CIRCUMSTELLAR HABITABLE ZONES IN TIGHT BINARY STAR SYSTEMS

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Abstract:

The fact that up to 70% of all stellar systems in our Galaxy may not be single-stellar systems but multi-stellar systems and the growing number of detected planets in binary star systems require methods for a quick assessment of possible habitability of a terrestrial planet in binary star systems.

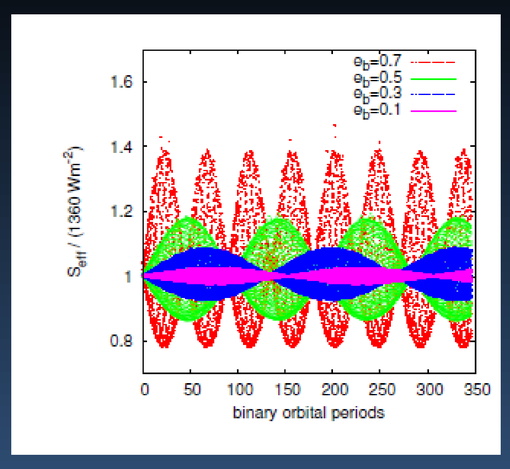
Planetary motion in a binary star system:
There are two types:
S-type or circum-stellar motion where the Planet orbits one of the two stars; and
P-type or circum-binary motion where the Planet orbits both stars.
This study concentrates on the S-type motion.

A single planet in a binary star system:
Applying the study by Eggl et al. (ApJ, 2012) one can easily calculate the habitable zone (HZ) in a binary systems, where the combined gravitational and radiative influence plays an important role.

Two planets in a binary star systems:
In case a binary star systems habors a giant planet and a terrestrial planet additional pertrubations arise that can influence the motion in the HZ

Application: HD41004 AB
A tight binary star system (about 43 pc from the Sun) where the two stars -- a K2V star (0.7 Msun) and a M2V star (0.4 Msun) -- have a stellar separation of about 20 AU.
The eccentricity of the binary is not well defined and the eccentrictiy of the planet is 0.39+/- 0.17

S-type Habitable Zone: Combined Gravitational and Radiative Influence

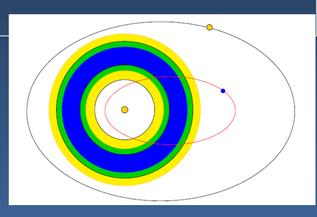


Different HZs can be defined in Binary Stars

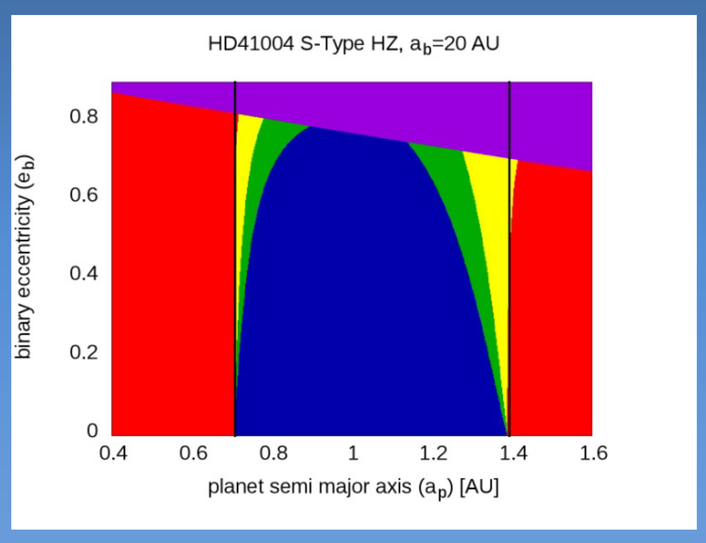
PHZ (Permanently Habitable Zone): planet is always within habitable insolation limits

EHZ (Extended Habitable Zone): planet is almost always within habitable insolation limits

AHZ (Average Habitable Zone): planet is on average within habitable insolation limits



Insolation onto an Earth-like planet in a G2-G2 binary star system: The planet was started on an initially circular orbit around one of the two Sun-like stars. The eccentricity of the binary (e_b) was varied from 0.1 to 0.7 – signals of different colors correspond to different e_b. Even though almost no direct radiative influence of the secondary star can be detected, its gravitational influence on the planet causes long-term amplitude variations in planetary insolation. This is due to the secular changes in the planet's eccentricity, bringing the planet closer to its host star periodically.



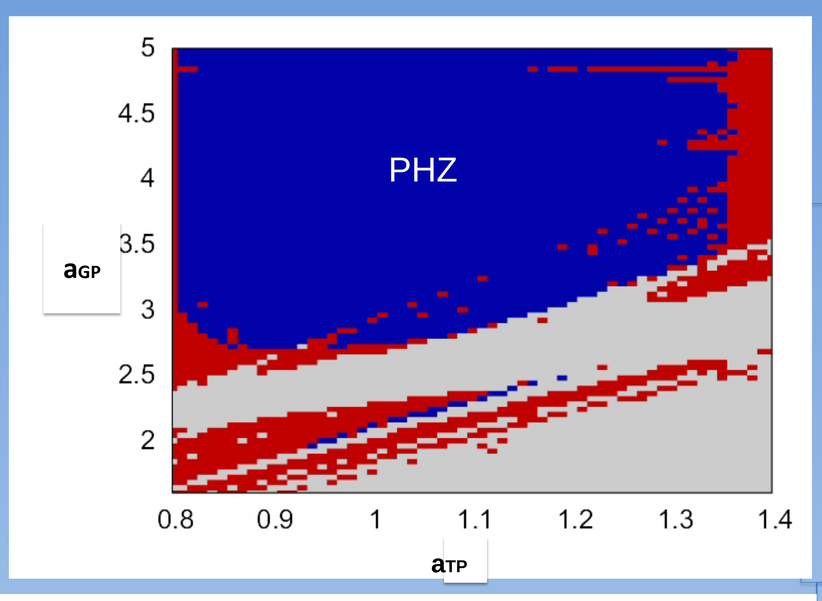
HZ of HD41004A

Calculations for an Earth-like planet in the binary HD41004AB – ignoring the giant planet .

Blue = PHZ
Green = EHZ
Yellow = AHZ
Red = NOT HABITABLE
Purple = UNSTABLE

Computations with the discovered giant planet at 1.64 AU -- > the dynamics changes a lot

Configurations for PHZ of HD41004A



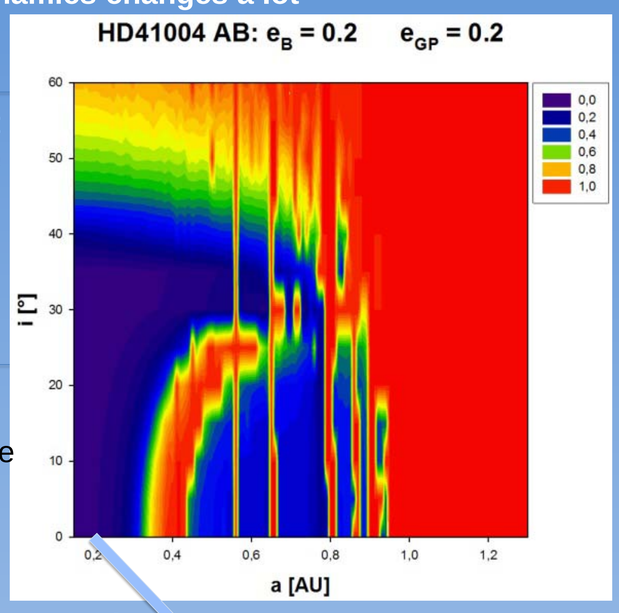
Maximum-eccentricity map in the (a,i) -plane for a test-planet moving in the gravitational field of the binary stars and the giant planet. The dynamics in this region shows:
(i) mean motion resonances due to the giant planet
(ii) a secular resonance due to the giant planet and the secondary star
(iii) Kozai resonance for i > 40°

The (a_{TP}, a_{GP}) plot shows that the HD41004 System allows an habitable planet under the assumptions:

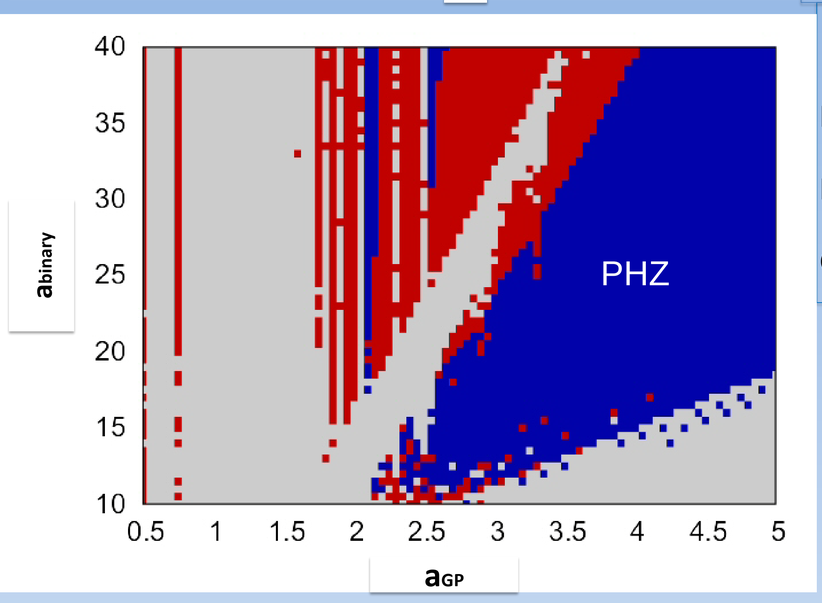
low eccentricity of the binary (e_b = 0.2)
low eccentricity of the giant planet (e_{GP} = 0.2)
semi-major axis of the giant planet > 2.5 AU

Red = unstable

Blue =stable



dark-blue area: the motion is ~ circular → best region for a habitable planet



Blue = habitable

Red = non habitable

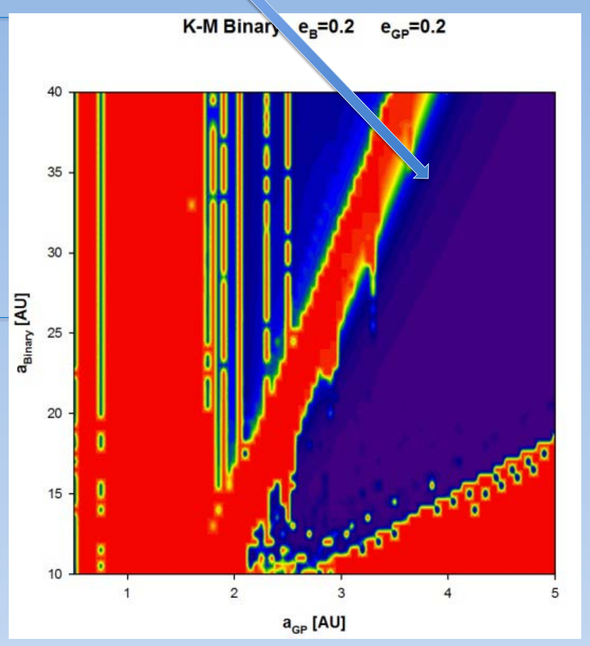
Grey= unstable

The (a_{GP},a_{Binary})-plots show which configurations provides best conditions for habitability for an Earth-like planet at 1AU from HD 41004A from the dynamical point of view (ie. circular or low-eccentric motion)

a_{GP} > 2.5 AU

Blue=stable

Red= unstable



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