Resonance Phenomena in the Habitable Zone caused by Giant Planets

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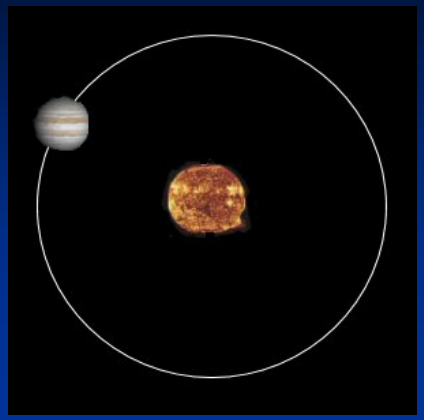
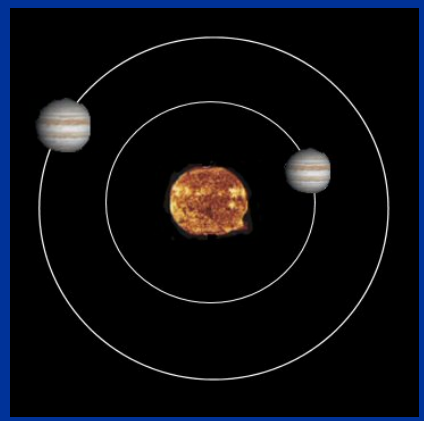
Extra-solar planetary systems:



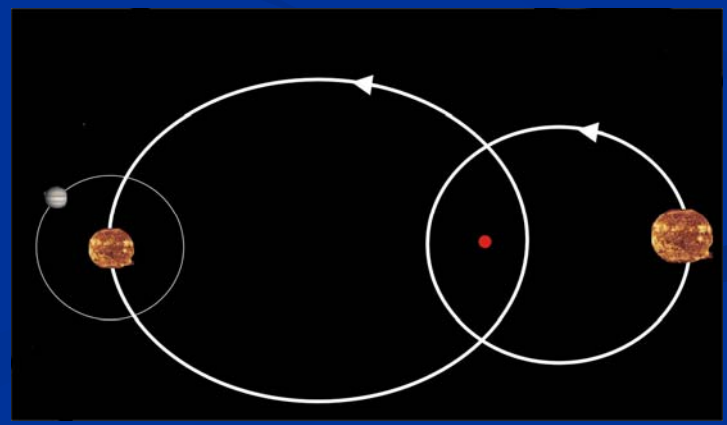
➢ **Single Star and Single Planet Systems**



➢ **Multi-planetary systems**

342 Extra-solar planets:

33 Multi-planet systems
- 1 system – 5 planets
- 1 system -- 4 planets
- 8 systems – 3 planets
- 23 systems – 2 planets



➢ **Binaries**

Why do we need stability studies?

(1)To be sure that a detected system is likely to exist

(2) Long-term stability of the planetary system is one of the basic requirements for the evolution of life on a terrestrial-like planet

Numerical Methods

Chaos Indicators:

Fast Lyapunov Indicator (FLI)

C. Froeschle, R.Gonczi, E. Lega (1996)

(MEGNO – RLI – GALI -- ….)

Lyapunov Exponent

Long-term numerical integration:

Stability-Criterion:

No close encounters within the Hill‘ sphere

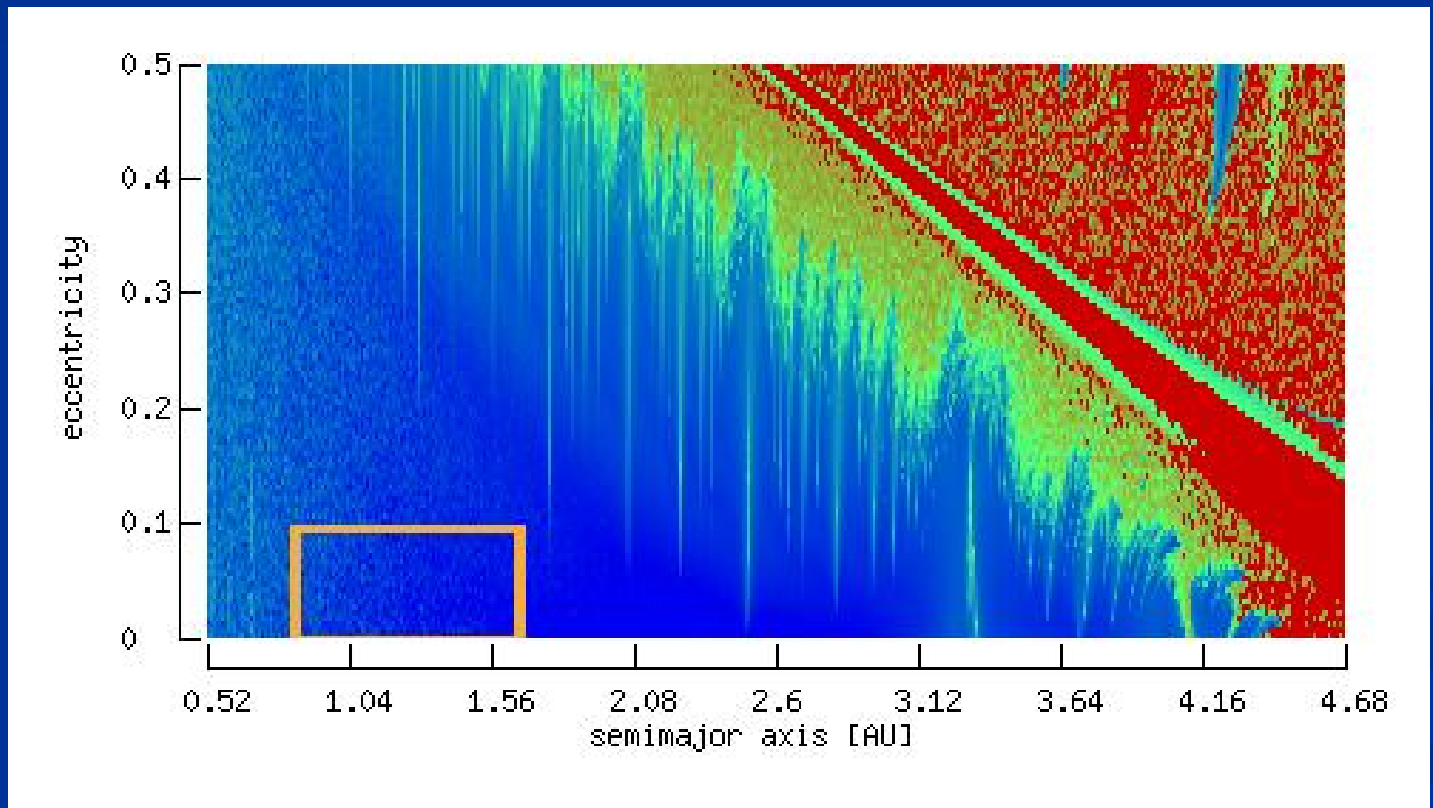
(i)Escape time

(ii) Study of the eccentricity: maximum eccentricity

Stability of a terrestrial Planet in a Single-Star -- Single-Giant Planet System

Exocatalogue (Sandor et al., 2007)

ExoStab: http://univie.ac.at/adg/exostab



color code
for orbital motion

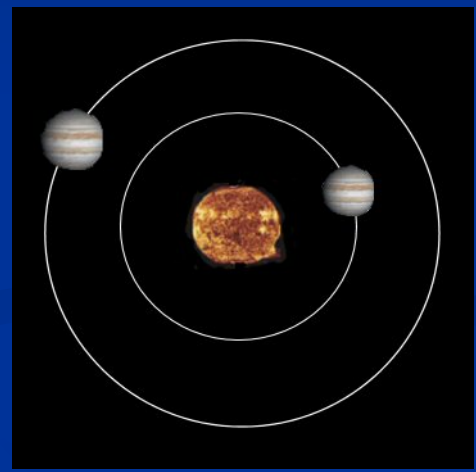
chaotic

stable

Multi-Planetary Systems

Dynamical classification (S.Ferraz-Mello, 2005)

- Class Ia –> Planets in mean motion resonance
- Class Ib → Low-eccentricity near-resonant planet pairs
- Class II→ Non-resonant planets with significant secular dynamics
- Class III→ Hierarchical planet pairs



Initial Conditions and Computations

Jupiter: on its orbit

Saturn: $a_{sat} = 8 \ldots\ldots 11$ AU

$m_{sat} = 1 \ldots\ldots 30 \times m_{Sat}$

Testplanets in the HZ:

$a_{tp} = 0.6 \ldots\ldots 1.6$ AU

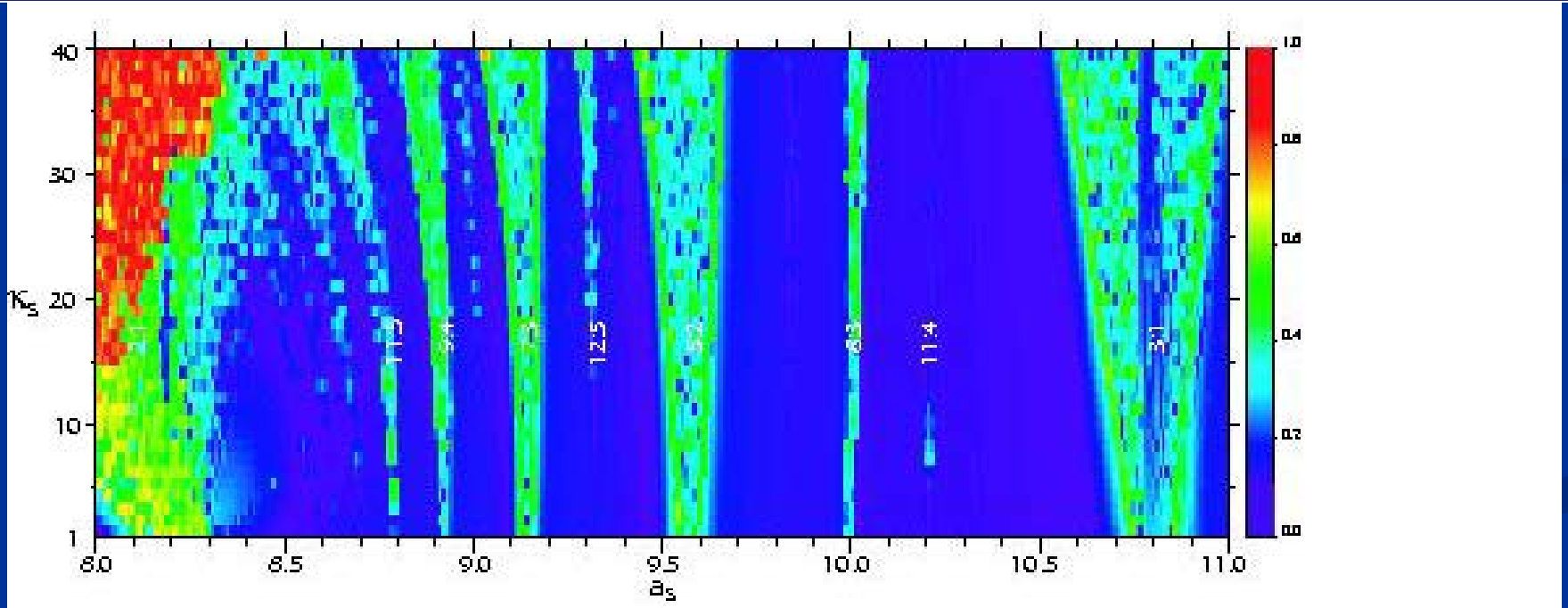
Mercury 6 (J. Chambers)

Integration time:

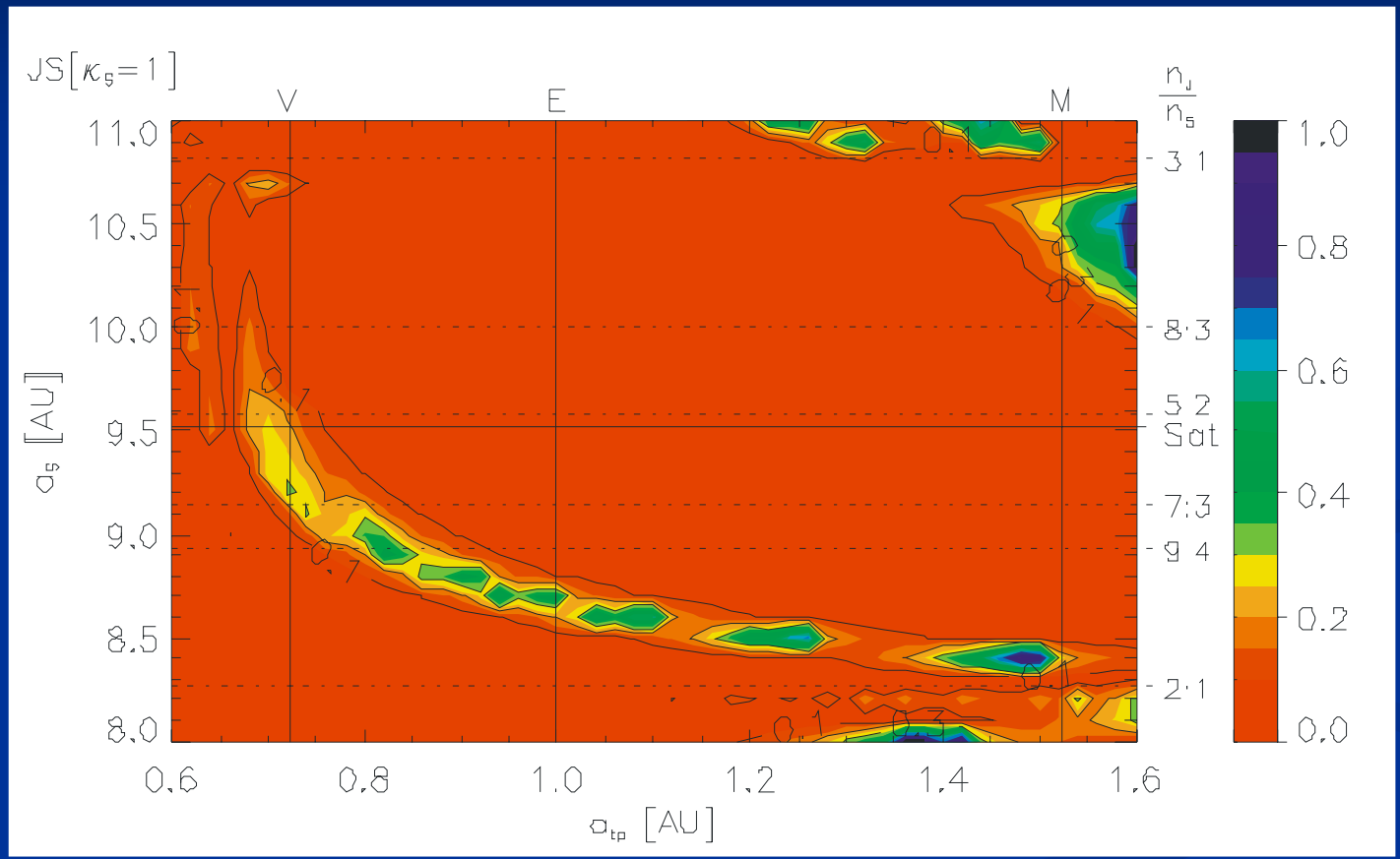
20 mio years

HZ: maximum ecc.

Mean Motion Resonances of Jupiter and Saturn



Perturbations of the HZ in the Sun – Jupiter – Saturn System:



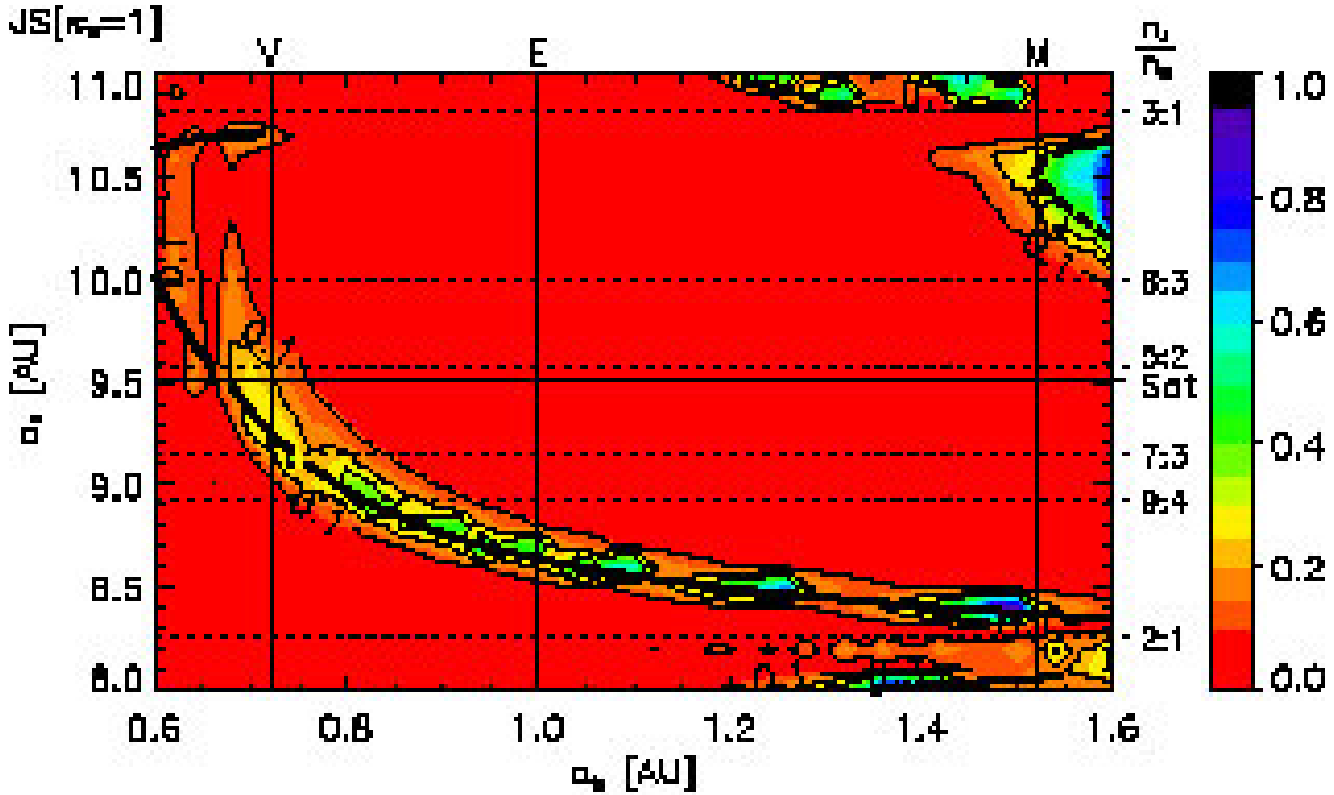
For details see Pilat-Lohinger et al., 2008, ApJ

HZ im Sonnensystem:

- Kasting: 0.93 – 1.3 AU
- Mischna: 0.93 – 1.7 AU
- Forget: 0.93 – 2 AU

a< 0.93 AU → H_2O becomes a major atmospheric compound and is rapidly lost to space after UV photolysis

a>1.3 AU → CO2 condensates in the atmosphere producing CO_2-clouds, that can affect significantly the T-CO_2 coupling



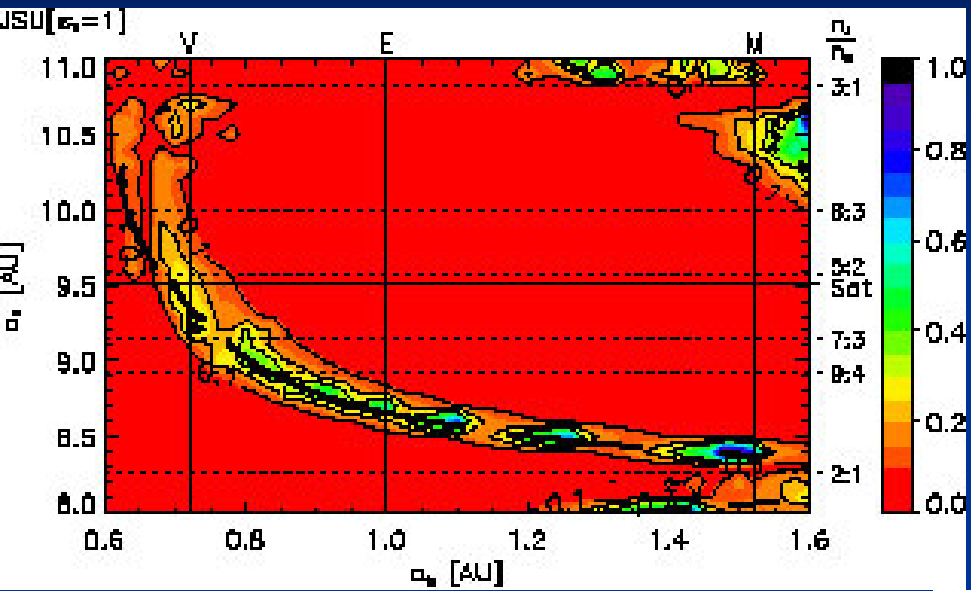
$$g = \frac{n}{4}\left(\frac{m_J}{M_{Sun}}\alpha_J^2 b_{3/2}^{(1)}(\alpha_J) + \frac{m_S}{M_{Sun}}\alpha_S^2 b_{3/2}^{(1)}(\alpha_S)\right)$$

$\alpha_J = \frac{a_{st}}{a_J}$, $\alpha_S = \frac{a_{st}}{a_S}$,

$b_{3/2}^{(1)}$ is a Laplace

HZ perturbed by 3 Giant Planets

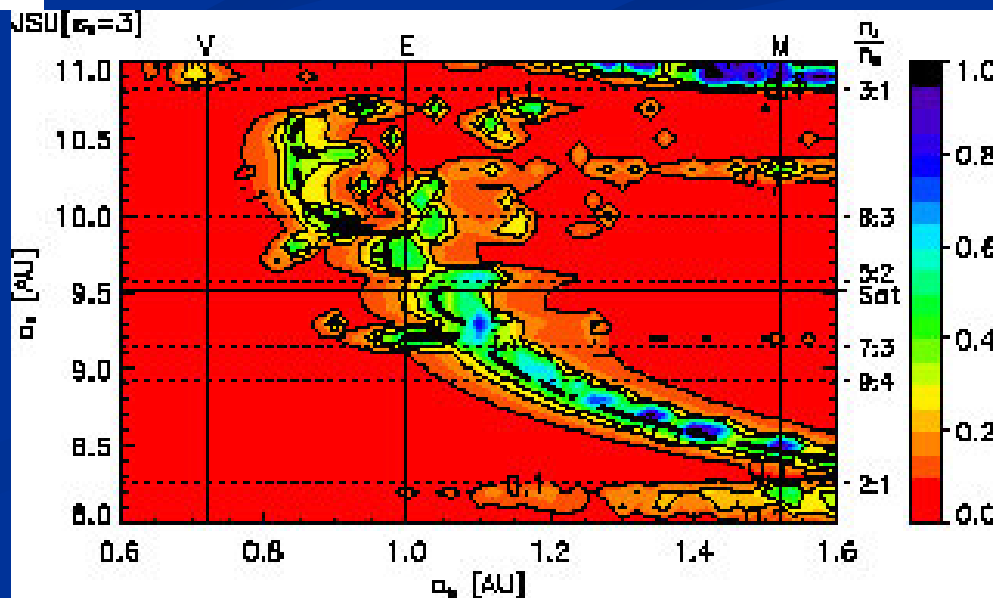
(Jupiter, Saturn and Uranus)

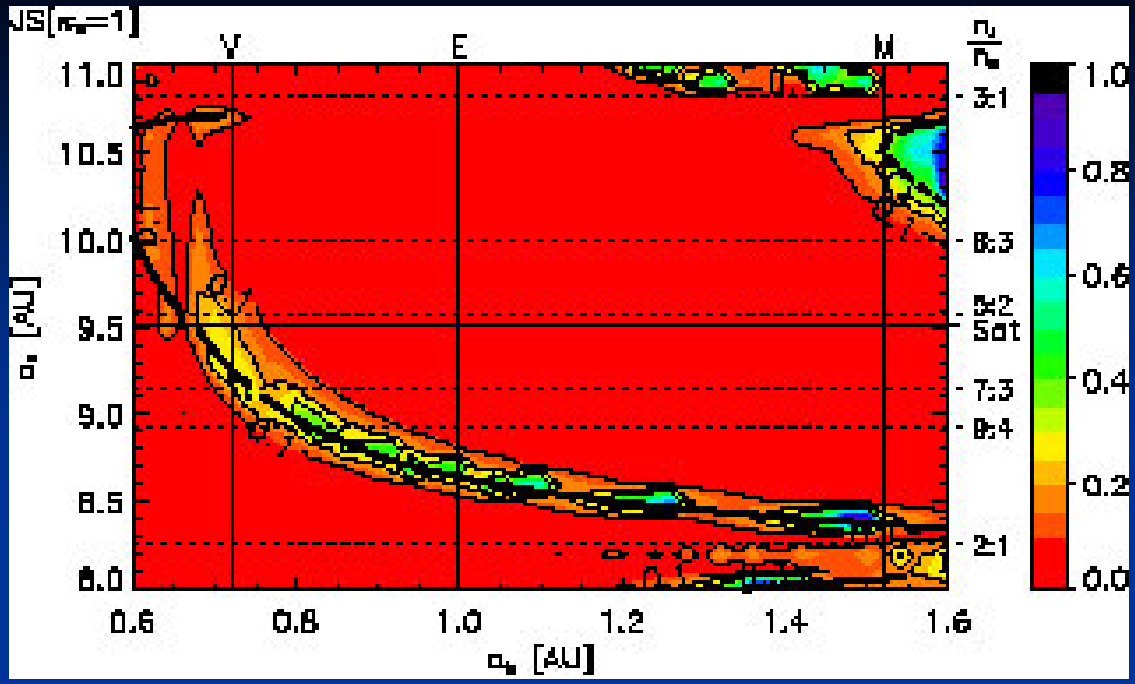


Masses like in the Solar System

MMRs Saturn and Uranus:
5:2 at 10.4 AU
8:3 at 9.2 AU

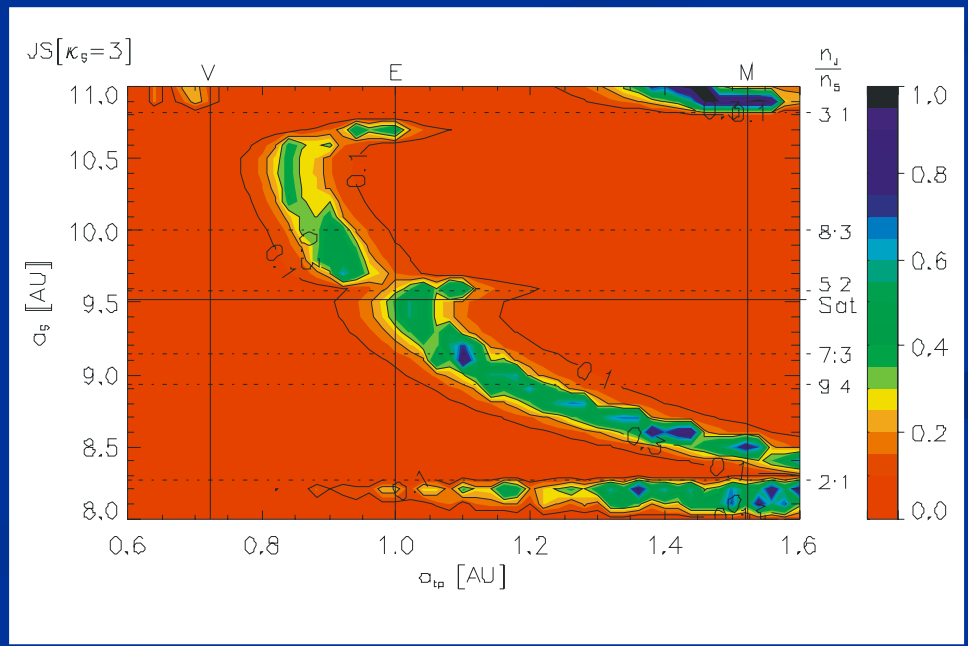
larger Saturn mass:
(3 m_{sat})





HZ perturbed by Jupiter and Saturn

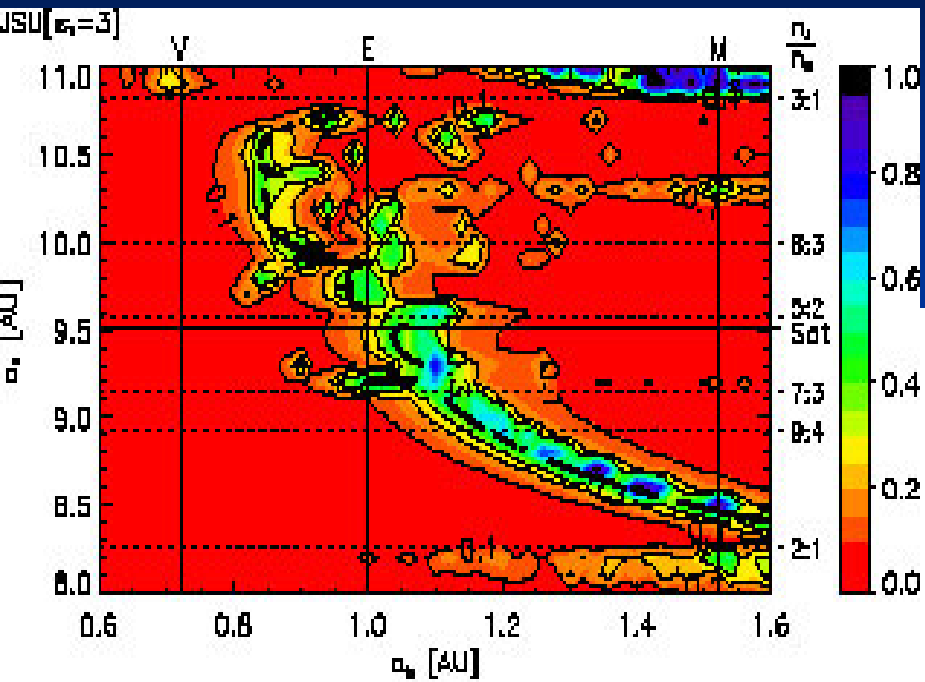
masses like in the Solar System



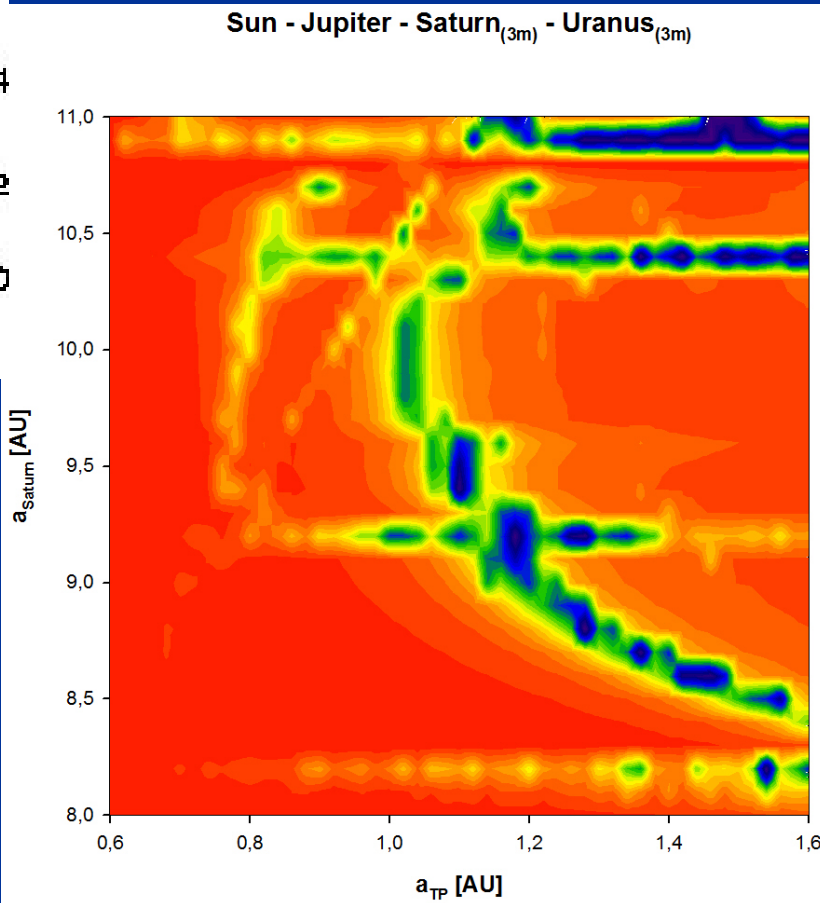
larger Saturnmass (3 mSat)

HZ perturbed by 3 Giant Planets

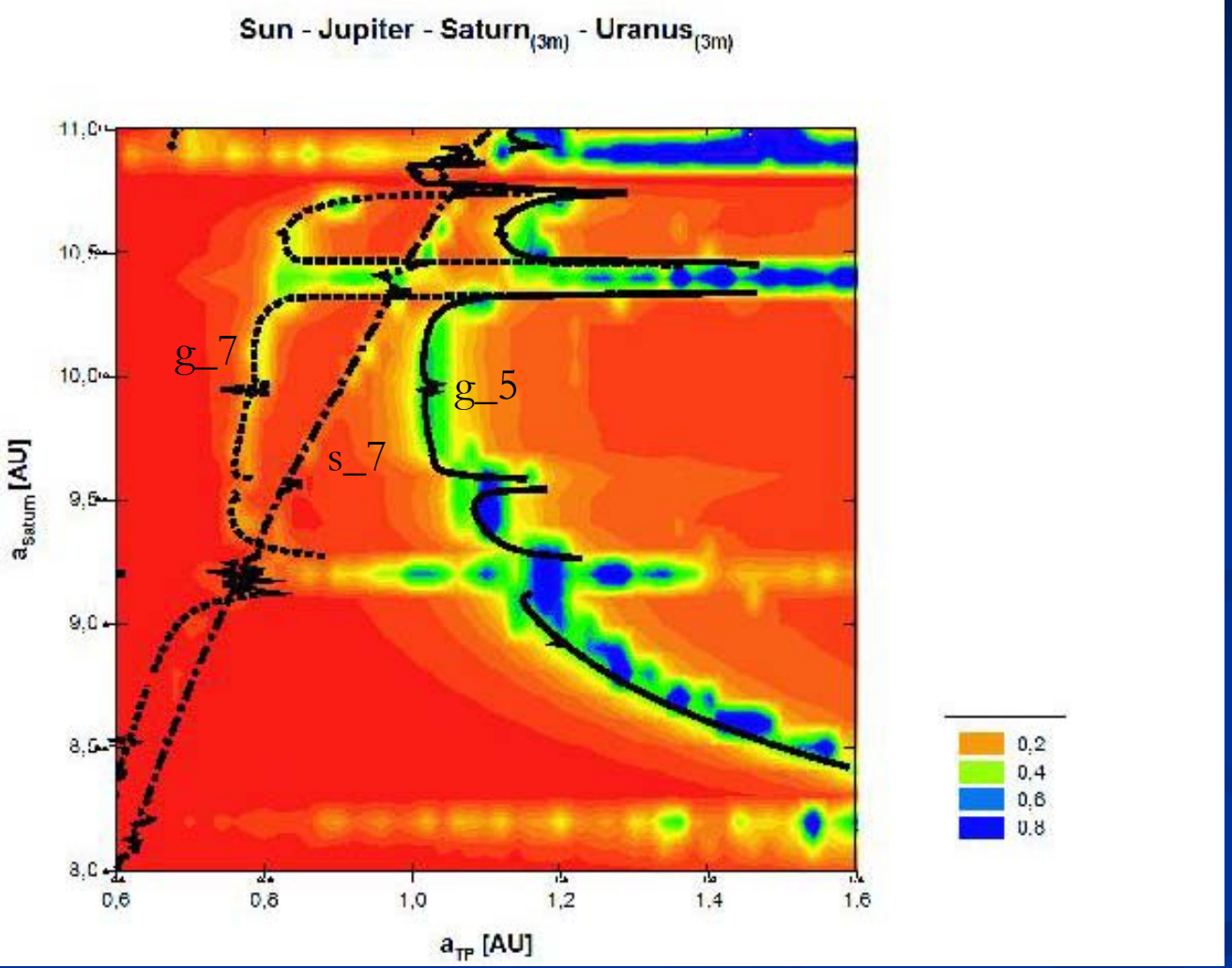
(Jupiter, Saturn and Uranus)



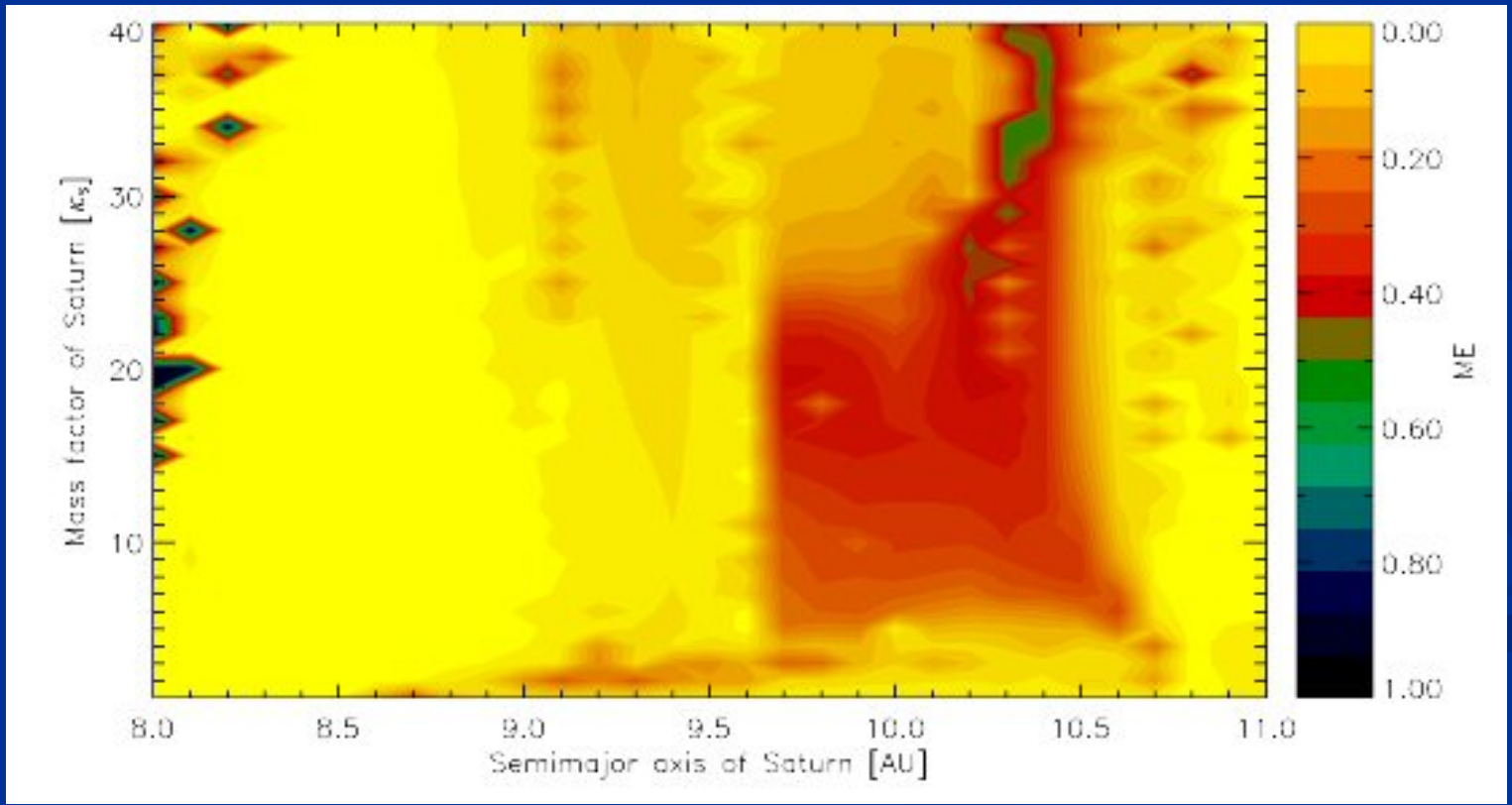
Larger Saturnmass



Larger Saturn- and Uranusmass

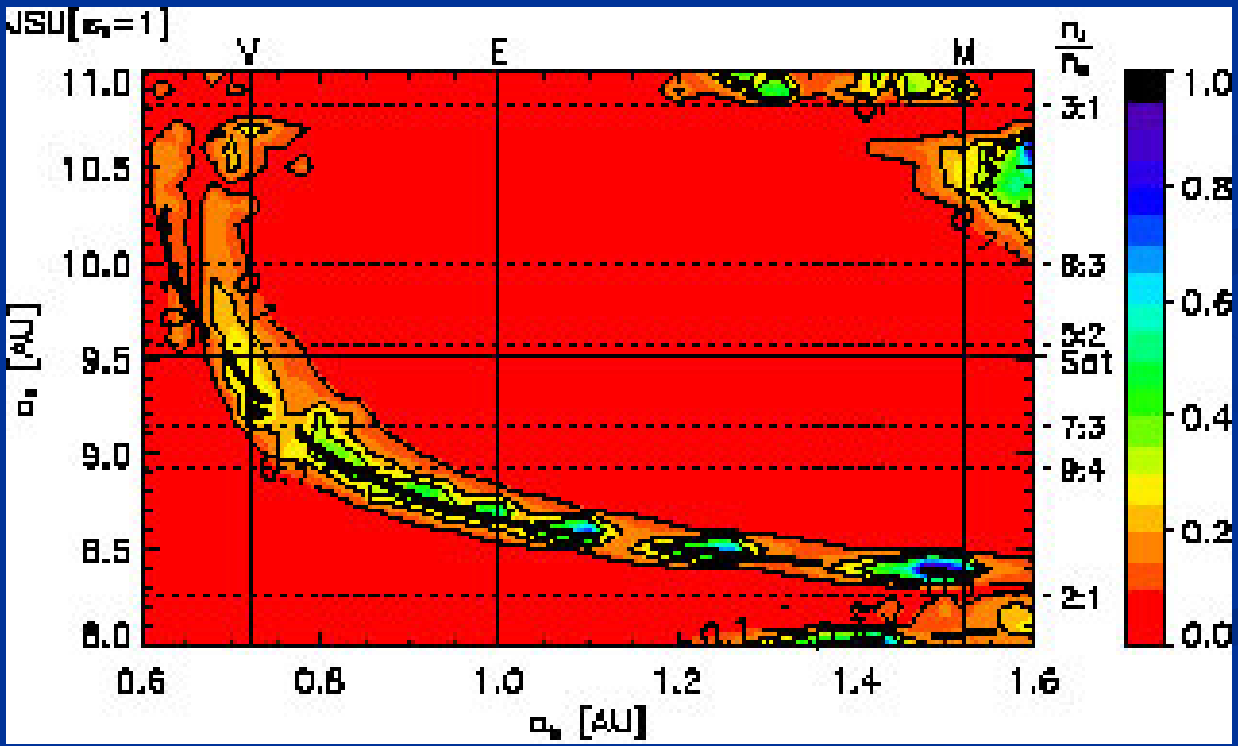

Sun - Jupiter - Saturn(3m) - Uranus(3m)
g_7
g_5
s_7
a_Saturn [AU]
a_TP [AU]
11,0
10,5
10,0
9,5
9,0
8,5
8,0
0,6
0,8
1,0
1,2
1,4
1,6
0,2
0,4
0,6
0,8

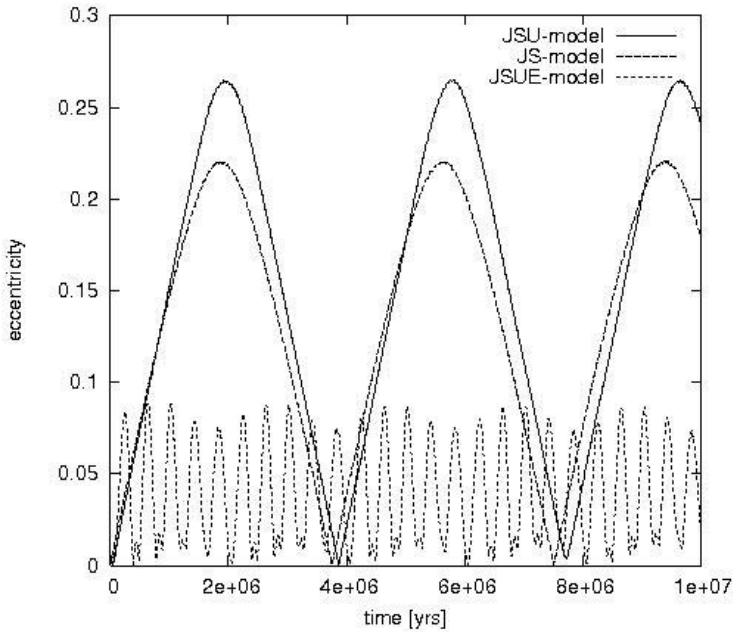
Maximum eccentricity of an Earth-like planet at 1 AU for the different starting positions (x-axis) and masses (y-axis) of Saturn



Interesting Result:

The test-planet at Venus position has a maximum eccentricity > 0.2 for the Solar System parameters:



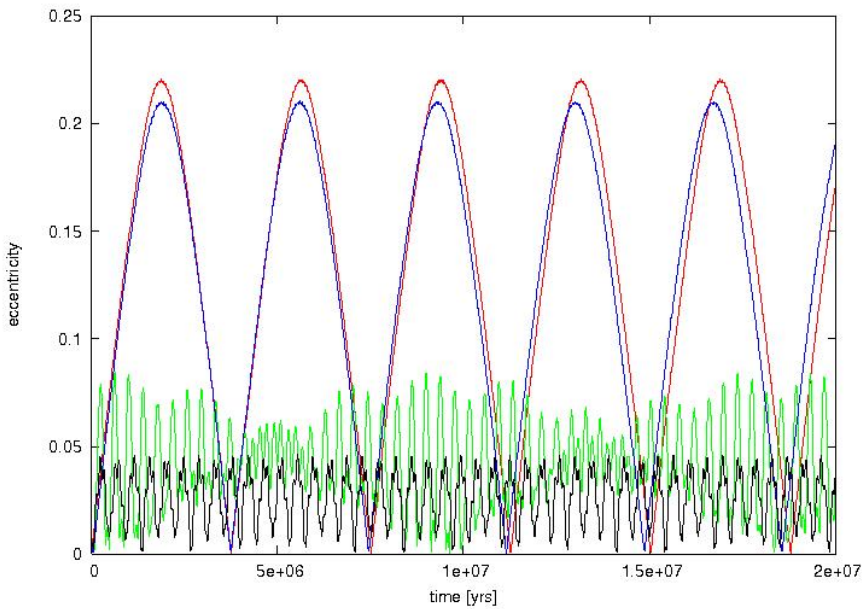


Time evolution of the eccentricity of a test-planet (e_tp) at Venus position:

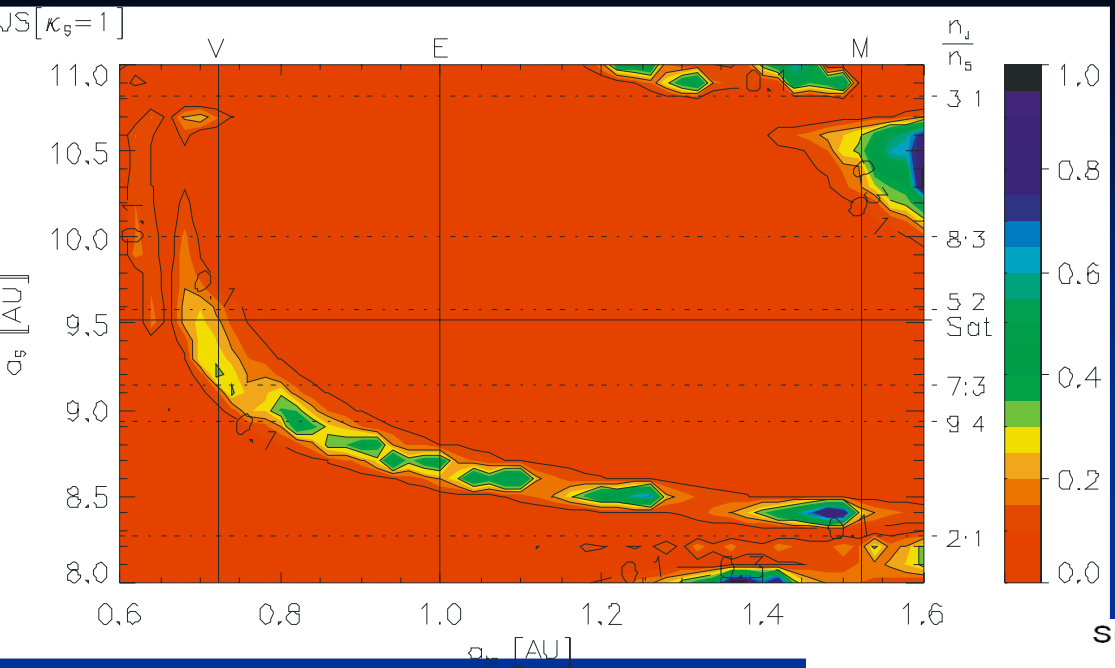
JSU model = Jupiter-Saturn-Uranus model
JS model = Jupiter-Saturn model
JSUE model= Jupiter-Saturn-Uranus-Earth model

red line: e_tp in JS model (m_tp=0)
blue line: e_tp in JS model (m_tp=m_{Venus})

green line : e_tp in JSE model (m_tp=0)
black line: e_tp in JSE model (m_tp= m_{Venus})



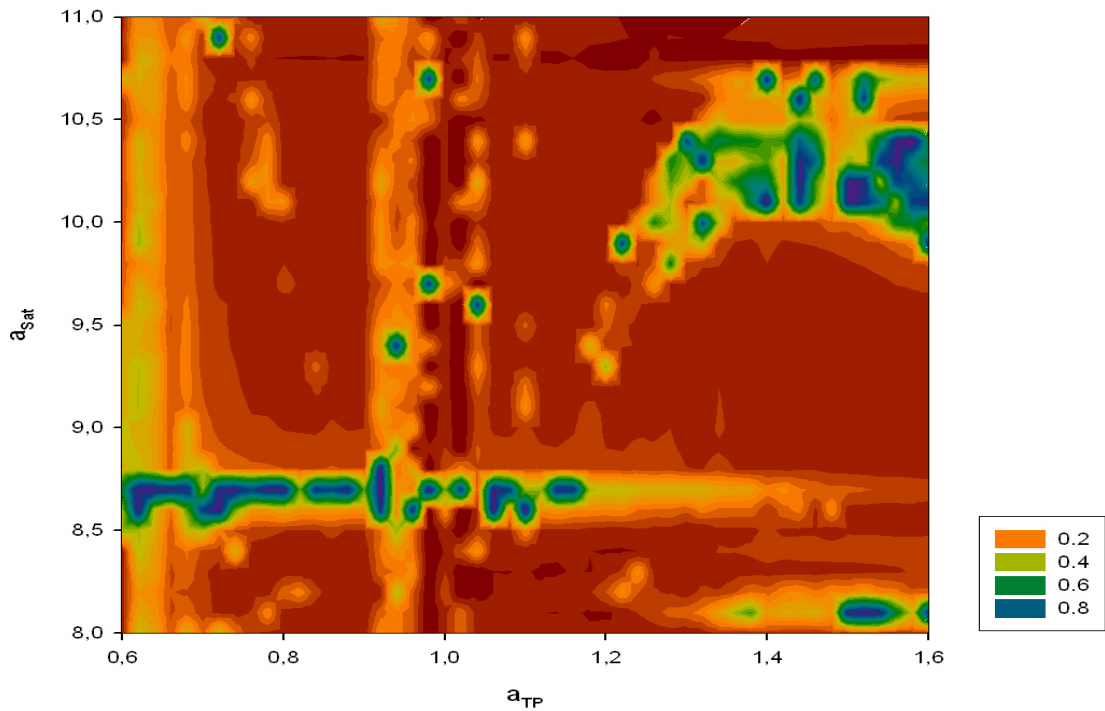
Perturbations of the HZ in two different dynamical models



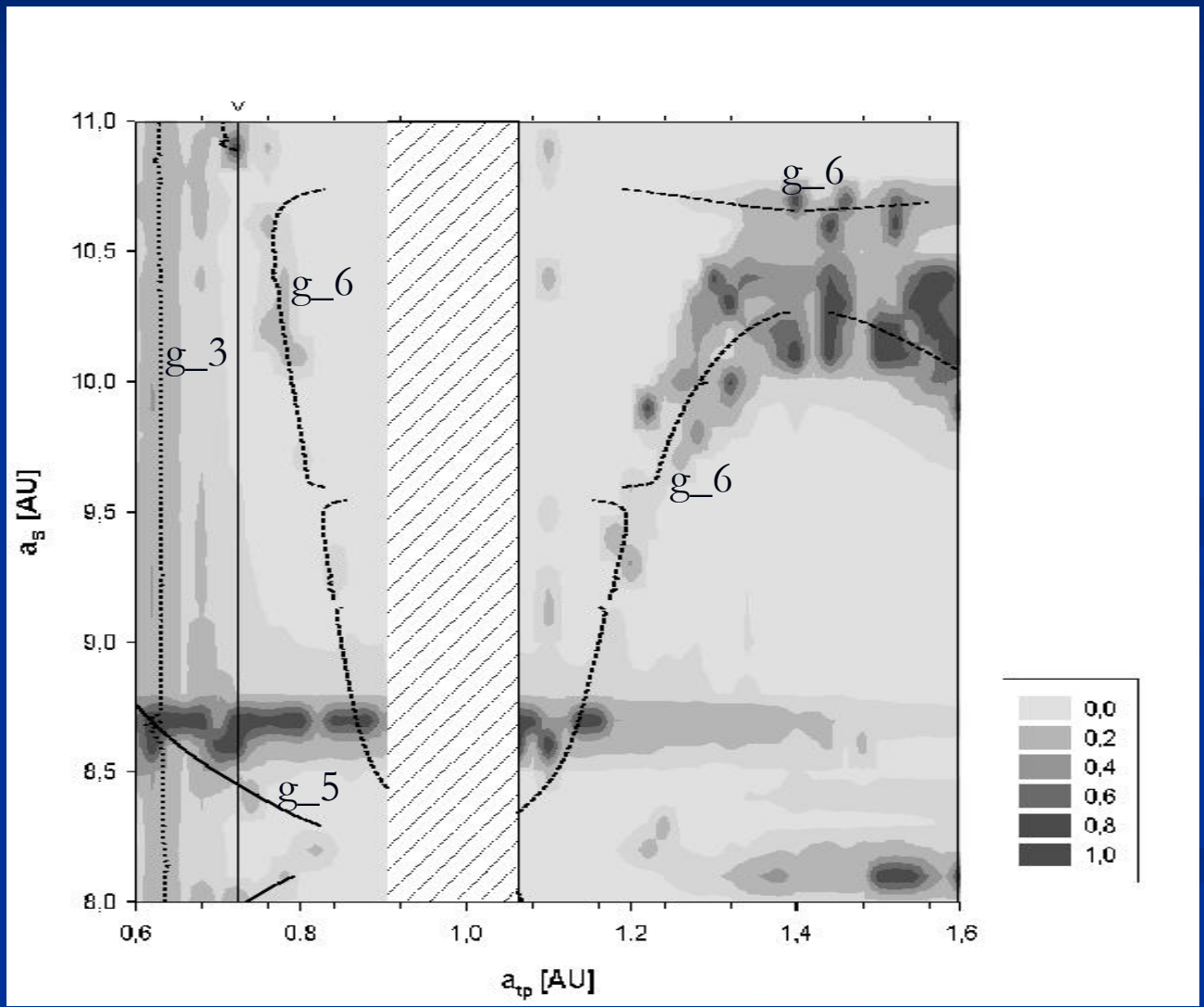
Sun - Jupiter - Saturn - Earth/Moon

Pilat-Lohinger, E., Süli, A., Robutel, P., Freistetter, F., 2008, ApJ, 681, p.1639

Pilat-Lohinger,E., Robutel, P., Süli, A., Freistetter, F. ,2008, CeMDA, 102, p.83



Secular Perturbations of Jupiter, Saturn and Earth on the motion in the HZ:



Summary

- General stability studies are useful but only possible for simple systems like: detection of a small terrestrial planet in a single-star single-planet – perturbations due to MMRs

- In multi-planetary systems: secular perturbations occur in addition to the MMRs; both might lead to instabilities