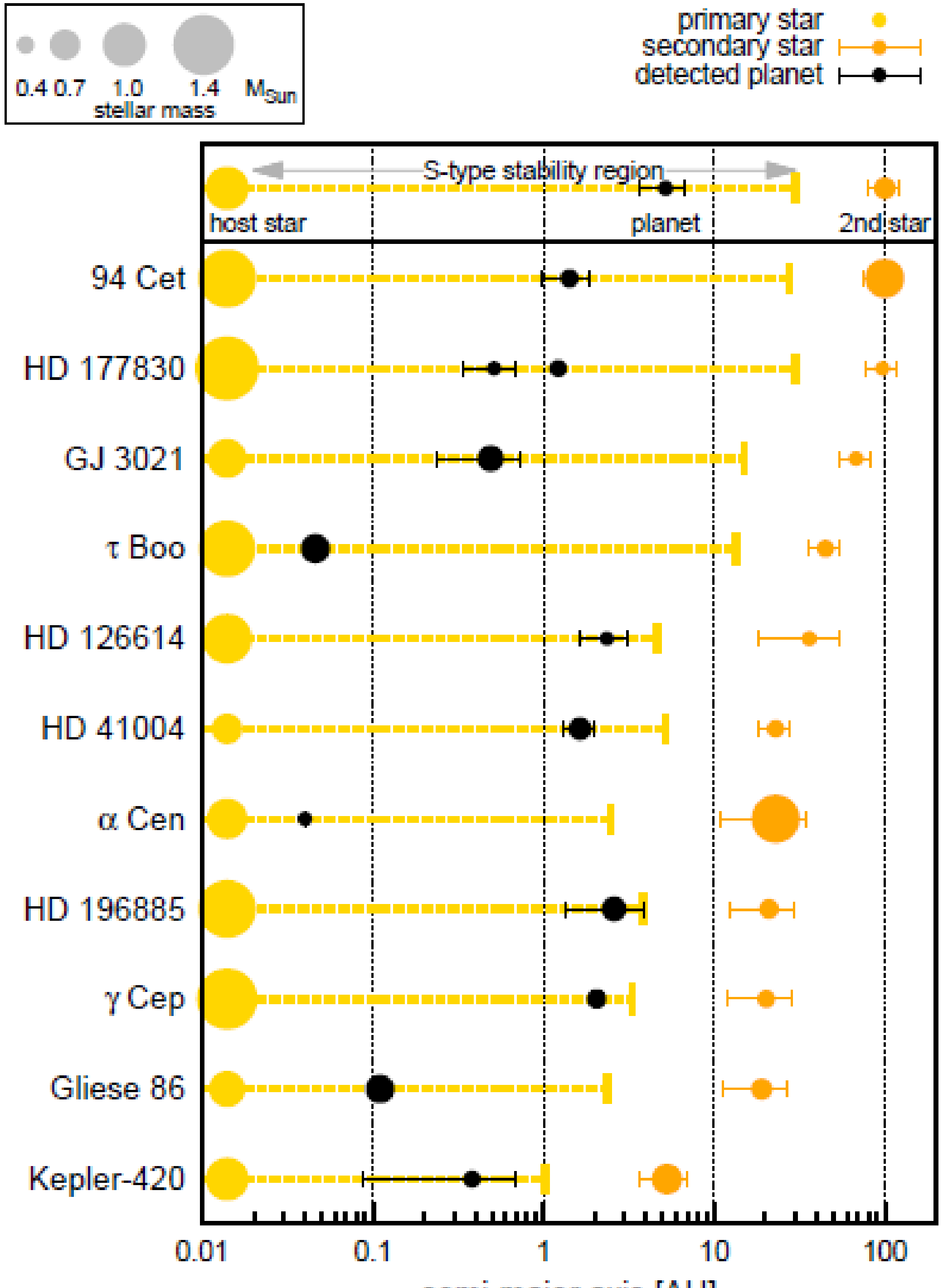
Habitable Zones in Binary Stars

Combined gravitational and radiative perturbations

→ eccentricity motion of planets → additional insolation
→different HZs
(permanent, extended,averaged)



Mutual gravitational interaction is important!



Bazso et al., 2016

Eccentric Planetary Motion:

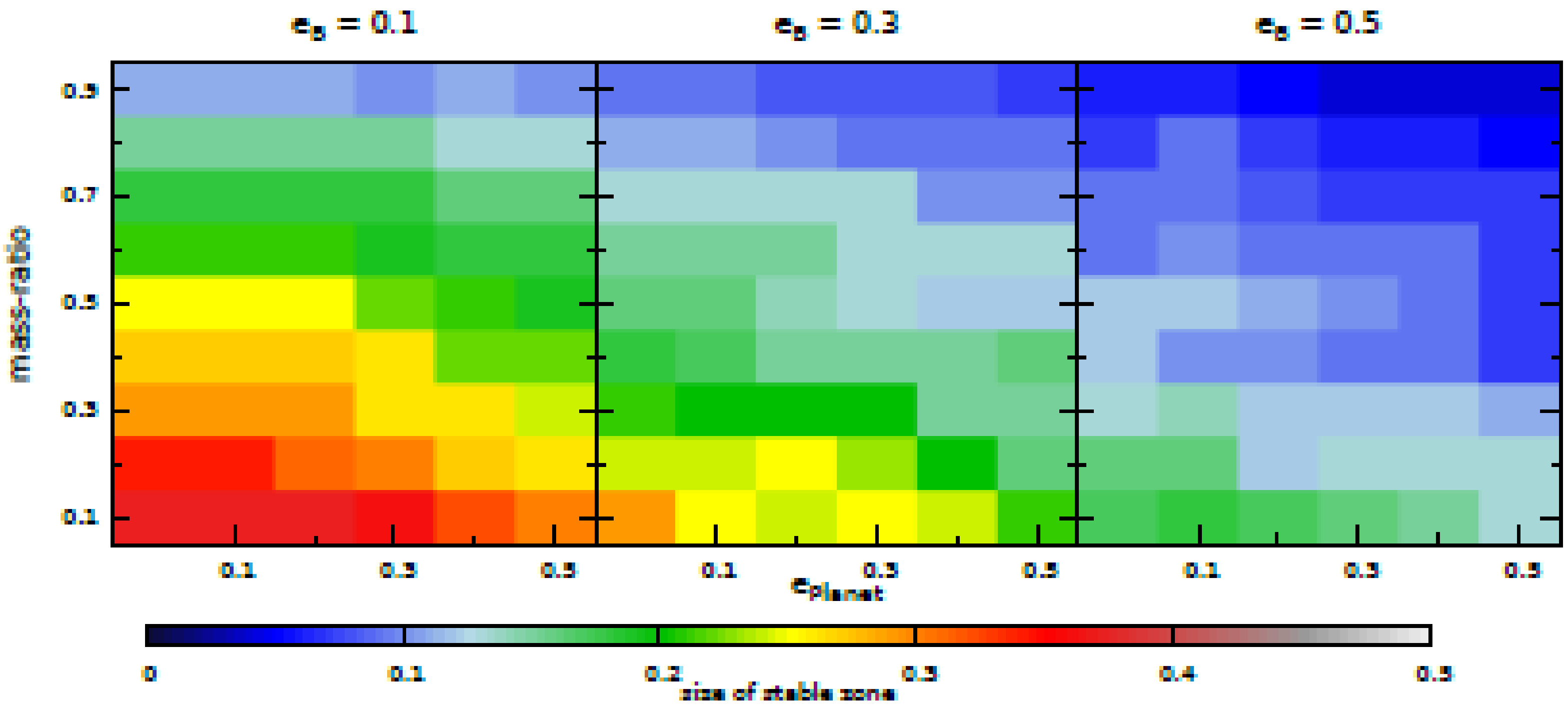


Figure 2.7 Stability of eccentric S-type motion in binary stars for different eccentricities of the binary.

γ Cephei System:

	a_{binary} [AU]	e_{binary}	m_1 [MSun]	m_2 [MSun]
γ Cephei	~20	0.44	1.6	0.4

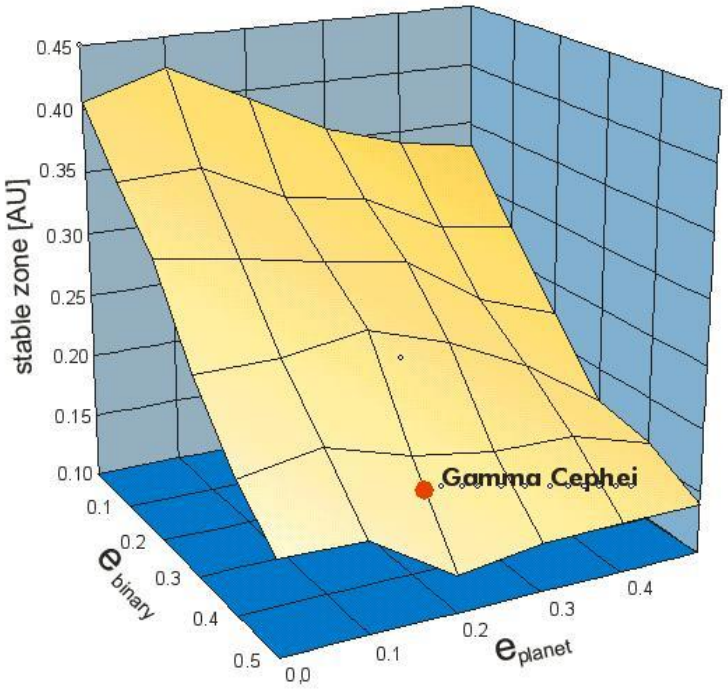
Planet:

m sin i = 1.6 MJ

a = 2.15 AU

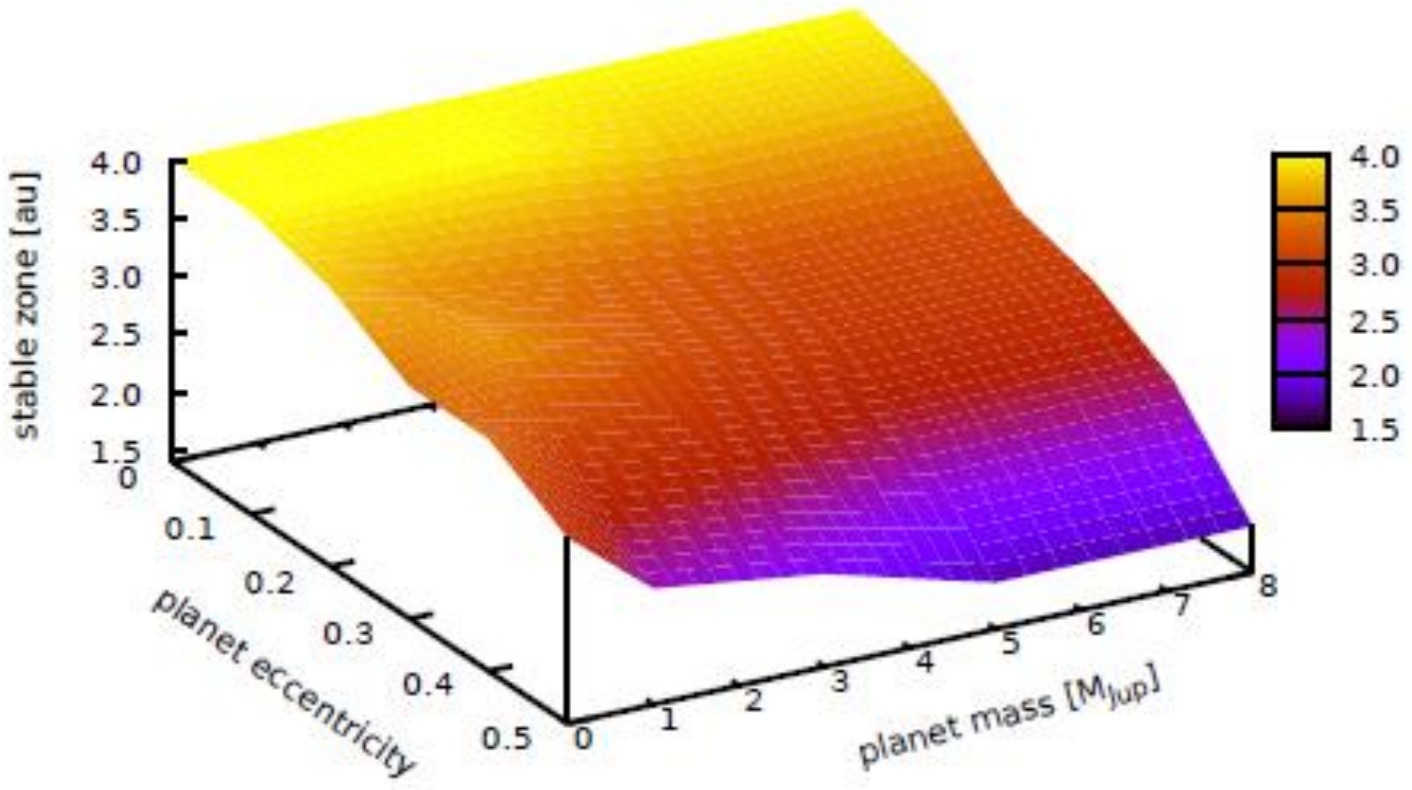
e = 0.11 – 0.2

mass-ratio = 0.2

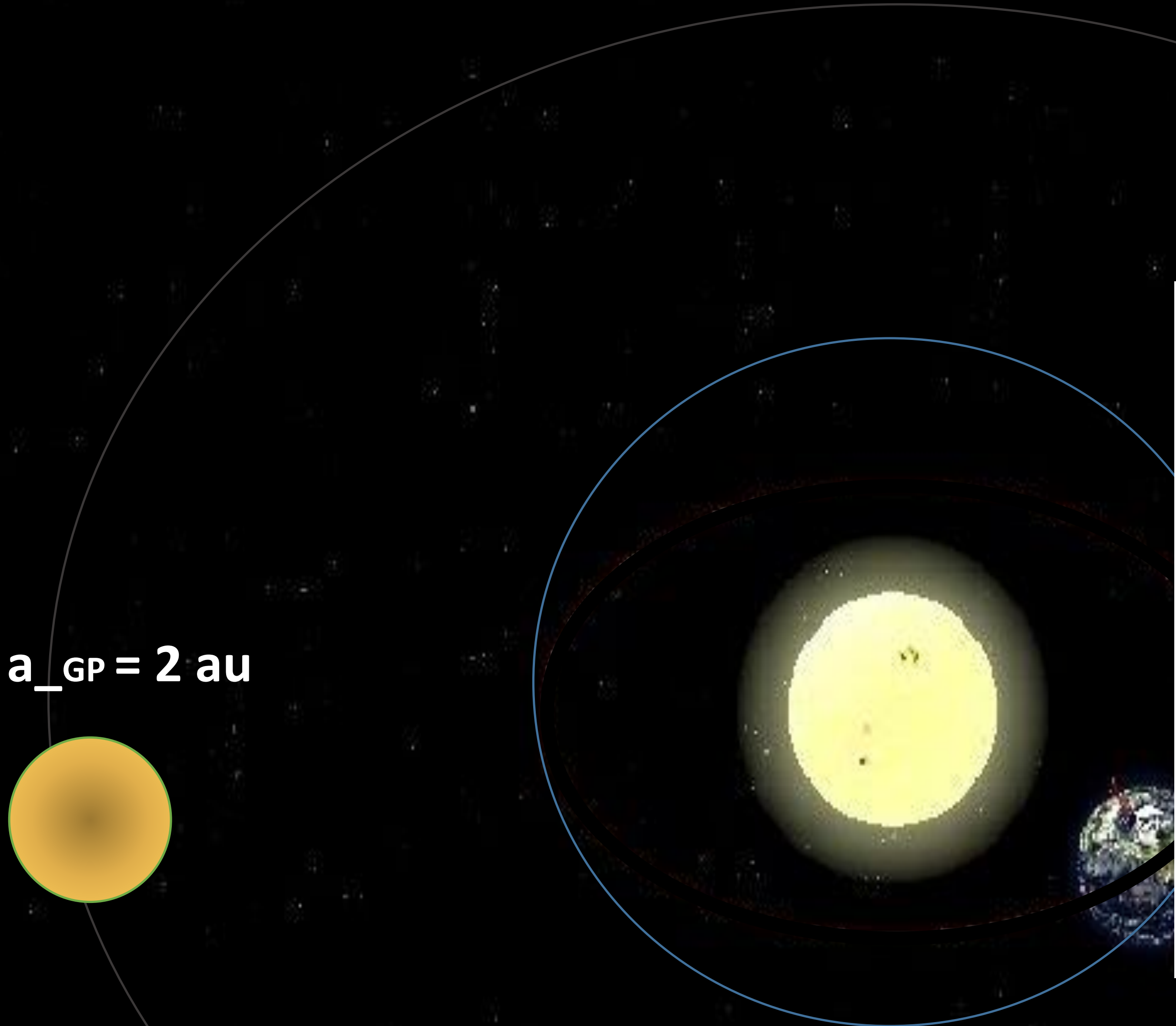


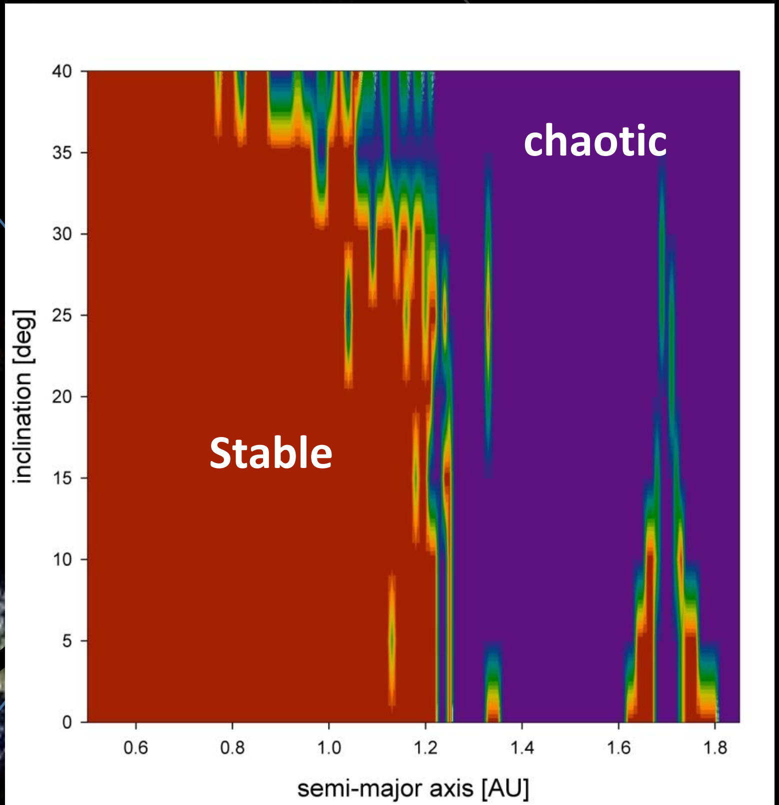
e_plan	RTBP	1Mj
0.0	4.0	4.0
0.1	4.0	4.0
0.3	3.4	3.6
0.5	3.0	2.4

Stability of massive planets



2 Planets in circumstellar motion:





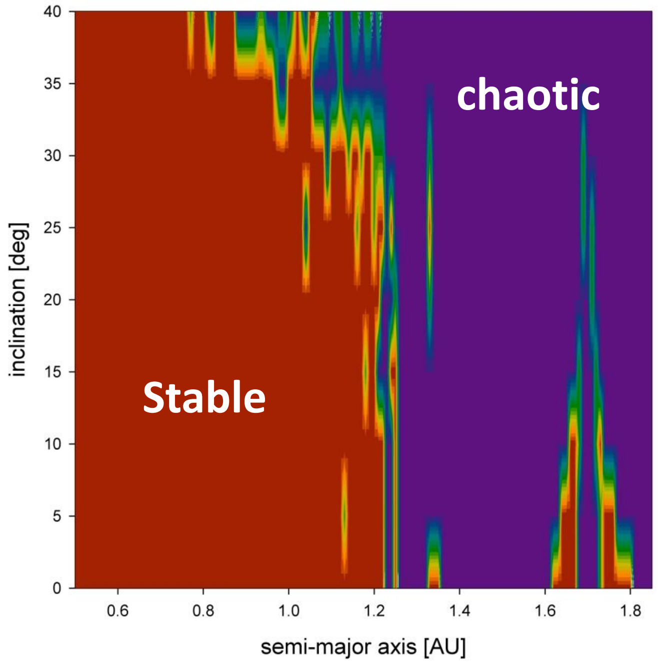
Mean Motion Resonances due to a Giant Planet

like in the **gamma Cephei** system we consider:

a giant planet at 2 au in an eccentric orbit (e=0.2)

A study of test-planets in the area between 0.5 and 1.9 au
Shows the following orbital behaviour :

Stable area for a < 1.2 au
Mean Motion Resonances (MMRs)
→ chaotic and stable ones



FLI (Fast Lyapunov Indicator) maps

Mean Motion Resonances due to a Giant Planet

like in the **gamma Cephei** system we consider:

a giant planet at 2 au in an eccentric orbit (e=0.2)

A study

Shows tl

Stable ar

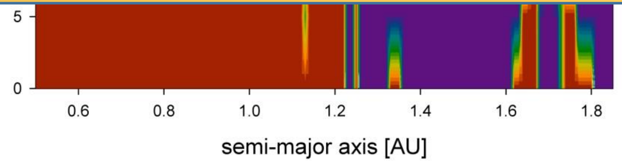
Mean M

→ ch

MMRs between 2 bodies (m, m‘) can be easily calculated using the third Kepler law:

$$a_{\mathrm{res}} = a' \left(\frac{n'}{n}\right)^{2/3} \left(\frac{M+m}{M+m'}\right)^{1/3}$$

FLI (Fast Lyapunov Indicator) maps



We have to distinguish two different cases:

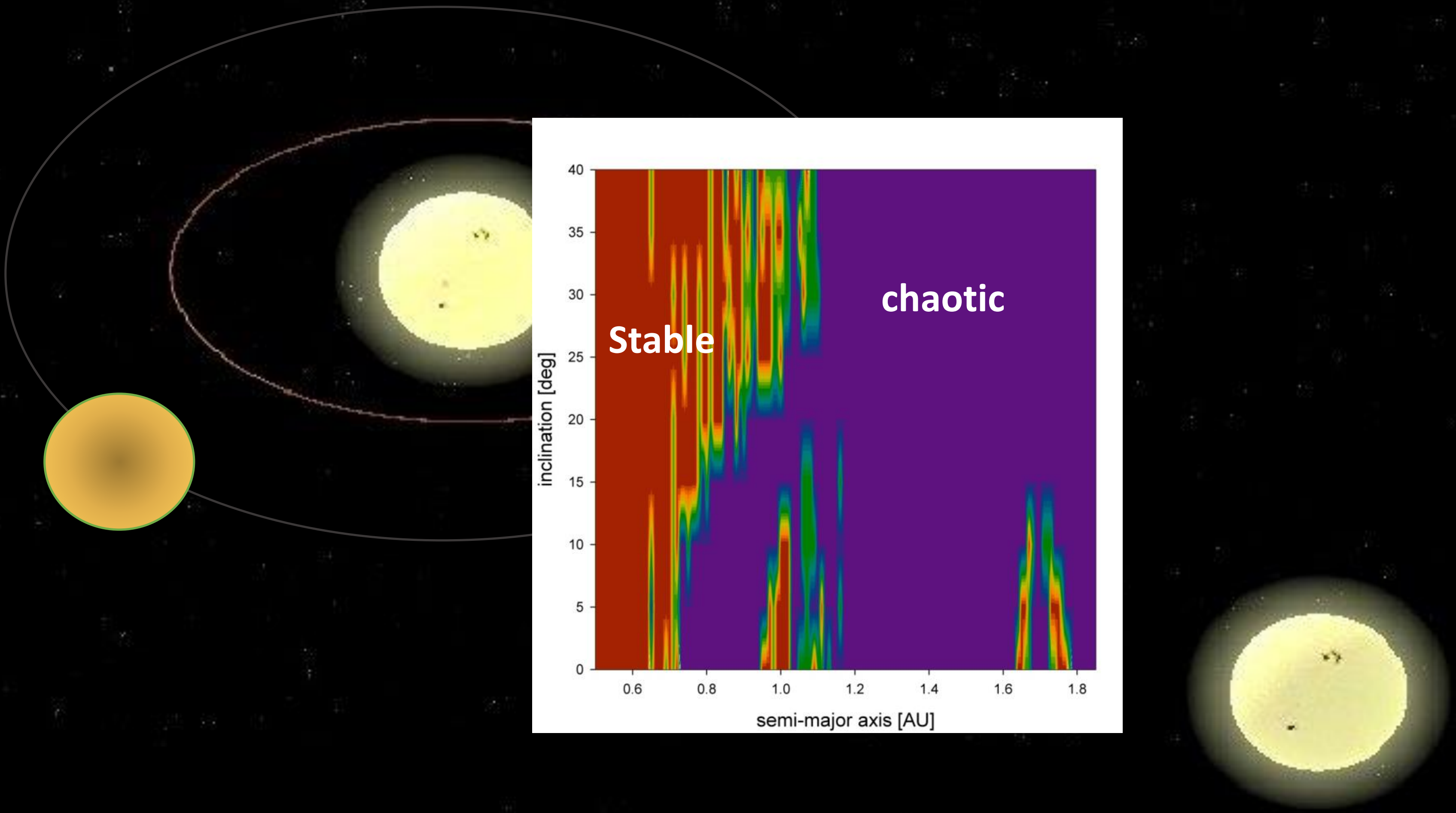
(1) If $n'/n < 1$ then it follows that $a_{\rm res} < a'$ and this is an internal resonance. The body m orbits closer to the central body than m'.

(2) If $n'/n > 1$ then it follows that $a_{\rm res} > a'$ and it is an external resonance. In this case m moves outside the orbit of m'.

In order to quickly visualise these cases one can write $n'/n = p/(p+q)$ for internal resonances, and $n'/n = (p+q)/p$ for external ones. Here, p, q are integers, and q is called the order of the resonance.

2 Planets in circumstellar motion in a binary:

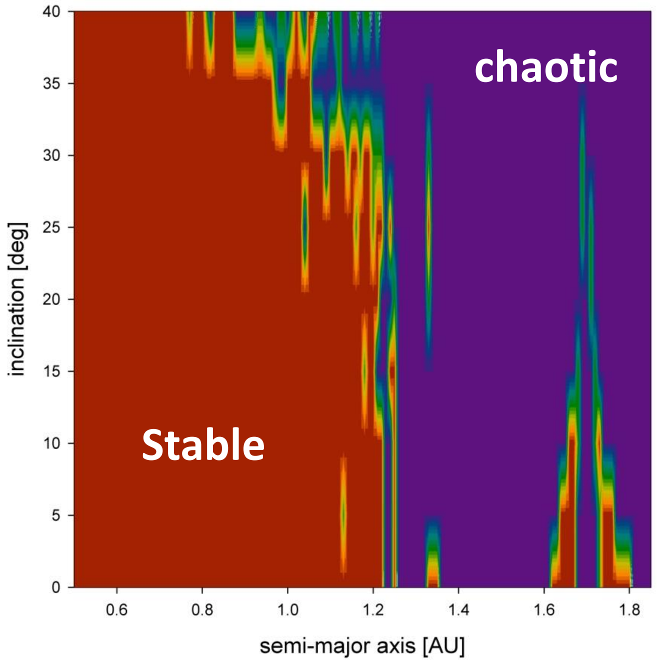
2 Planets in circumstellar motion in a binary:



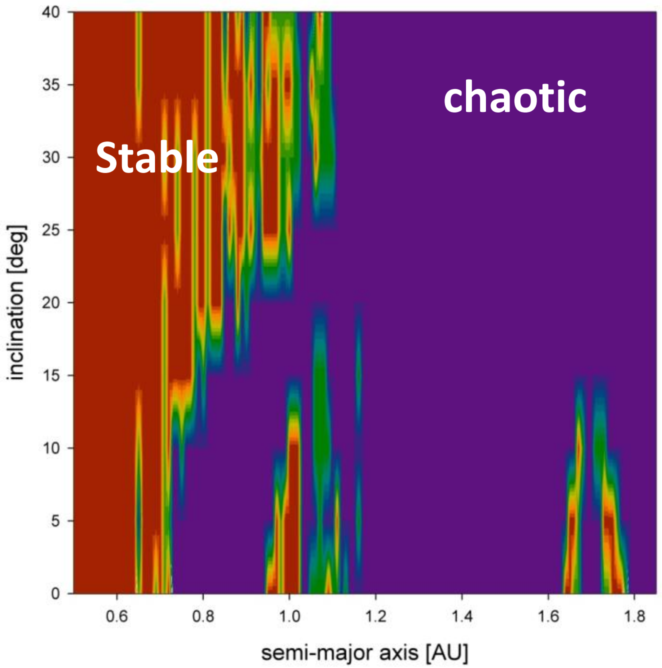
Influence of a secondary star at 20 au:

giant planet (a=2 au) + test-planet   in circumstellar motion

Single Star



Binary Star



FLI (Fast Lyapunov Indicator) maps

(Pilat-Lohinger, IAU Coll. Belgrade)

Tight binary star systems:

binary	a_{binary} [AU]	e_{binary}	m_1	m_2
Gliese86	~22	?	0.7	0.5
γ Cephei	~20	0.4	1.6	0.4
HD41004	~23	?	0.7	0.4

HD 41004A:

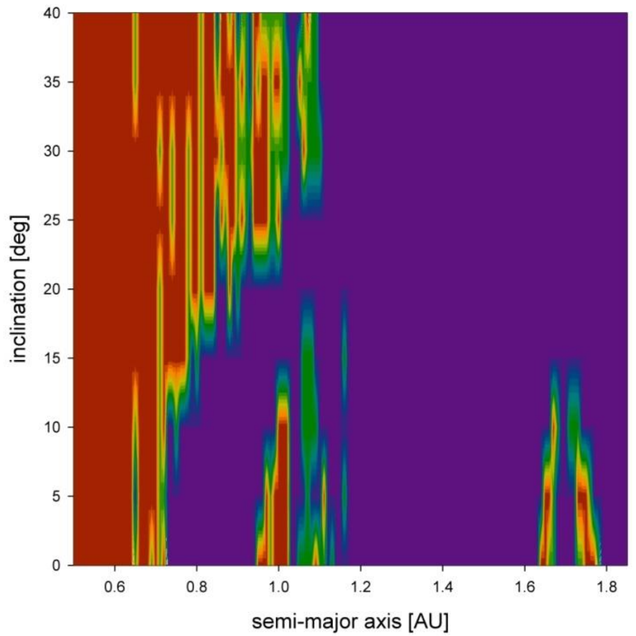
m sin i = 2.3 MJ

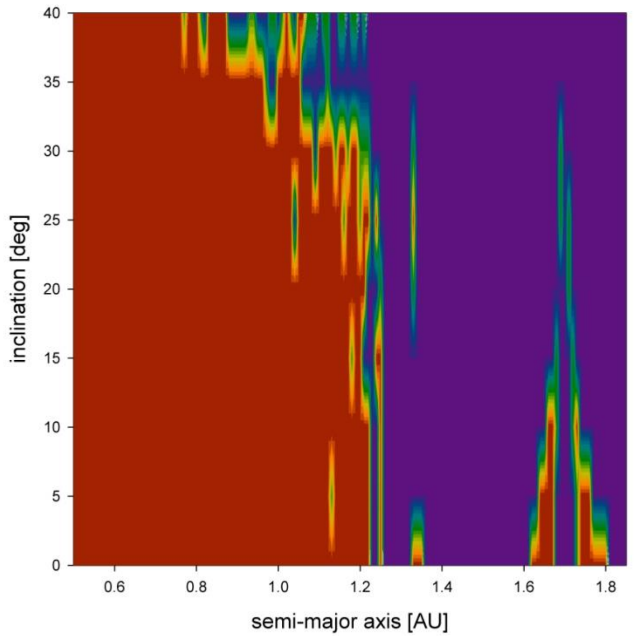
a = 1.3 AU (1.6 or 1.7)

e = 0.39 +/- 0.17 ?

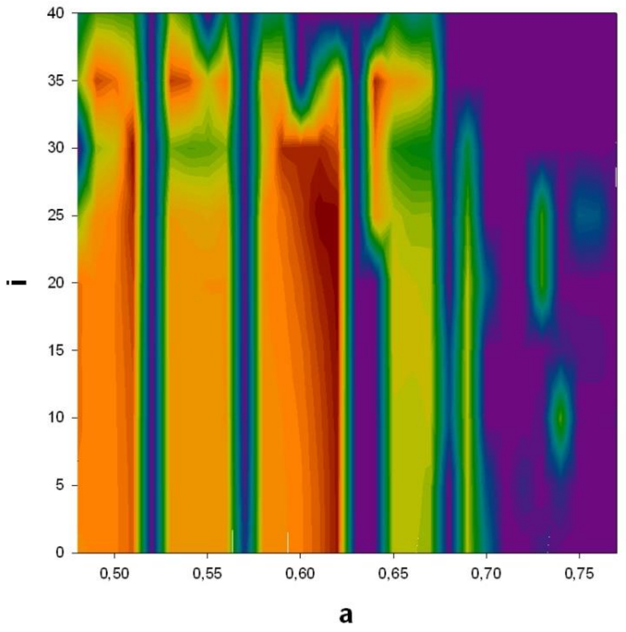
with secondary

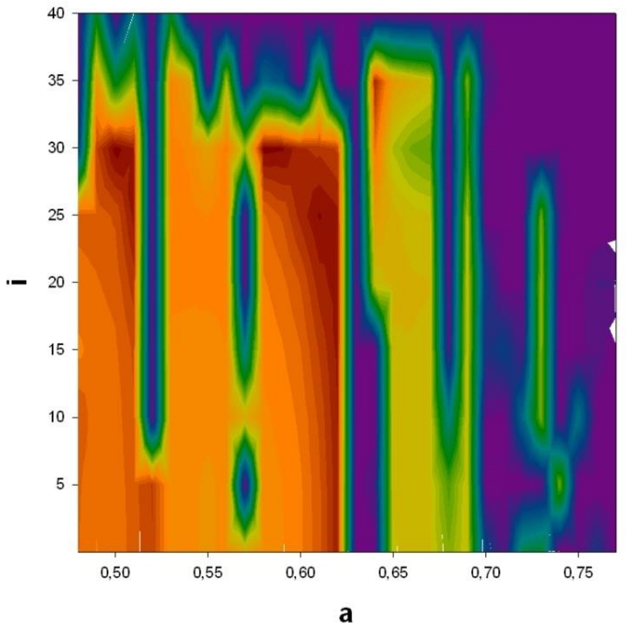
without secondary





gammaCep
e_b=0.44
e_pl=0.209

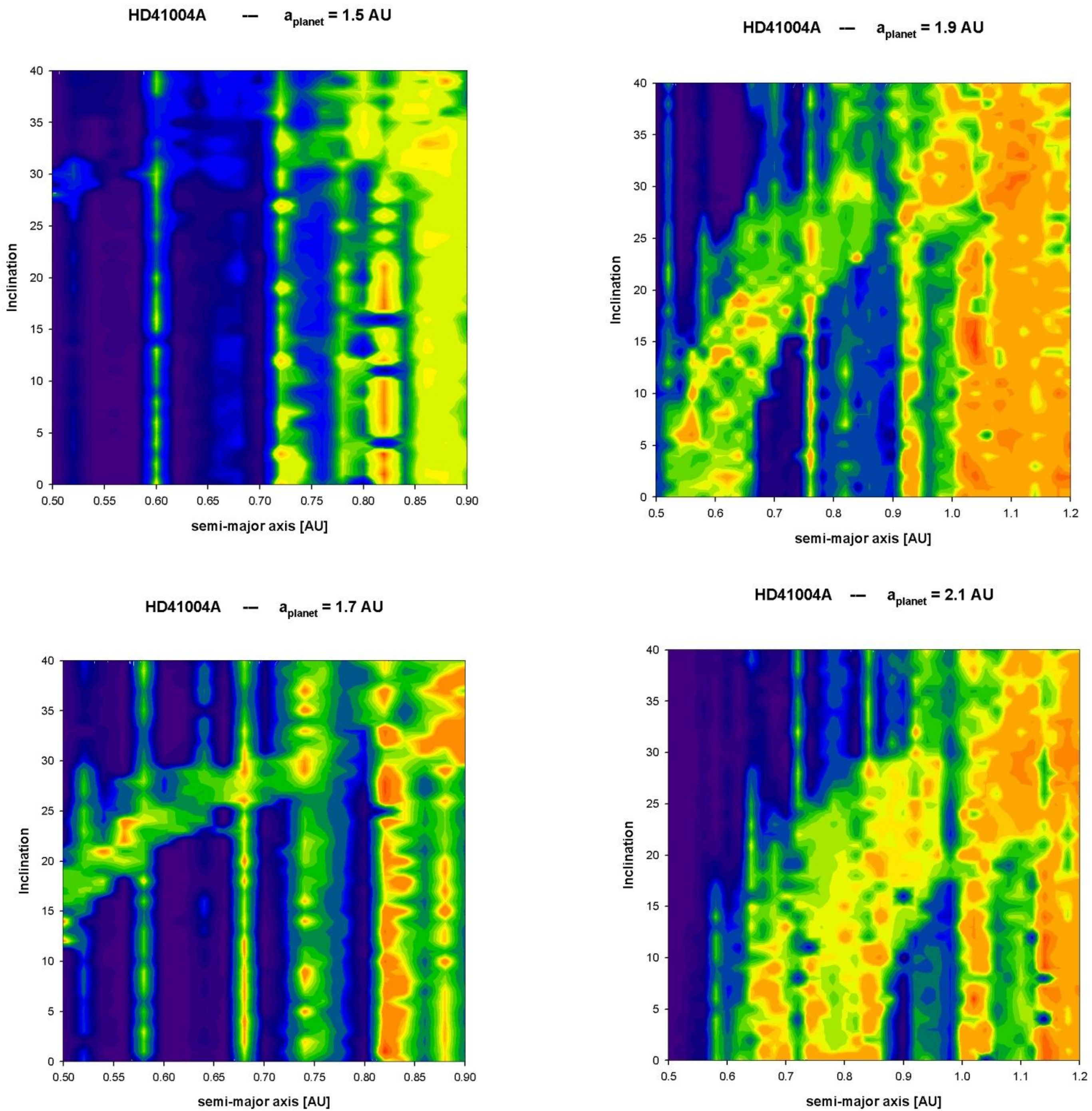




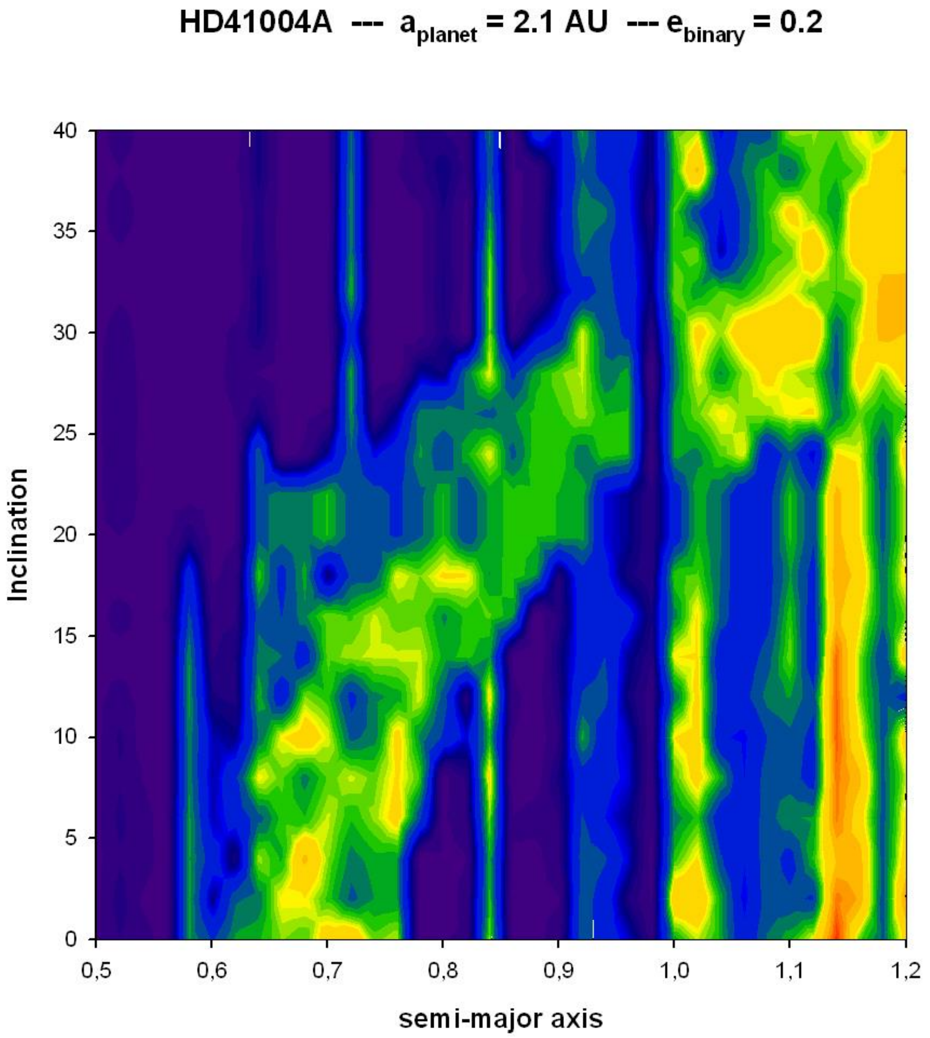
HD41004
e_b=0.2
e_pl=0.22

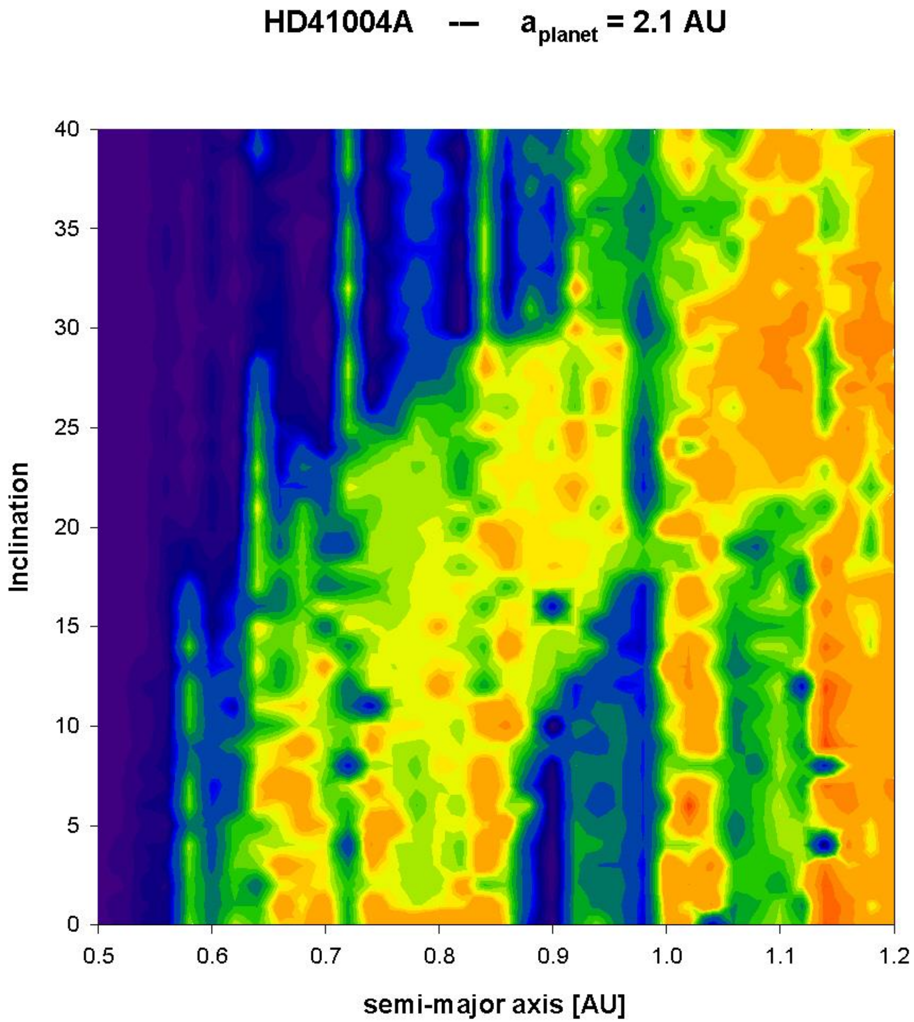
Differences of the two planetary systems:

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

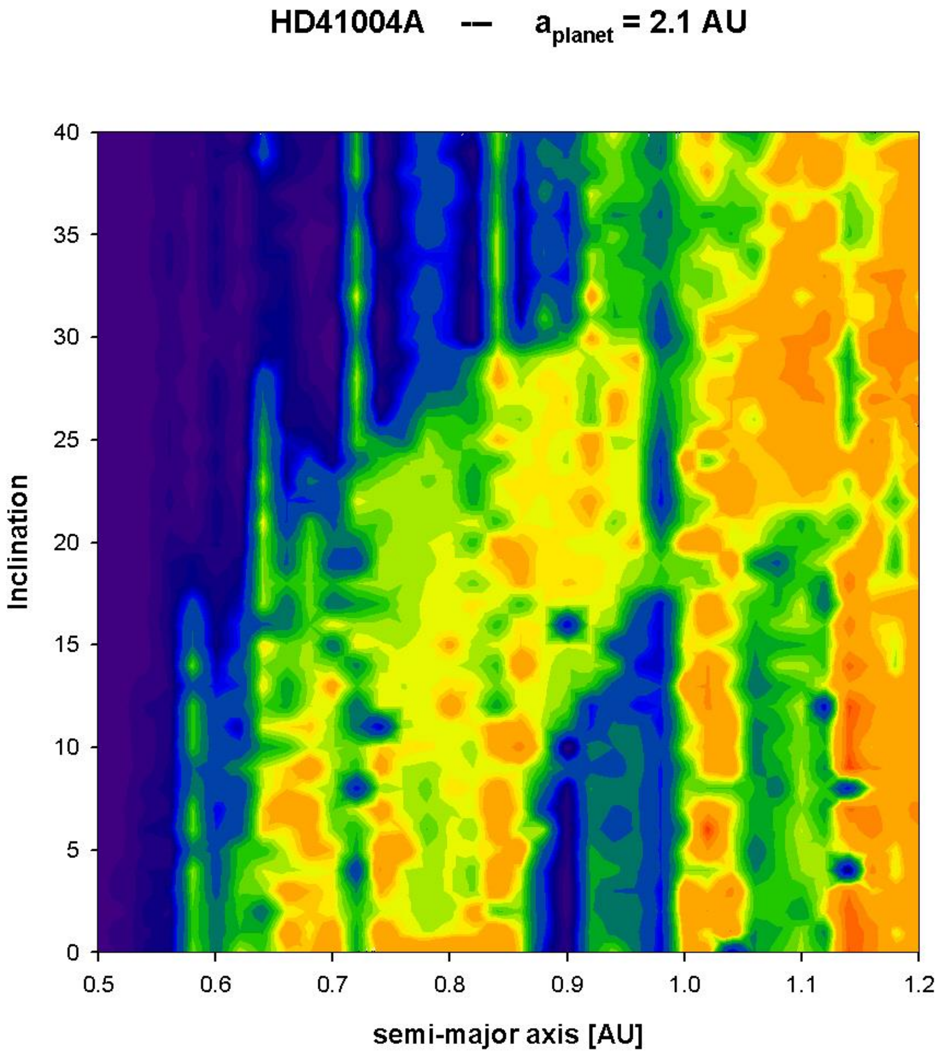

HD41004A — a_{planet} = 1.5 AU
HD41004A — a_{planet} = 1.9 AU
HD41004A — a_{planet} = 1.7 AU
HD41004A — a_{planet} = 2.1 AU
Inclination
semi-major axis [AU]
0
5
10
15
20
25
30
35
40
0.50
0.55
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2

different e_binary

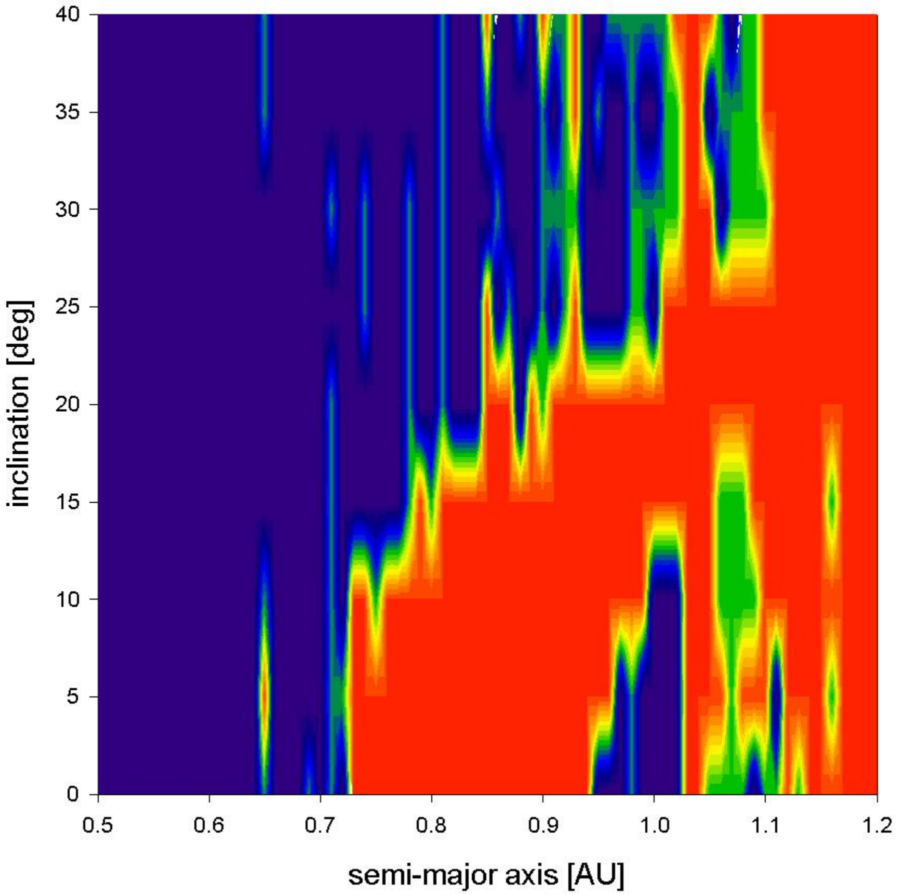




different mass-ratio



Gamma Cephei



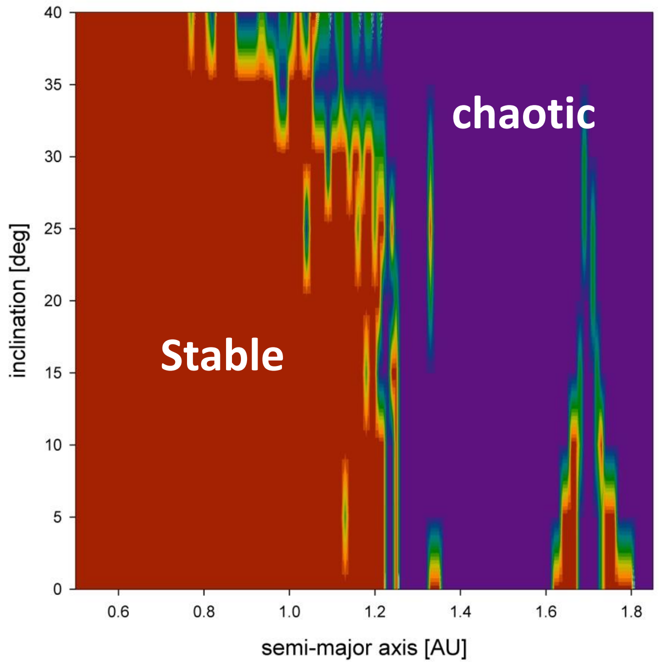
- Planet is close to the host-star: The region is mainly influenced by the mean motion resonances

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

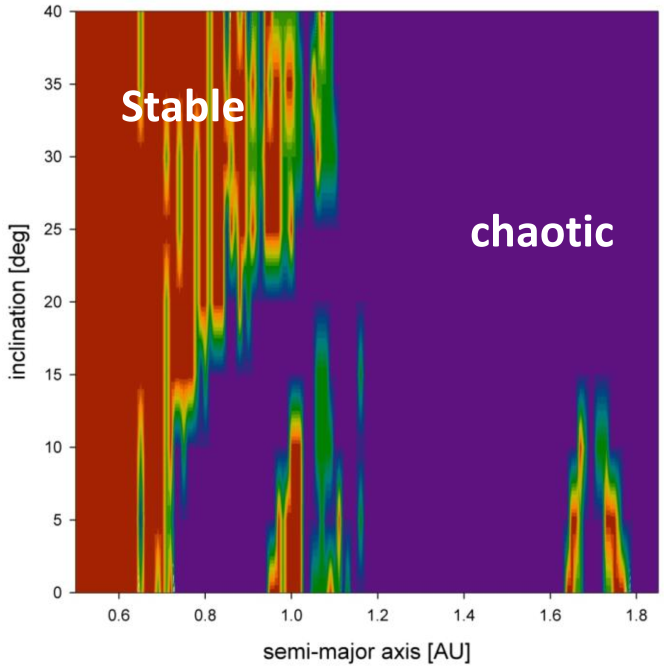
Influence of the secondary:

gamma Cephei: giant planet (a=2 au) + test-planet in circumstellar motion

without secondary



with secondary at ~ 20 AU

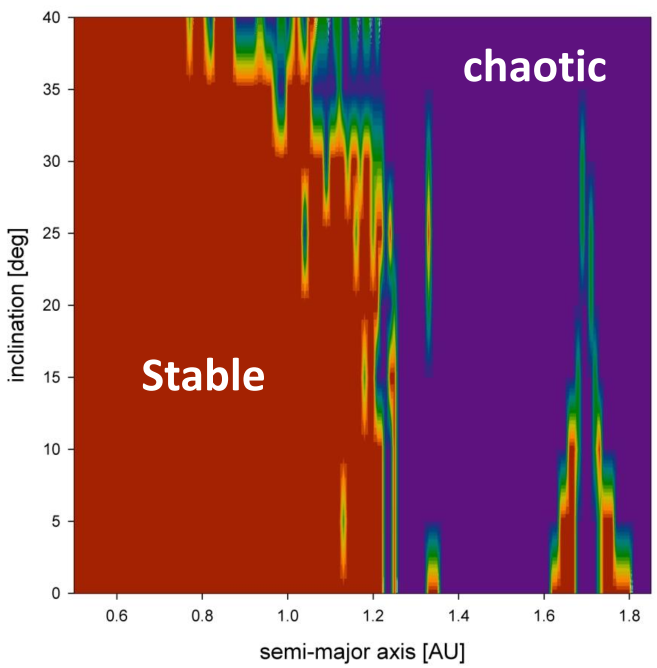


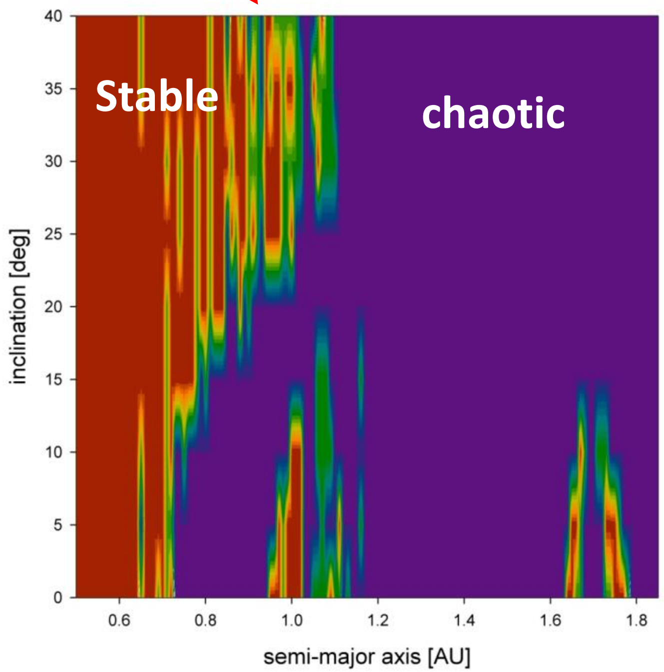
FLI (Fast Lyapunov Indicator) maps

(Pilat-Lohinger, IAU Coll. Belgrade)

gravitational perturbations lead to ...

- mean motion resonances (MMR)



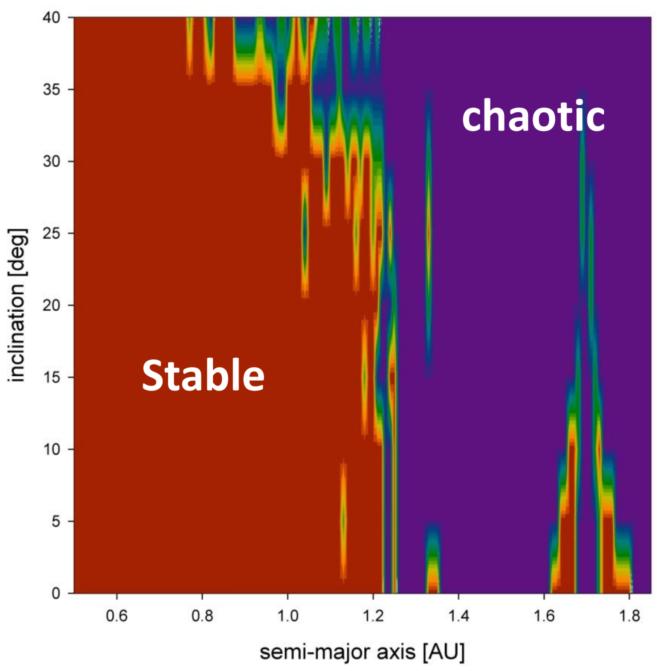


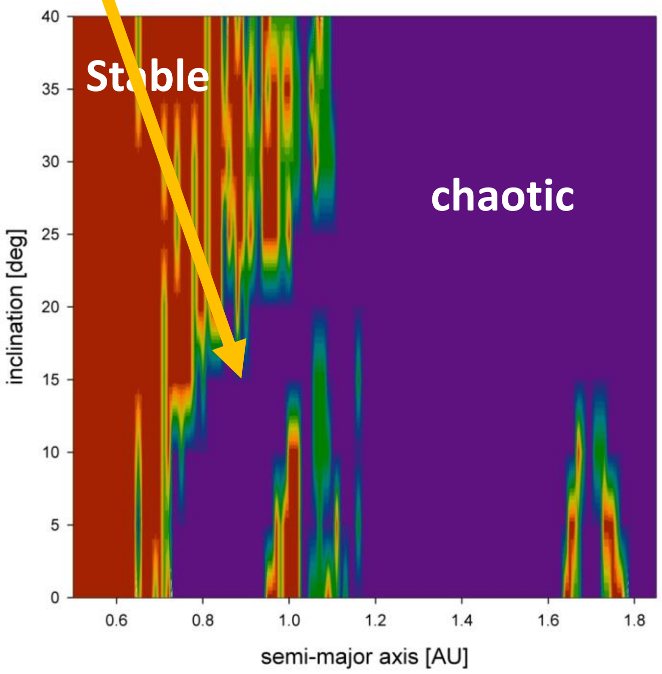
FLI (Fast Lyapunov Indicator) maps

(Pilat-Lohinger, 2005, IAU Coll. 197)

gravitational perturbations lead to ...

- mean motion resonances (MMR)
- **secular resonances** (SR)





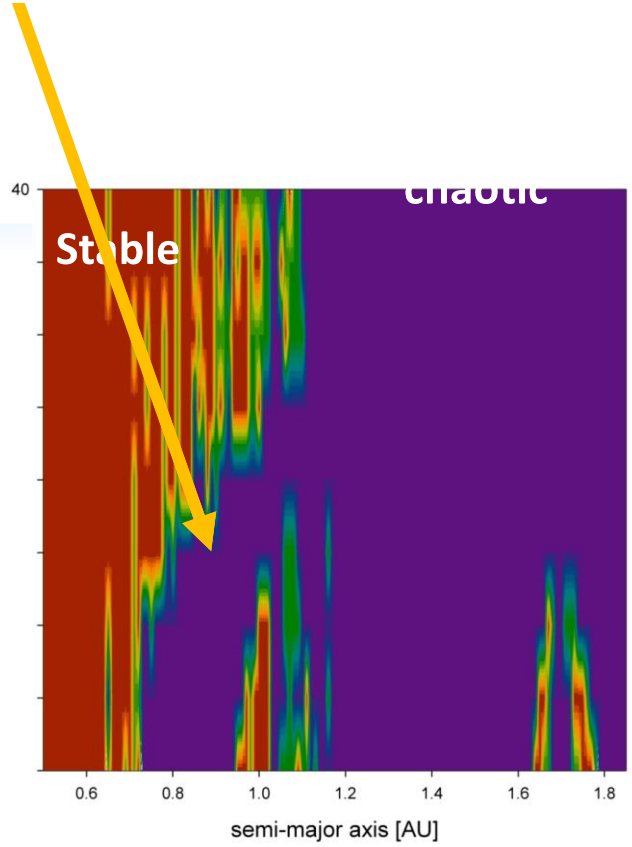
FLI (Fast Lyapunov Indicator) maps

(Pilat-Lohinger, 2004, IAU Coll. 197)

gravitational perturbations lead to ...

- mean motion resonances (MMR)
- **secular resonances** (SR)

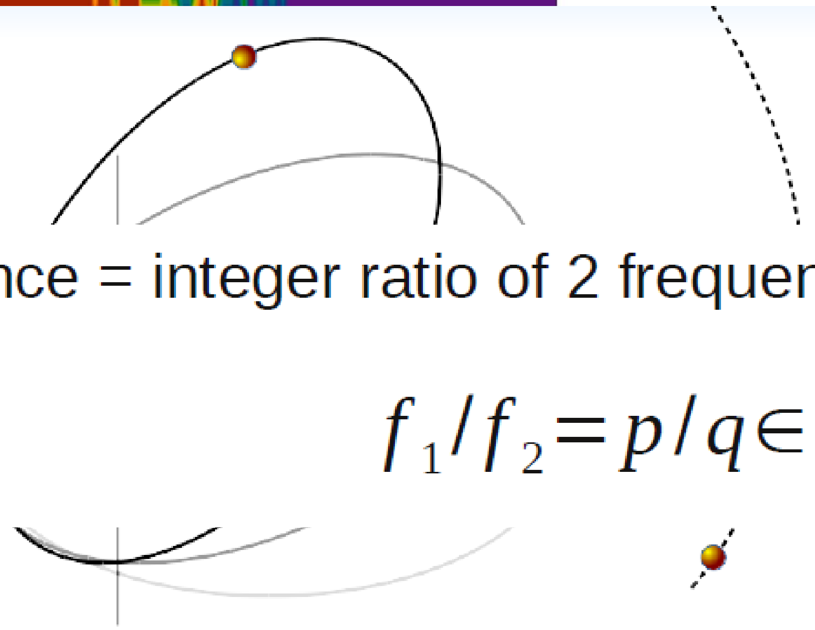
precession of pericenter (and line of nodes) with time



.ohinger, 2004, IAU Coll. 197)

gravitational perturbations lead to ...

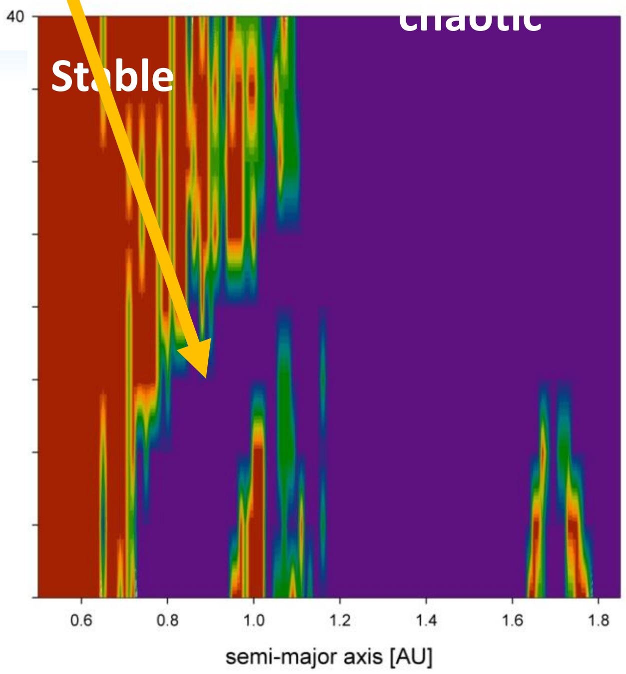
- mean motion resonances (MMR)
- **secular resonances** (SR)



resonance = integer ratio of 2 frequencies

$$f_1/f_2 = p/q \in \mathbb{Q}$$

precession of pericenter (and line of nodes) with time



.ohinger, 2004, IAU Coll. 197)

HD41004 AB

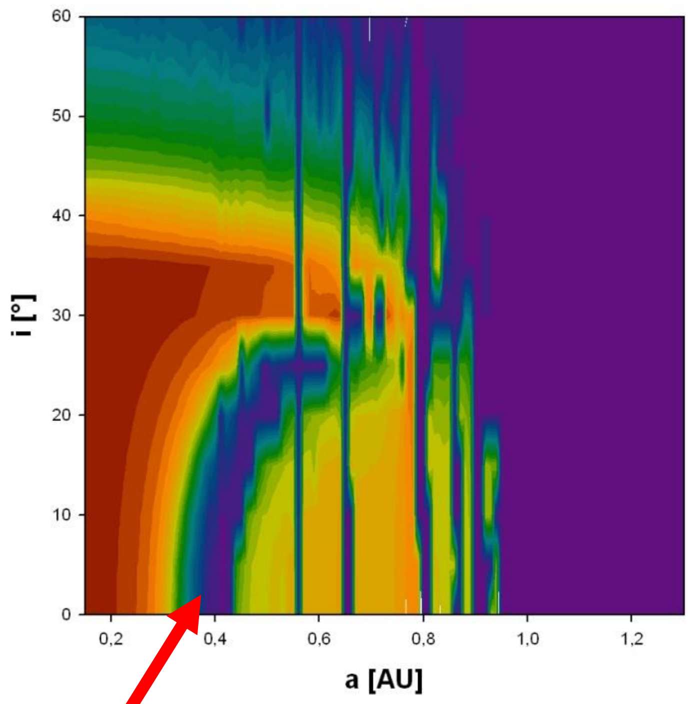
a_bin=23 au
e_bin = ?
planet: a = 1.64 au
e= 0.39 +/- 0.17
m=2.54 MJ

Secular perturbation:
area where the eccentricity of a test-planet increases rapidly → **escape**

Location of this perturbation depends on
masses
semi-major axes
eccentrcitites →

red: e=0
orange: e=0.2
yellow: e=0.2
green: e=0.4
blue: e=0.8

m_sec = 0.4, a_bin = 20



a_{SR} (m_i, a_i,e_i)

Semi-analytic Method

Pilat-Lohinger, Bazso, Funk (in prep.)

Secular perturbation theory

(see e.g. Murray & Dermott)

$$g = \frac{n}{4}\left[\frac{m_J}{M_\odot}\alpha_J^2 b_{3/2}^{(1)}(\alpha_J) + \frac{m_S}{M_\odot}\alpha_S^2 b_{3/2}^{(1)}(\alpha_S)\right]$$

Mean motion of TP

mass of Jupiter

mass of secondary

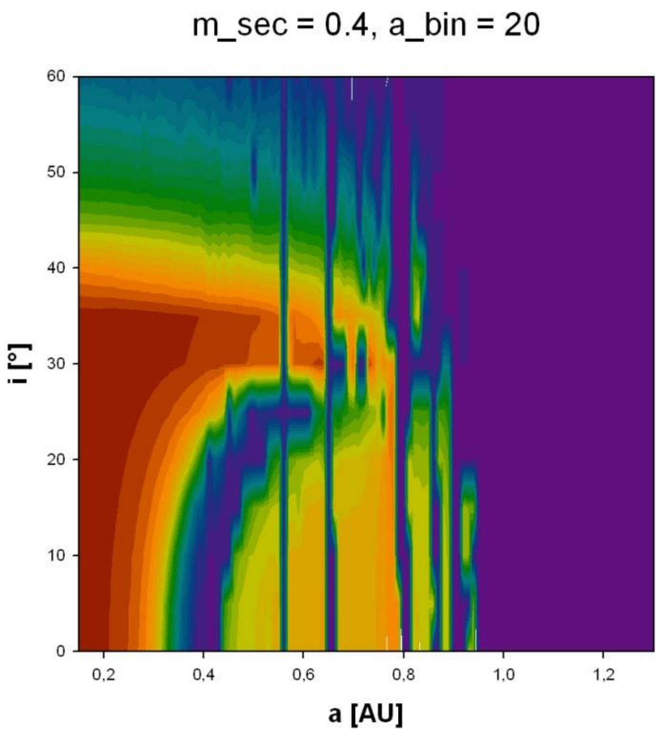
mass of primary

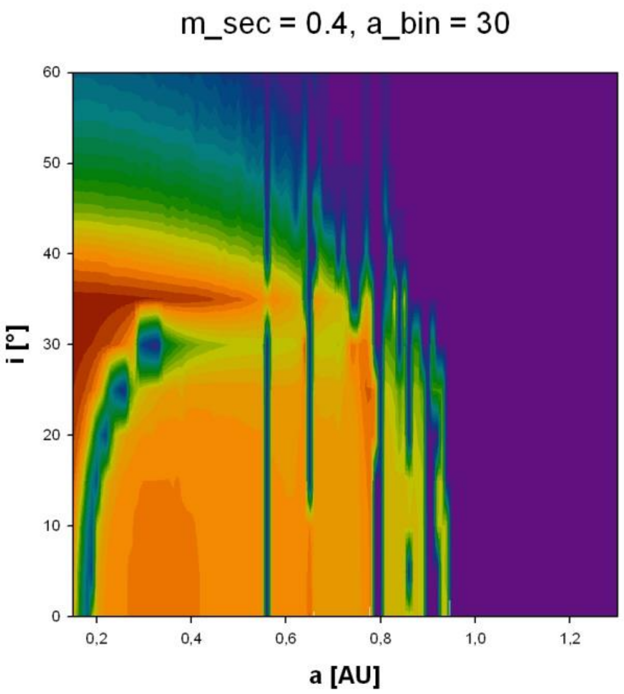
Laplace coefficient

$\alpha_S = a/a_S$

$\alpha_J = a/a_J$

max-e maps for different a_binary



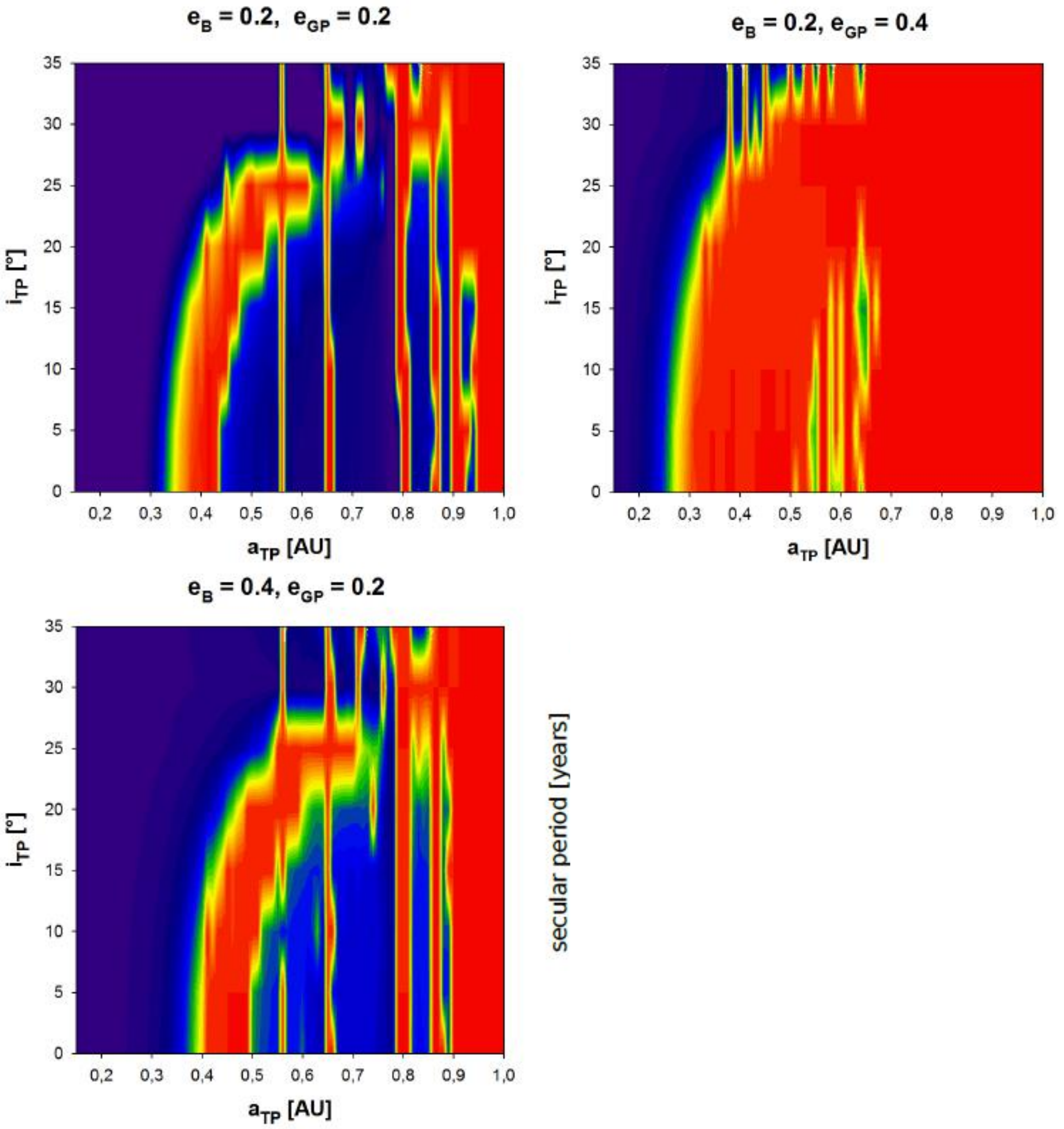


a_{Binary} increased

a_{GP} increased

(maximum eccentricity plots)

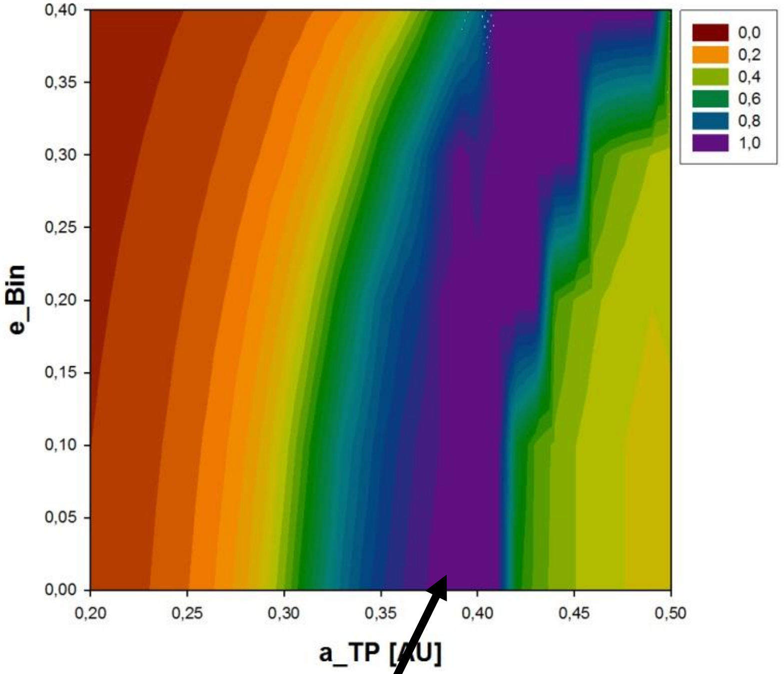
Influence of eccentricities



Variation of the eccentricity of:

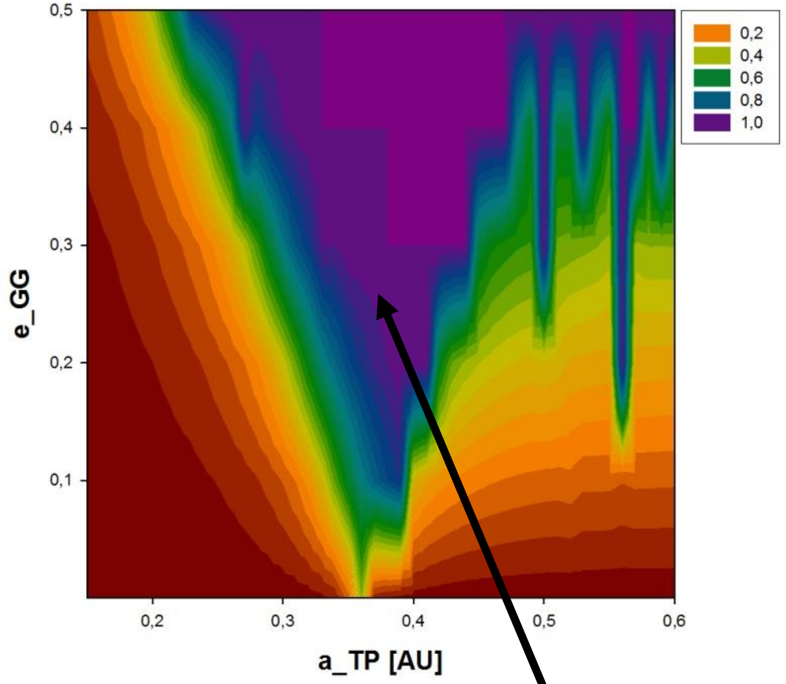
(maximum eccentricity plots)

Binary

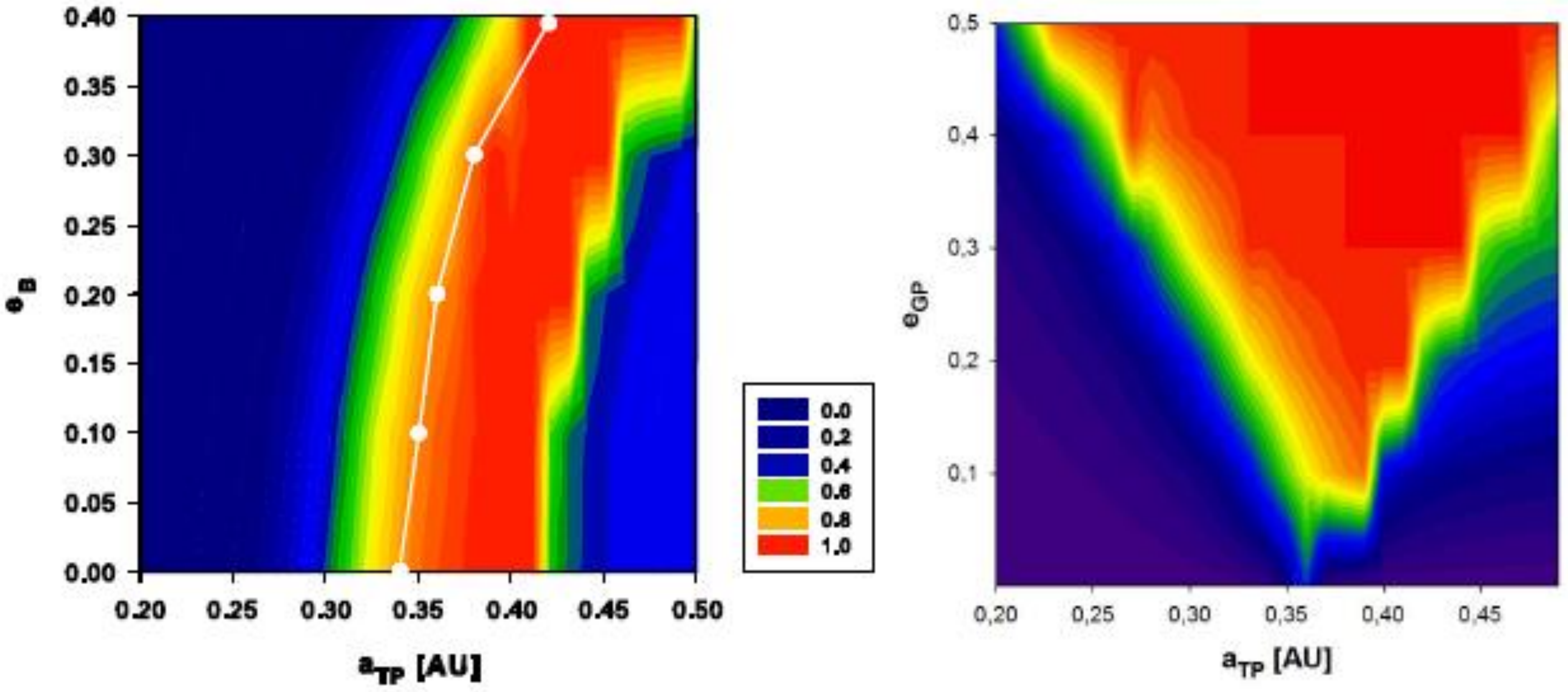


width doesn‘t change a lot, but the position when e_bin is varied

Giant Planet



V-shape like for MMRs



0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
e_B
0.20
0.25
0.30
0.35
0.40
0.45
0.50
a_{TP} [AU]
0.0
0,2
0,4
0,6
0,8
1,0
0,5
0,4
0,3
0,2
0,1
e_{GP}
0,20
0,25
0,30
0,35
0,40
0,45
a_{TP} [AU]

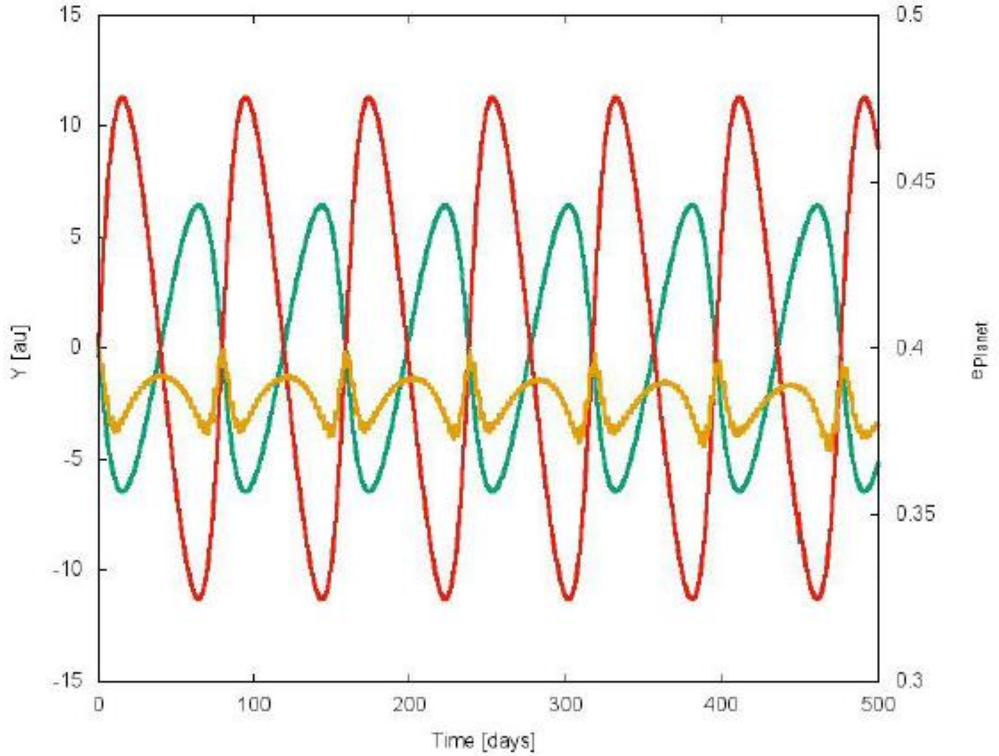
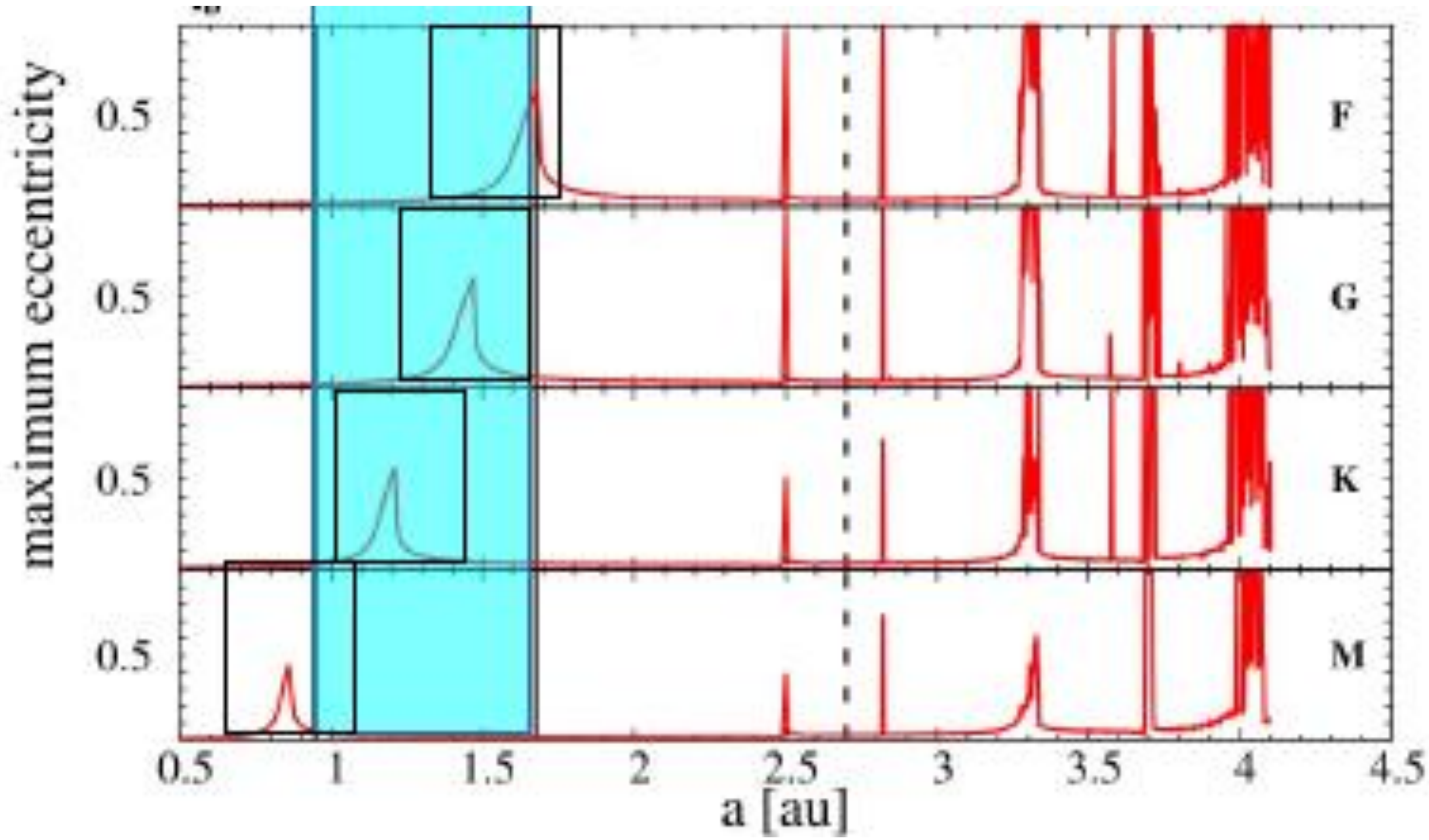


Figure 5.2 Time evolution of the barycentric y-coordinate of the two stars (red and green lines) and of the giant planet's eccentricity (yellow line). The latter indicates jumps at every pericenter passage of the stars which can be seen at multiples of the orbital period of 80 years

Influence on the HZ



Binary: a_Binary = 100 au
e_Binary = 0.3

P-type motion:

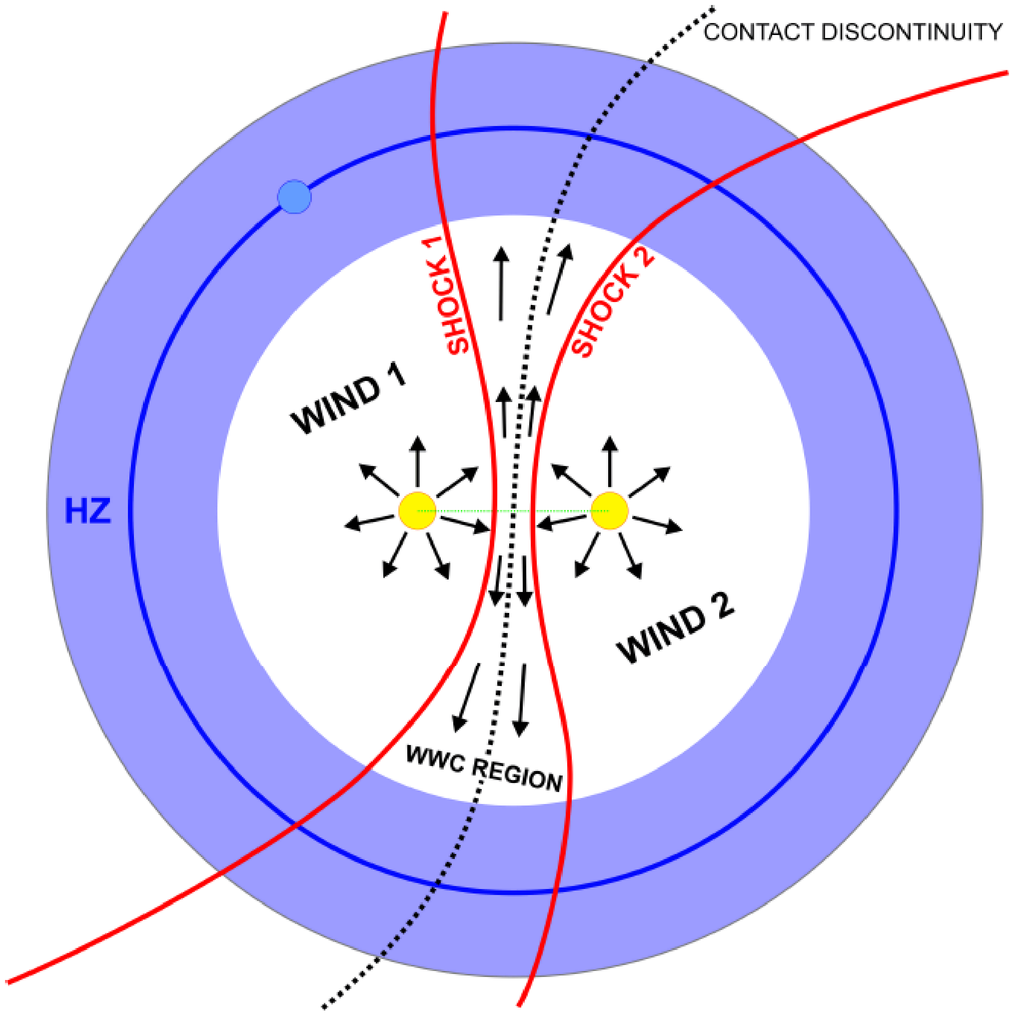


Figure 5.8 Main features of wind-wind interactions in a binary system with two identical winds. The wind–wind collision region (WWC) takes the form of two shock waves (red lines) and has a spiral geometry due to the orbital motion of the stars. The blue ring indicates the HZ which is obviously influenced by the WWC region.