Stability of an additional planet in the Gliese 581 exoplanetary system

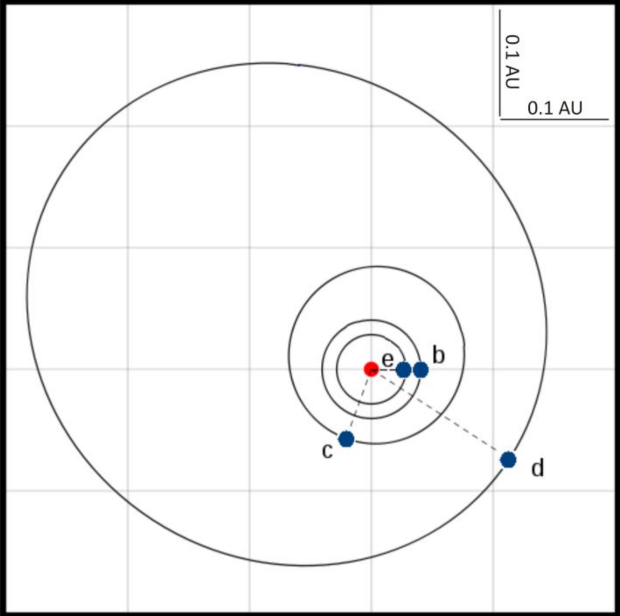
Zsuzsanna **Tóth**[1],
Imre **Nagy**,[2] Vera **Dobos**[2]

[1]Department of Geosciences,
University of Bremen, Germany
[2]Department of Astronomy,
Eötvös Loránd University, Budapest

5th Austrian-Hungarian Workshop, 9-10 April 2010

The **Gliese 581** exoplanetary system

Star	Gliese 581
Distance	6,26 pc
Spectral type	M3V
Apparent magnitude	10,55
Mass	0,31 M_{Sun}
Age	~ 2 Gyr
Radius	0,38 R_{Sun}
Metallicity [Fe/H]	-0,33 (±0,12)



Planet	b	c	d	e
Discovered in	2005[a]	2007[b]	2007[b]	2009[c]
Mass (in M_{Earth})	> 15,65	> 5,36	> 7,09	> 1,94
Semi major axis (AU)	0,041	0,07	0,22	0,03
Orbital period (days)	5,37	12,93	66,8	3,15
Eccentricity	0	0,17 (±0,07)	0,38 (±0,09)	0
ω	--	-110 (±25)°	-33 (±15)°	--

[a] Bonfils et al., 2005
[b] Udry et al., 2007
[c] Mayor et al., 2009

Recent stability investigations

- Beust et al., 2008 – 3-planet system
  - numerically integrated the planetary system over 10^8 yr, starting from the fitted solution
  - additional simulations varying the inclination
  - considered additional (outer) planets
  - computed the Lyapunov exponents to quantify the level of chaos in the system

  conclusions: The system is dynamically stable. Chaotic, but stable. (a – extremely stable, e – undergoes small amplitude variations)
- Zollinger & Armstrong, 2009 – 3+1 planets
  - 4th lower mass planet between planet c and d, numerical integration for 10^7 yr

  result: Dynamically stable system, additional planet between 0,11-0,21 AU with a mass of 2,5 M_{Earth}.
- Mayor et al., 2009 – 4-planet system

More additional planets?

- inherent uncertainty in the radial velocity measurements
- the contribution of the unseen planet to the radial velocity signal might be just below the actual measurement uncertainty
- the system appears to be stable with a lower mass additional planet between planet c and d

→ The Gliese 581 planetary system may harbour undetected planets.

We address the possible existence of a fifth, undetected, lower mass planet.

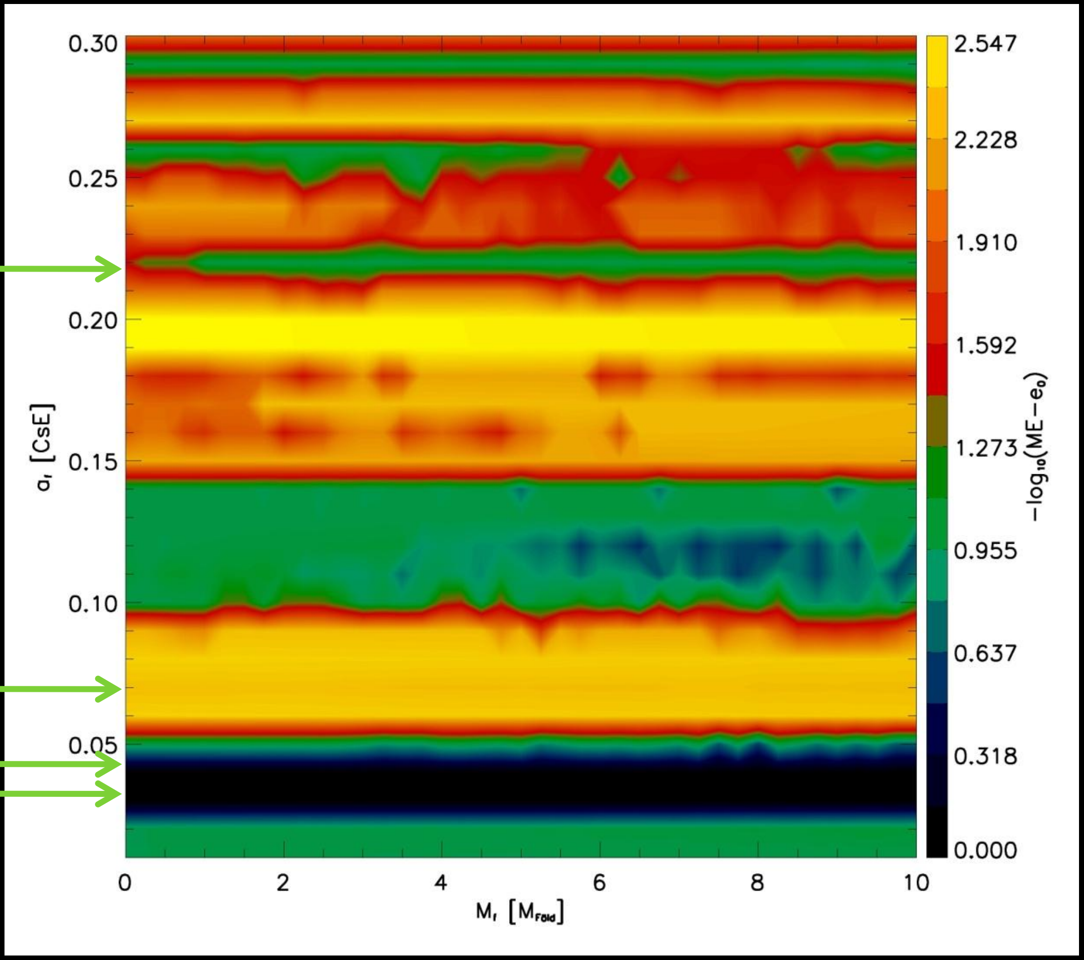
Methods

- numerical integration of a 6-body system (star + 5 planets)
- time: 50.000 orbital periods of the outmost planet, planet d
- Bulirsch-Stoer integrator
- our study area: between 0.01-0.3 AU
- mass of the hypothetical planet "f" between 1-10 Earth-masses

- we examine the dynamical stability of the system through
  - the maximum eccentricity of the planets
  - the minimum distance between the adjacent planets

STABILITY MAPS
- Maximum eccentricity

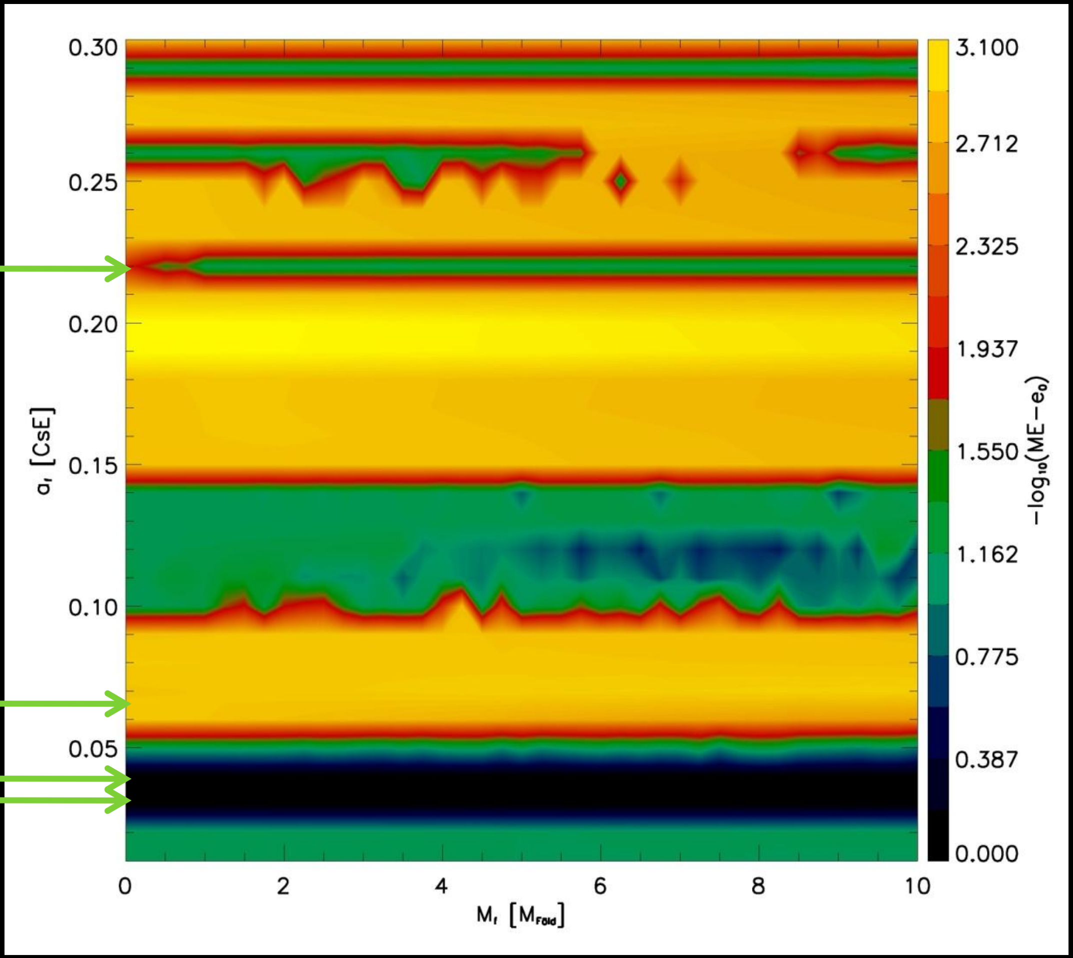
planet d
0,22 AU



planet c
0,07 AU
planet b
0,04 AU
planet e
0,03 AU

planet e

STABILITY MAPS
- Maximum eccentricity

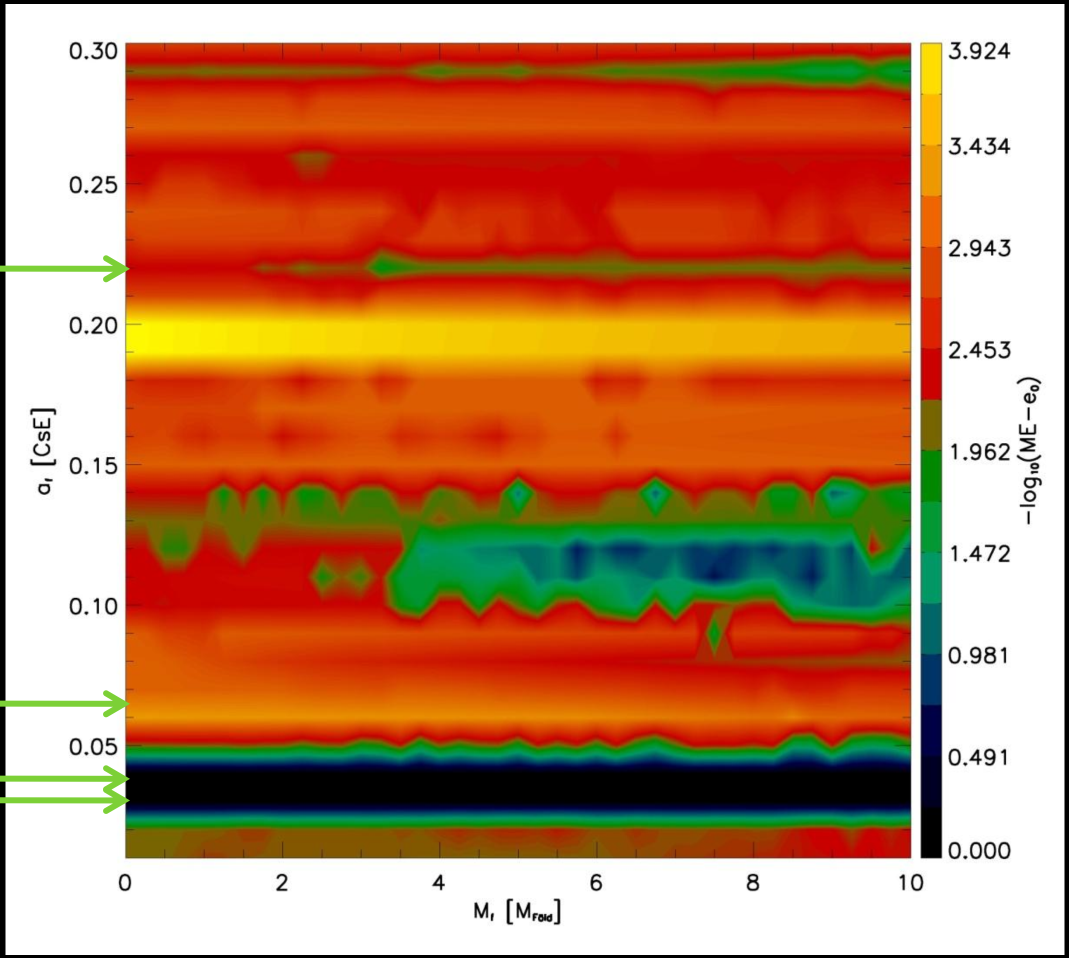


planet d
0,22 AU

planet c
0,07 AU
planet b
0,04 AU
planet e
0,03 AU

planet b

STABILITY MAPS
- Maximum eccentricity



planet d
0,22 AU

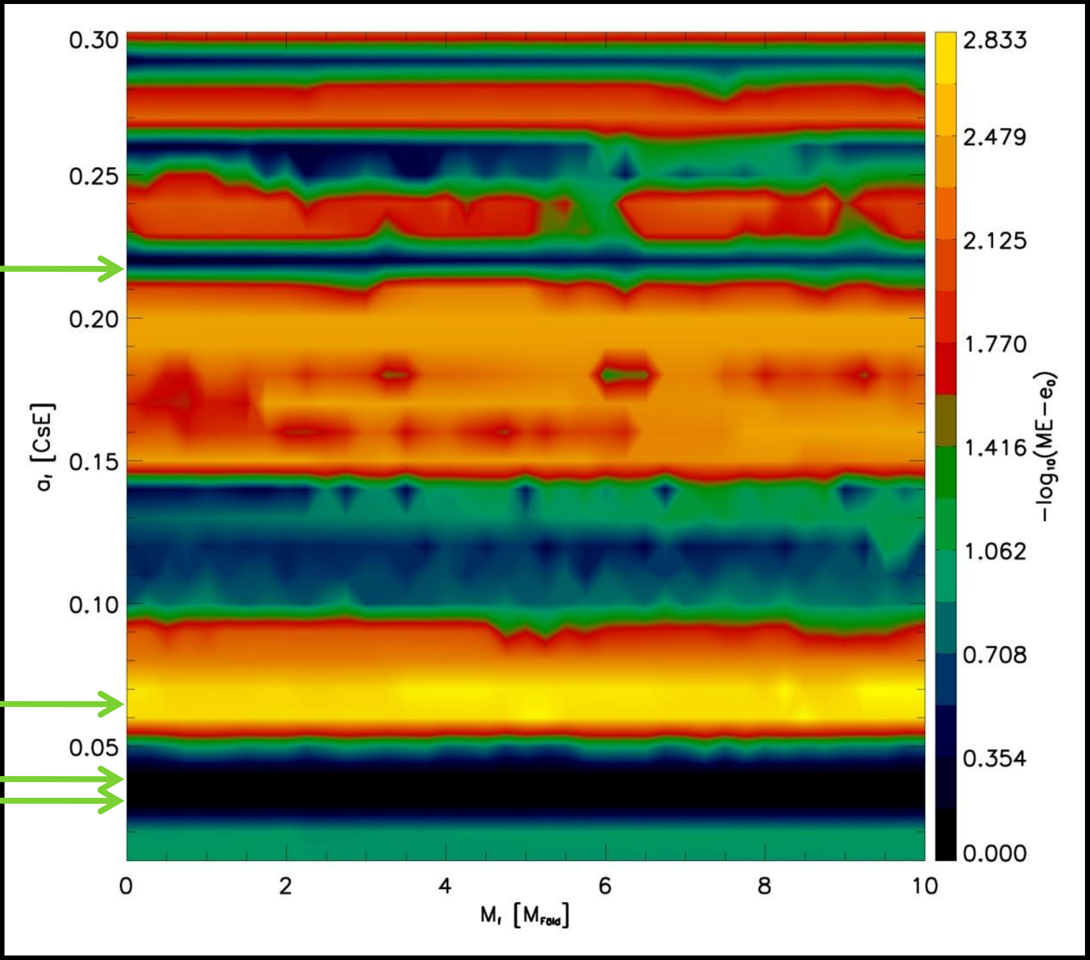
planet c
0,07 AU

planet b
0,04 AU

planet e
0,03 AU

planet c

STABILITY MAPS
- Maximum eccentricity



planet d
0,22 AU

planet c
0,07 AU
planet b
0,04 AU
planet e
0,03 AU

planet „f”

Titius-Bode's law, Ragnarsson's law

$a = 0{,}03 + 0{,}01 * 2^n$ $a = a_b[(5/2)^{2/3} |m|]^{\text{sign}(m)}$

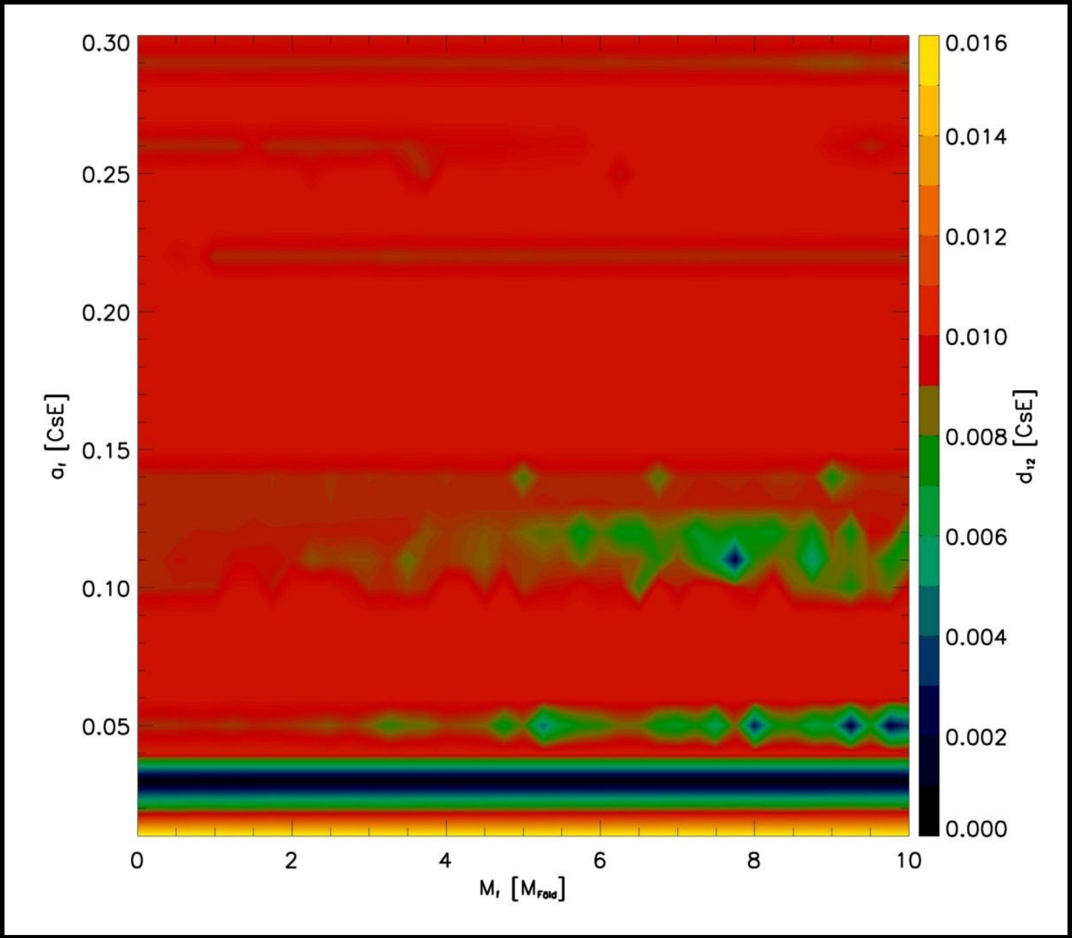
Planet	Semi major axis (AU)	Titius-Bode's law (AU)		Ragnarsson's law* (AU)		
e	0,03	1	0,03	1	m=-1	0,0217
b	0,04	2	0,04	2	m= 0	0,04 (fixed)
		3	0,05			
c	0,07	4	0,07	3	m= 1	0,0737
		5	0,11	4	m= 2	0,1474
		6	0,19			--
d	0,22			5	m= 3	0,221
		7	0,35			

*Ragnarsson, 1995

STABILITY MAPS - Minimum distance

a_e = 0,03 AU
a_b = 0,04 AU
a_c = 0,07 AU
a_d = 0,22 AU

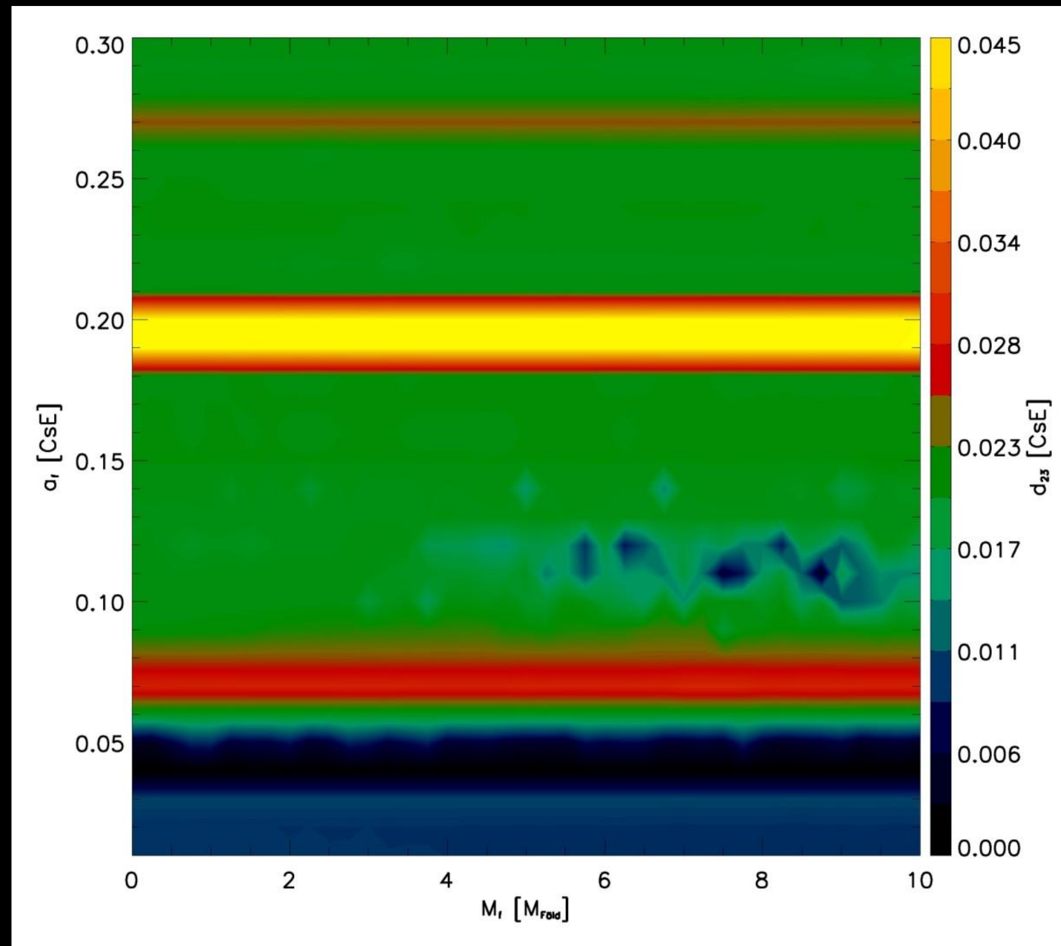
planet 1, 2 are,
when planet „f” is
between
0,01-0,03 AU: f, e
0,03-0,04 AU: e, f
0,04-0,3 AU: e, b
→ e



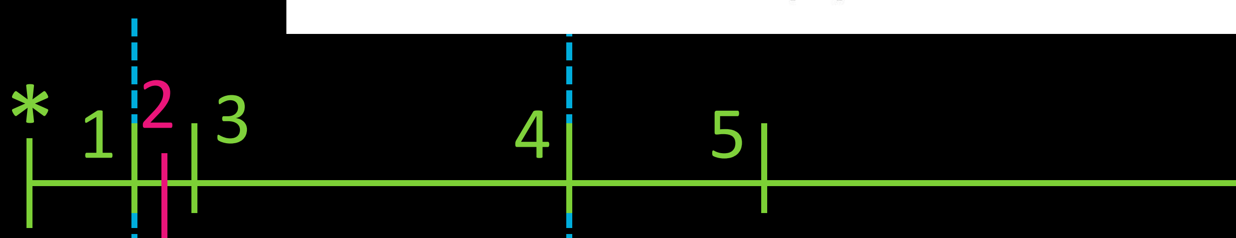
d_{12}

STABILITY MAPS - Minimum distance

a_e = 0,03 AU
a_b = 0,04 AU
a_c = 0,07 AU
a_d = 0,22 AU



planet 2, 3 are,
when planet „f” is
between
0,01-0,03 AU: e, b
0,03-0,04 AU: f, b
0,04-0,07 AU: b, f
0,07-0,03 AU: b, c
→ b

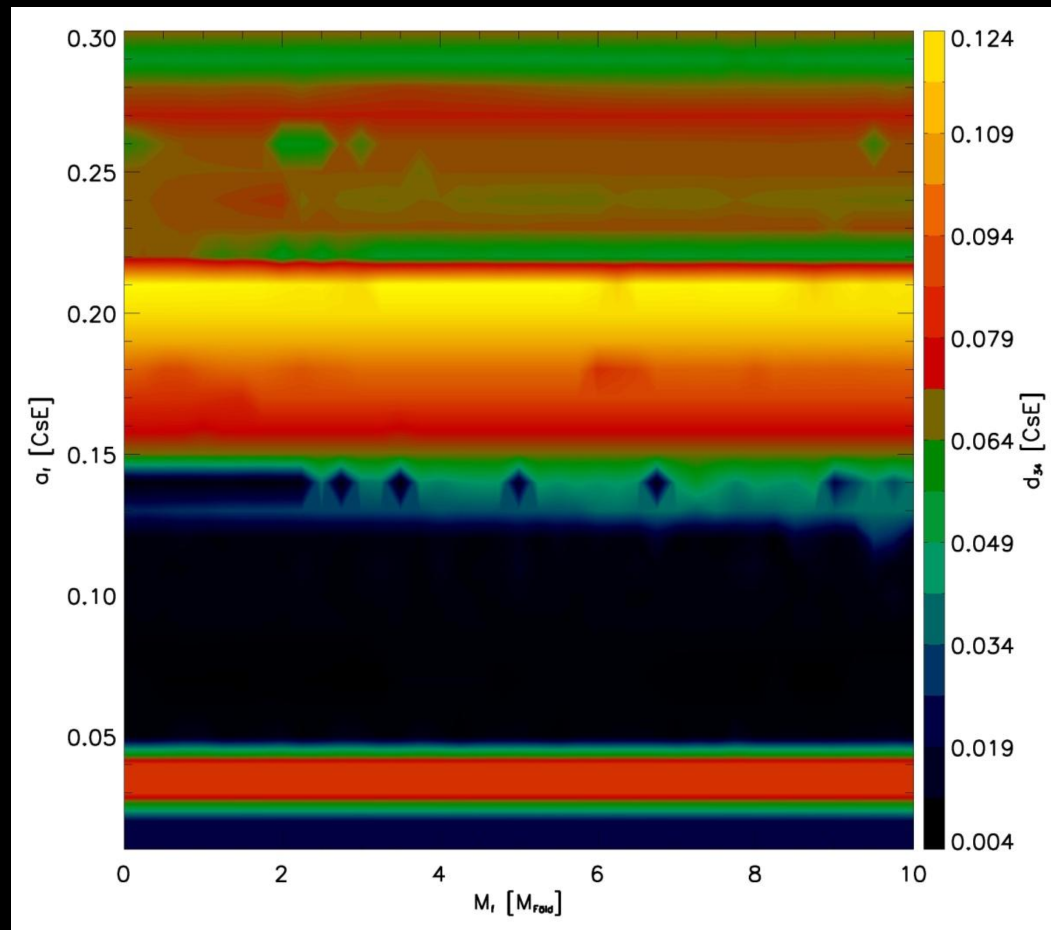


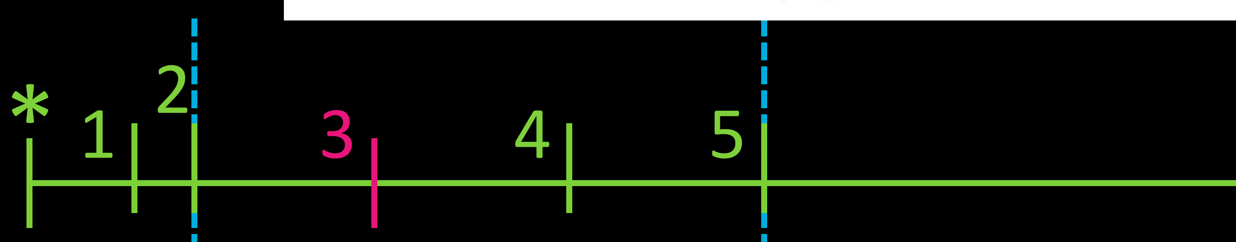
d_{23}

STABILITY MAPS - Minimum distance

a_e = 0,03 AU
a_b = 0,04 AU
a_c = 0,07 AU
a_d = 0,22 AU

planet 3, 4 are,
when planet „f" is
between
0,01-0,04 AU: b, c
0,04-0,07 AU: f, c
0,07-0,22 AU: c, f
0,22-0,3 AU: c, d
→ c



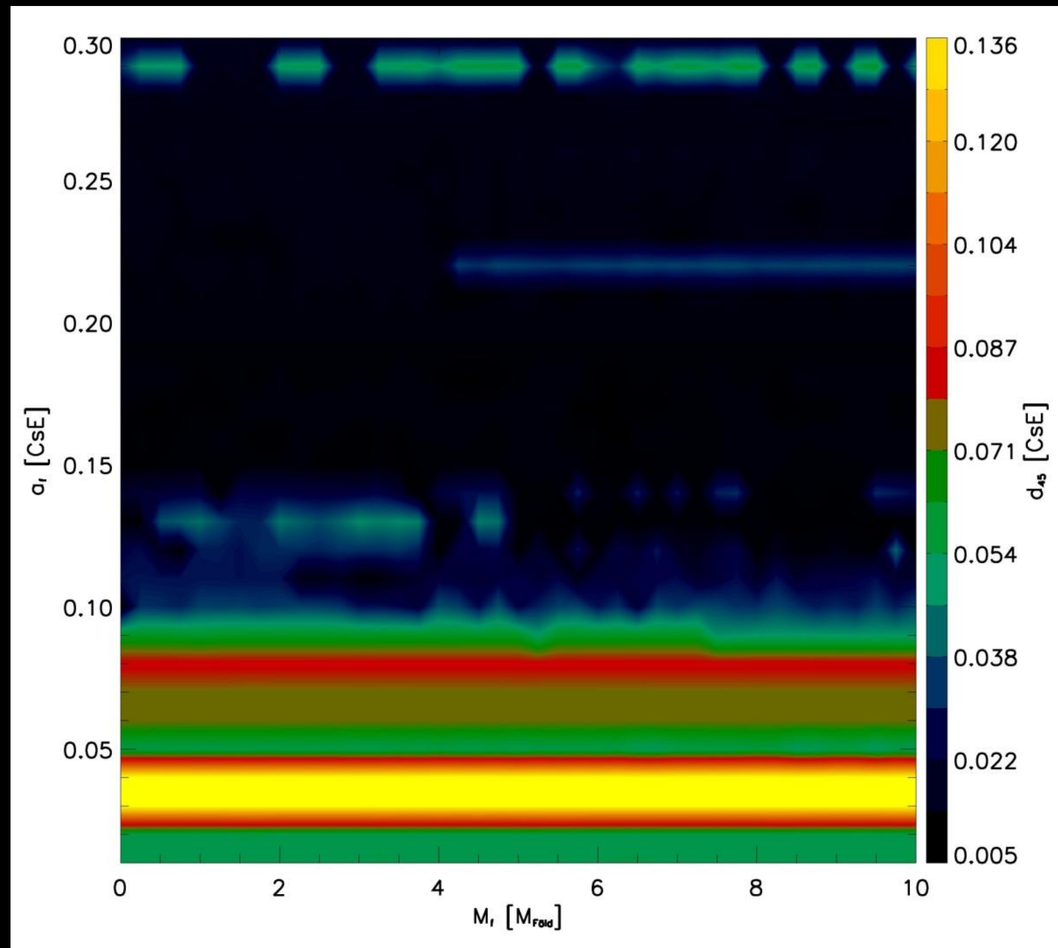


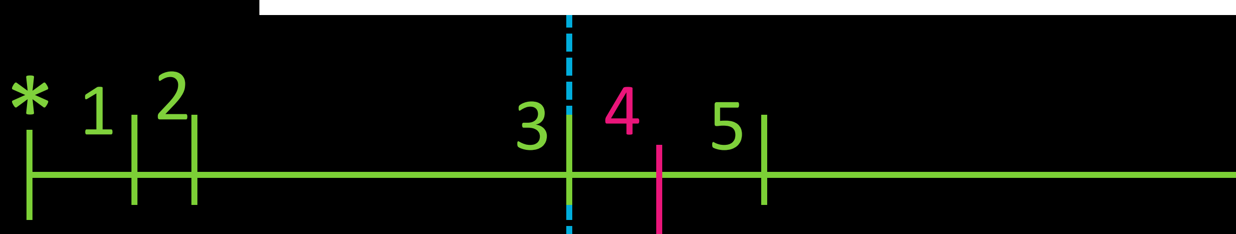
d_{34}

STABILITY MAPS - Minimum distance

a_e = 0,03 AU
a_b = 0,04 AU
a_c = 0,07 AU
a_d = 0,22 AU

planet 4, 5 are, when planet „f” is between
0,01-0,07 AU: c, d
0,07-0,22 AU: f, d
0,22-0,3 AU: d, f
→ d

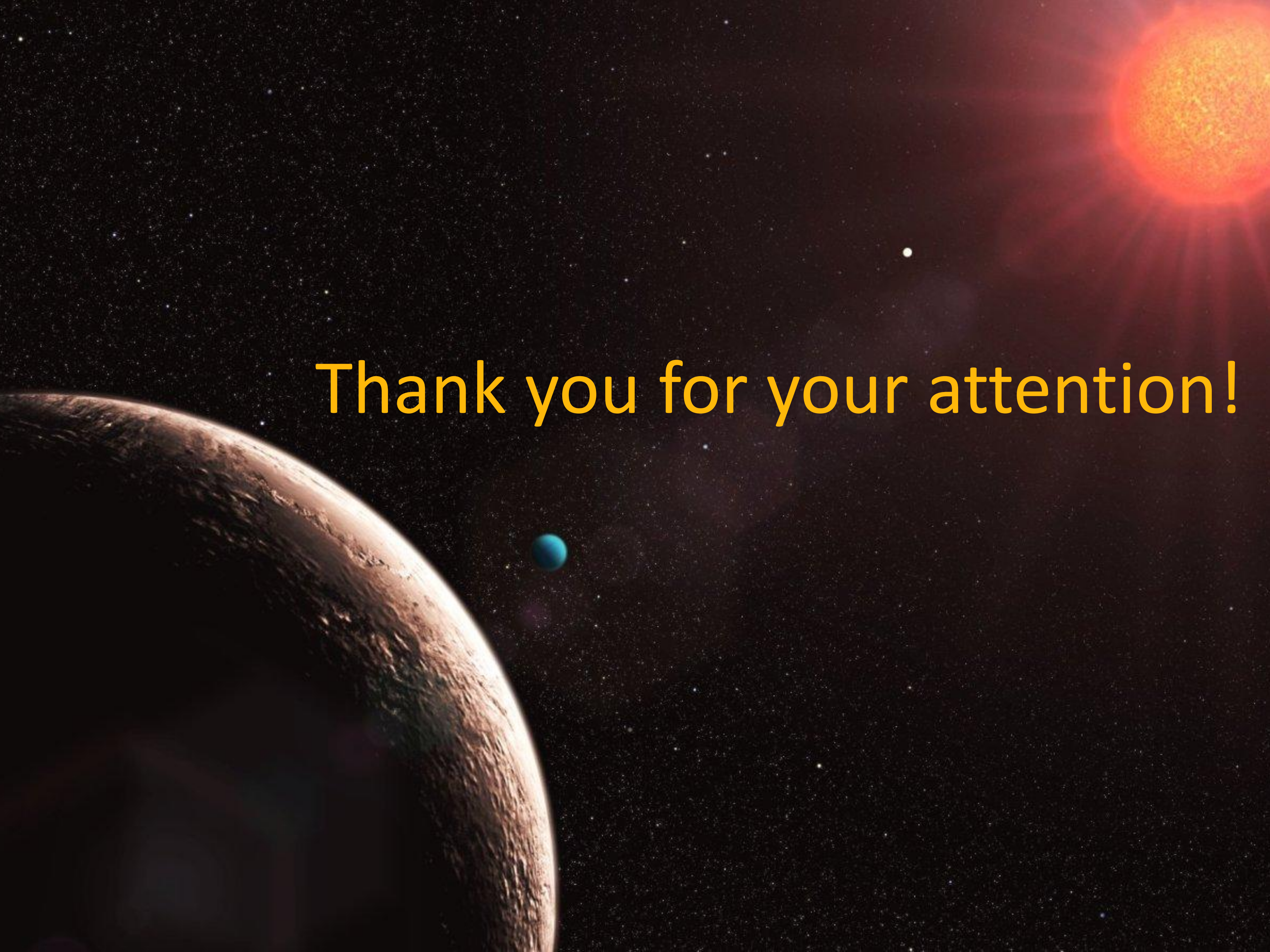




d_{45}

Conclusions

- Based on our stability investigations an additional planet's orbit around Gliese 581 is stable in the following region: 0,15-0,2 AU
- Based on the Titius-Bode's law and Ragnarsson's law, reasonable predictions for an additional planet in the planetary system is between 0,15-0,19 AU



Thank you for your attention!