Inclined orbits in the HZ of multiplanetary systems

Barbara Funk
Eötvös University

AHW 2010 - Vienna, 09.04.2010

Table of contents

- Multiplanetary systems in the DASSC-Catalogue
- Calculating the HZ
- Model and Methods
- Kozai-Resonances
  - In the restricted 3 body problem
- Investigated Systems
  - Examples
    - 47 Uma
    - HD 190360
- Summary

Multiplanetary systems in the DASSC

- The DASSC (Darwin All Sky Target Star Catalogue) lists all stars suitable for the search for Earth like planets
  - Combined data from Hipparcos, 2MASS catalogue, Catalogue of Components of Double and Multiple stars (CCDM), and the ninth catalogue of spectroscopic binary orbits (SB9) were used
  - Then all F, G, K and M stars within 30 pc were selected
  - By using the HR Diagram, all main sequence stars were selected in the next step
- The resulting DASSC contains a sample of 2303 identified objects, of which 284 are F, 464 G, 883 K and 672 M type stars.

- For Details see: Kaltenegger, L., Eiroa, C., Fridlund, M.: 2008, "Target star catalogue for Darwin: Nearby Stellar sample for a search for terrestrial planets", submitted to A & A

Multiplanetary systems in the DASSC

HIP	HD	Planet Name	St. Mass [MSun]	St. Spec. Type	Pl. Mass [MJup]	Pl. Semi-axis	Pl. Ecc	omega	HZ_I (AU)	HZ_O (AU)
40693	69830	HD 69830 b	0,86	K0 V	0,0330	0,0785	0,1	340	0,75	1,47
40693	69830	HD 69830 c	0,86	K0 V	0,0380	0,186	0,13	221	0,75	1,47
40693	69830	HD 69830 d	0,86	K0 V	0,0580	0,63	0,07	224	0,75	1,47
43587	75732	55 Cnc b	0,94	K0/G8 V	0,8240	0,115	0,014	248,9	0,66	1,30
43587	75732	55 Cnc c	0,94	K0/G8 V	0,1690	0,24	0,086	77,9	0,66	1,30
43587	75732	55 Cnc d	0,94	K0/G8 V	3,8350	5,77	0,025	181,3	0,66	1,30
43587	75732	55 Cnc e	0,94	K0/G8 V	0,0340	0,038	0,07	248,9	0,66	1,30
43587	75732	55 Cnc f	0,94	K0/G8 V	0,1440	0,781	0,2	181,1	0,66	1,30
47007	82943	HD 82943 b	1,15	G0	1,8400	1,18	0,18	237	1,03	2,04
47007	82943	HD 82943 c	1,15	G0	1,8500	0,75	0,38	124	1,03	2,04
71395	128311	HD 128311 b	0,84	K0 V	2,1800	1,099	0,25	110,9	0,52	1,03
71395	128311	HD 128311 c	0,84	K0 V	3,2100	1,76	0,17	195,5	0,52	1,03
86796	160691	HD 160691 b	1,08	G3 IV-V	1,6760	1,497	0,128	22	1,10	2,18
86796	160691	HD 160691 c	1,08	G3 IV-V	0,0332	0,09094	0,172	212,7	1,10	2,18
86796	160691	HD 160691 d	1,08	G3 IV-V	0,5219	0,921	0,0666	189,6	1,10	2,18
86796	160691	HD 160691 e	1,08	G3 IV-V	1,8140	5,235	0,0985	57,6	1,10	2,18
98767	190360	HD 190360 b	1,04	G6 IV	1,5020	3,92	0,36	12,4	0,88	1,75
98767	190360	HD 190360 c	1,04	G6 IV	0,0570	0,128	0,01	153,7	0,88	1,75
53721	95128	47 Uma b	1,063	G0 V	2,5300	2,1	0,032	334	1,05	2,07
53721	95128	47 Uma c	1,063	G0 V	0,5400	3,6	0,098	295	1,05	2,07
53721	95128	47 Uma d	1,063	G0 V	1,6400	11,6	0,16	110	1,05	2,07
74995		Gl 581 e	0,31	M3	0,0061	0,03	0	0	0,08	0,17
74995		Gl 581 b	0,31	M3	0,0492	0,04	0	0	0,08	0,17
74995		Gl 581 c	0,31	M3	0,0169	0,07	0,17	250	0,08	0,17
74995		Gl 581 d	0,31	M3	0,0223	0,22	0,38	327	0,08	0,17
113020		Gl 876 b	0,334	M4 V	2,6400	0,211	0,029	275,52	0,14	0,28
113020		Gl 876 c	0,334	M4 V	0,8300	0,132	0,266	275,26	0,14	0,28
113020		Gl 876 d	0,334	M4 V	0,0198	0,021	0,139	170,6	0,14	0,28

Calculating the HZ

The HZ is defined as the region, where liquid water can exist on the surface of a terrestrial planet.

Depends on: Luminosity (L), Spectraltyp, Mass, Age,... of the Star

To calculate the inner and outer border of the HZ (d) we used the following formula (based on a climate model, for Details: Kaltenegger et al. 2008)

$$d = \sqrt{\frac{\frac{L}{L_{Sun}}}{S_{eff}}}$$

Where S_{eff} is the normalized solar flux factor that takes the wavelength dependent intensity distribution of the spectrum of dierent spectral classes into account

Spectral-Type	Inner boarder	Outer boarder
F	1.90	0.46
G	1.41	0.36
K	1.05	0.27
M	1.05	0.27

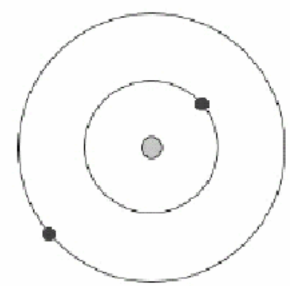
Calculating the HZ

Additional the possibility for life on a terrestrial planet depends on:

- The orbits of the known planets
- The orbit of the terrestrial planet
- Mass,
- Atmosphere,... of the terrestrial planet
- ….

Model and Methods

- **Configuration: Multiple planetary system** around a **single star**



- **Dynamical model:** Additional to the known components of these systems we calculated test-planets inside the HZ. Therefore we used:
    - the **restricted n-body problem** consisting of the star, the discovered planets and massless test-planets in the same plane and on inclined orbits

Model and Methods – Initial conditions

Initial conditions for the test-planets:

	Test-planets
a	HZ, Δa = 0.05 or 0.01 AU
e	0
i	i = 0° to 60°, Δi = 5°
ω, Ω, M	0°

Model and Methods – Integration and analysis

- **Integrators:**
  - **Lie-Series** Integration Method
    - Integration – Time: 500 000 years
- **Analysis:**
  - The **maximum eccentricity**
  - The **escape time**

Kozai-Resonances

- Characterized by a libration of ω around 90° or 270°
- Coupling of the eccentricity and the inclination

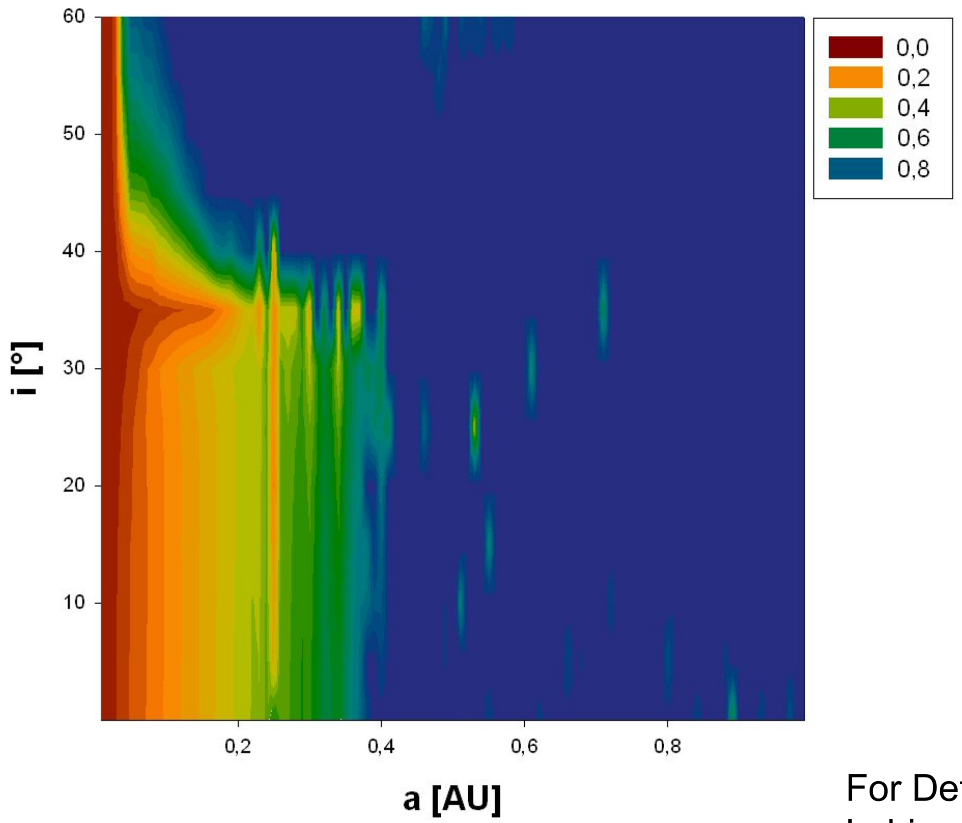
- Earlier Investigations:
  - Restricted 3 body problem

	gas giant	test-planet
Semi-major axis [AU]	1.0	0.01, 0.02,..., 0.99
Eccentricity	0.0, 0.1,... 0.9	0.0
Inclination [deg]	0	0, 5,..., 60
$\mu = \frac{M_{planet}}{M_{star}+M_{planet}}$	0.0005, 0.001, 0.003	
Integration time	100,000 years	

  - ω, Ω, M = 0°

Kozai-Resonances

- Some examples in the restricted 3 body problem:



$\mu = 0.0005$
$e_{GG} = 0.5$

For Details see: B. Funk, A.-S. Libert, Á. Süli, E. Pilat-Lohinger: On the influenze of Kozai resonances in the habitable zones of extrasolar planetary systems, A & A, in preparation

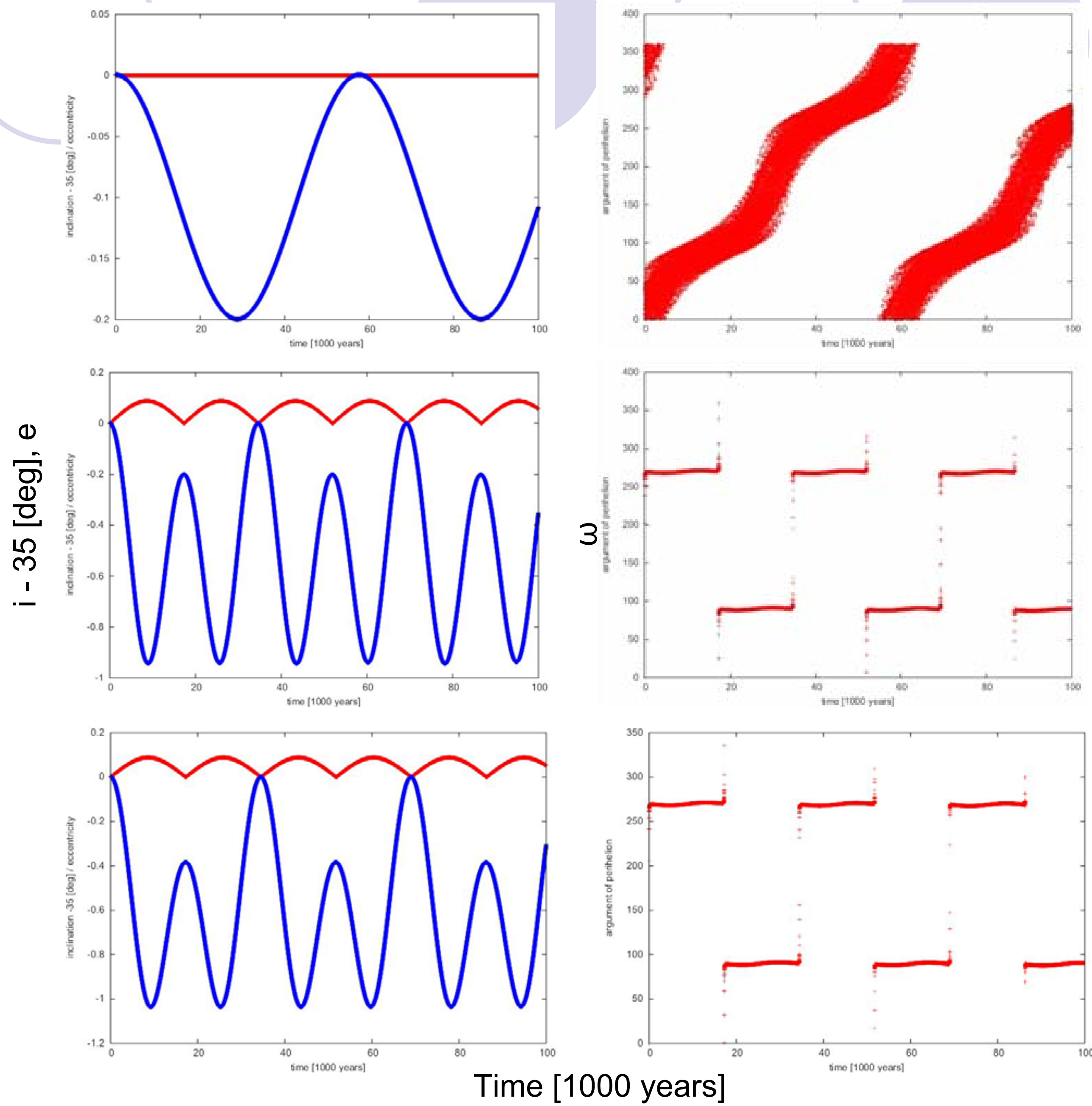
Kozai-Resonances

a = 0.15 AU
i = 35°

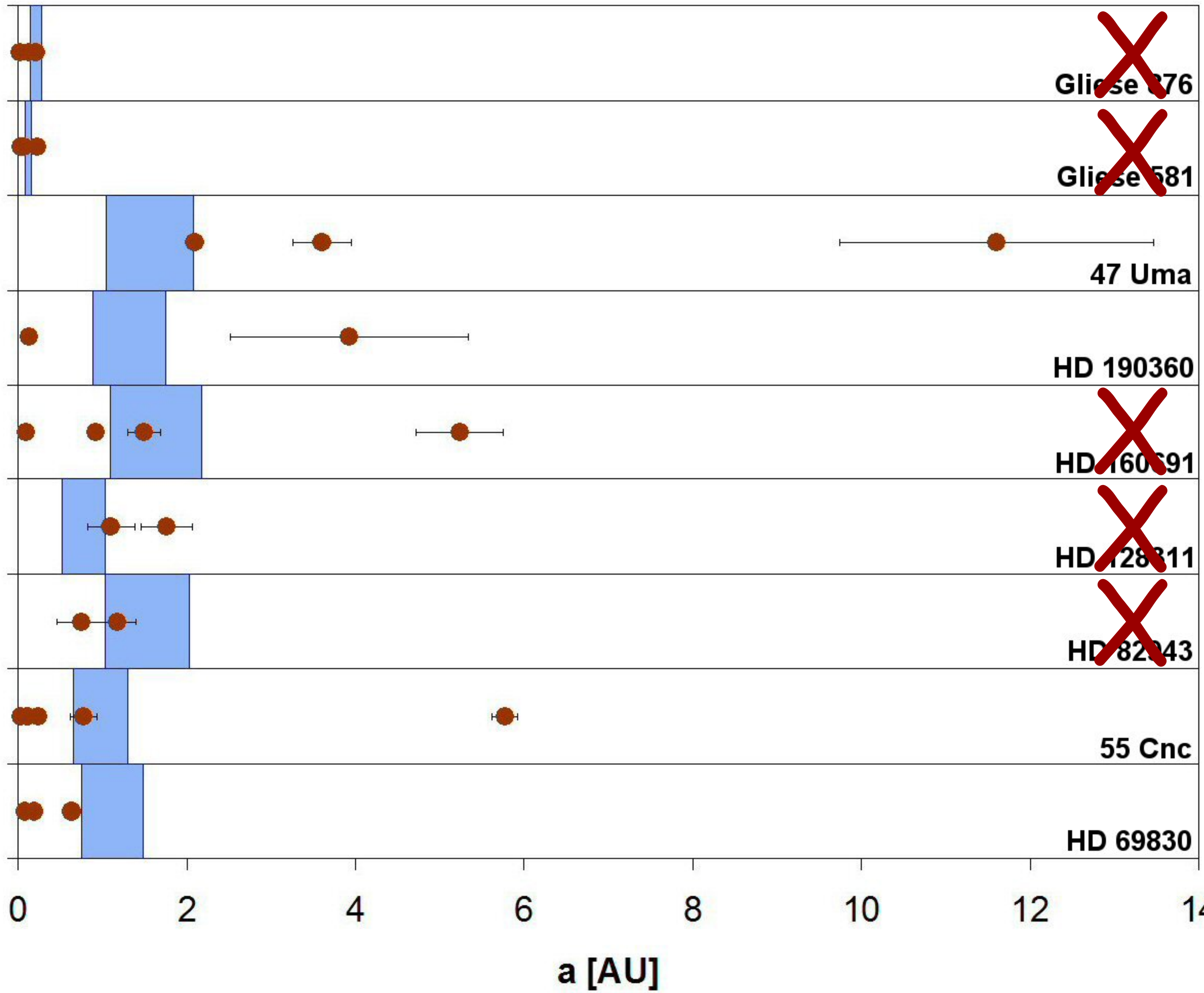
μ = 0.0005
e_{GG} = 0.0

μ = 0.0005
e_{GG} = 0.5

μ = 0.0005
e_{GG} = 0.5
m_{TP} = 10 m_{Earth}

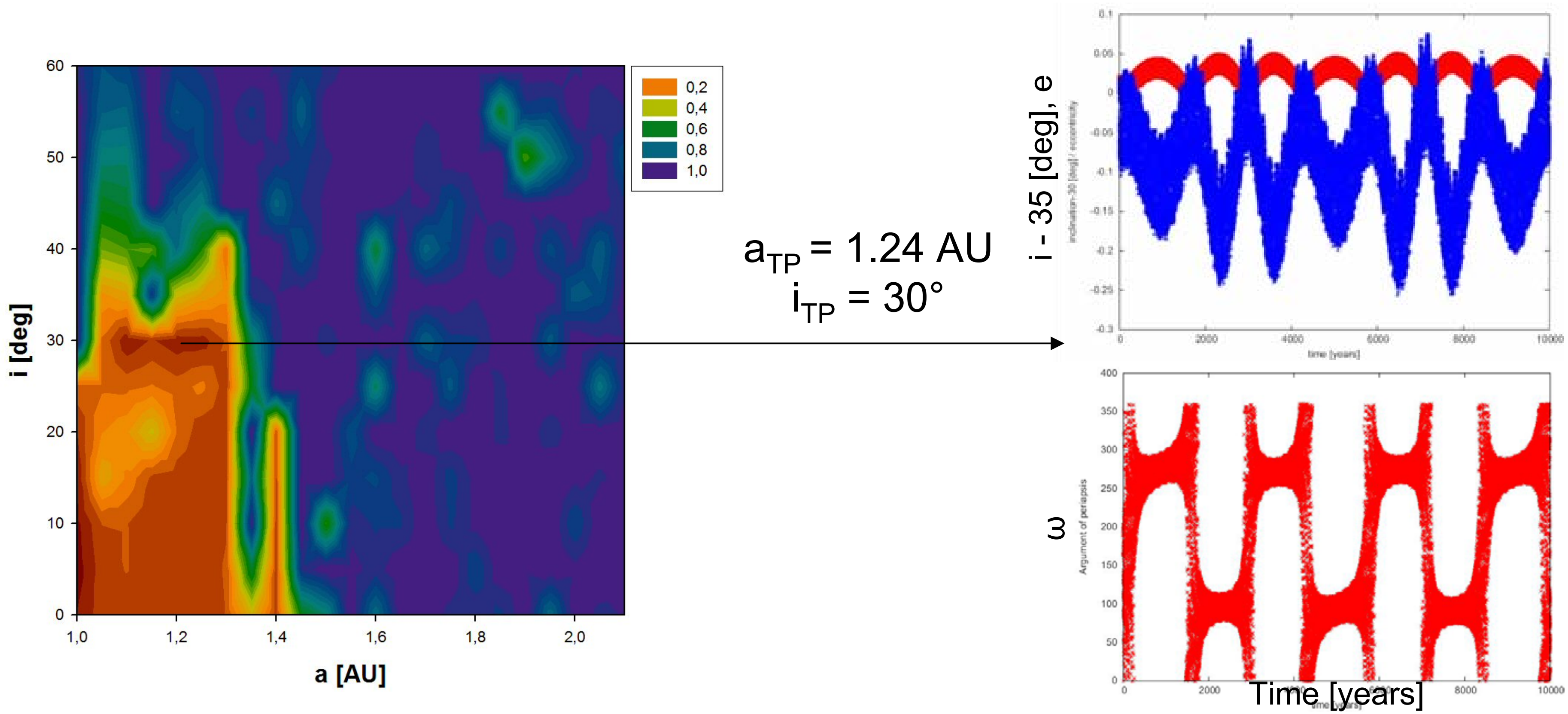


Investigated Systems



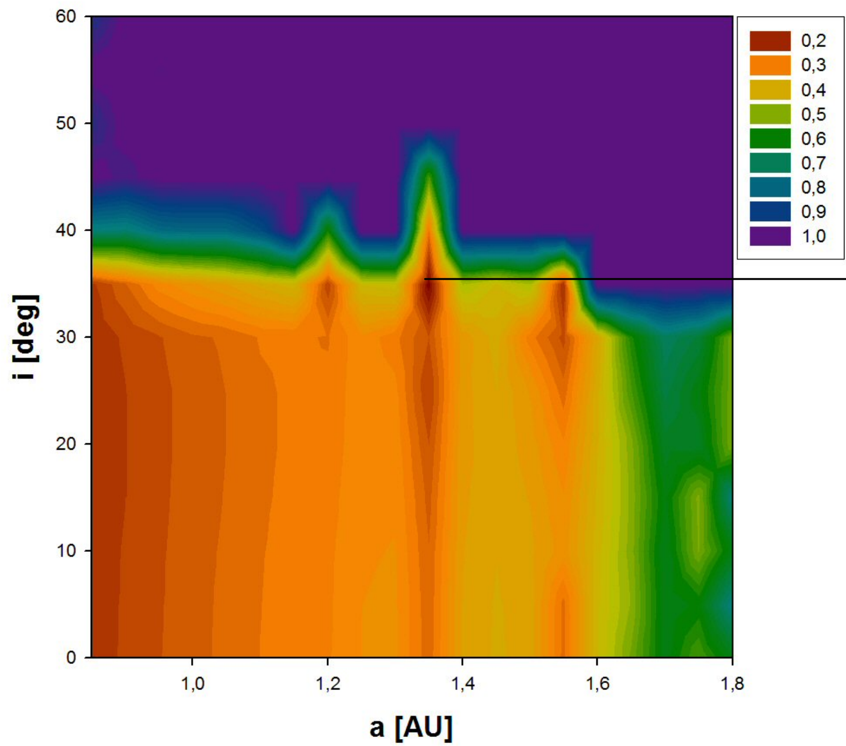
Investigated Systems – 47 Uma

Name	M	Spec. Type	a [AU]	e	ω	i [°]	HZ [AU]
47 Uma	1.063 M_{Sun}	G0 V	-	-	-	-	1.05 – 2.07
47 Uma b	2.53 M_{Jup}	-	2.1	0.032	334	-	-
47 Uma c	0.54 M_{Jup}	-	3.6	0.098	295	-	-
47 Uma d	1.64 M_{Jup}	-	11.6	0.16	110	-	-
47 Uma – TP	0	-	1.05 – 2.07 $\Delta a = 0.05$	0	0	0 – 60 $\Delta i = 5$	-

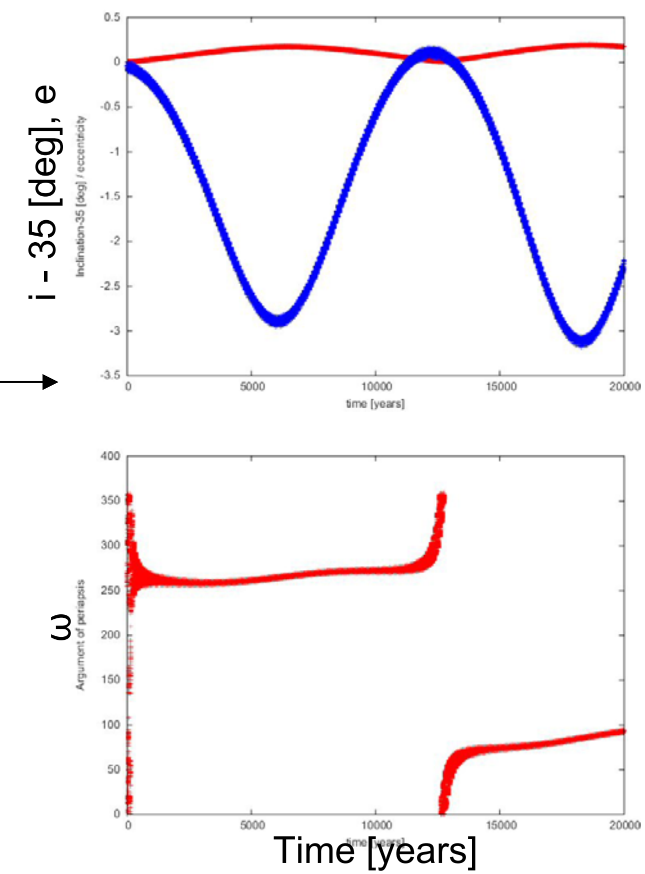


Investigated Systems – HD 190360

Name	M	Spec. Type	a [AU]	e	ω	i [°]	HZ [AU]
HD 190360	1.04 M_{Sun}	G6 IV	-	-	-	-	0.85 – 1.8
HD 190360 b	1.502 M_{Jup}	-	3.92	0.36	12.4	-	-
HD 190360 c	0.057 M_{Jup}	-	0.128	0.01	153.7	-	-
HD 190360 –TP	0	-	0.85 – 1.8 Δa = 0.05	0	0	0 – 60 Δi = 5	-



a_{TP} = 1.36 AU
i_{TP} = 35°



Summary

- (partly) stable habitable zone:
  - 47 Uma
  - HD 190360
  - 55 Cnc
  - HD 69830

- Stabilising Effect of Kozai Resonances
  - Allready shown for the restricted 3 body problem
  - Despite the perdurbing influence of additional planets, still visible in multiplanetary system
  - → The Kozai-Resonance can protect terrestrial planets with inclinations between ~ 30° and 35°