On the habitability of circumstellar planets in binary stars

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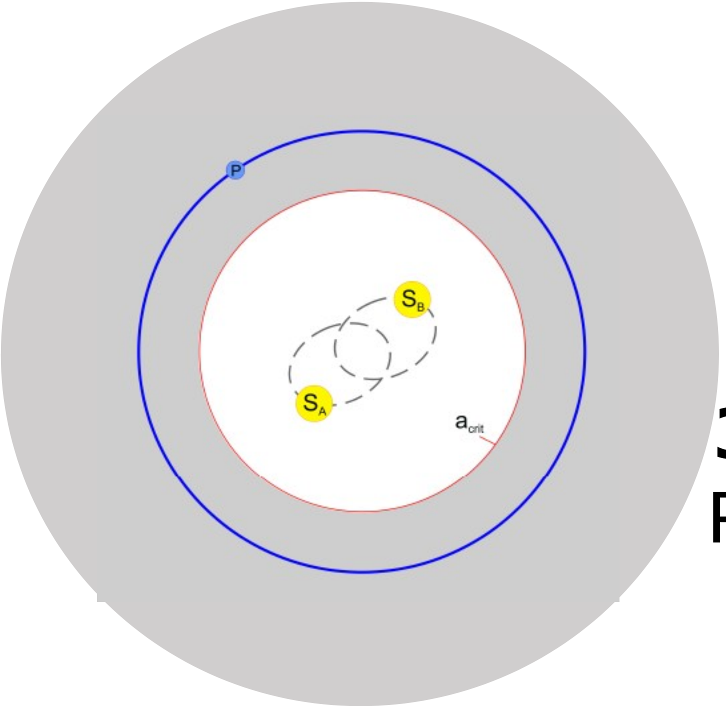
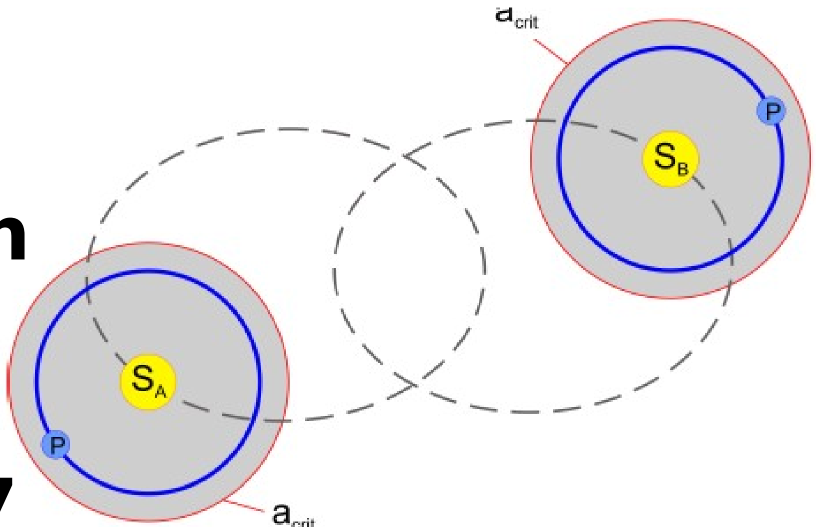
Institute of Theoretical and Computational Physics, TU Graz (Austria)

Detection and Dynamics of Exoplanets – Coimbra – July 9th 2025

Planetary motion



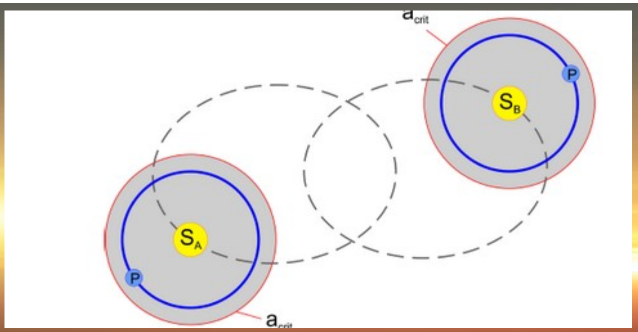
31
P-type Planets



747
S-type Planets

according to **„Planets in Binary Systems“**
https://exoplanet.eu/planets_binary/

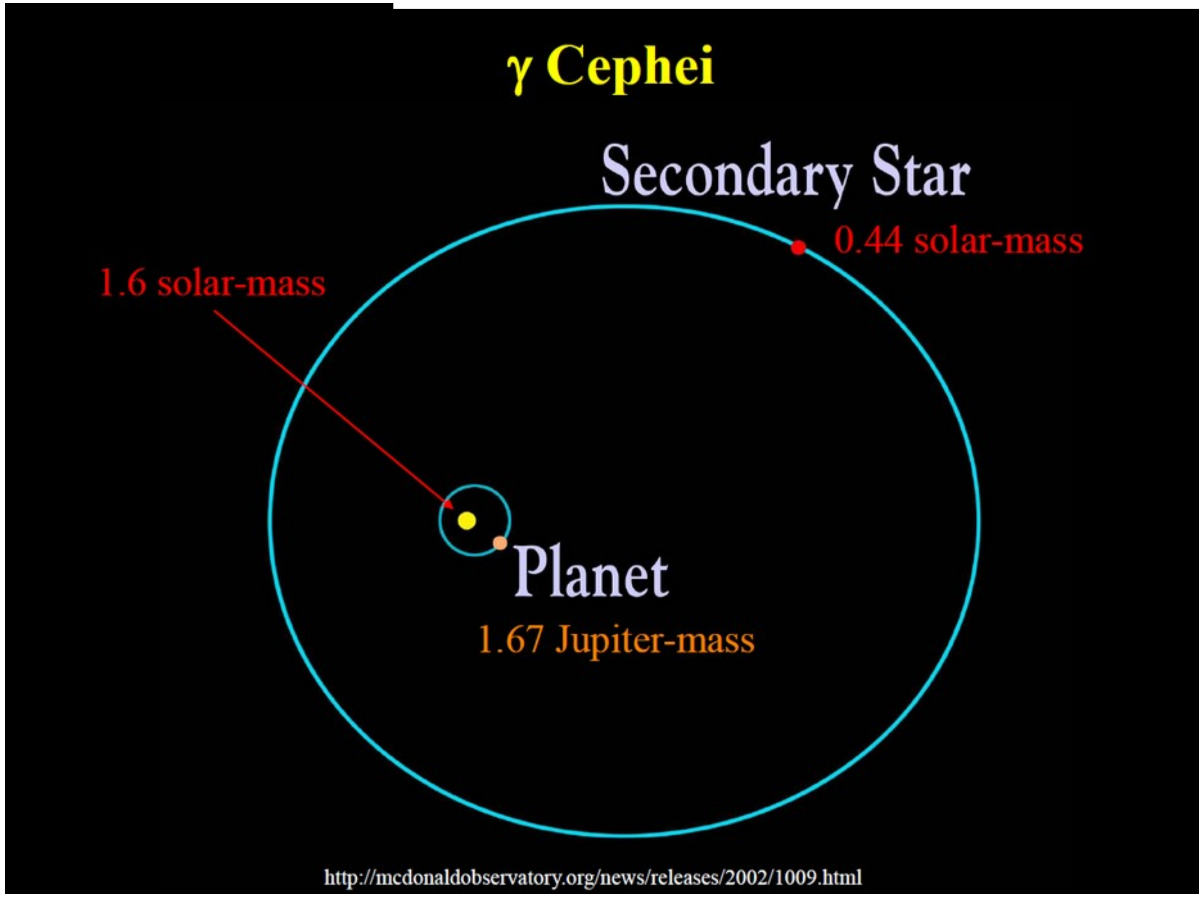
S-type Configurations

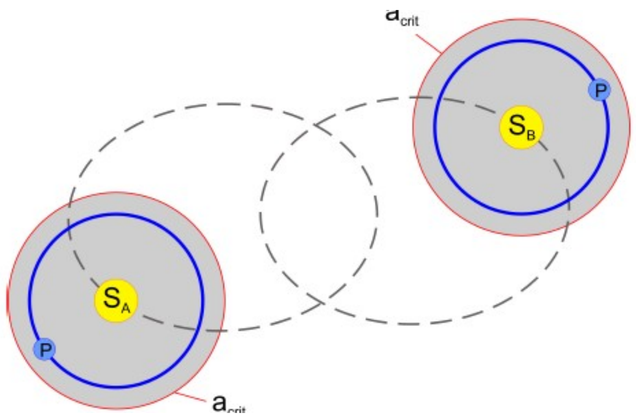


Most famous example

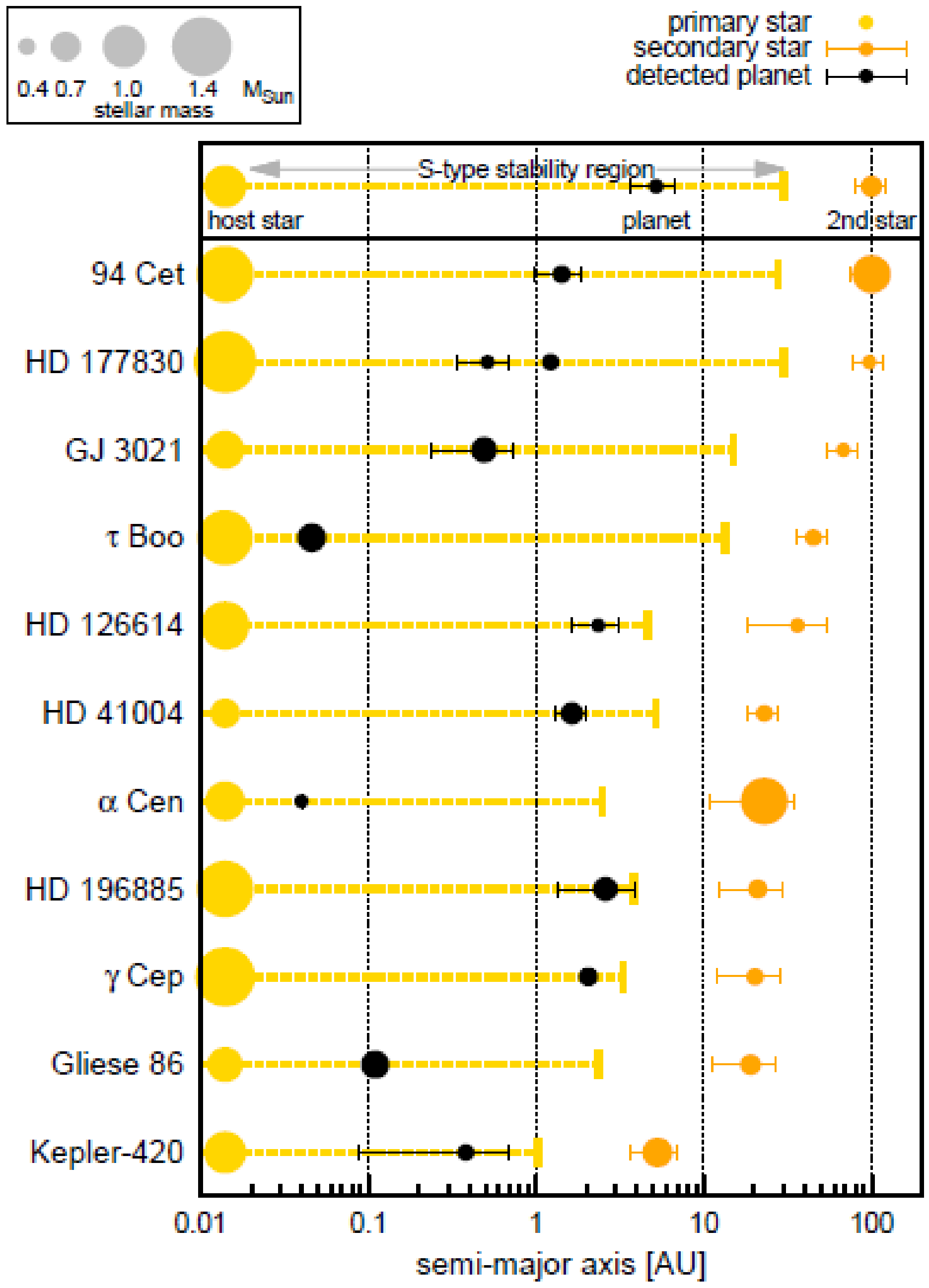
a_{binary}~20au
e_{binary}~0.4

Jupiter-mass Planet at~2au

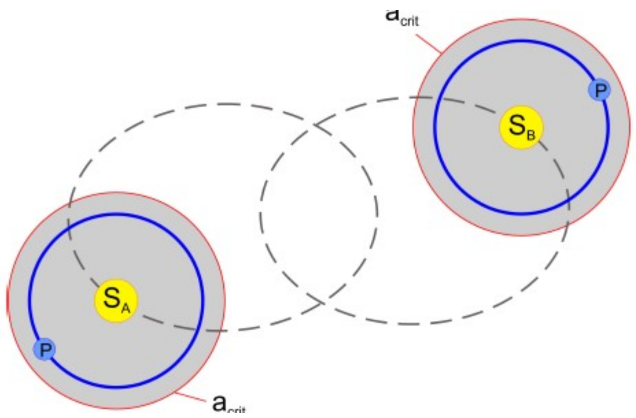




Secondary star restricts the region for stable planetary motion



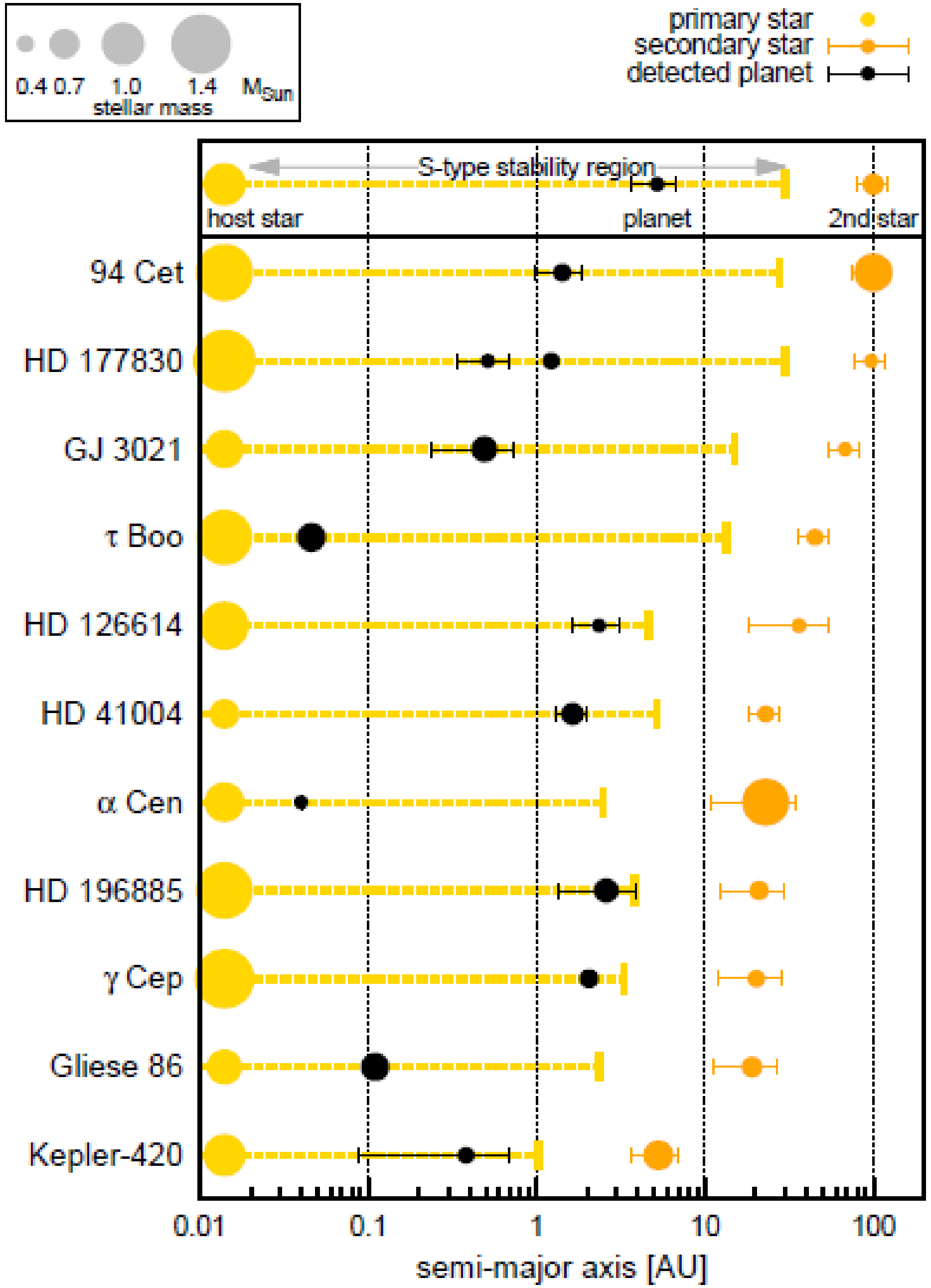
Bazsó, Pilat-Lohinger et al., MNRS, 2017



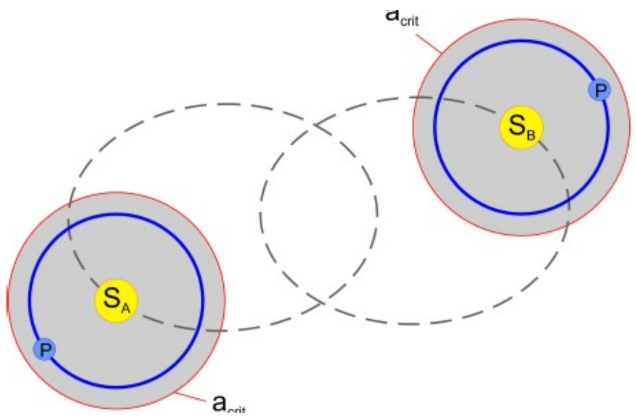
Secondary star restricts the region for stable planetary motion

Harrington (1977)
Graziani & Black (1981)
Black (1982)
Pendleton & Black (1983)
Dvorak (1984, 1986)
Rabl & Dvorak (1988)
Dvorak , Froeschlé (1989)

Holman & Wiegert (1999)
Pilat-Lohinger & Dvorak (2002)
……

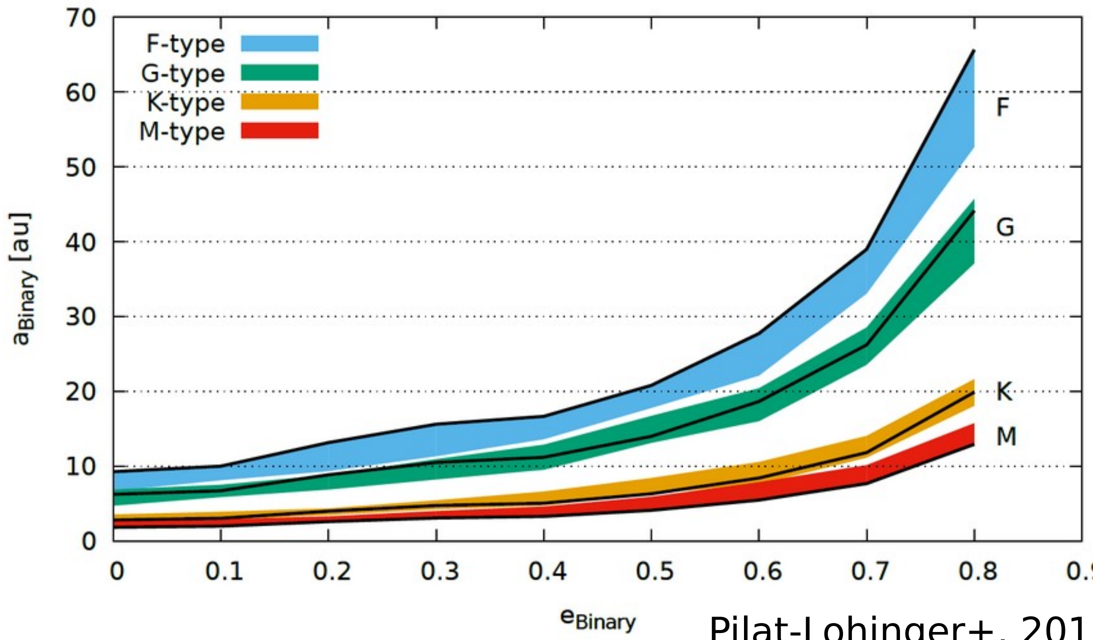


Bazsó, Pilat-Lohinger et al., MNRS, 2017

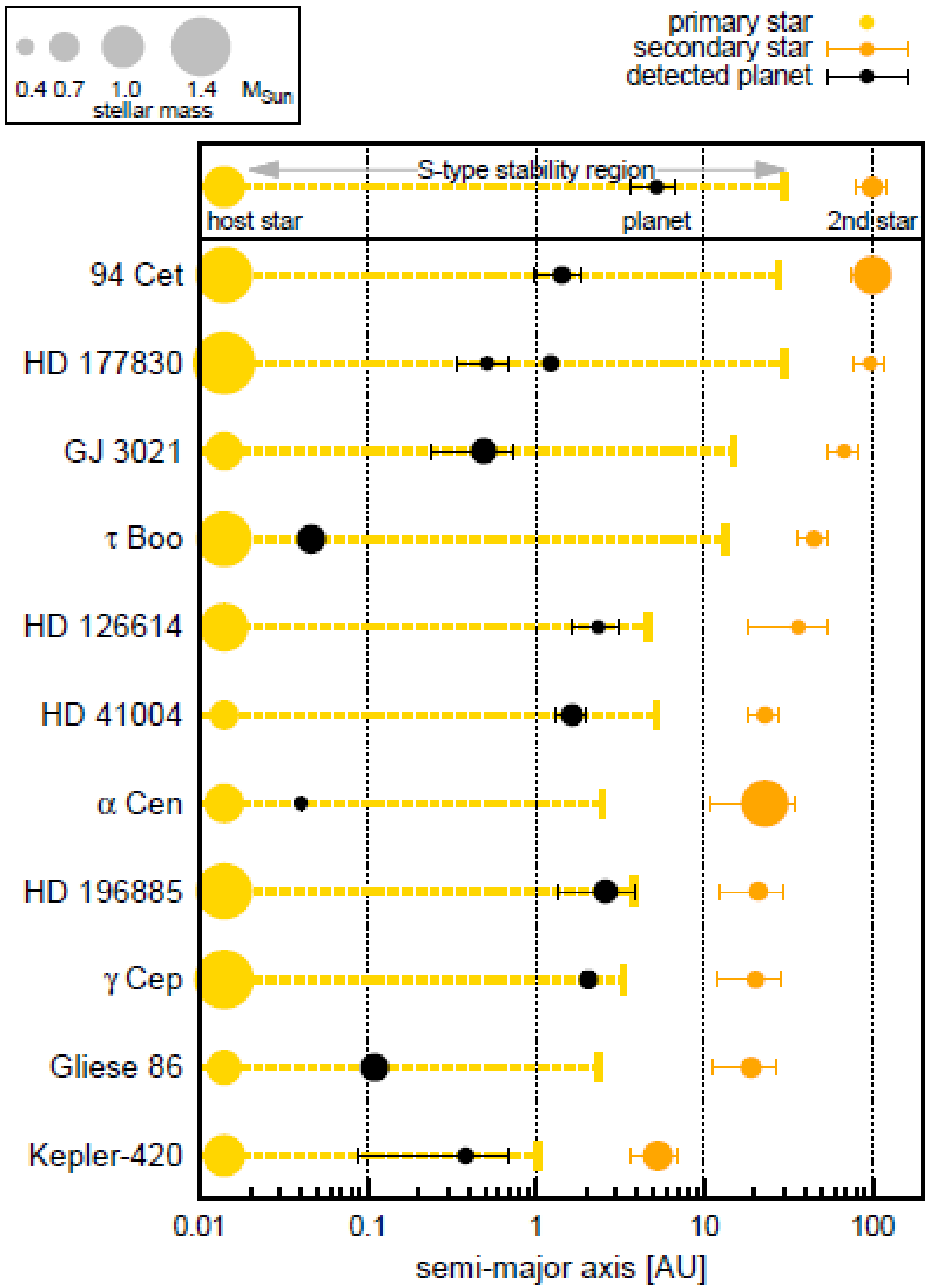


Secondary star
restricts the region for
stable planetary motion

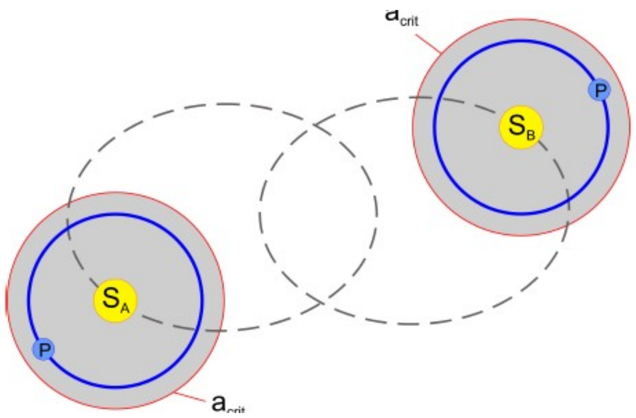
HZ must be in the stable zone



Pilat-Lohinger+, 2019



Bazsó, Pilat-Lohinger et al., MNRS, 2017



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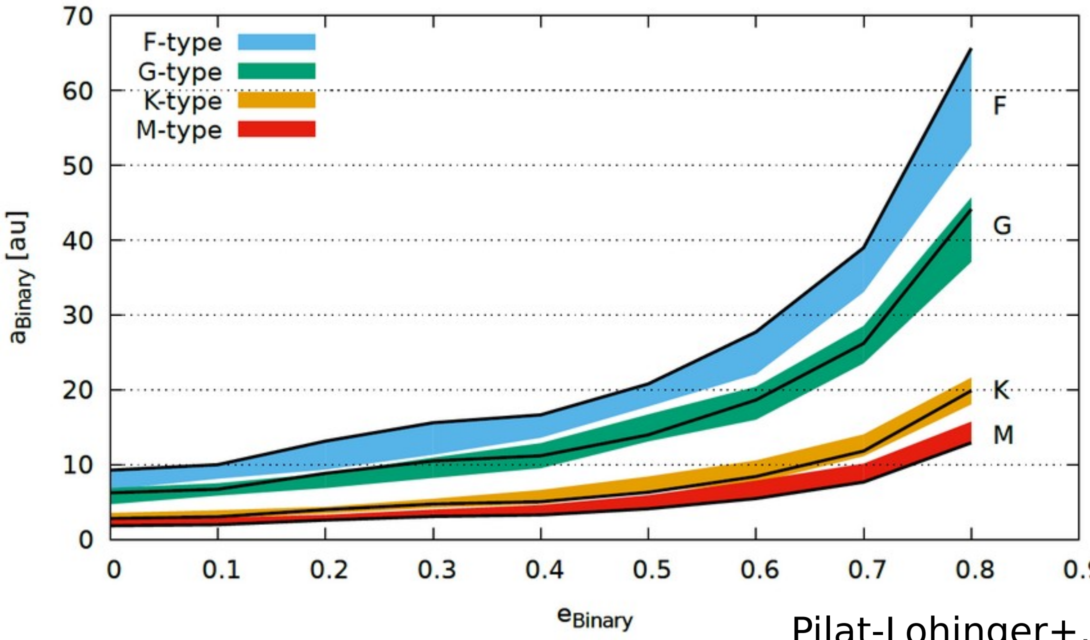
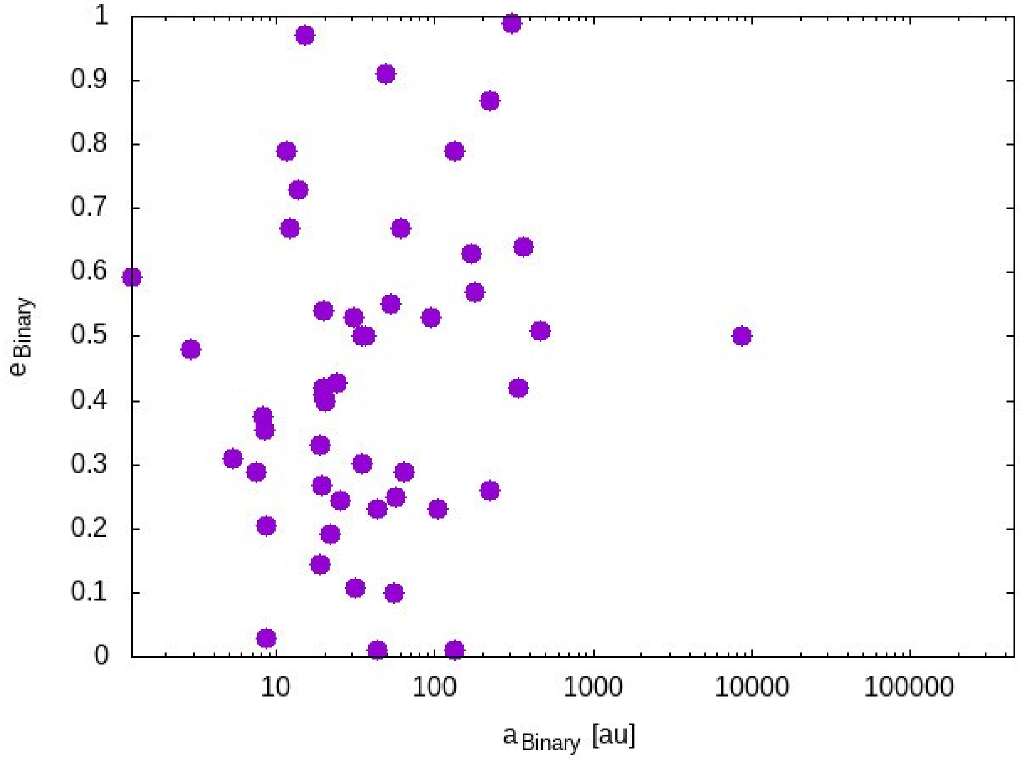
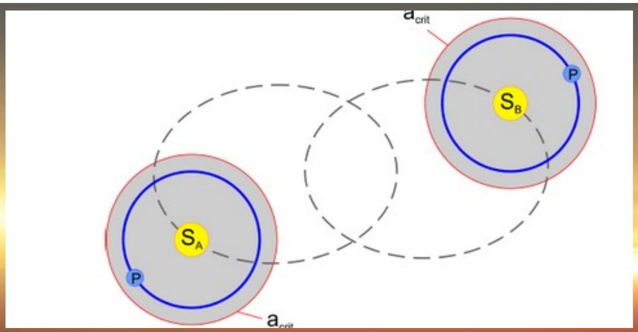




Pilat-Lohinger+, 2019

S-type Configurations

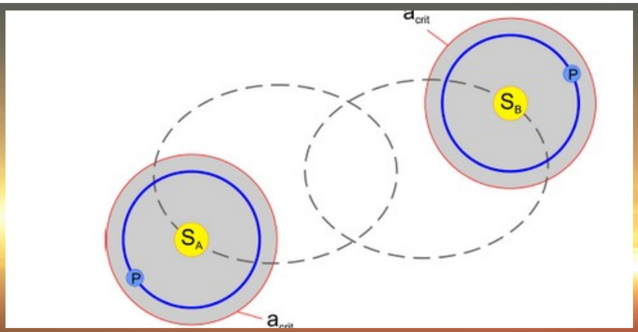


747 Systems

Binary star separations: 1.2 – 449326 au

Eccentricities: 0.01 – 0.99 / unknown (most cases)

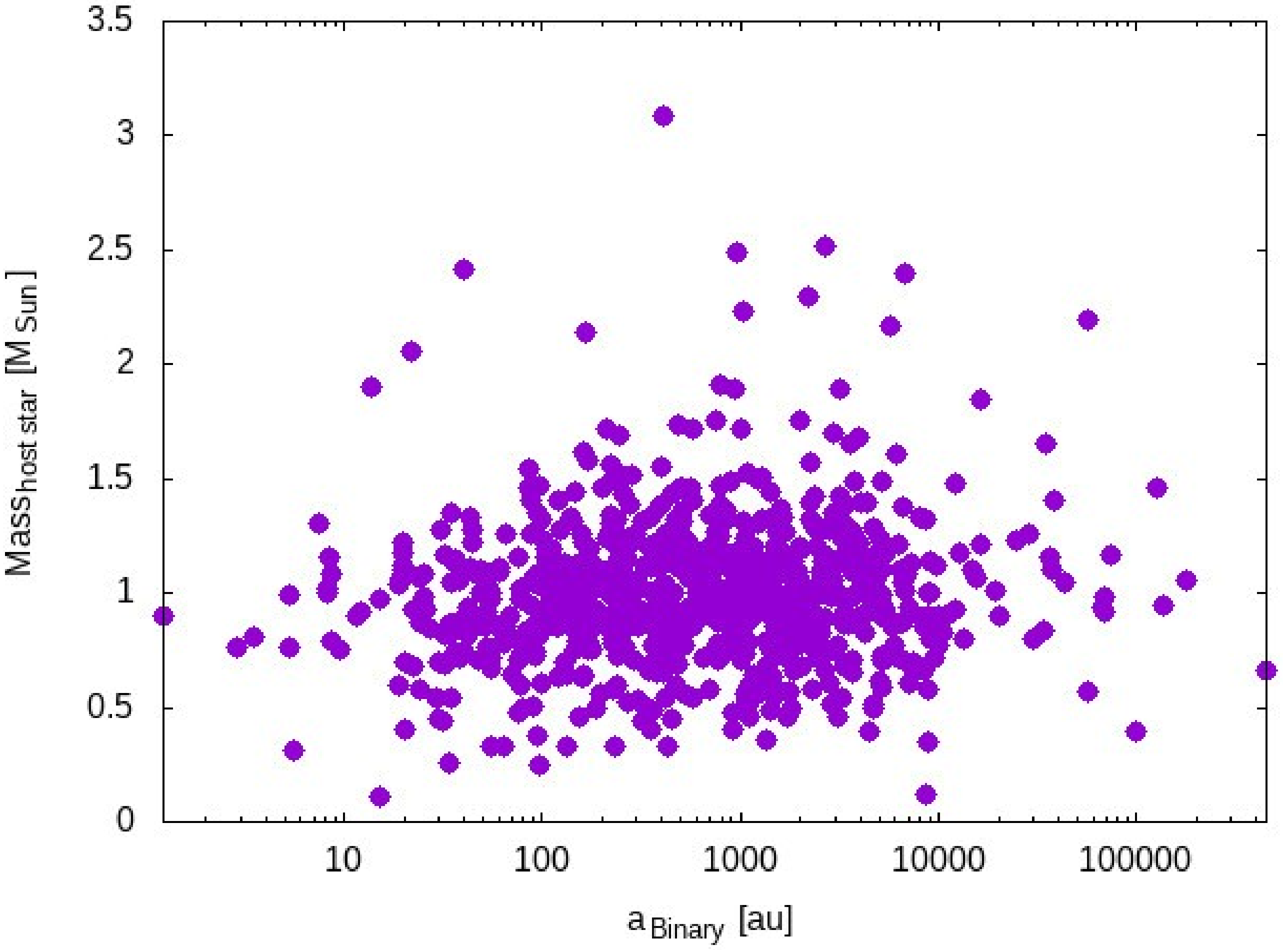
S-type Configurations



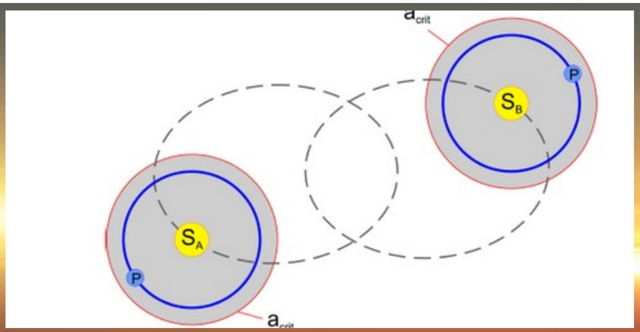
747 Systems

Binary star separati

Eccentricities: 0.01



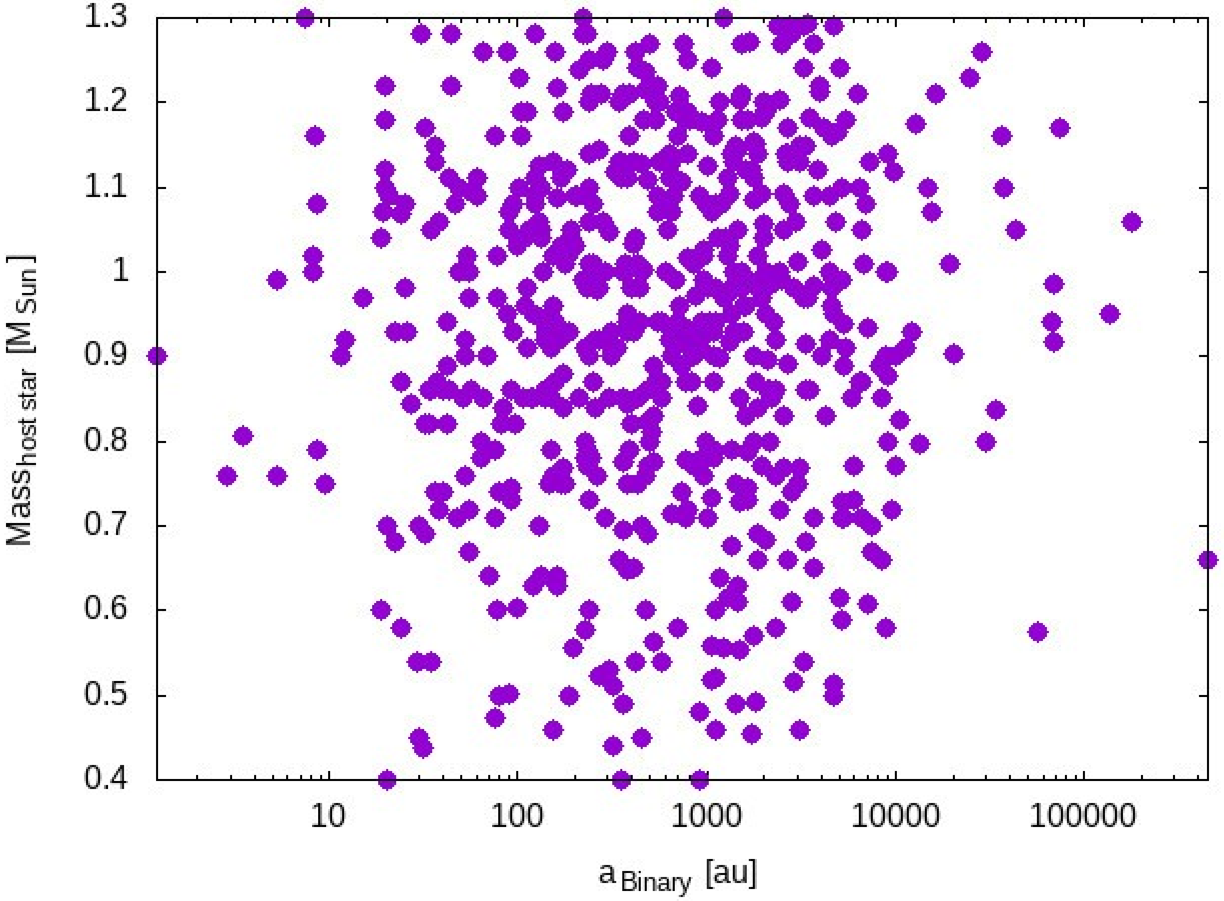
S-type Configurations



747 Systems

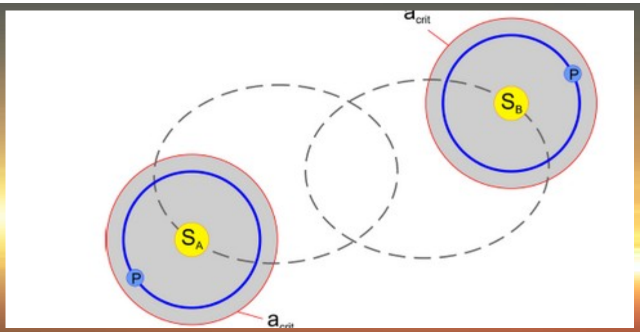
Binary star separations:

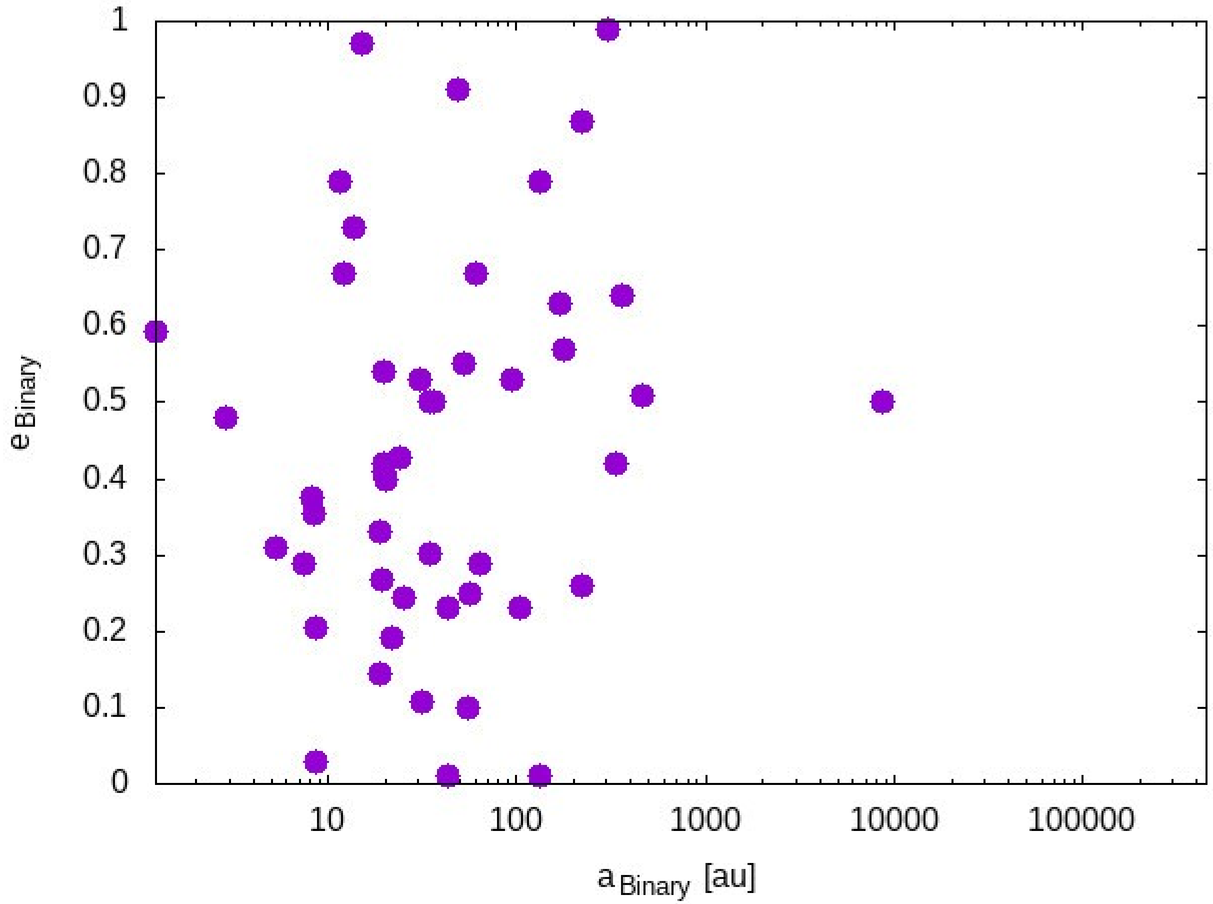
Eccentricities: 0.01 – 0.9



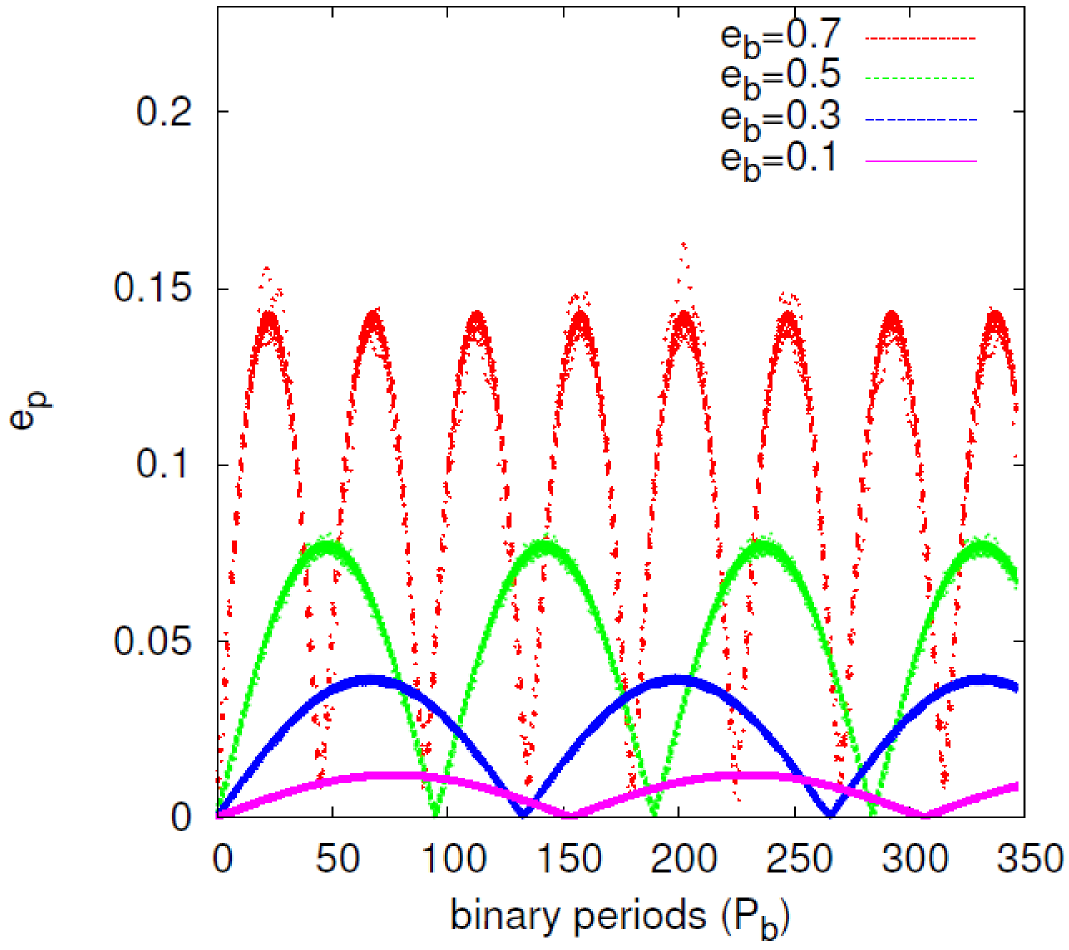
627 systems

S-type Configurations





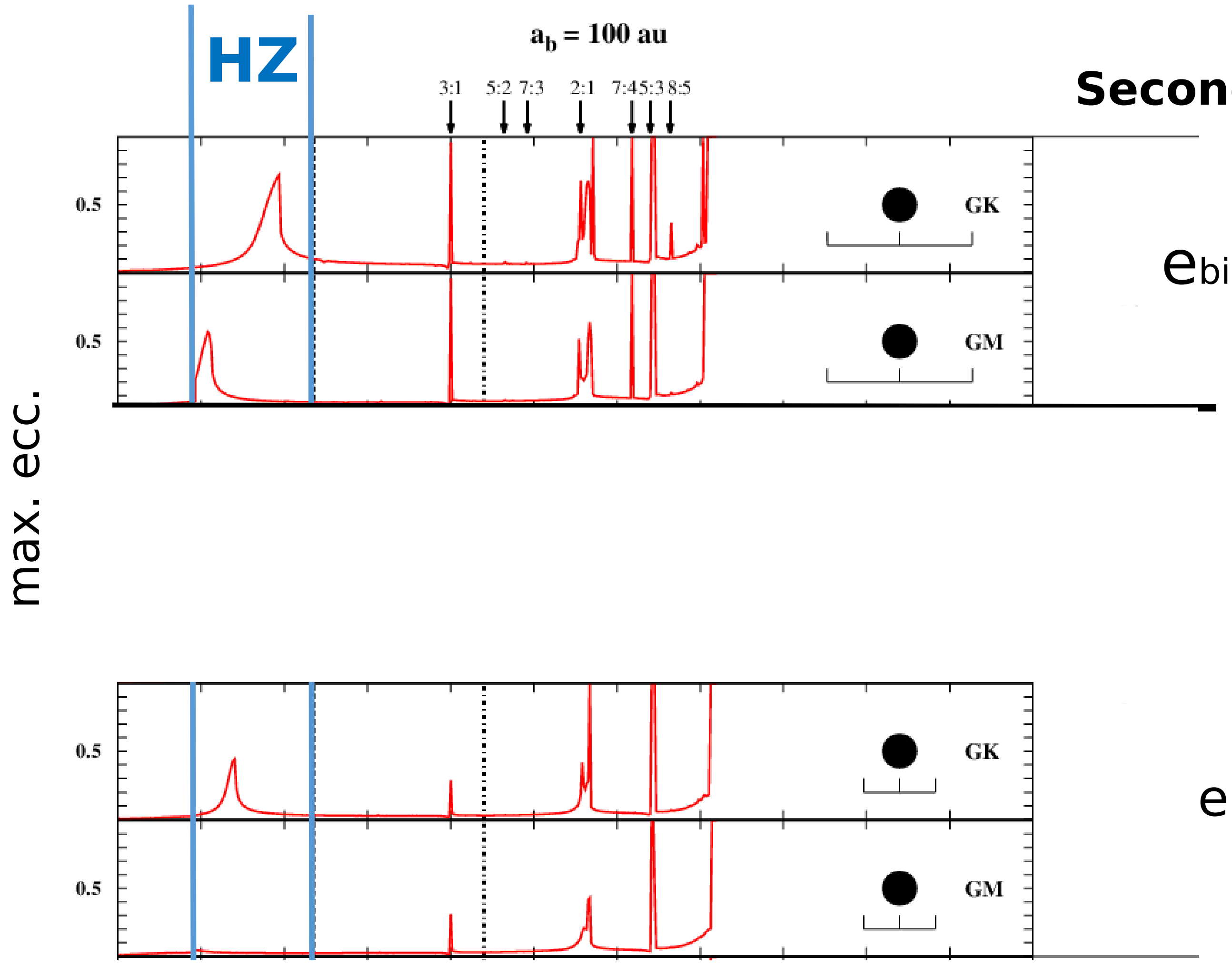
Secondary star cause variations in planetary eccentricity



Binary star: 2 G2V
Distance: ~20 au
Earth-mass planet at 1 au

See studies by
Eggl, Pilat-Lohinger + (2012,….)
Georgakarakos+ (2013 ….)

A secondary stars may perturb planets in HZs



Secondary Star at 100 au

$e_{binary} = 0.5$

$e_{binary} = 0.3$

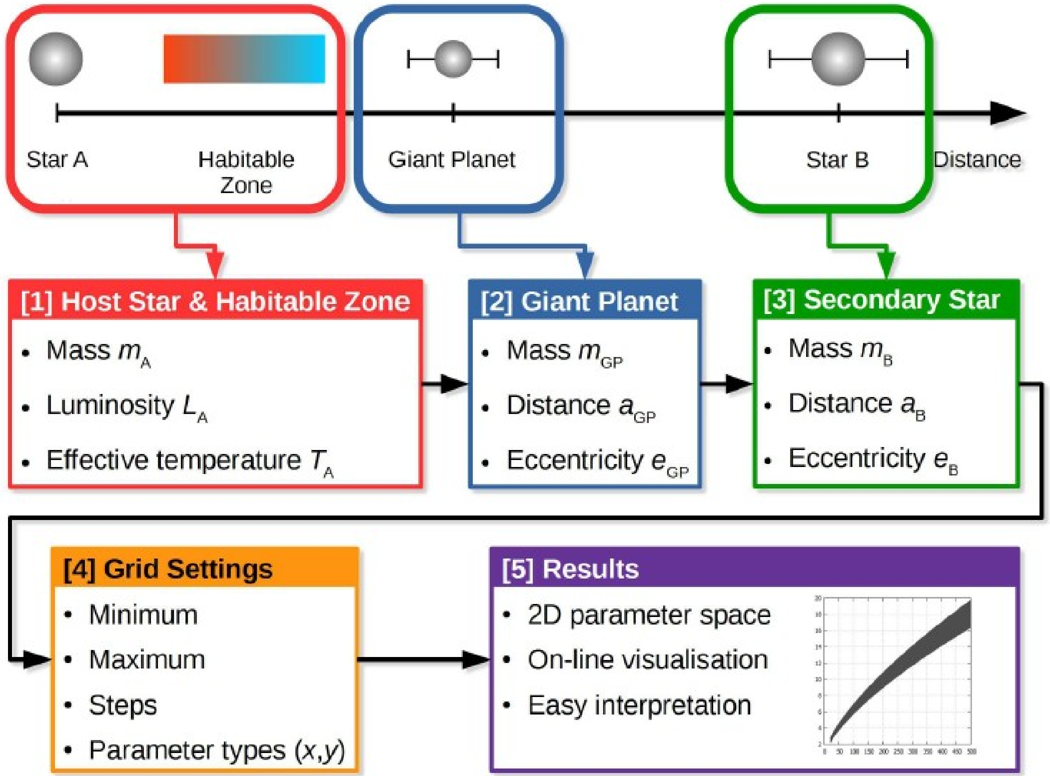
(Bancelin, Pilat-Lohinger+, 2016)

S H a D o S (online tool)

= Secular perturbations in Habitable Zones of Double Stars

https://adg.univie.ac.at/shados/

- Steps 1–4 provide input for different objects
- Step 5 visualizes results



Combined Analytical Model -- CAM

= a combination of two analytical models

1. Laplace Lagrange Theory for g_TP
2. Andradea-Ines & Eggl model (2017) for g_GP

$$g_{And} = g_{Hep}\left(1 - \delta_g\right)$$

$$g_{Hep} = \frac{3}{4}\mu\alpha^3 n\left(1 - e_B^2\right)^{-3/2}$$

$$\mu = m_B/m_A$$

$$\alpha = a_P/a_B$$

$$n^2 = Gm_A/a_P^3$$

S H a D o S (online tool)

= **S**ecular perturbations in **Ha**bitable Zones of **Do**uble **S**tars

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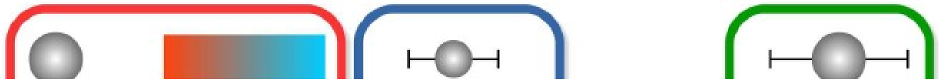

$$\delta_g = \alpha^{3/2}[-4.6274\mu^{1/2} - 4.0190\mu + 0.25041\mu^2 - 3.41e_2^2\mu^{1/2} + 11.09e_2^2\mu - 0.9823e_2^2\mu^2 - 20.13e_2^4\mu^{1/2} - 85.49e_2^4\mu + 4.996e_2^4\mu^2] + \alpha^{9/2}[123.67\mu^{1/2} - 799.20\mu - 201.49\mu^2 + 180e_2^2\mu^{1/2} - 5555e_2^2\mu - 617.7e_2^2\mu^2 + 2.671\times 10^4 e_2^4\mu^{1/2} - 1.0229\times 10^5 e_2^4\mu - 23076e_2^4\mu^2],$$

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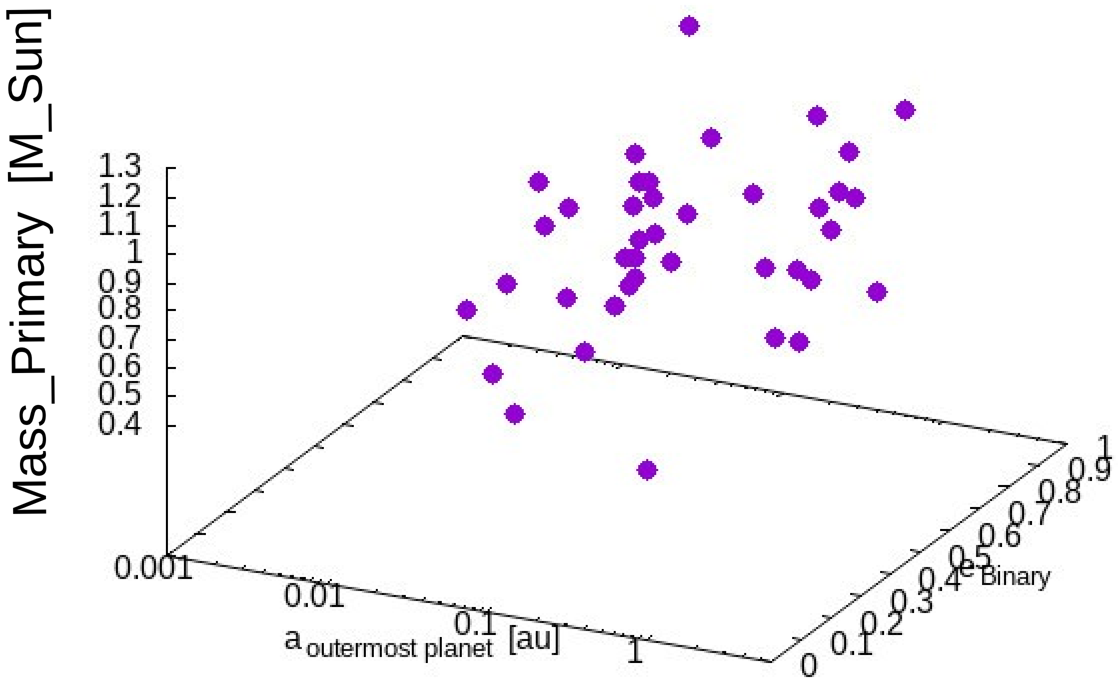
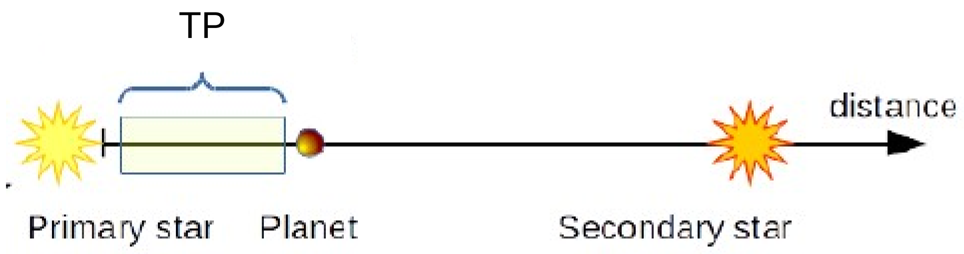
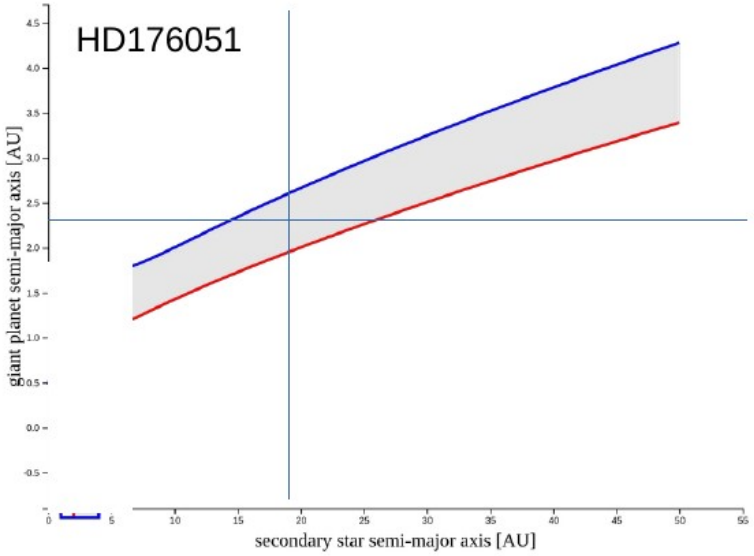
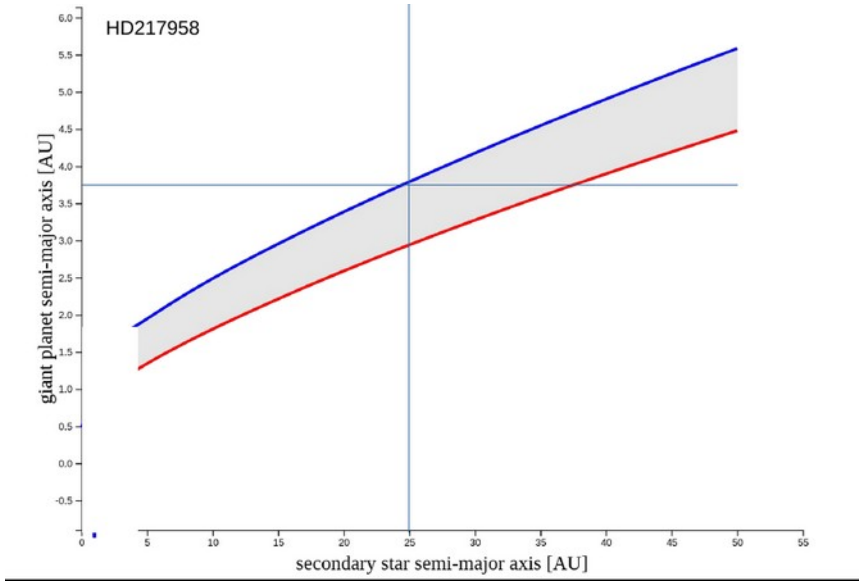

Mass_Primary [M_Sun]
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.001
0.01
0.1
1
a outermost planet [au]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
e Binary


TP
distance
Primary star
Planet
Secondary star

Secular resonance in HZ

HIP90988
HD176051
HD196885
HD41004A
HD217958
HD5608
HD7449
HD126614





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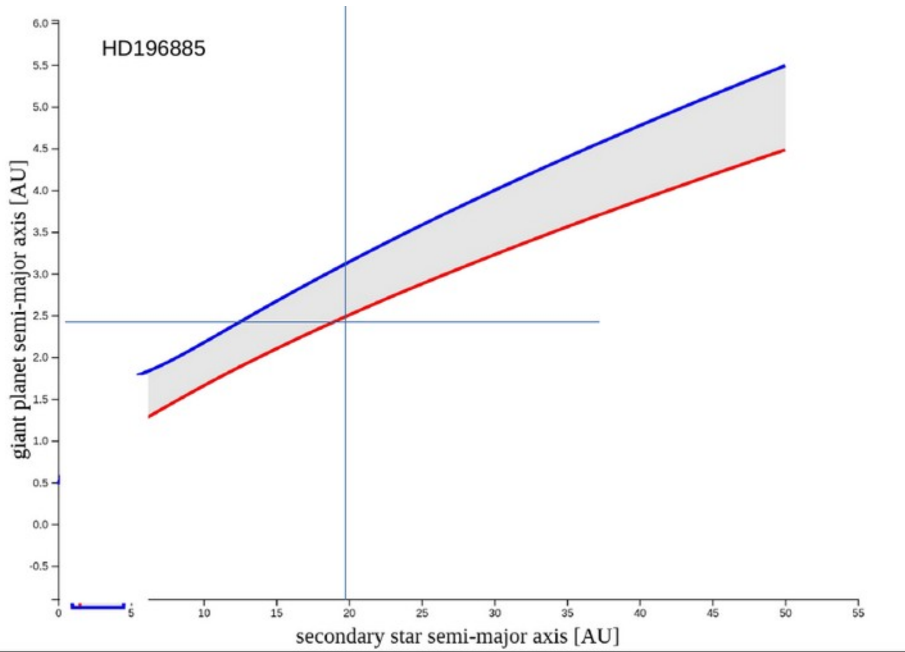
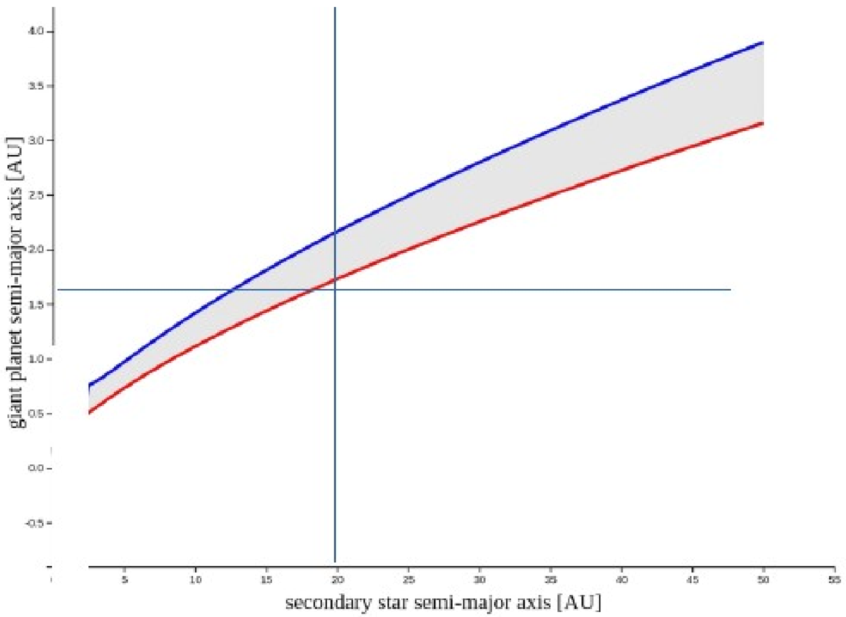
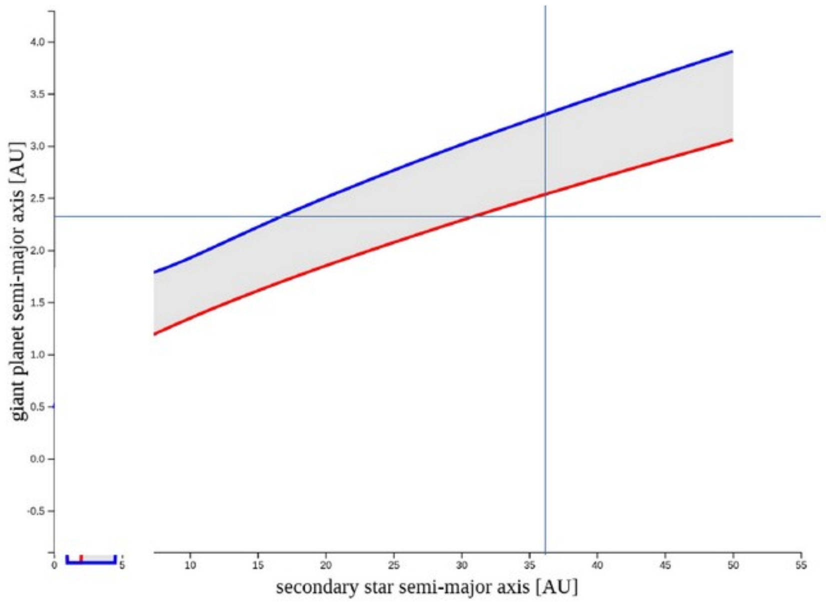
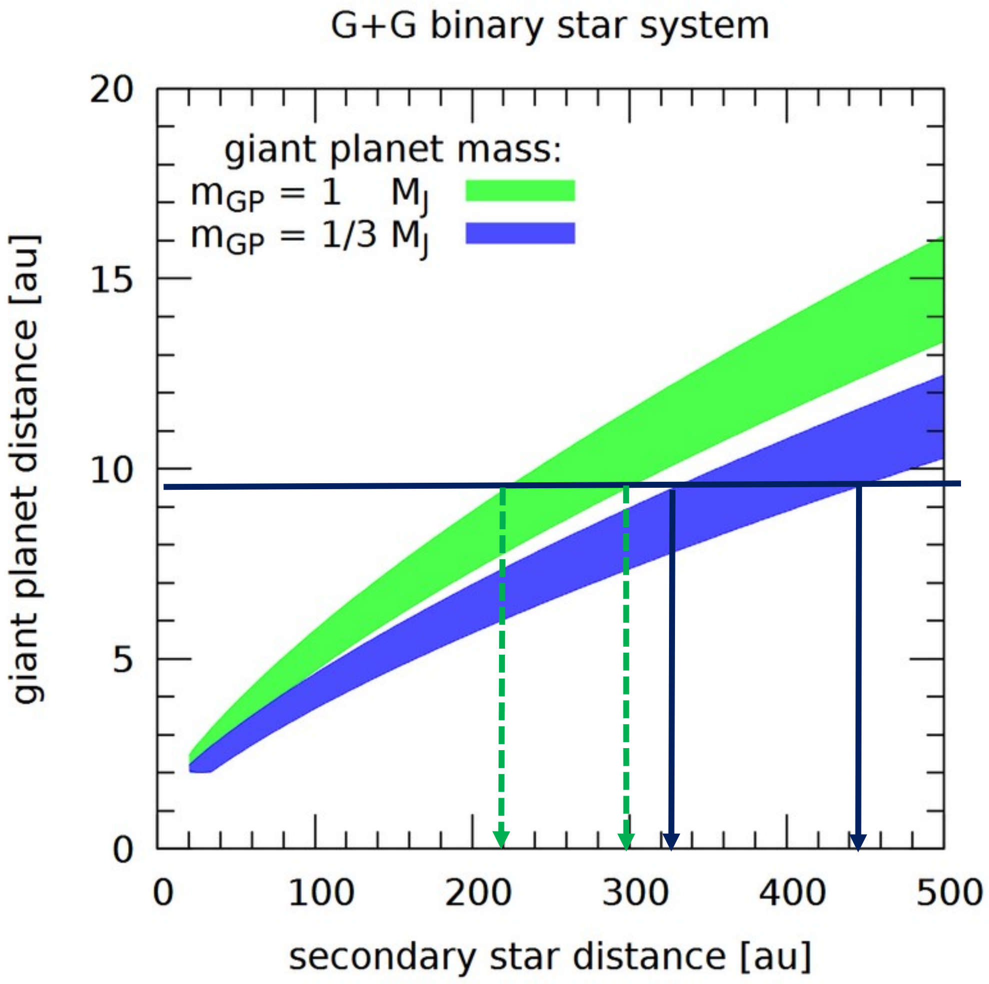






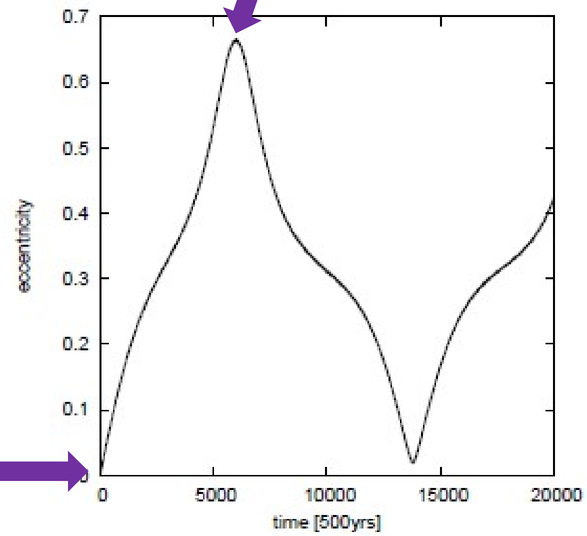
A secondary stars may perturb planets in HZs



Secular Resonances in HZ

- eccentricity motion
- variations in eccentricity

eccentric orbit



circular orbit

Influence on the habitability of a planet in the HZ

Ongoing work

N-body simulation using our GPU-N-body code 'GANBISS'

Study TP formation applying the

Collision model of Leinhardt & Stewart (2012)