Earth-like planets in multi-planetary systems similar to the Solar system

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Motivation

The discovery of
the planetary system

OGLE 06-109l

Classification of the known multi-planet systems
(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 ..... 11 AU

i_{sat} = 10 .... 60 deg

Testplanets in the HZ:

a_{tp} = 0.6 ..... 1.6 AU

Mercury 6 (J. Chambers)

Integration time:

20 mio years

HZ: maximum ecc.

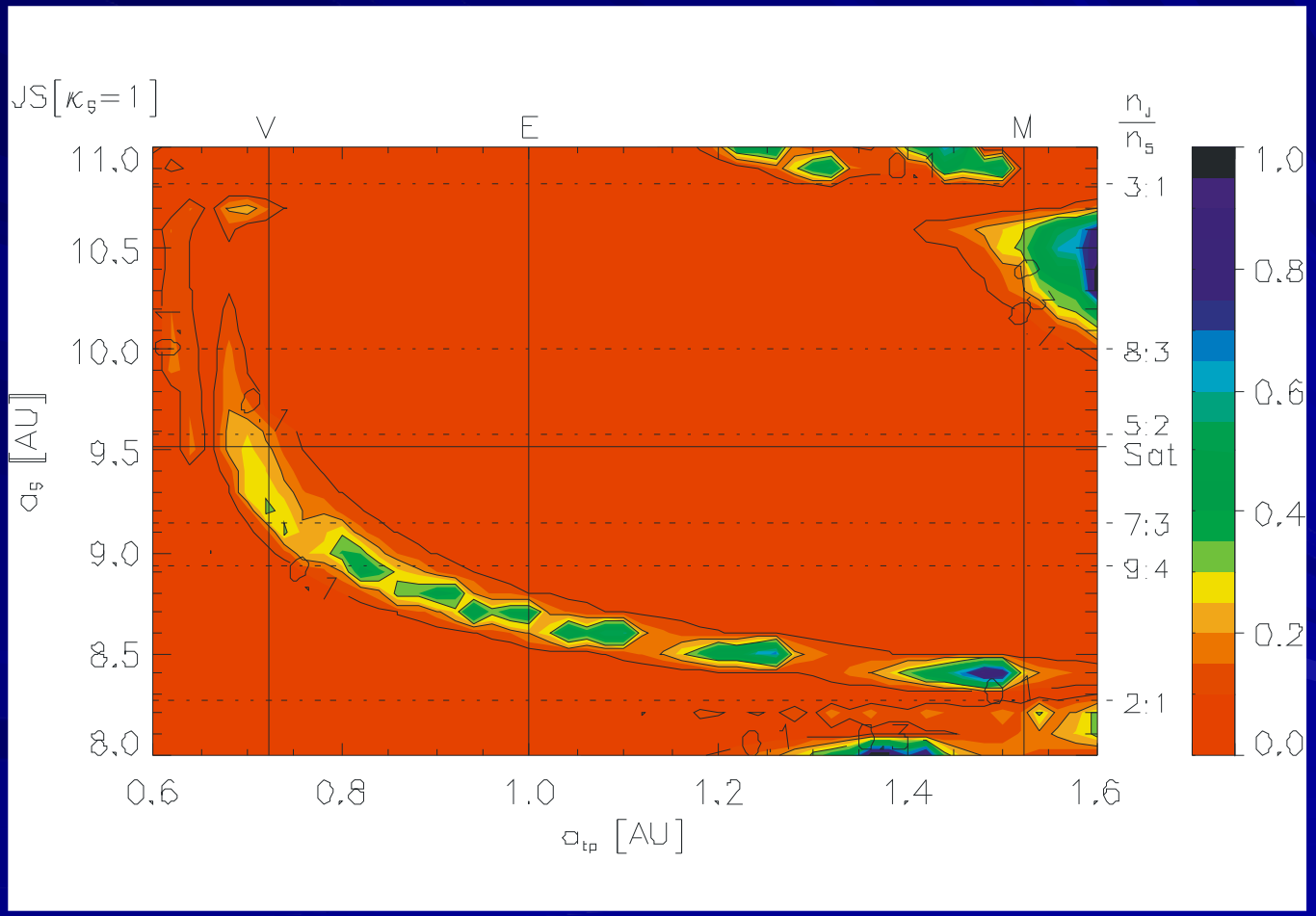
HZ im Sonnensystem:

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

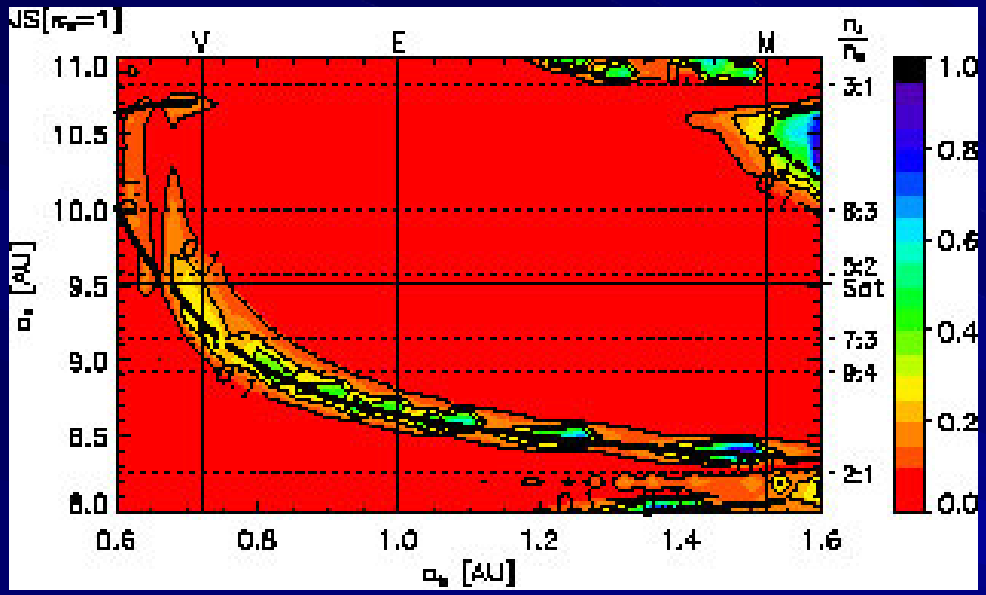
a< 0.93 AU → H_2O becomes a major atmospheric compound and is rapidly lost to space after UV photolysis

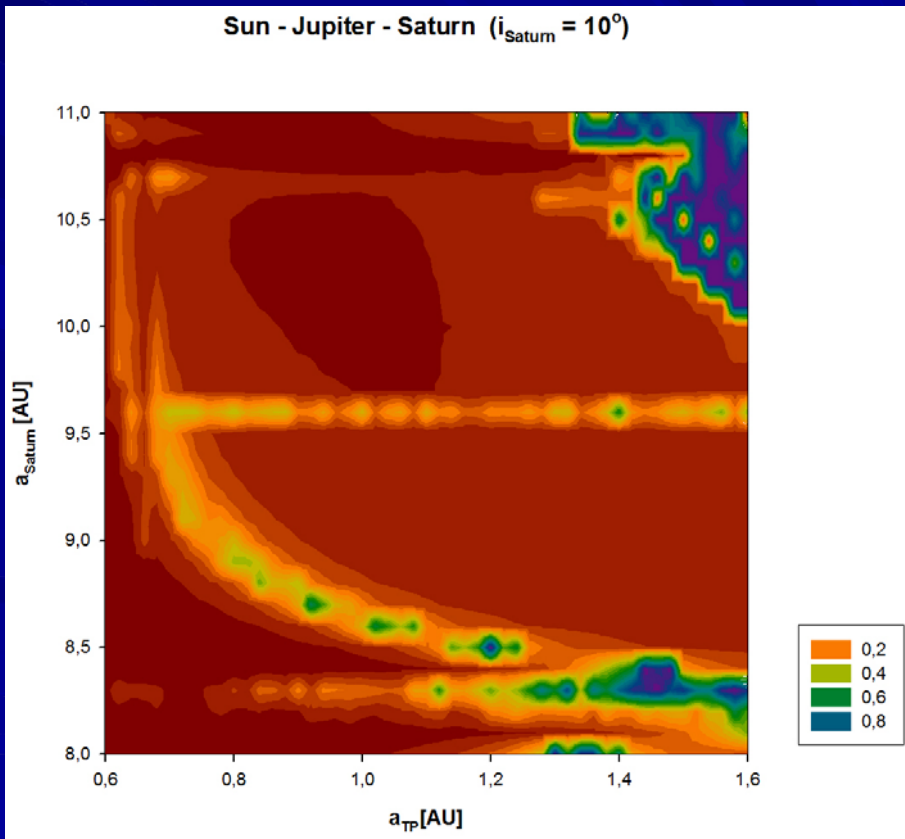
a>1.3 AU → CO2 condensates in the atmosphere producing CO_2-clouds, that can affect significantly the T-CO_2 coupling

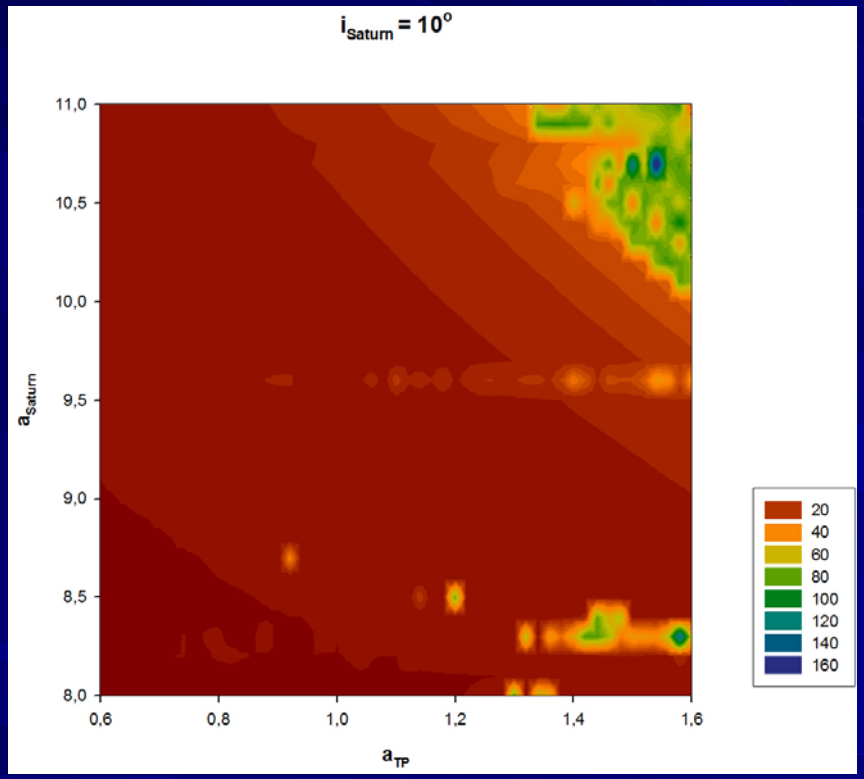
Sun – Jupiter – Saturn

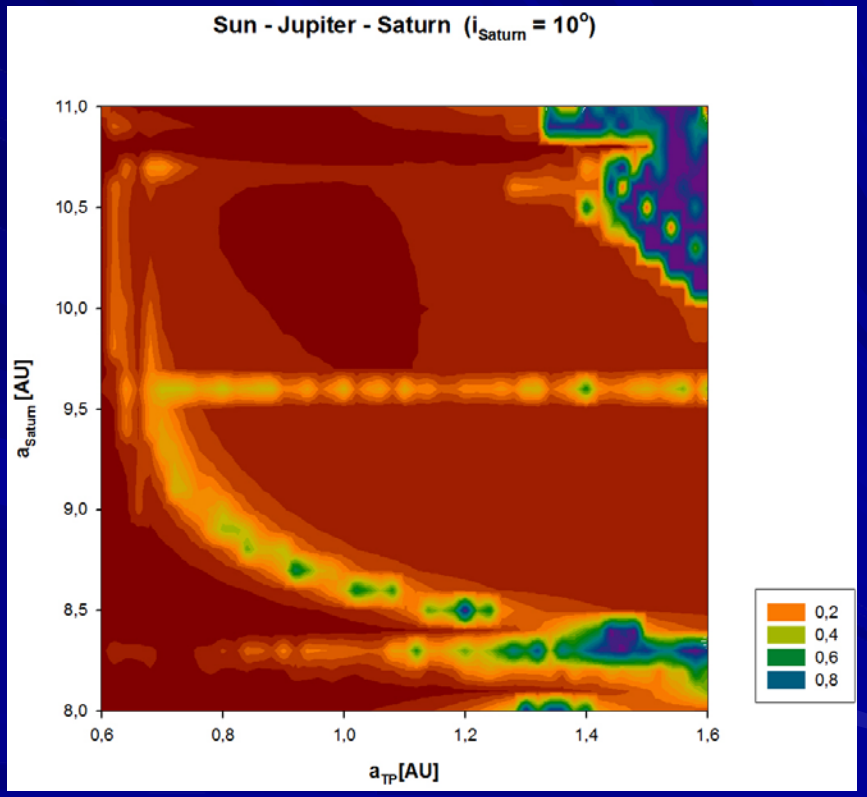


Increase of i_{Saturn} = 10 deg

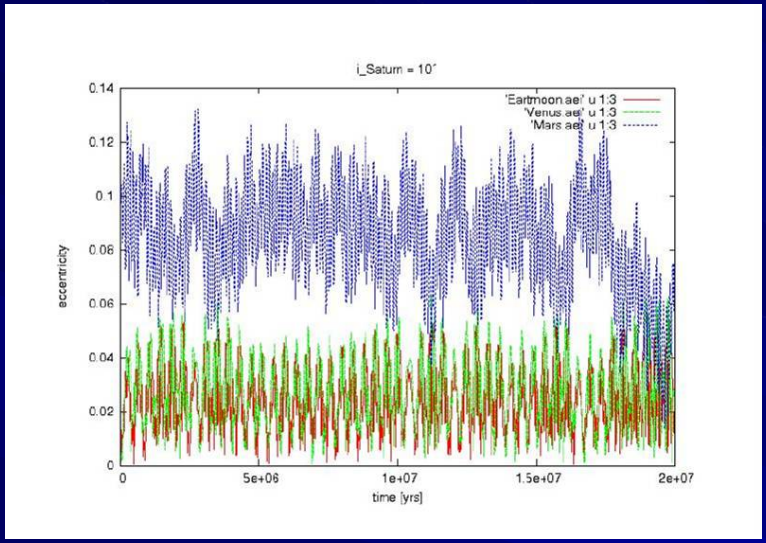


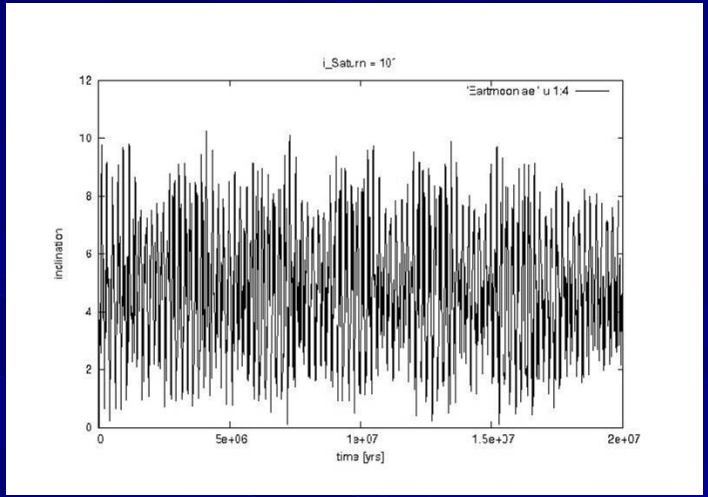


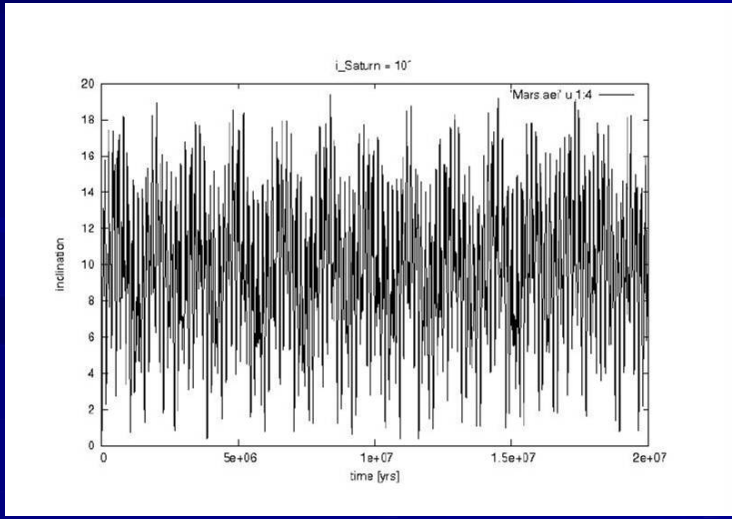

$i_{Saturn} = 10^o$
11,0
10,5
10,0
9,5
9,0
8,5
8,0
a_{Saturn}
0,6
0,8
1,0
1,2
1,4
1,6
a_{TP}
20
40
60
80
100
120
140
160

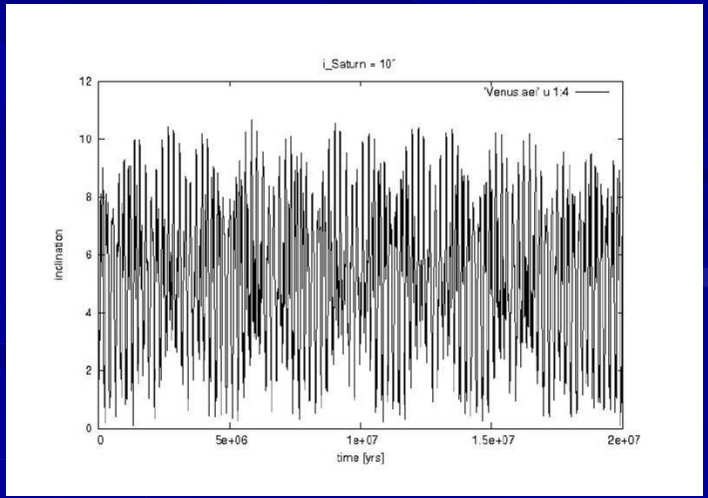

Sun - Jupiter - Saturn ($i_{Saturn} = 10^o$)
11,0
10,5
10,0
9,5
9,0
8,5
8,0
a_{Saturn} [AU]
0,6
0,8
1,0
1,2
1,4
1,6
a_{TP}[AU]
0,2
0,4
0,6
0,8

Orbits of Venus, Earth and Mars

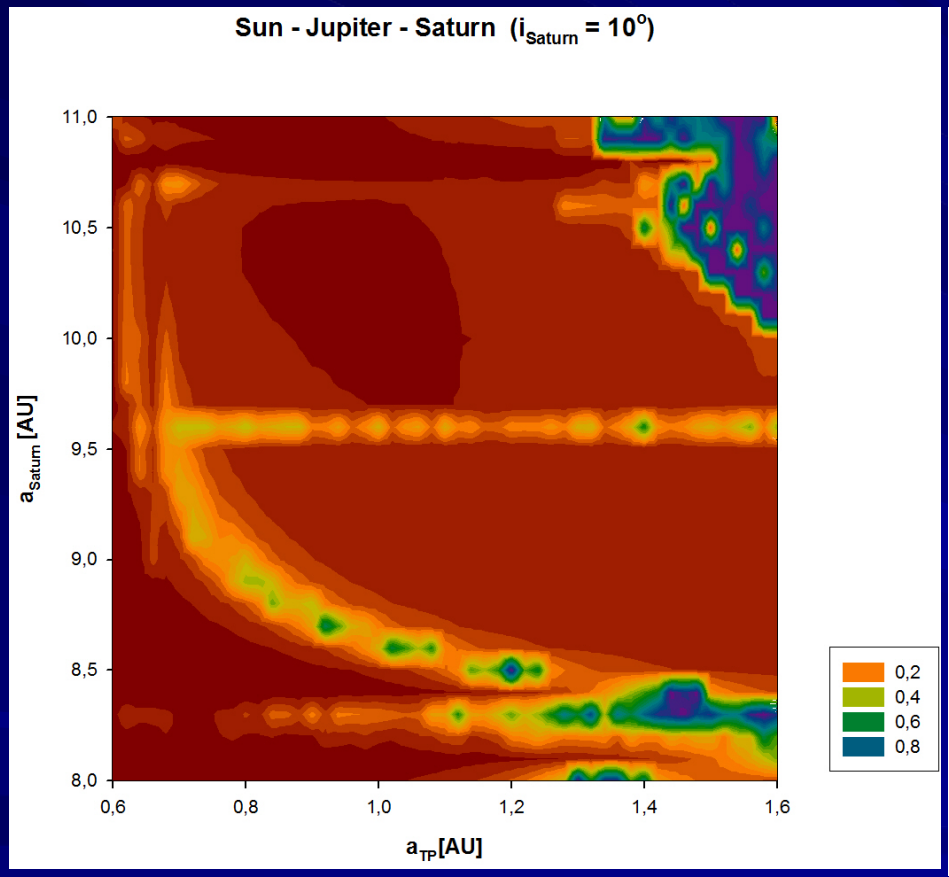


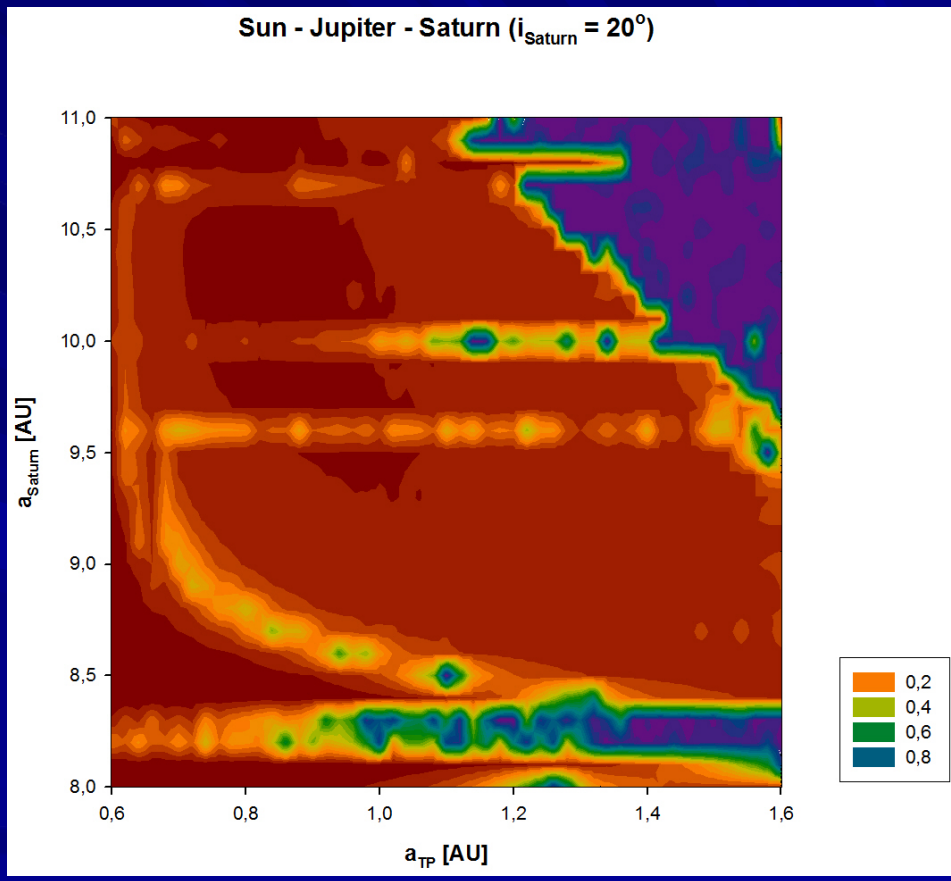




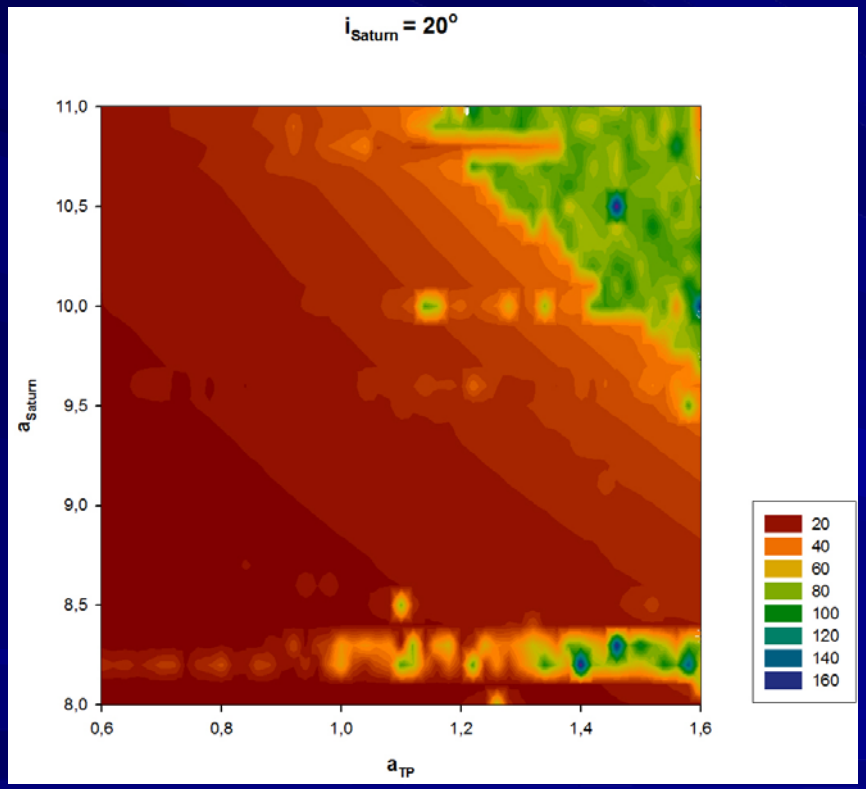


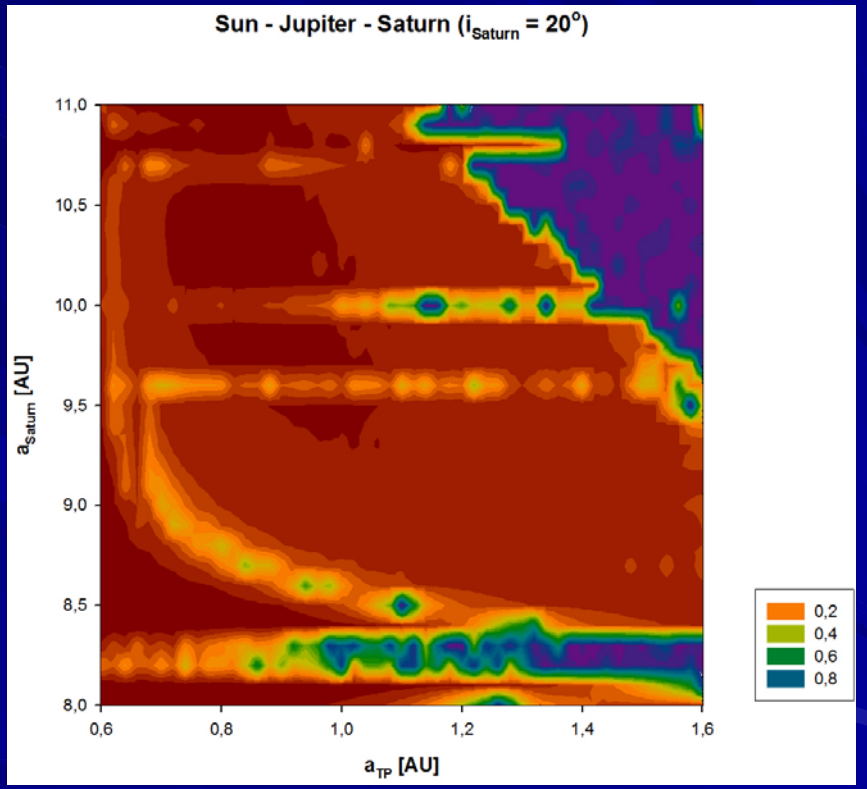
i_{Saturn} = 20deg

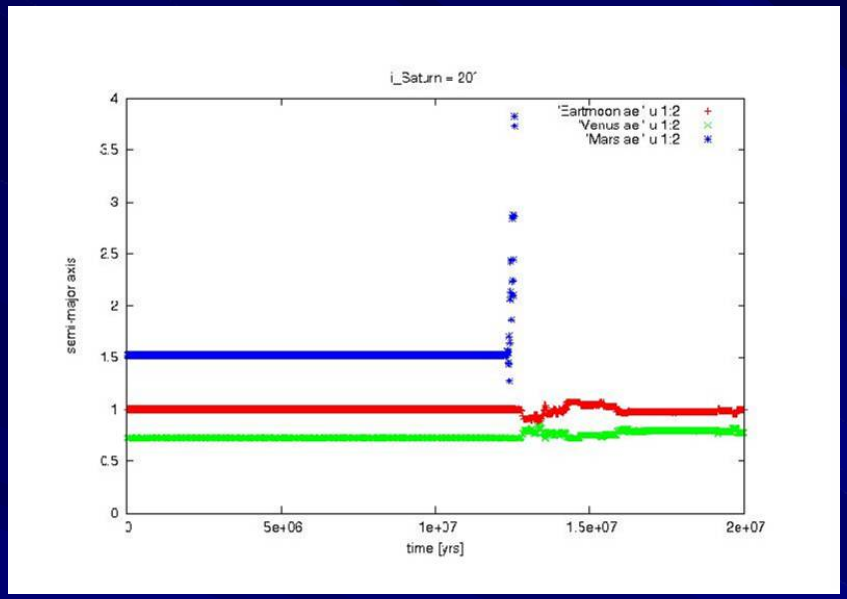


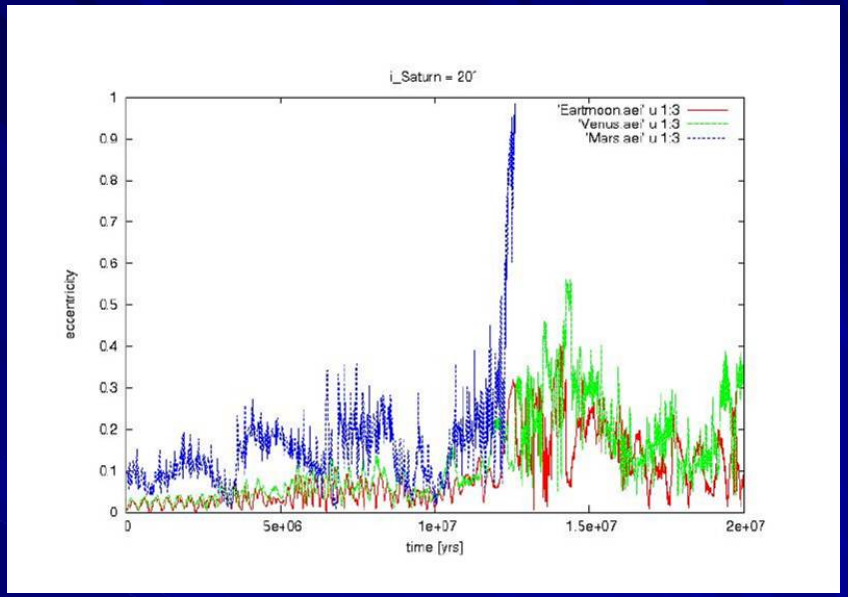


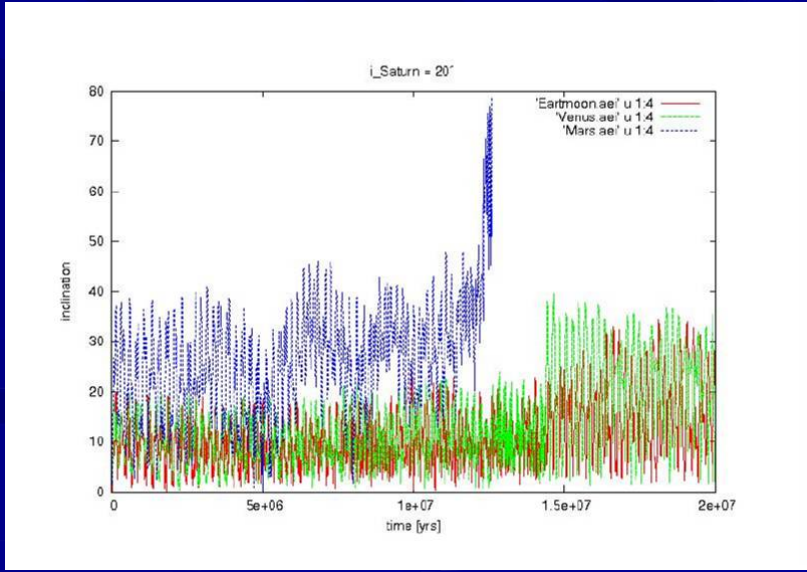
Escape of Saturn for a_Sat = 8.2 AU


i_{Saturn} = 20°
11,0
10,5
10,0
9,5
9,0
8,5
8,0
a_{Saturn}
0,6
0,8
1,0
1,2
1,4
1,6
a_{TP}
20
40
60
80
100
120
140
160

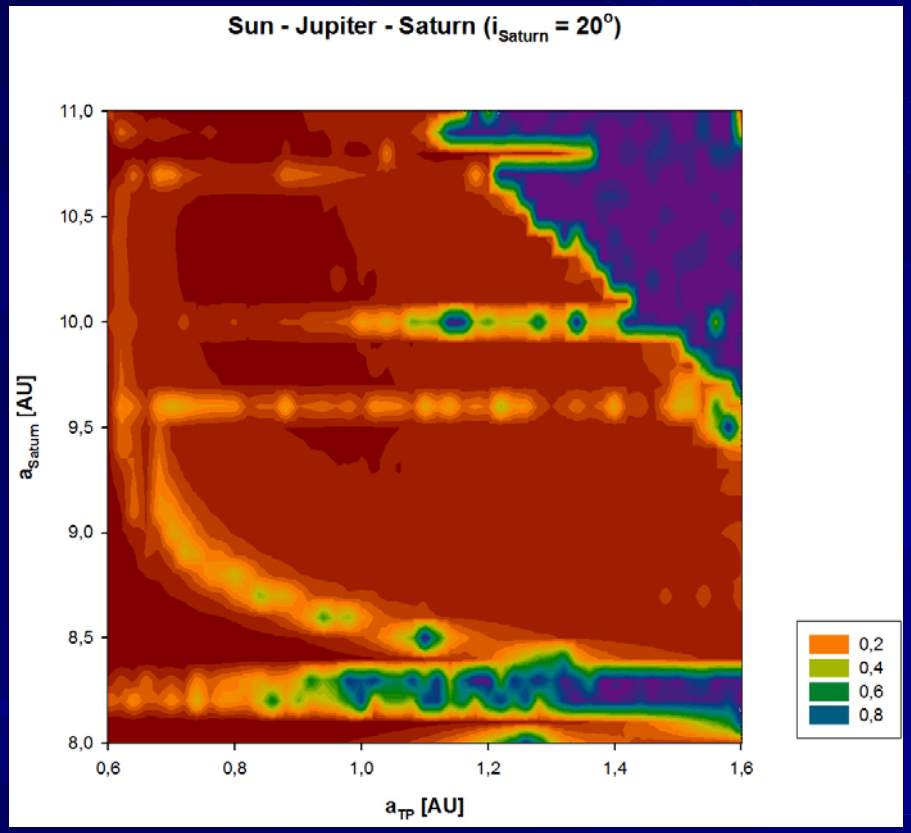

Sun - Jupiter - Saturn (i_{Saturn} = 20°)
11,0
10,5
10,0
9,5
9,0
8,5
8,0
a_{Saturn} [AU]
0,6
0,8
1,0
1,2
1,4
1,6
a_{TP} [AU]
0,2
0,4
0,6
0,8

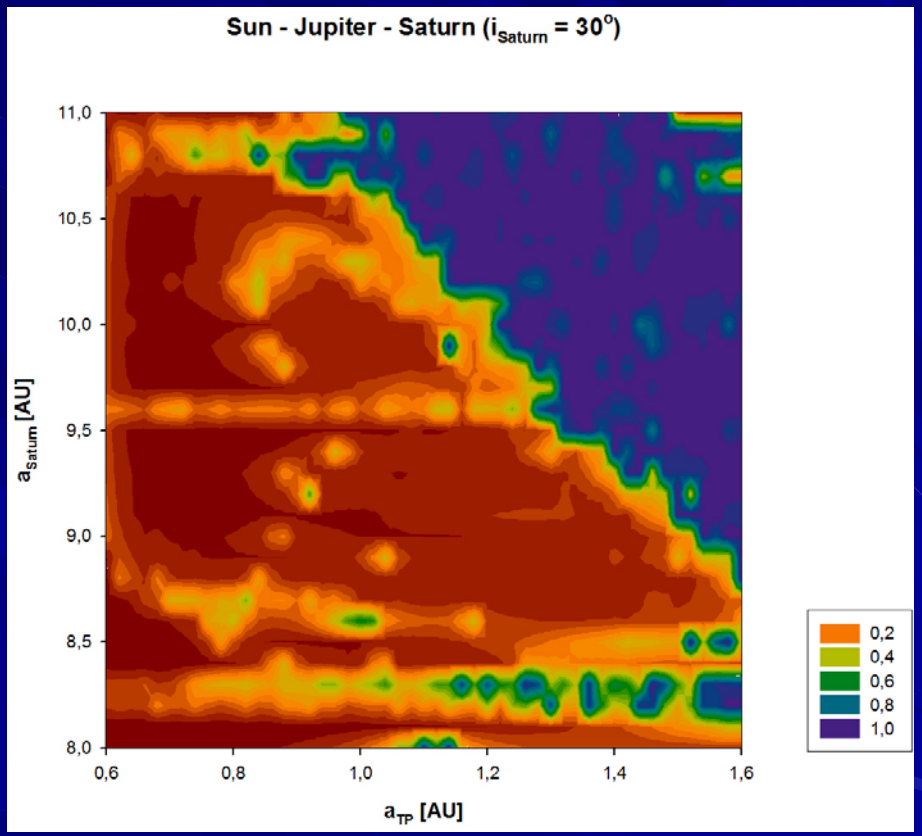

i_Saturn = 20°
'Earthmoon.ae' u 1:2
'Venus.ae' u 1:2
'Mars.ae' u 1:2
semi-major axis
time [yrs]
0
0.5
1
1.5
2
2.5
3
3.5
4
5e+06
1e+07
1.5e+07
2e+07

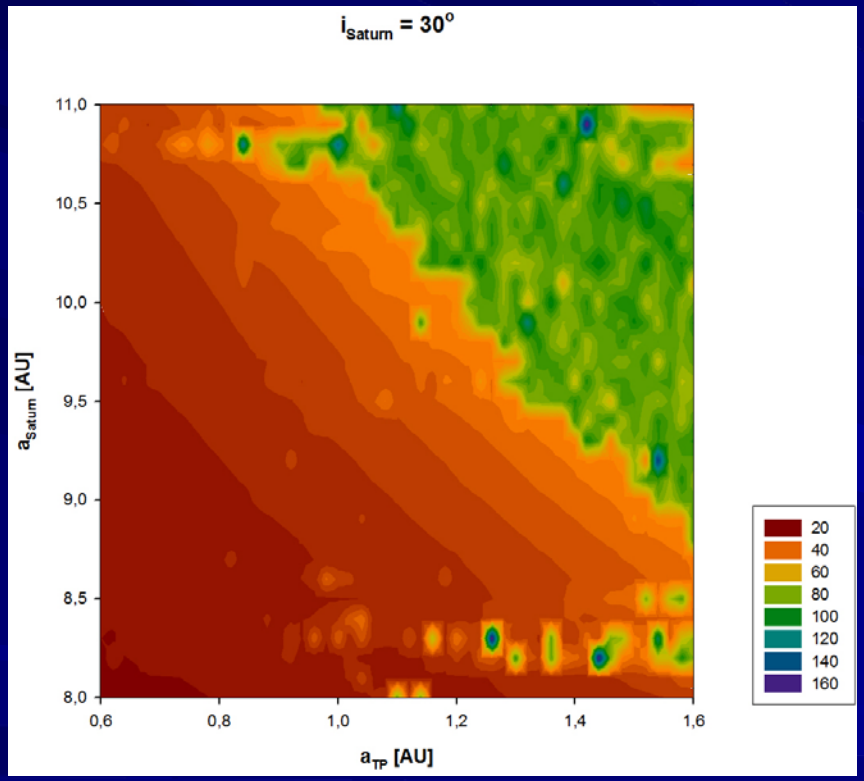

i_Saturn = 20°
'Earthmoon.ae' u 1:3
'Venus.ae' u 1:3
'Mars.ae' u 1:3
eccentricity
time [yrs]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
5e+06
1e+07
1.5e+07
2e+07

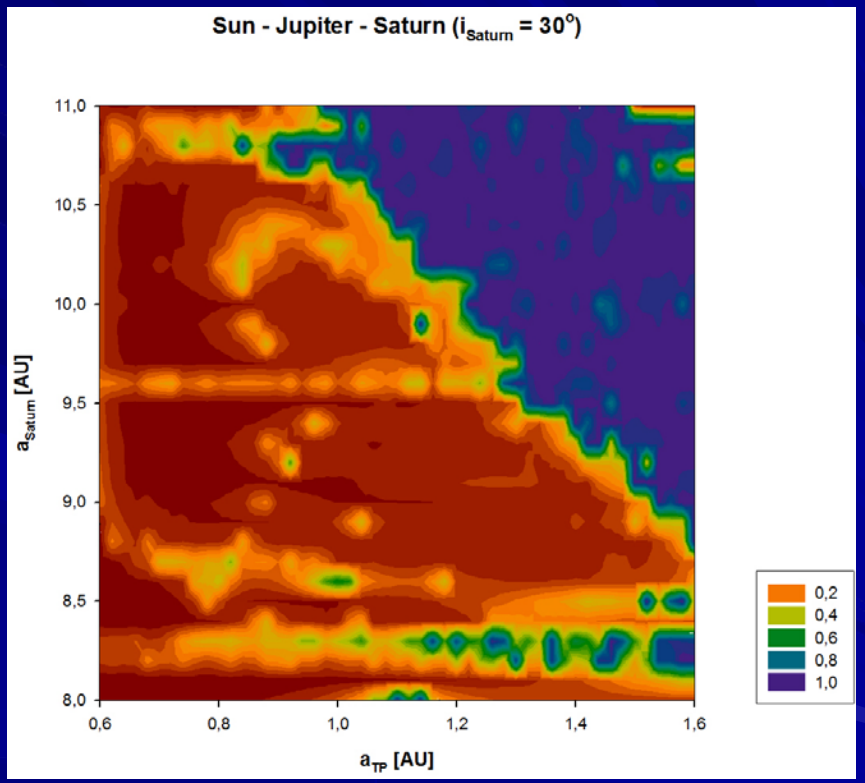

i_Saturn = 20°
'Earthmoon.ae' u 1:4
'Venus.ae' u 1:4
'Mars.ae' u 1:4
inclination
time [yrs]
0
10
20
30
40
50
60
70
80
5e+06
1e+07
1.5e+07
2e+07

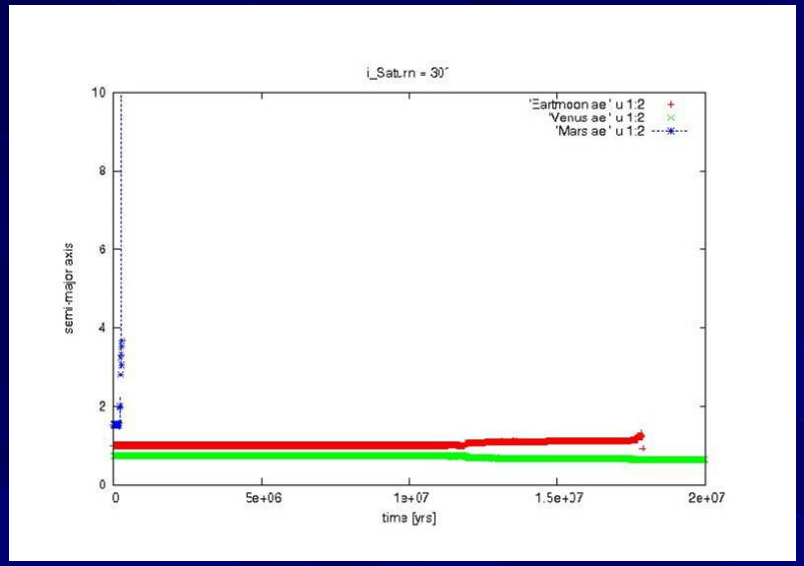
$i_{Saturn} = 30^{deg}$

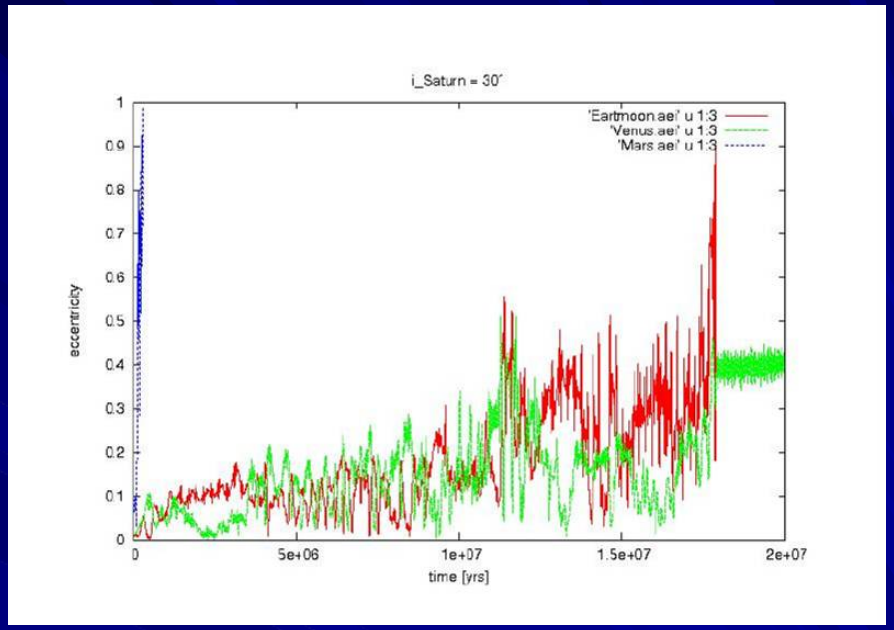


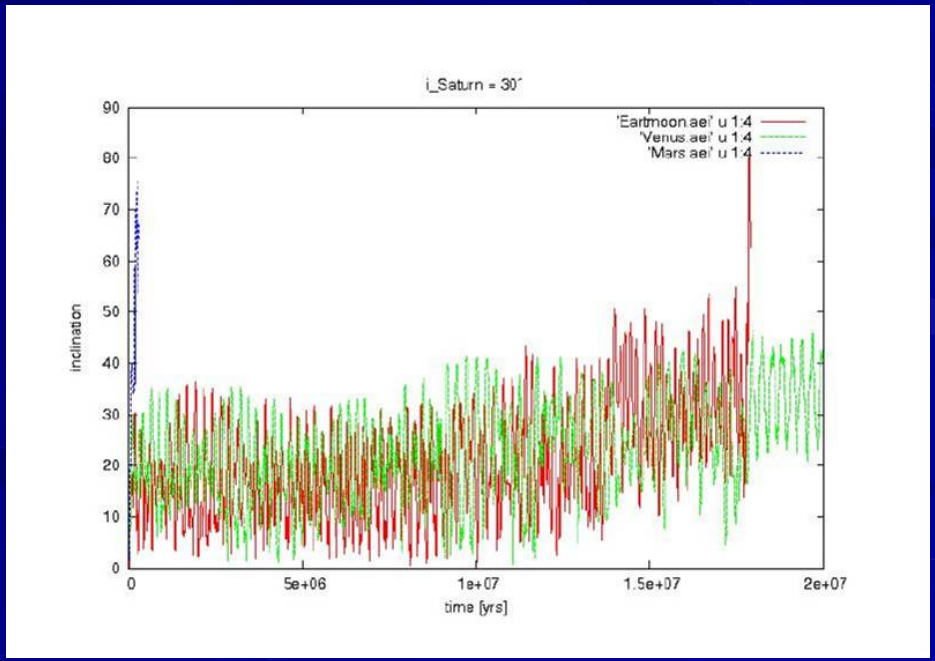



i_{Saturn} = 30°
11,0
10,5
10,0
9,5
9,0
8,5
8,0
a_{Saturn} [AU]
0,6
0,8
1,0
1,2
1,4
1,6
a_{TP} [AU]
20
40
60
80
100
120
140
160

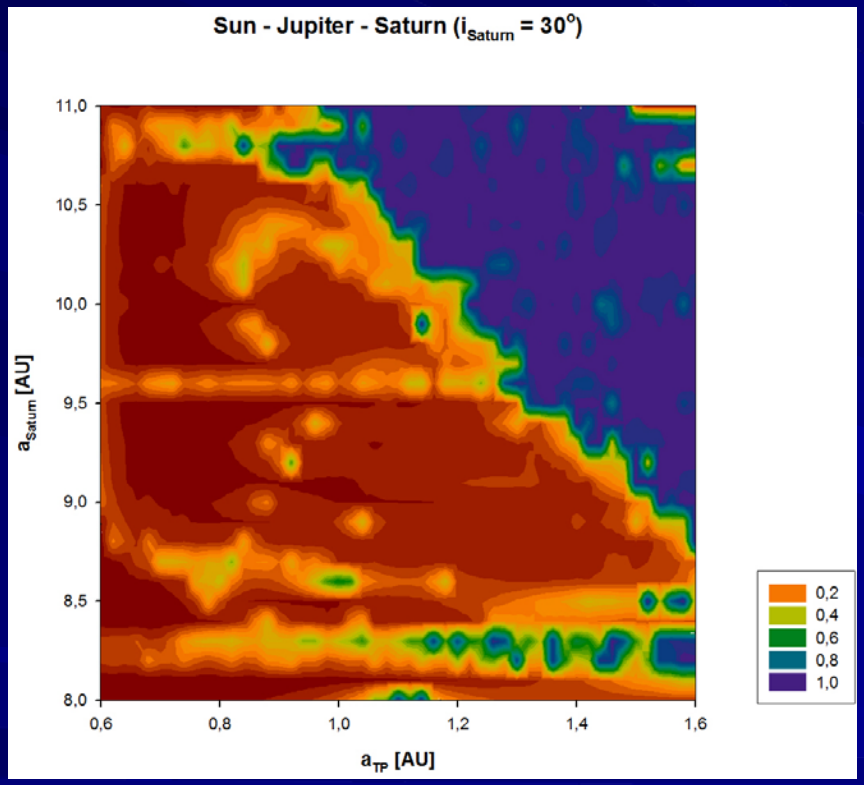

Sun - Jupiter - Saturn (i_{Saturn} = 30°)
11,0
10,5
10,0
9,5
9,0
8,5
8,0
a_{Saturn} [AU]
0,6
0,8
1,0
1,2
1,4
1,6
a_{TP} [AU]
0,2
0,4
0,6
0,8
1,0

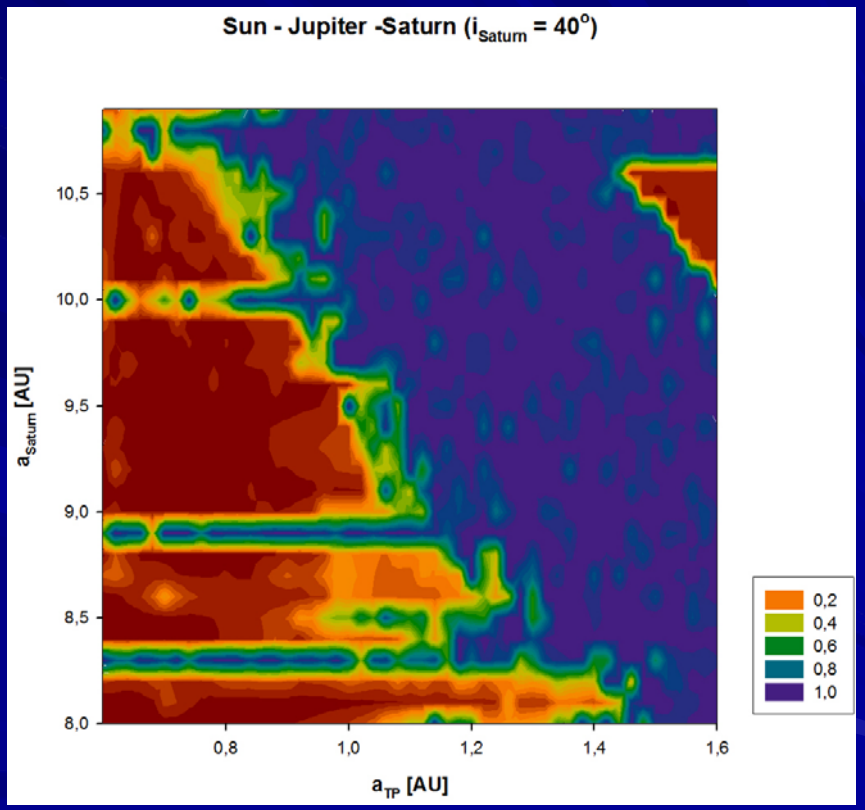

i_Saturn = 30°
'Eartmoon.ae' u 1:2
'Venus.ae' u 1:2
'Mars.ae' u 1:2
semi-major axis
time [yrs]
0
2
4
6
8
10
0
5e+06
1e+07
1.5e+07
2e+07

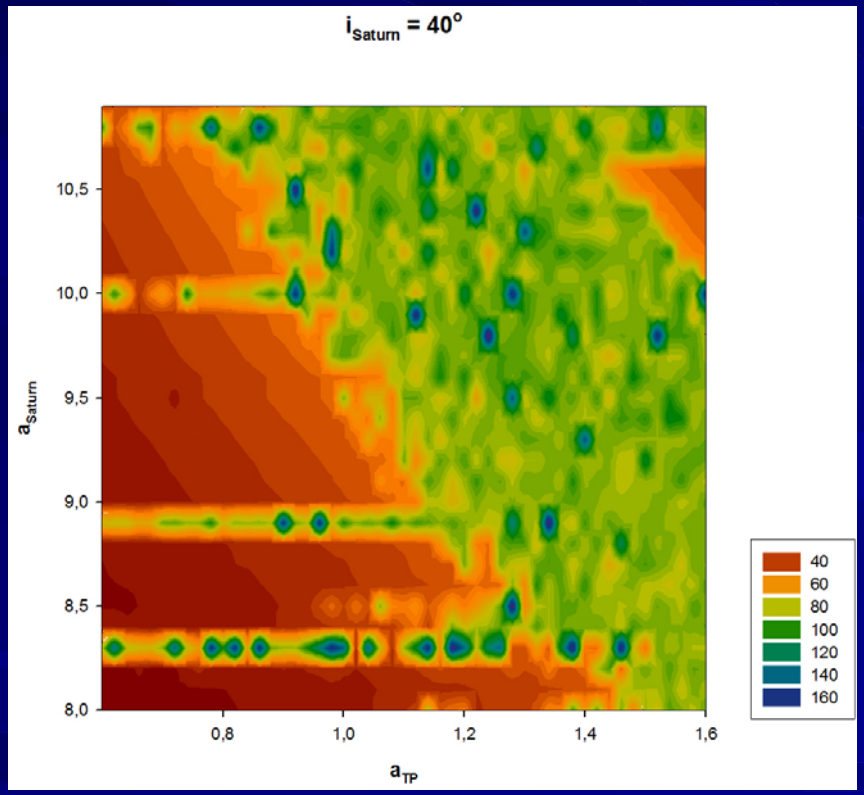

i_Saturn = 30°
'Eartmoon.ae' u 1:3
'Venus.ae' u 1:3
'Mars.ae' u 1:3
eccentricity
time [yrs]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5e+06
1e+07
1.5e+07
2e+07

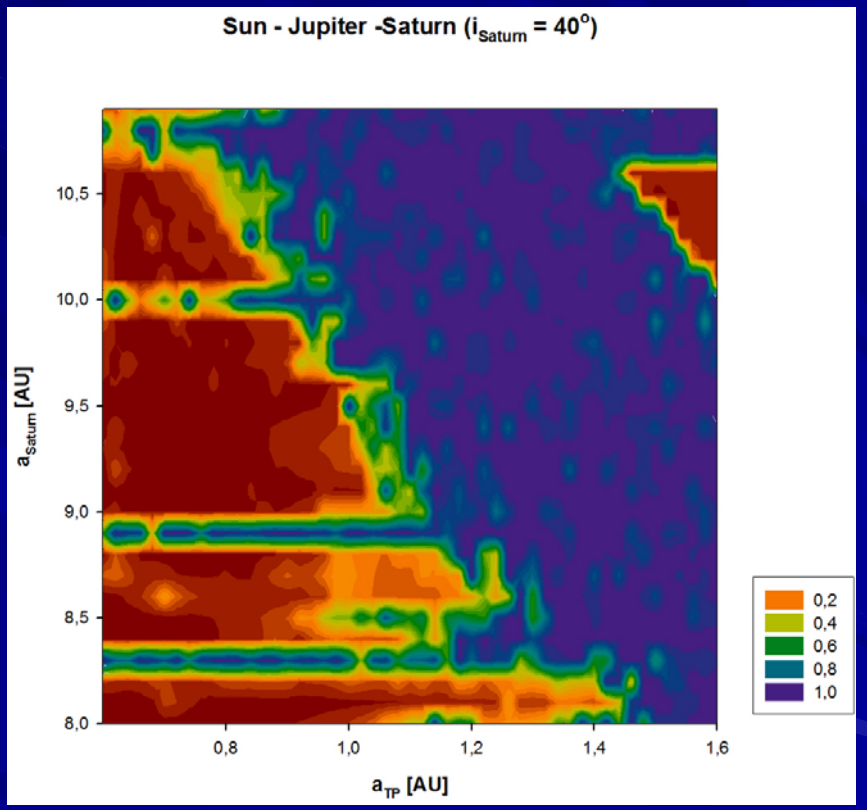

i_Saturn = 30°
'Eartmoon.ae' u 1:4
'Venus.ae' u 1:4
'Mars.ae' u 1:4
inclination
time [yrs]
0
10
20
30
40
50
60
70
80
90
0
5e+06
1e+07
1.5e+07
2e+07

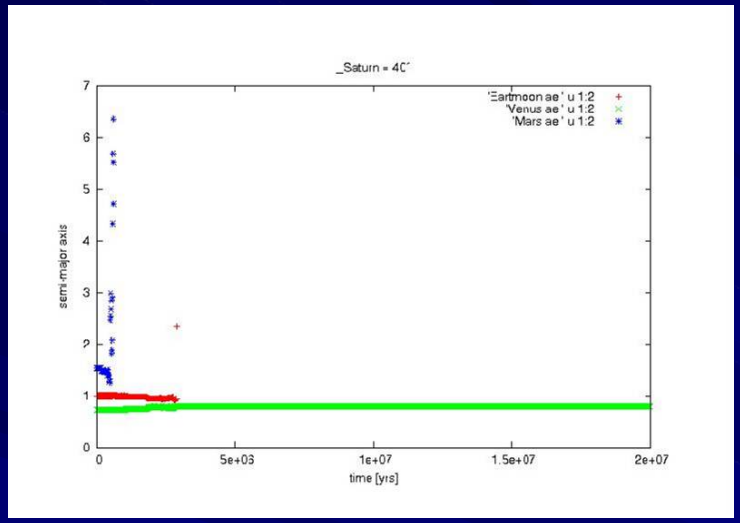
i_{Saturn} = 40 deg

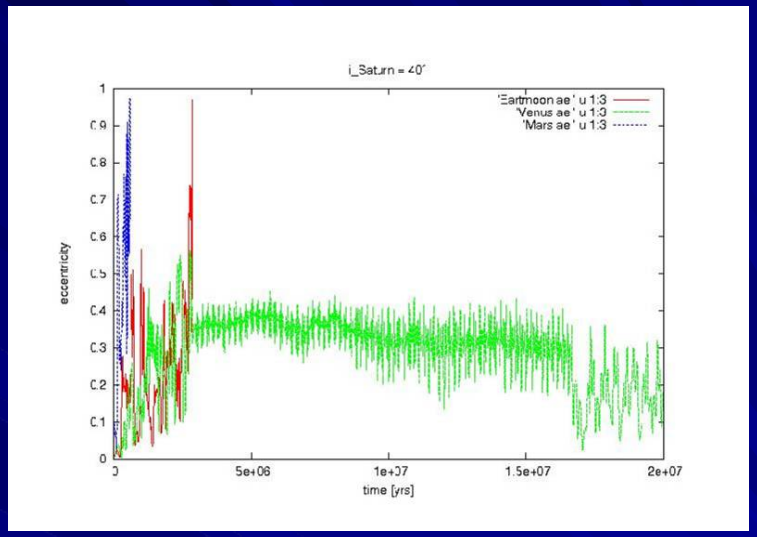


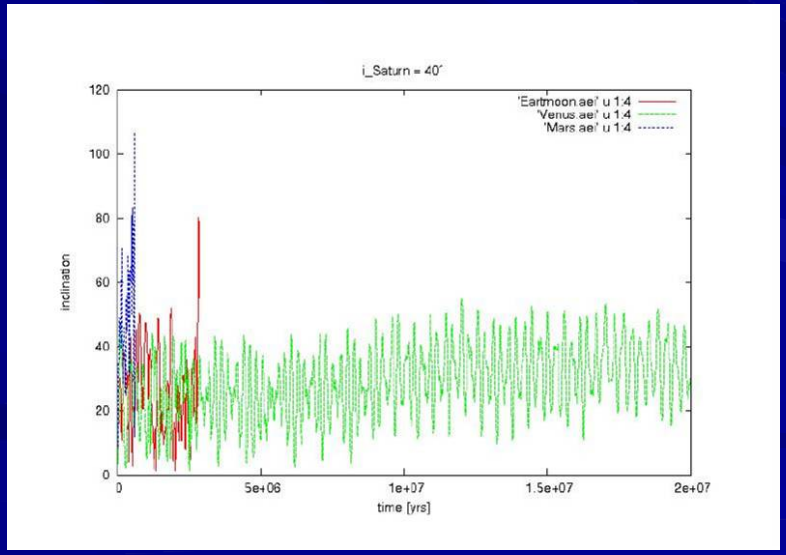



i_{Saturn} = 40°
10,5
10,0
9,5
9,0
8,5
8,0
a_{Saturn}
0,8
1,0
1,2
1,4
1,6
a_{TP}
40
60
80
100
120
140
160

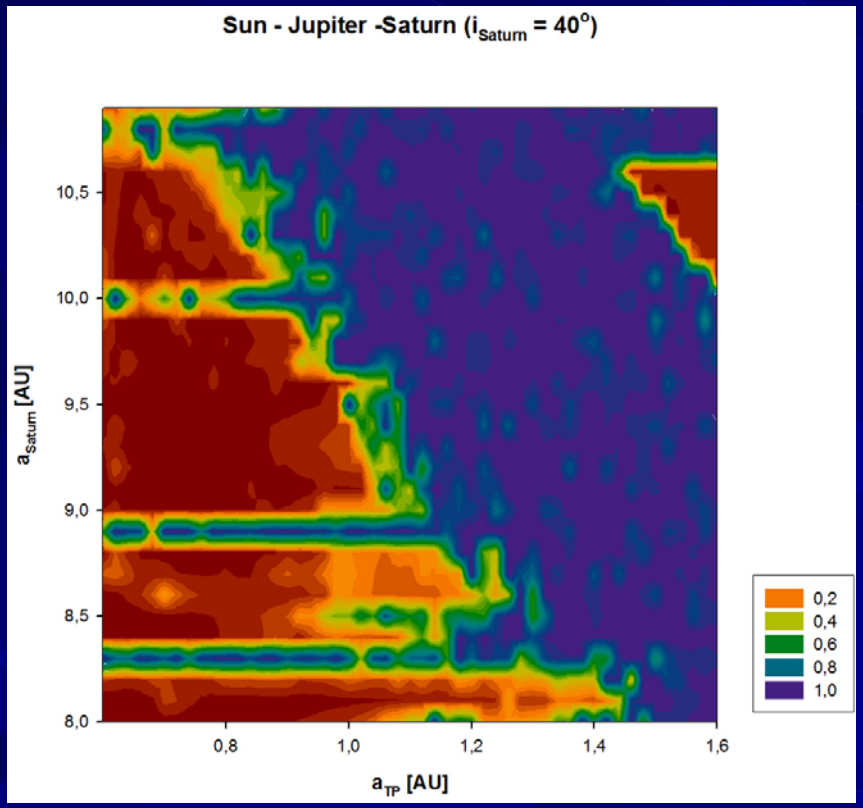

Sun - Jupiter -Saturn (i_{Saturn} = 40°)
10,5
10,0
9,5
9,0
8,5
8,0
a_{Saturn} [AU]
0,8
1,0
1,2
1,4
1,6
a_{TP} [AU]
0,2
0,4
0,6
0,8
1,0

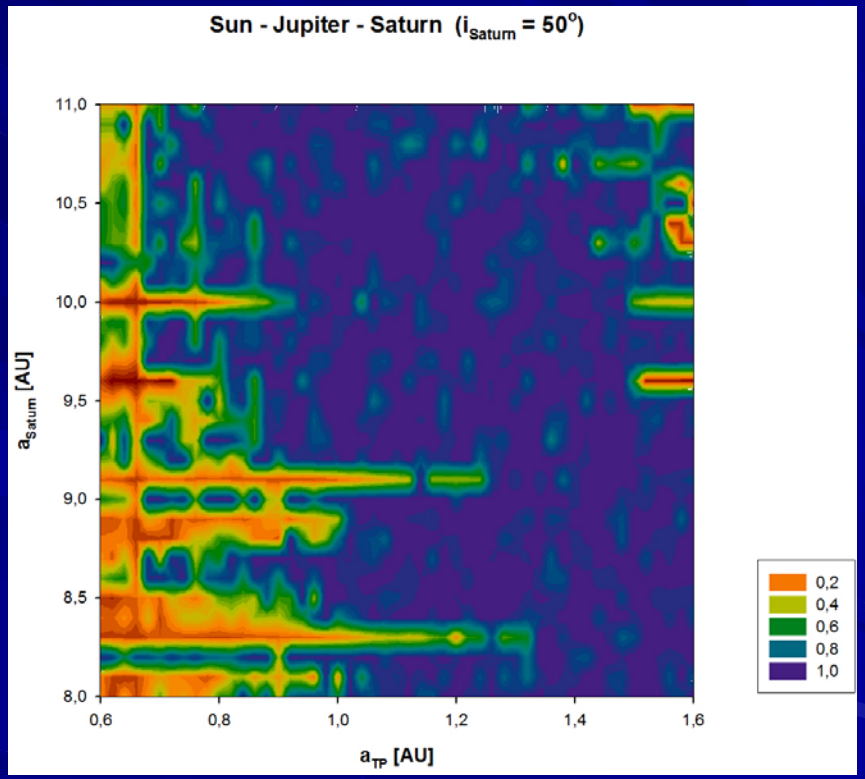

_Saturn = 40°
'Earthmoon.ae' u 1:2
'Venus.ae' u 1:2
'Mars.ae' u 1:2
semi-major axis
time [yrs]
0
1
2
3
4
5
6
7
5e+06
1e+07
1.5e+07
2e+07

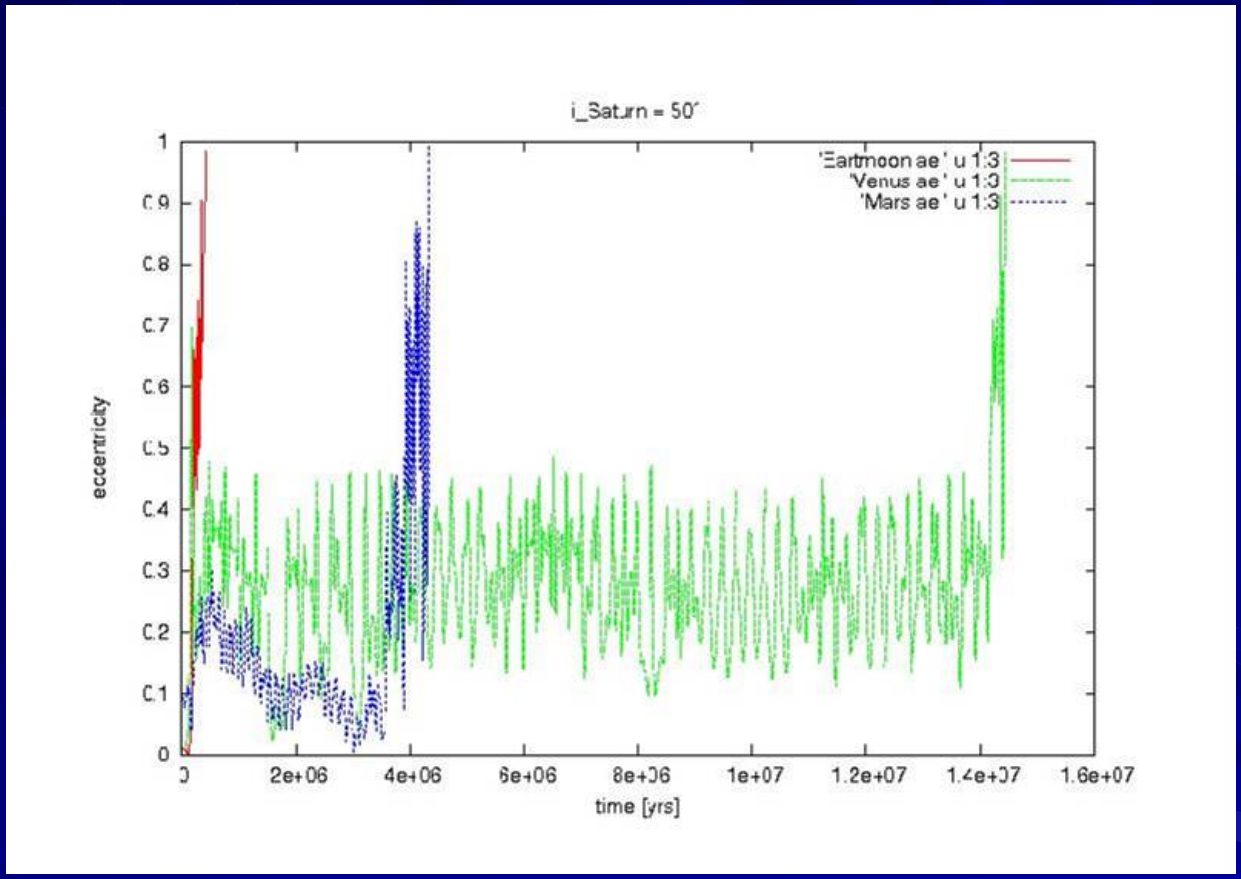

i_Saturn = 40°
'Earthmoon.ae' u 1:3
'Venus.ae' u 1:3
'Mars.ae' u 1:3
eccentricity
time [yrs]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
5e+06
1e+07
1.5e+07
2e+07

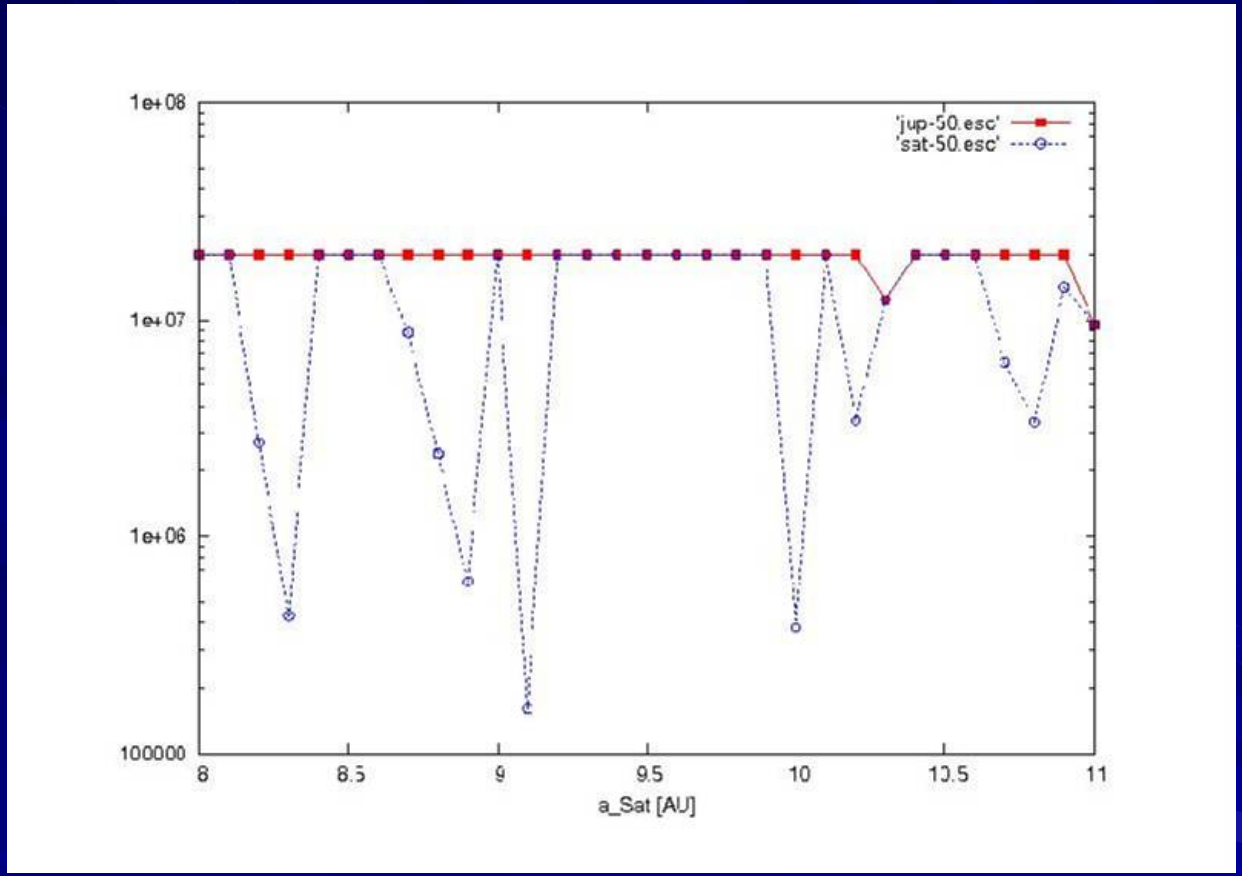

i_Saturn = 40°
'Earthmoon.ae' u 1:4
'Venus.ae' u 1:4
'Mars.ae' u 1:4
inclination
time [yrs]
0
20
40
60
80
100
120
5e+06
1e+07
1.5e+07
2e+07

$i_{Saturn} = 50$ deg

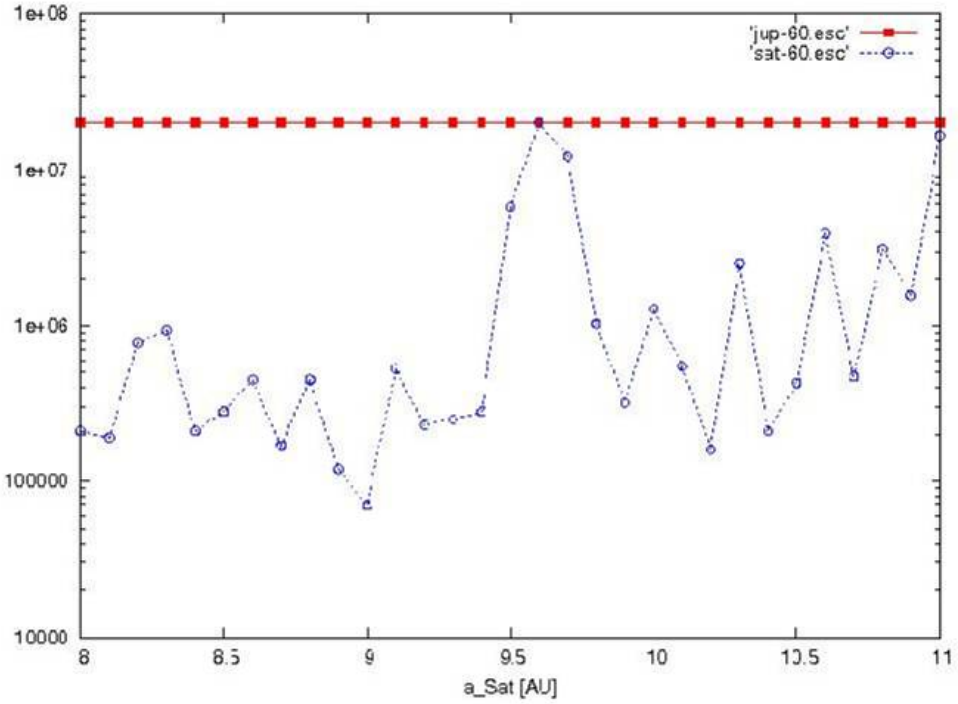





i_Saturn = 50°
'Earthmoon ae ' u 1:3
'Venus ae ' u 1:3
'Mars ae ' u 1:3
eccentricity
time [yrs]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
2e+06
4e+06
6e+06
8e+06
1e+07
1.2e+07
1.4e+07
1.6e+07


'jup-50.esc'
'sat-50.esc'
1e+08
1e+07
1e+06
100000
8
8.5
9
9.5
10
10.5
11
a_Sat [AU]

$i_{Saturn} = 60$ deg



Saturn will escape except for $a_{Saturn} = 9.6$ AU

Conclusion

- The inclination of Saturn influences the inner Solar system
- For small i -- the two planets in MMR
- High i -- may lead to escapes of Saturn
- For i > 60 all systems are unstable