Planetary motion in binary star systems

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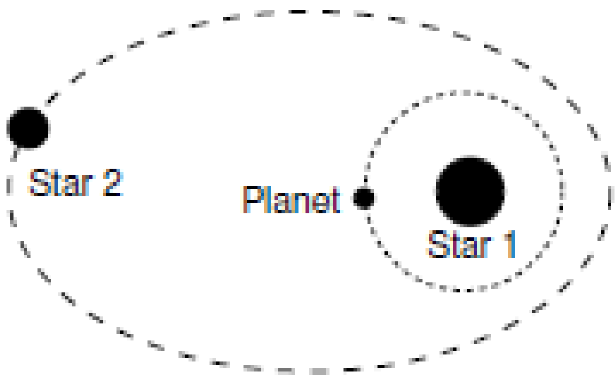
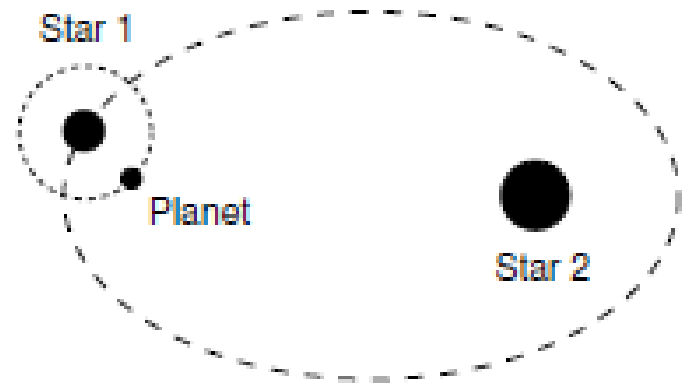
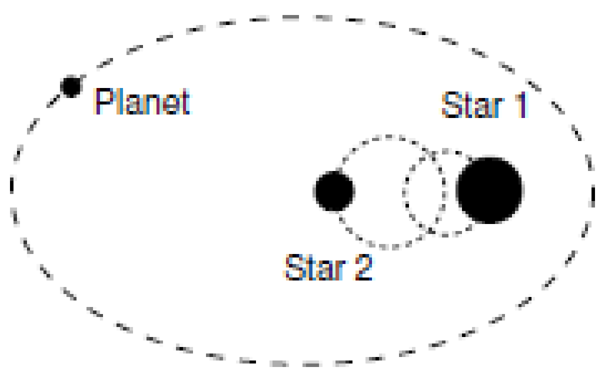
I. Different types of motion



S-Type A



S-Type B



P-Type

Stability of planetary motion in binary systems
using the restricted 3 body problem

- Harrington (1977)
- Graziani & Black (1981)
- Black (1982)
- Pendleton & Black (1983)
- Dvorak R.(1984 and 1986)
- Rabl & Dvorak R. (1988)
- Dvorak R., Froeschle C. & Froeschle Ch. (1989)
- Holman M. & Wiegert P. (1999)
- Pilat-Lohinger E. & Dvorak R. (2002)
- Pilat-Lohinger E., Funk B. & Dvorak R. (2003)
- Szenkovits F. & Mako Z. (2008)

Application of these stability studies:

gamma Cephei
a_bin ~ 20 AU, e_bin ~ 0.4

stability limits [AU]

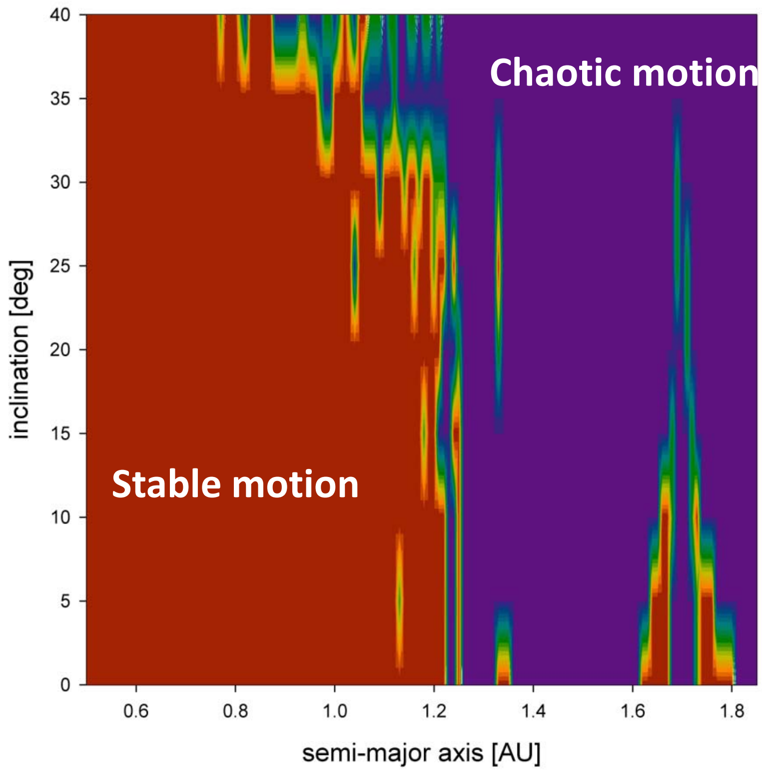
e_planet	RTBP	1Mj	3Mj	5Mj
0.0	4.0	4.0	4.0	4.0
0.1	4.0	4.0	4.0	3.8
0.2	3.8	3.6	3.4	3.2
0.3	3.4	3.6	3.2	3.0
0.4	3.4	3.0	2.8	2.6
0.5	3.0	2.4	2.2	1.8

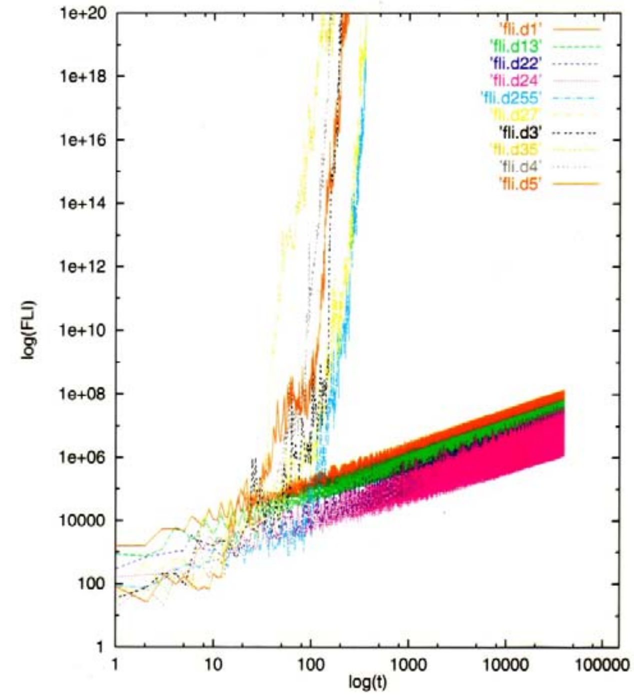
→ for small eccentricity motion

~~massive planets in high eccentricity motion~~

II. 2 Planets -- Influence of th

gamma Cephei: a_gp = 2 au;





Stability determined via
Fast Lyapunov Numbers **FLI**

length of the largest tangent vector:

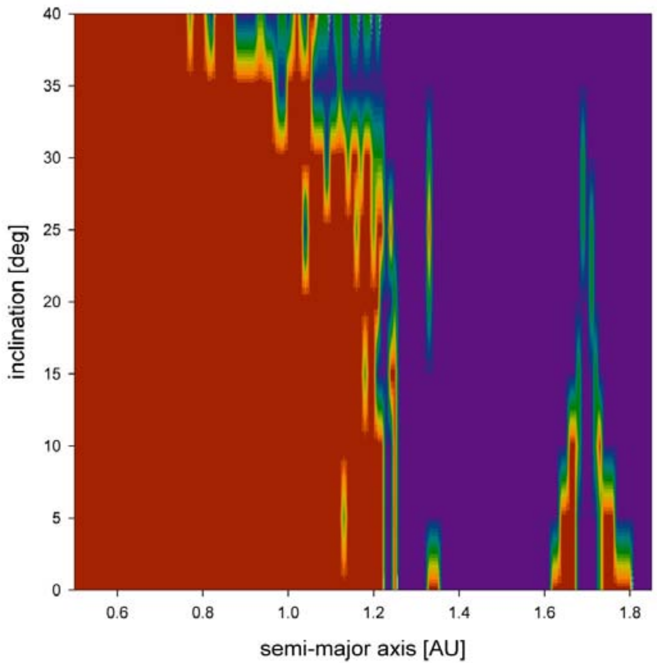
FLI(t) = sup_i |v_i(t)| i=1,.....,n

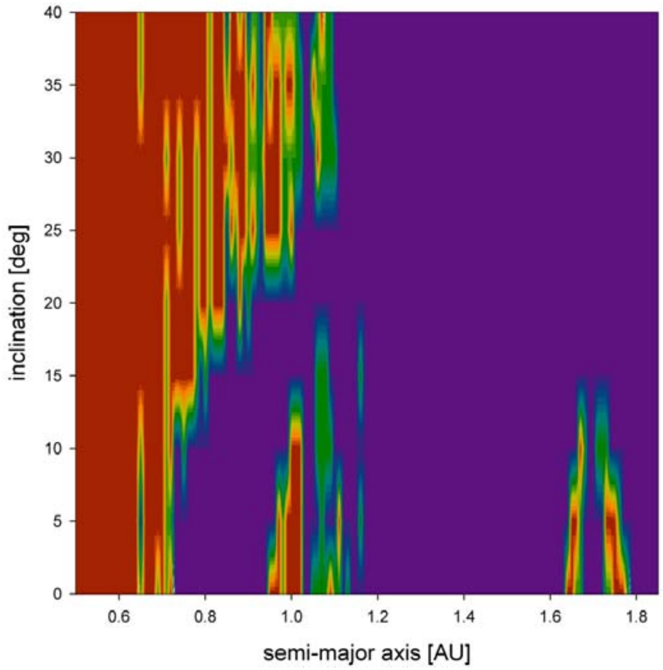
(n denotes the dimension of the phase space)

II. 2 Planets -- Influence of the secondary

gamma Cephei: a_gp = 2 au;

Secondary at ~ 20 AU





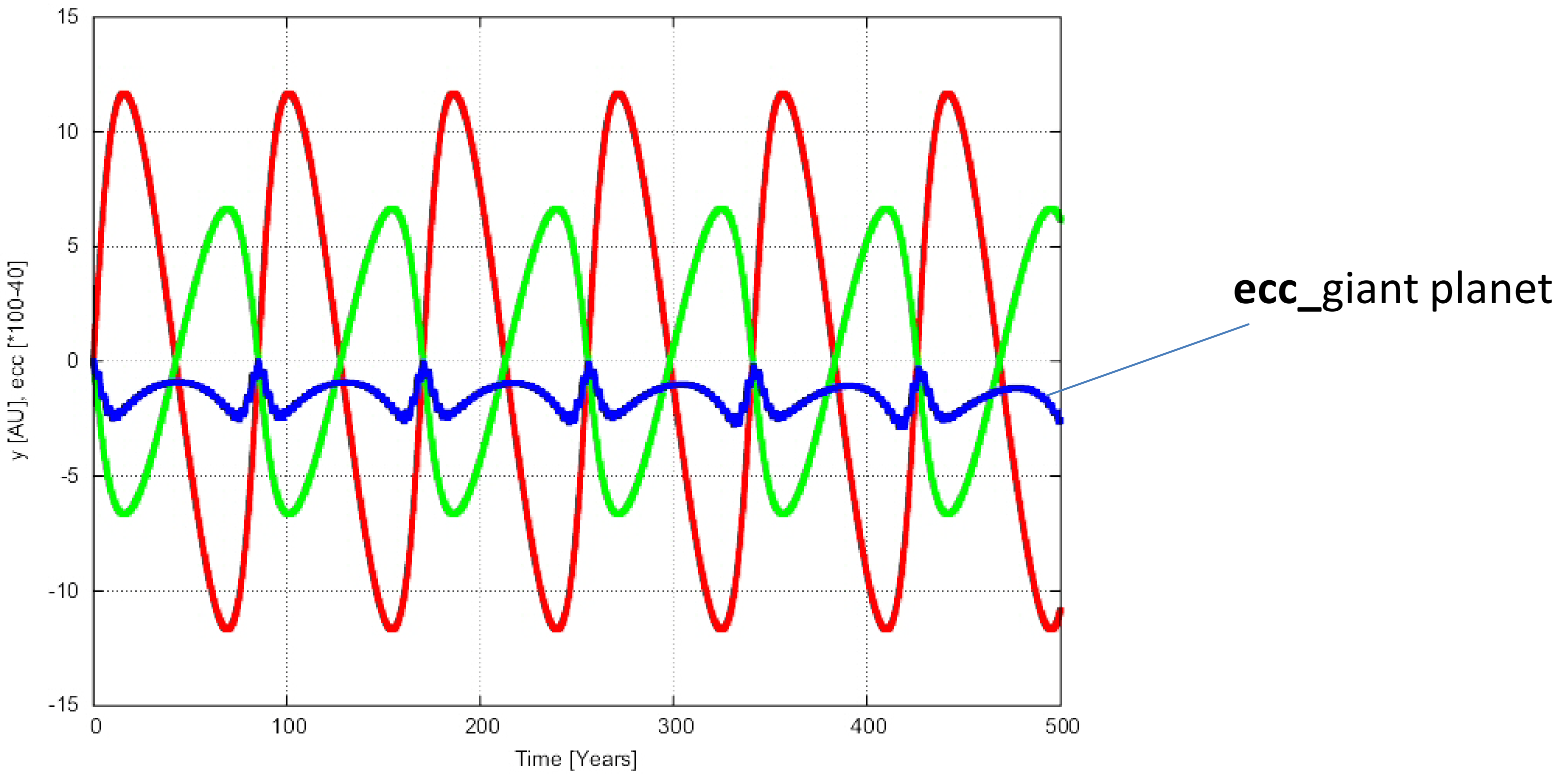
Perturbations:

Mean motion resonances (MMR)

Kozai resonance

Secular perturbation

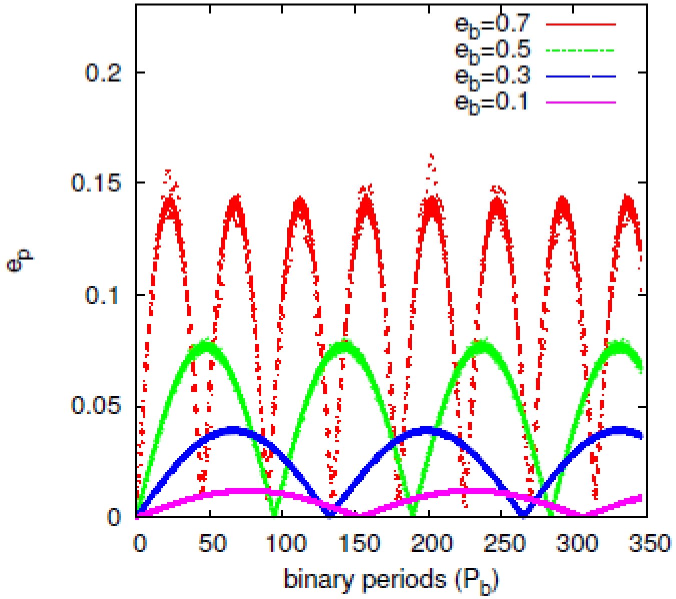
Perturbations at perihelion



cannot apply the standard secular theory -- high eccentricities

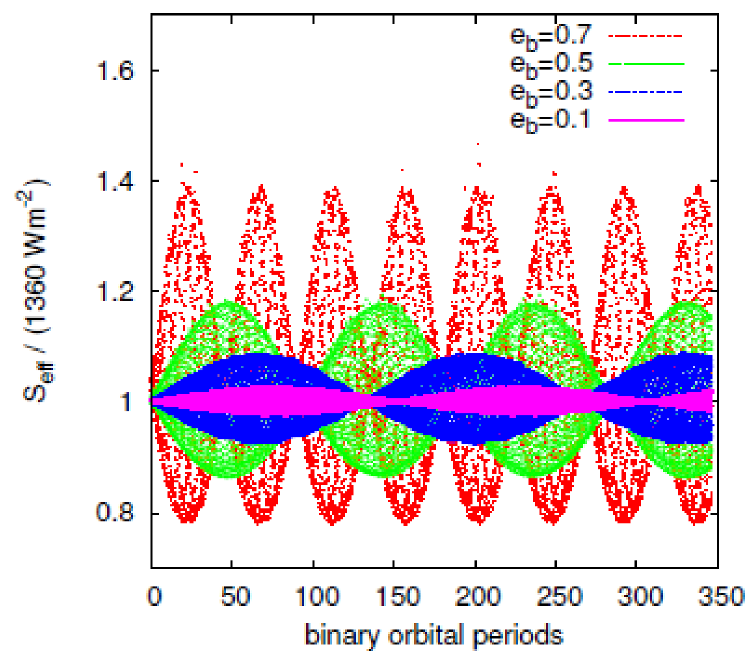
-- Binary star

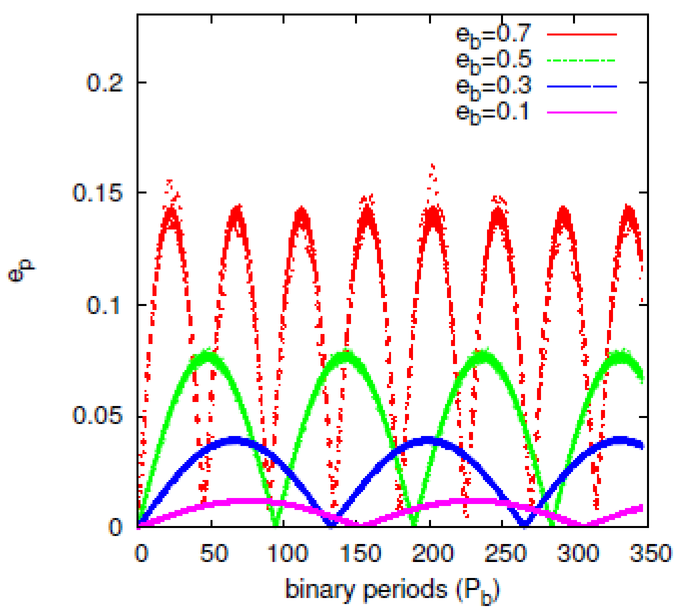
Perturbations may influence the motion of a terrestrial planet in the Habitable zone:



➔ circular motion will be eccentricic

➔ Variation in insolation

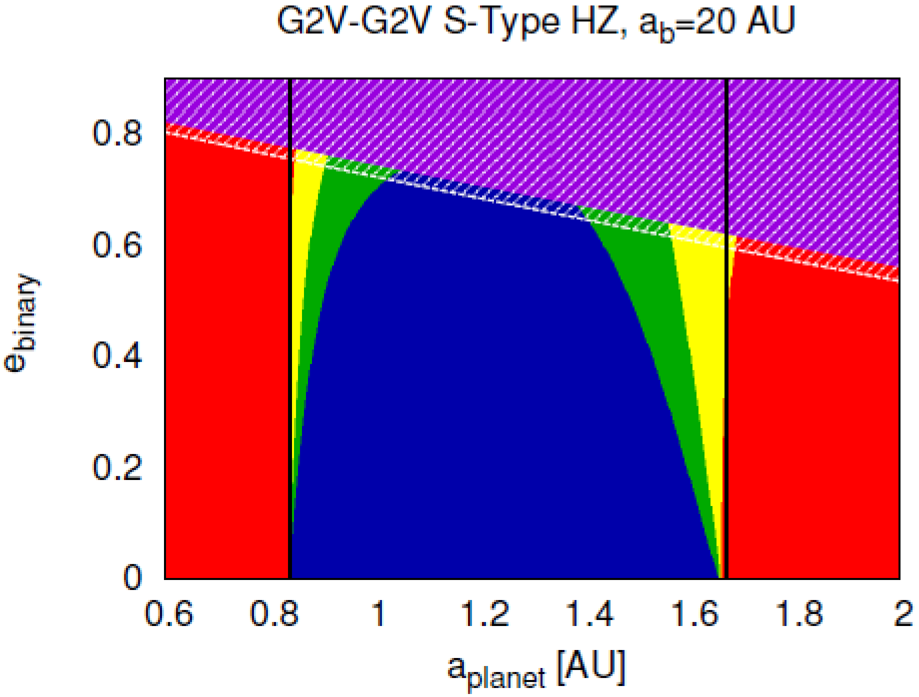




➔ additional insolation from the primary

Different types of habitable zones:

permanent extended averaged

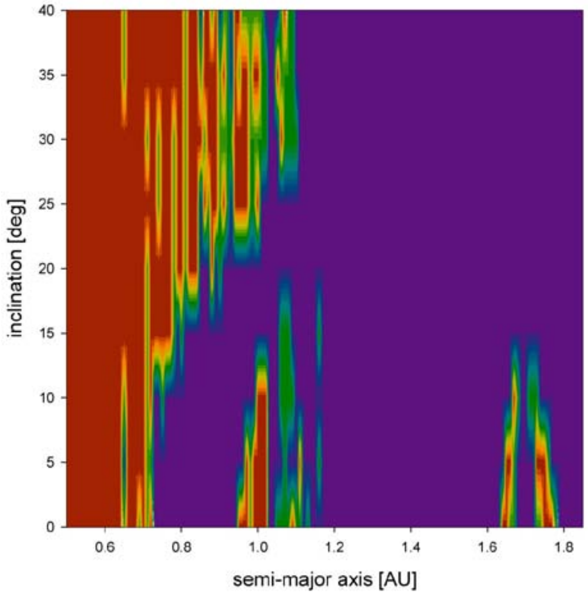


unstable

non-habitable

for details see Eggl et al., ApJ 2012

- **semi-major axes**
- **eccentricities**
- **mass-ratio of the binary**
- **mass of the giant planet**

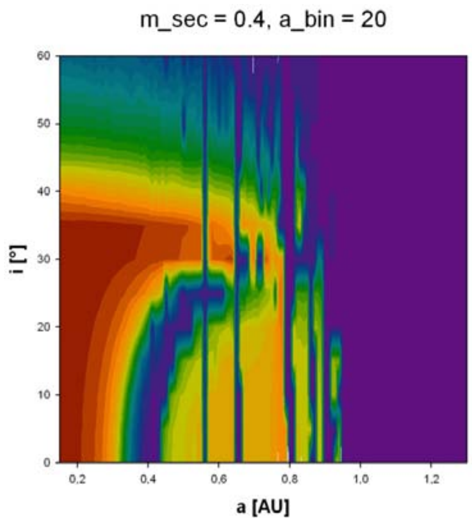


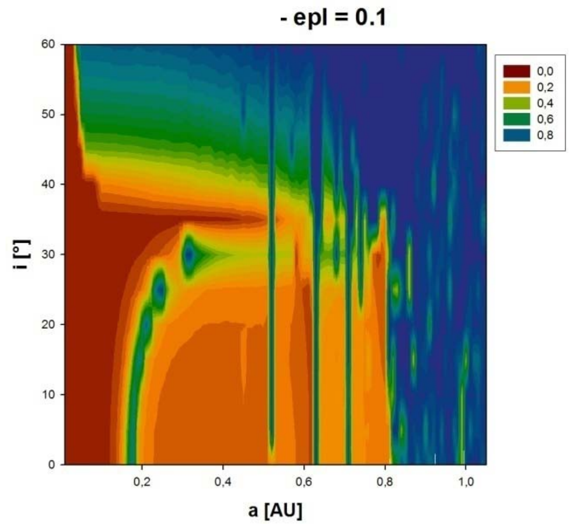
Pilat-Lohinger, IAU Coll 197, 2005

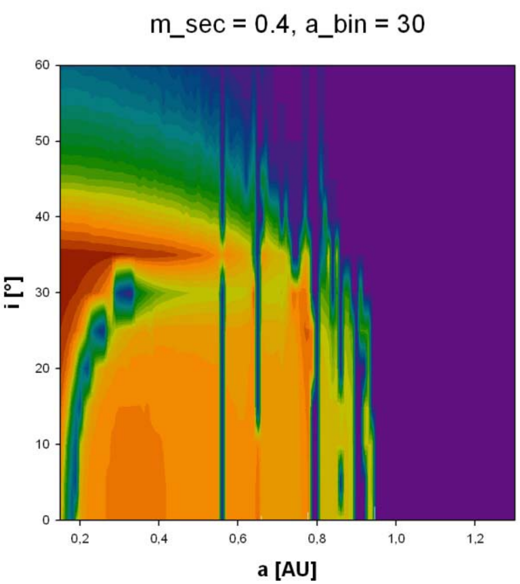
Maximum eccentriciy plots

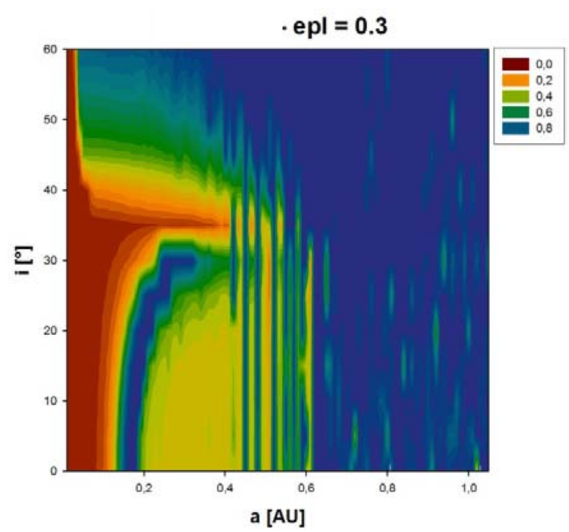
semi-major axis (binary)

eccentricity (planet)









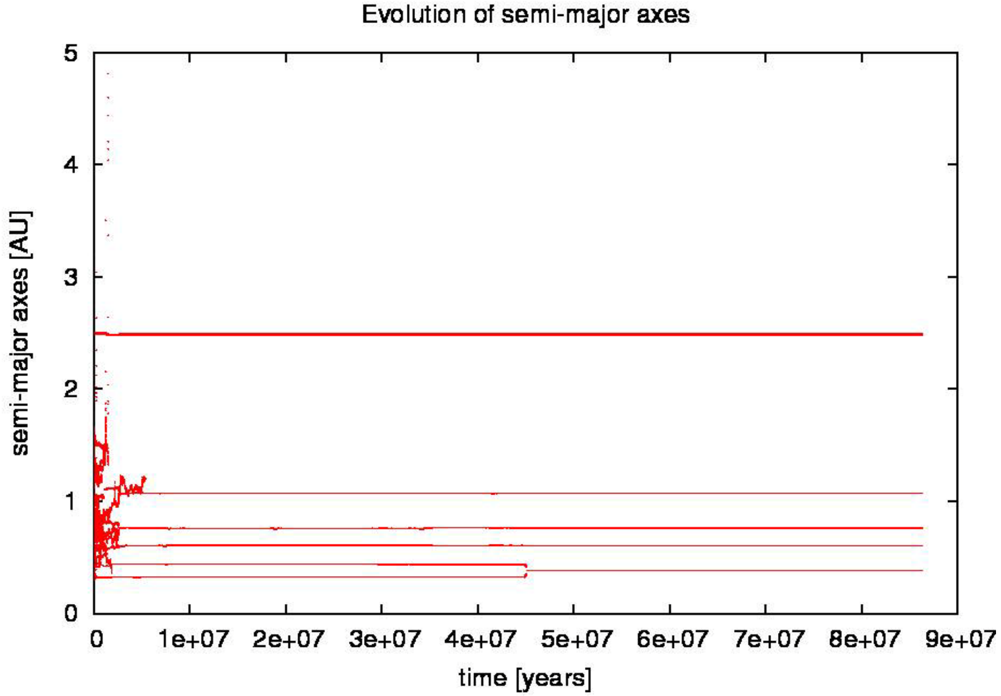
Multi-planet systems in tight binary stars possible ?

Numerical simulations: We studied die evolution of a disk of isolated embryos (Moon to Mars-size) which were placed around the primary stars up to the snow-line at 2.6 au distributed according

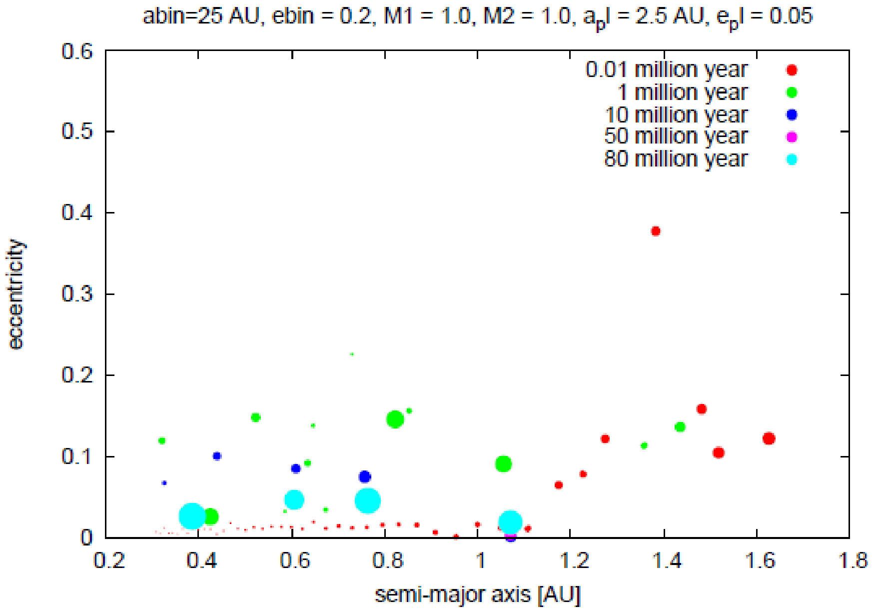
$$\Sigma \sim r^{-1}$$ (Dullemond et al. 2007)

for different binary configurations: G-G. G-K, G-M, G-F Stars, with different stellar distances and different eccentricities.

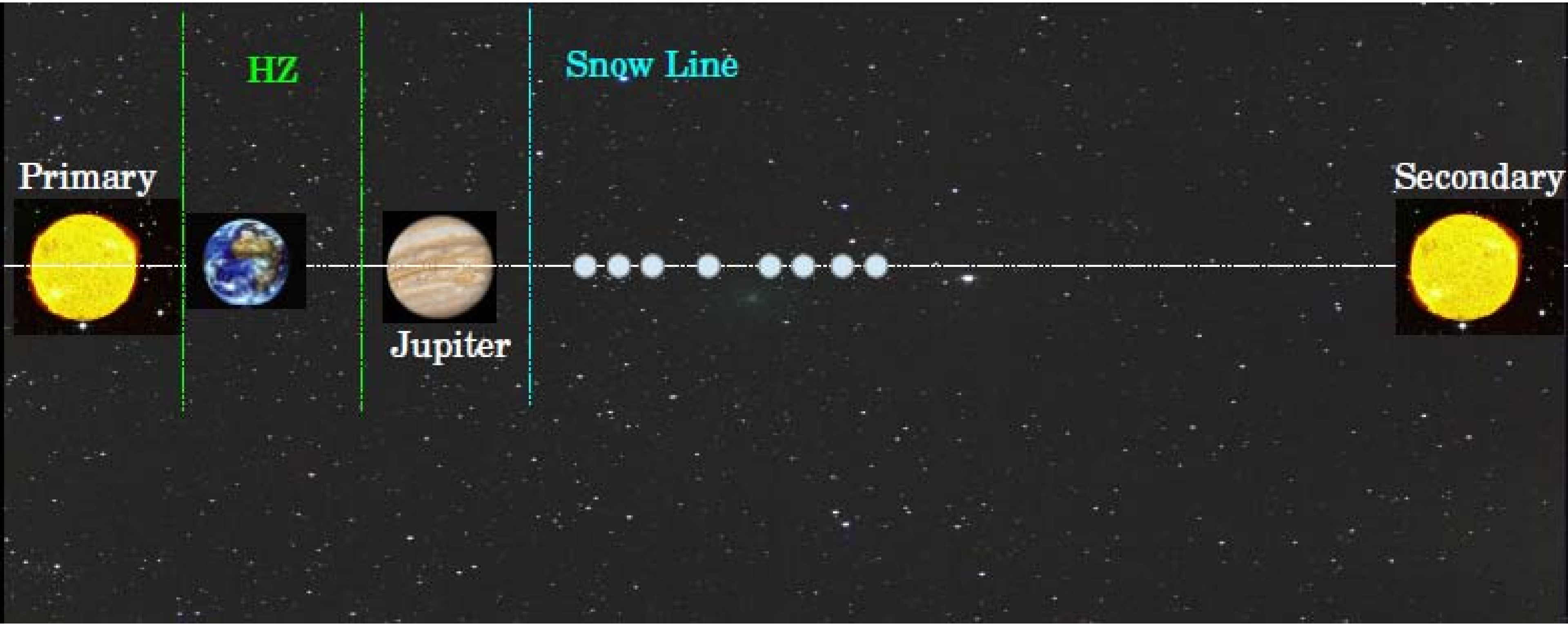
Out of these numerous computations we show the result of a tight G-G binary with 25 AU separation an 0.2 eccentricity:



Solar system analogue in a tight binary star system



Zs. Sandor



Initial conditions of the asteroid ring (100 asteroids)

Physical parameters:

- $M_{ring} = 0.005\ M_{\oplus}$
- $M_{max} = 1\ M_{ceres}$
- Water mass fraction (wmf) = 10 %

Orbital parameters (random):

- $a_{min} \geq 2.7$ AU (Snow line)
- asteroids are spaced by several mutual Hill Radius
- $e < 0.01$, $i < 1^{\circ}$

Water transport into the Habitable Zone

- **Statistical study** : 96 clones of the system <=> N_{TOT} = 9600 asteroids
- **Probability P_{HZ} to impact in the HZ :**
  - $P_{HZ} = \frac{n_{impactor}}{N_{TOT}}$ => $\mathbf{P_{HZ} = 0.69}$ ← Total number of different asteroids entering the HZ
- **Number O_{HZ} of ocean transported HZ** = water content (**including mass loss due to ice sublimation**) of asteroids at their 1st entry in the HZ : $\mathbf{O_{HZ} = 5.9}$ **oceans** [1 ocean = 1.5×10^{24} g of H_2O]
- **Probability P_p to impact the planet** : We consider the minimum orbital intersection distance **d** between the orbit of the planet and the asteroid and we compare with the radius **R** of the planet.
  - Probability P_i of an asteroid to impact : $P_i = \frac{n(d \leq 2R)}{n(crossing\, HZ)}$
    - Number of orbits fulfilling d ≤ 2R
    - Number of crossing in the HZ
  - $P_P = \frac{1}{N_{TOT}} \sum_{i=1}^{N_{TOT}} P_i$ => $\mathbf{P_p = 2.2 \times 10^{-4}}$
- **Ocean O_p delivered to the planet** : total mean value of wmf for n(d ≤ 2R) : $\mathbf{O_p = 3.6}$ **oceans**

D. Bancelin

Thank you !