Queen Mary
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Evolution and Dynamics of the Eccentric Planetary System HD 181433

NAM2012

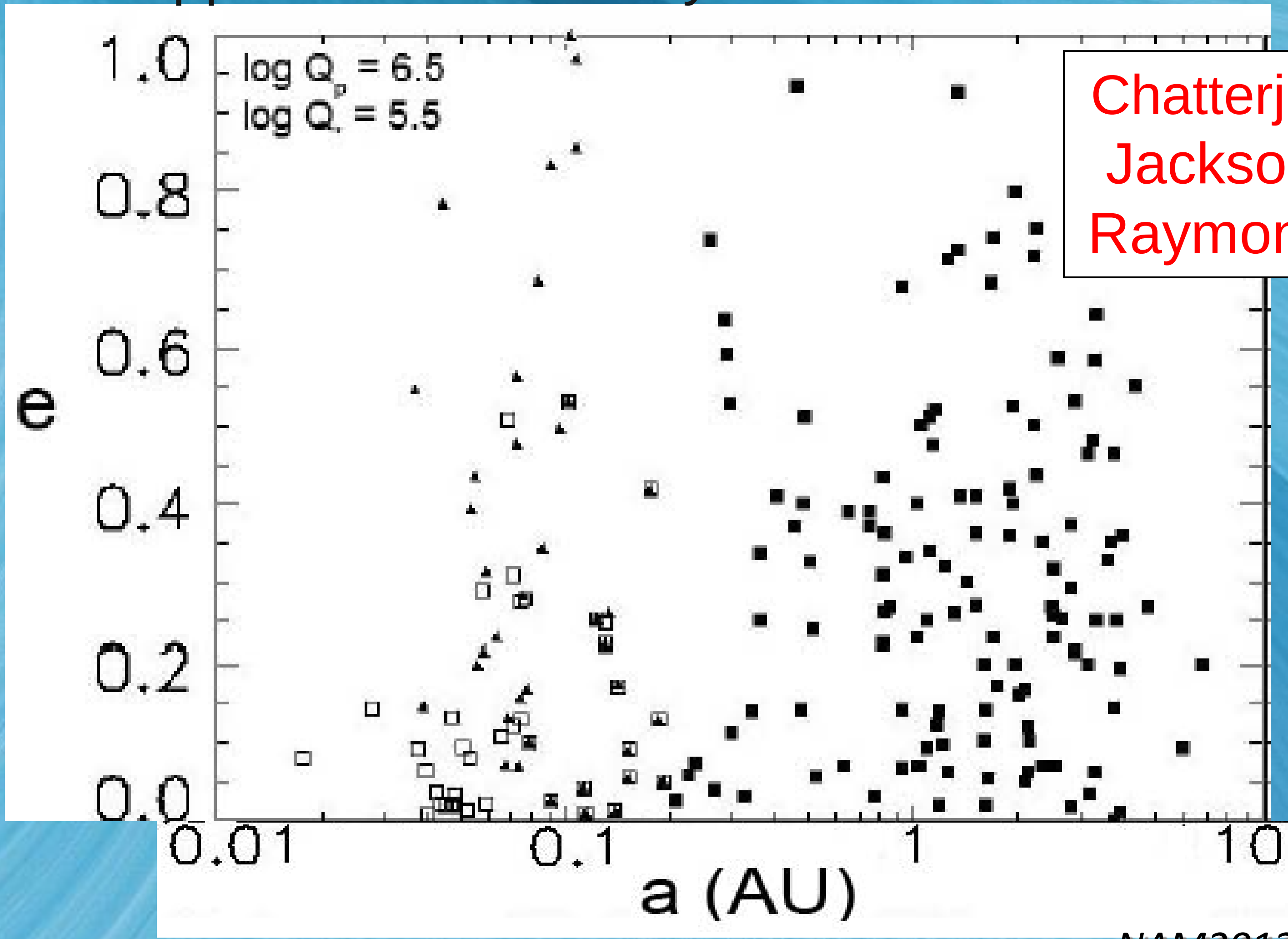
Giammarco Campanella

30th March 2012

Collaborators: Craig Agnor, Richard Nelson

101 Multiplanet Systems

- Explain the wide eccentricity distribution of exoplanets
- MMRs appear to be relatively common



Chatterjee et al. 2008
Jackson et al. 2008
Raymond et al. 2008

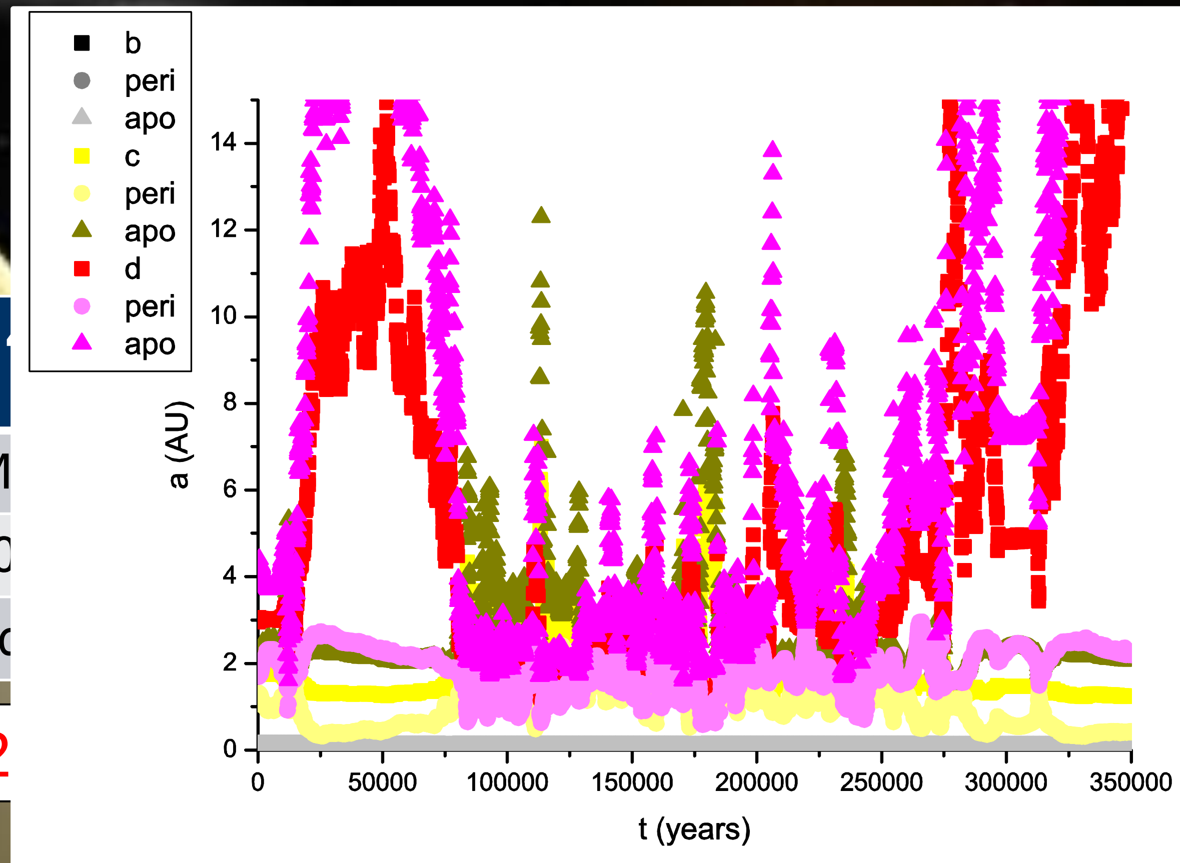
Mon. Not. R. Astron. Soc. 418, 1028–1038 (2011) doi:10.1111/j.1365-2966.2011.19553.x

Treating dynamical stability as an observable: a 5:2 mean motion resonance configuration for the extrasolar system HD 181433

Giammarco Campanella*

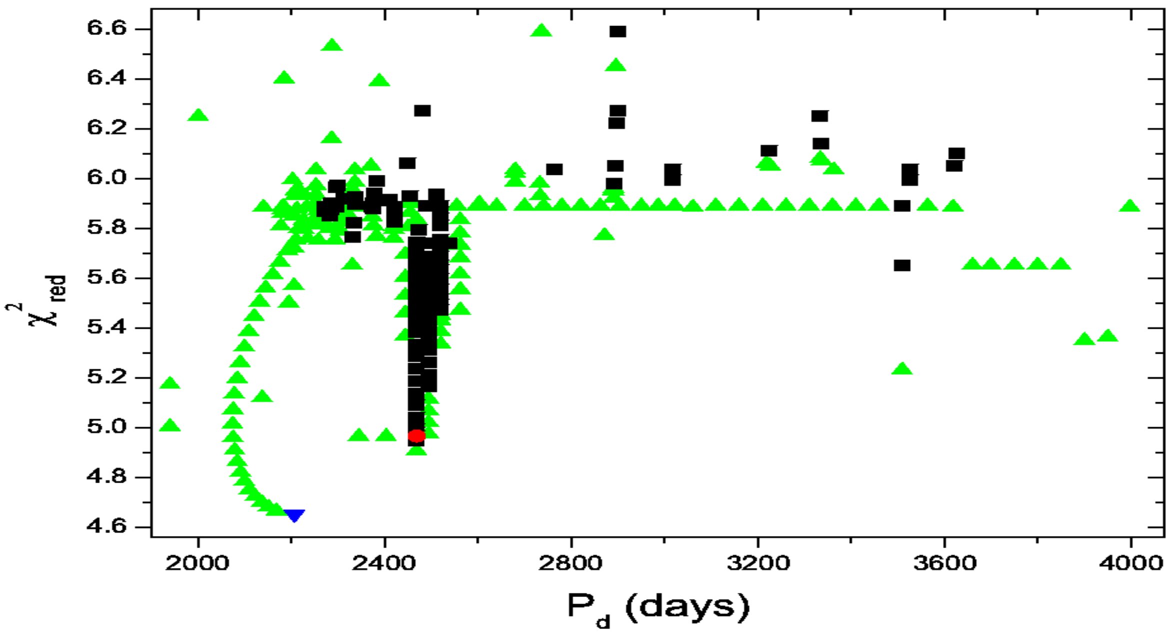
	HD 181
Mass	7.5 M
Ecc.	0.40
P	9.4 c

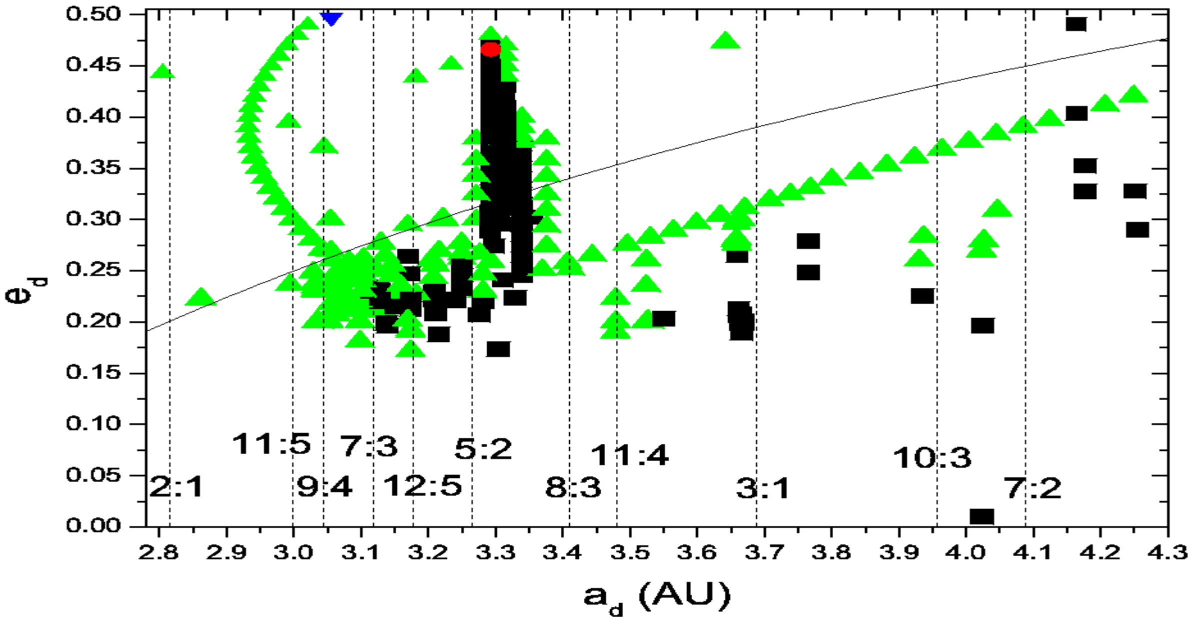
Bouchy et al. 2



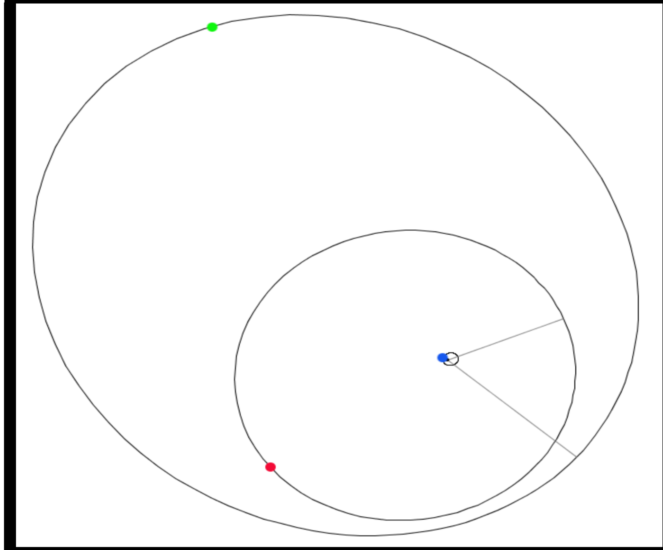
- The orbit of *d* was not completely sampled
- Dynamical stability as an additional observable

Retrieving the stable best-fit solution

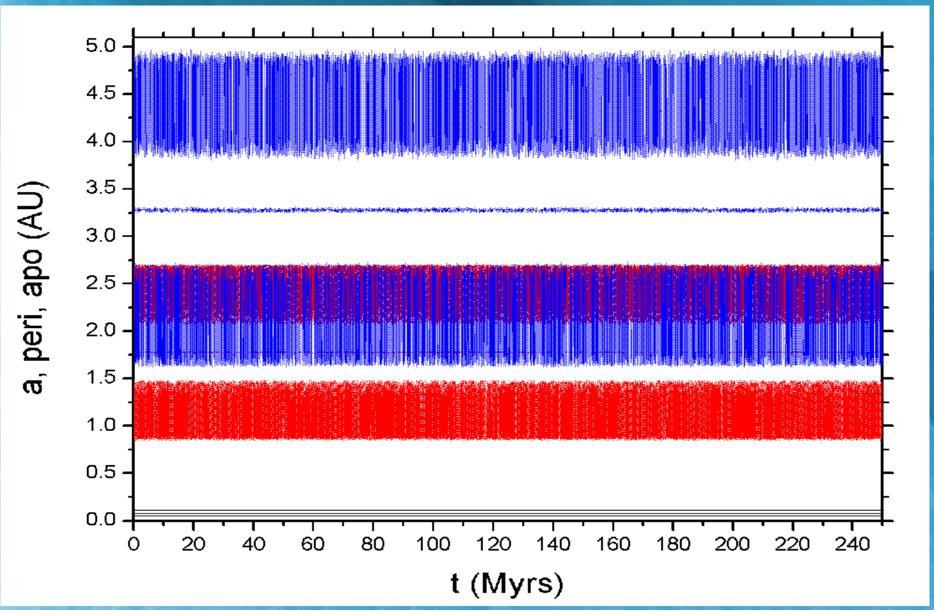


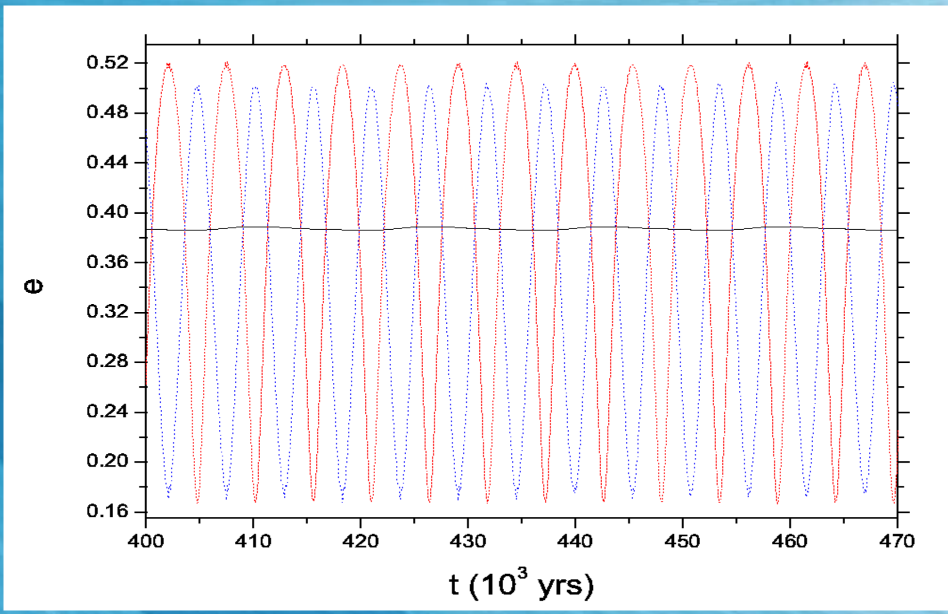


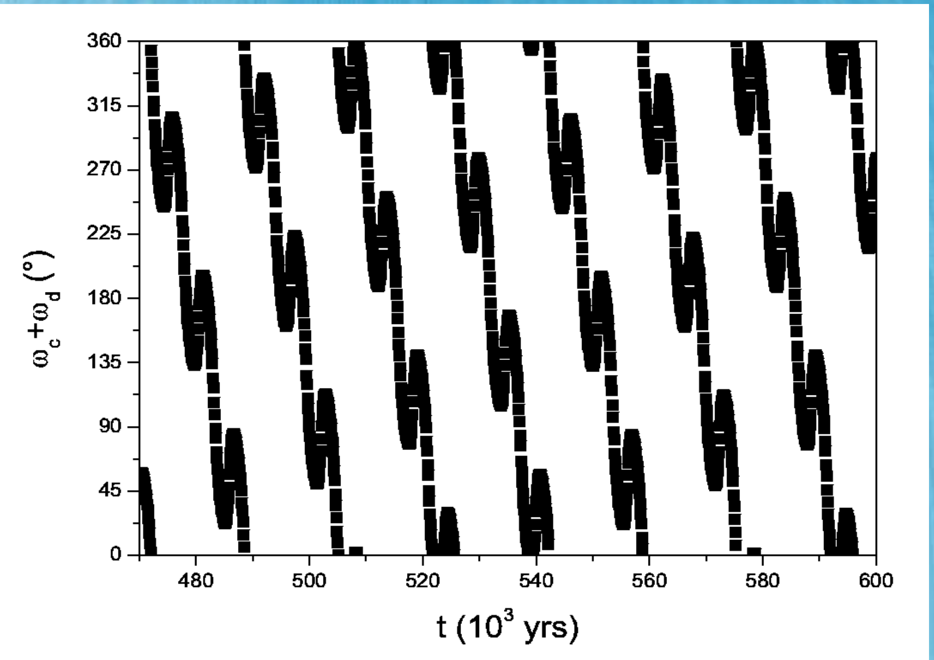
- We performe an independent analysis of the RV data.
- We test the long-term evolution of the retrieved solutions for Myrs.
- The uncertainity on a_d reduces dramatically to the narrow band where the 5:2 MMR is possible.

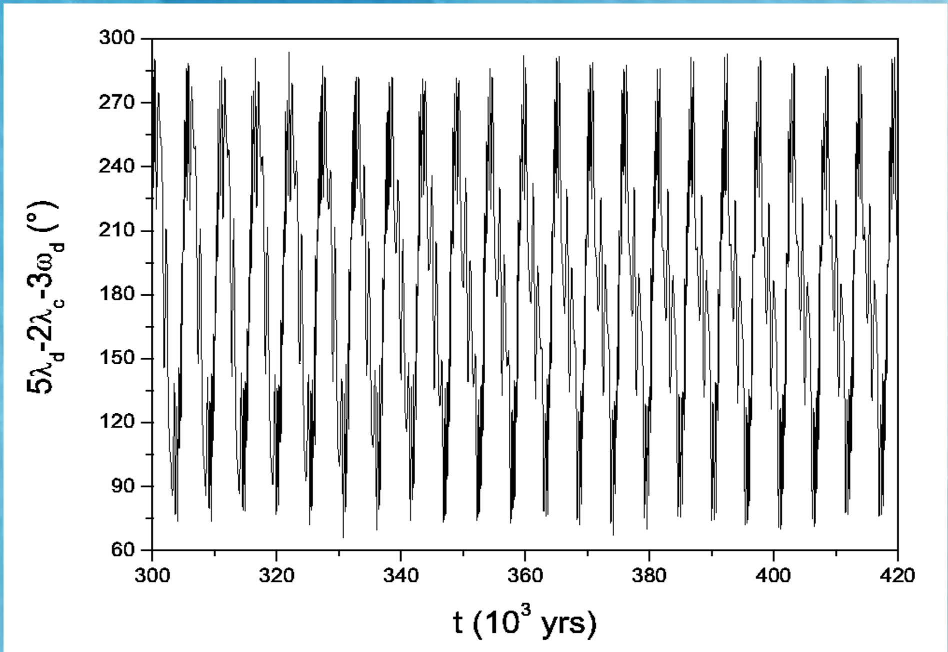


Characteristics of the stable best-fit









Possible scenarios for eccentricity growth in the extrasolar system HD 181433

Giammarco Campanella[1*], Craig Agnor[1] and Richard Nelson[1]

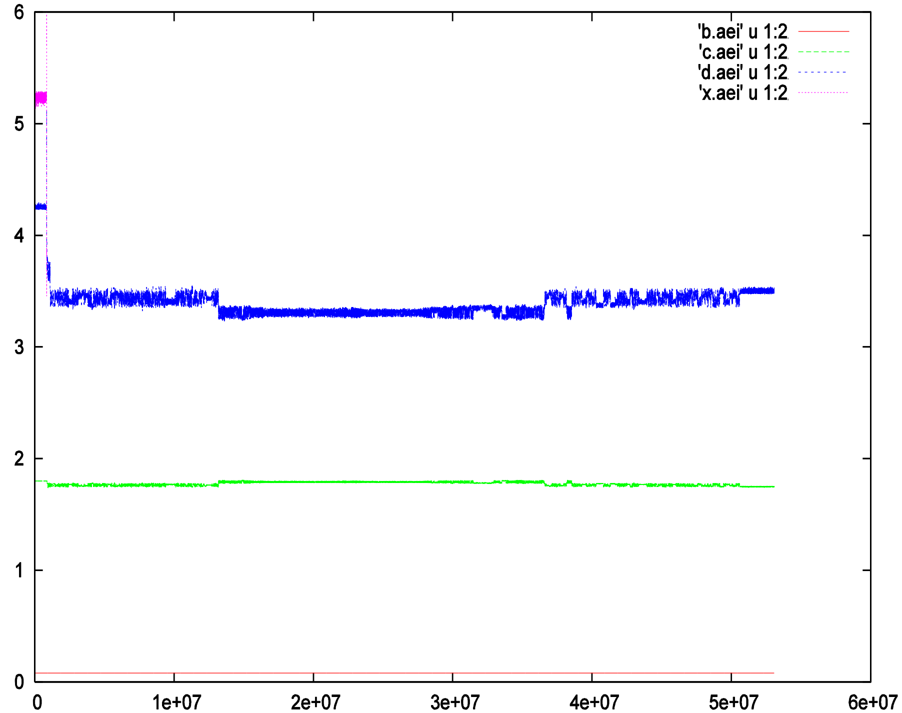
	HD 181 433b	HD 181 433c	HD 181 433d
Mass	7.4 $M_{\oplus}$	0.65 M_{Jup}	0.53 M_{Jup}
Ecc.	0.39	0.27	0.47
P (d)	9.4	975	2468

	Star
Mass	~ 0.8 $M_{\odot}$

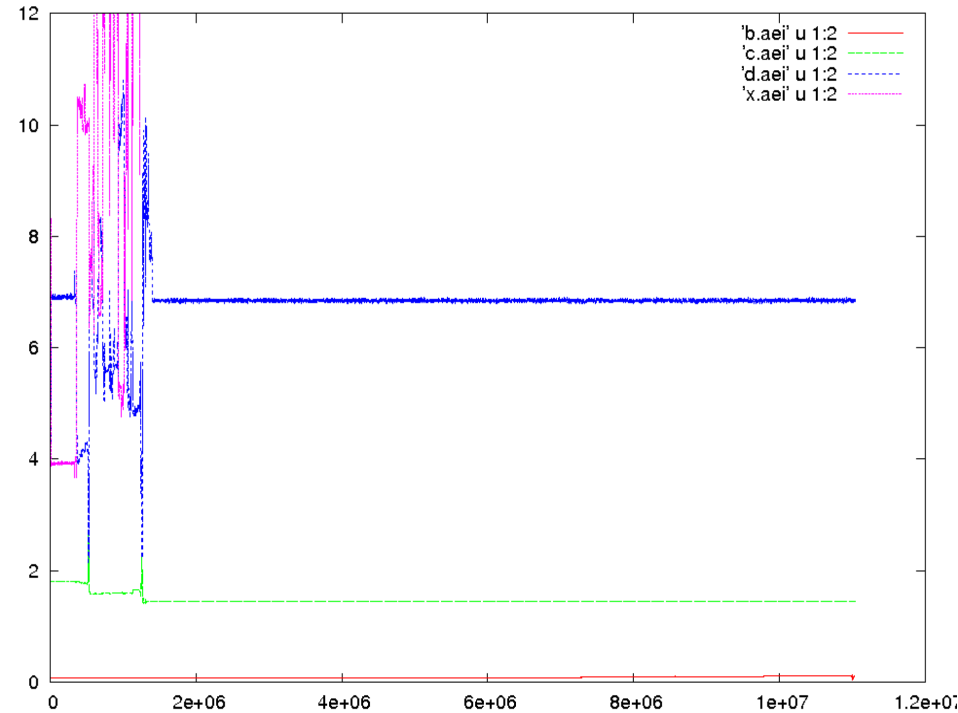
Campanella 2011

- SCATTERING

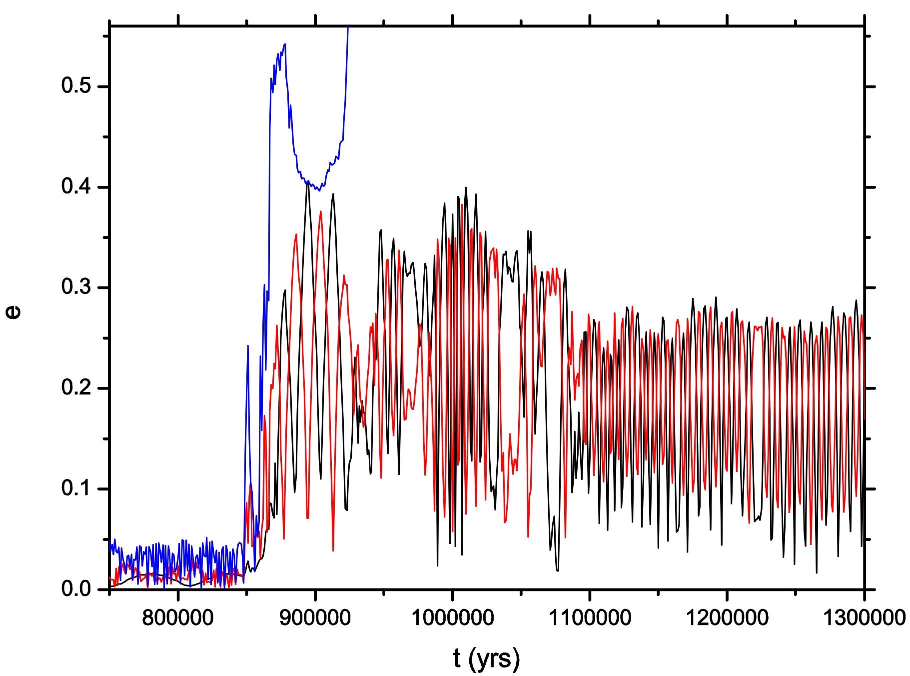
Planet x excites the others
x removed - c and d move inwards



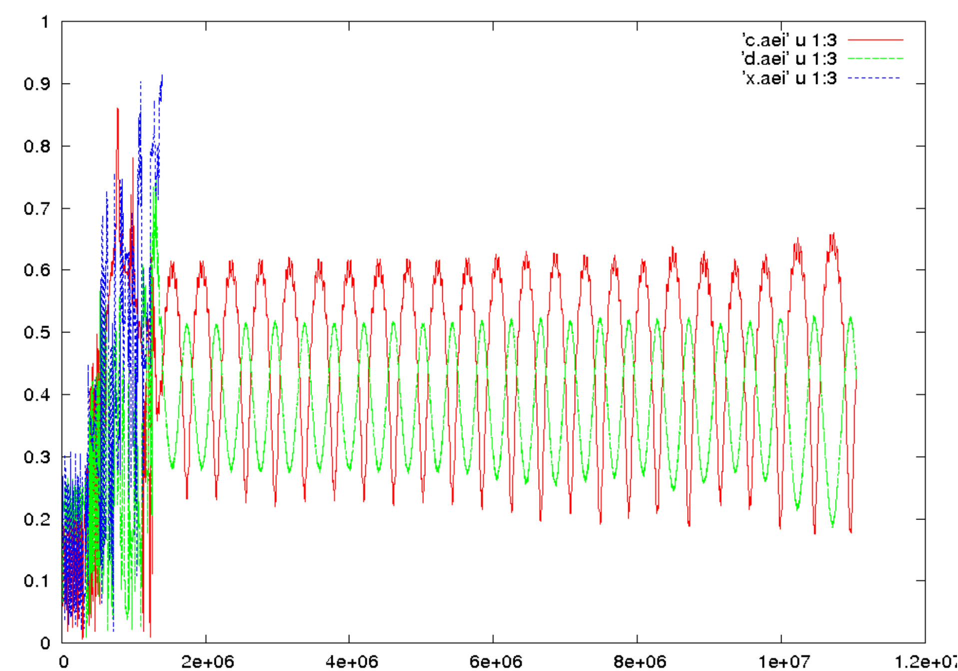
'b.aei' u 1:2
'c.aei' u 1:2
'd.aei' u 1:2
'x.aei' u 1:2
0
1
2
3
4
5
6
1e+07
2e+07
3e+07
4e+07
5e+07
6e+07



'b.aei' u 1:2
'c.aei' u 1:2
'd.aei' u 1:2
'x.aei' u 1:2
0
2
4
6
8
10
12
2e+06
4e+06
6e+06
8e+06
1e+07



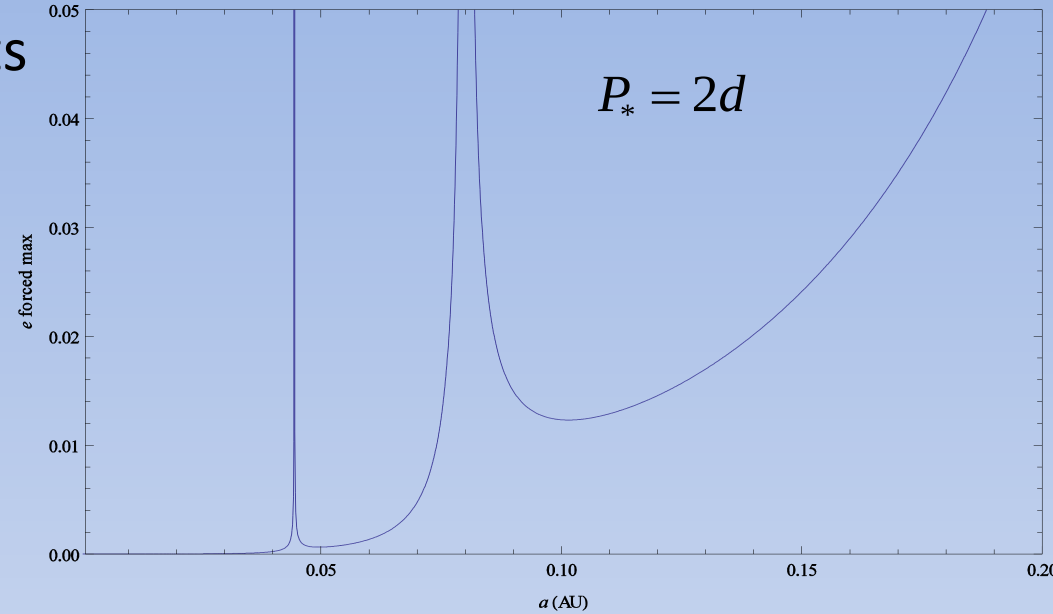
e
0.0
0.1
0.2
0.3
0.4
0.5
800000
900000
1000000
1100000
1200000
1300000
t (yrs)

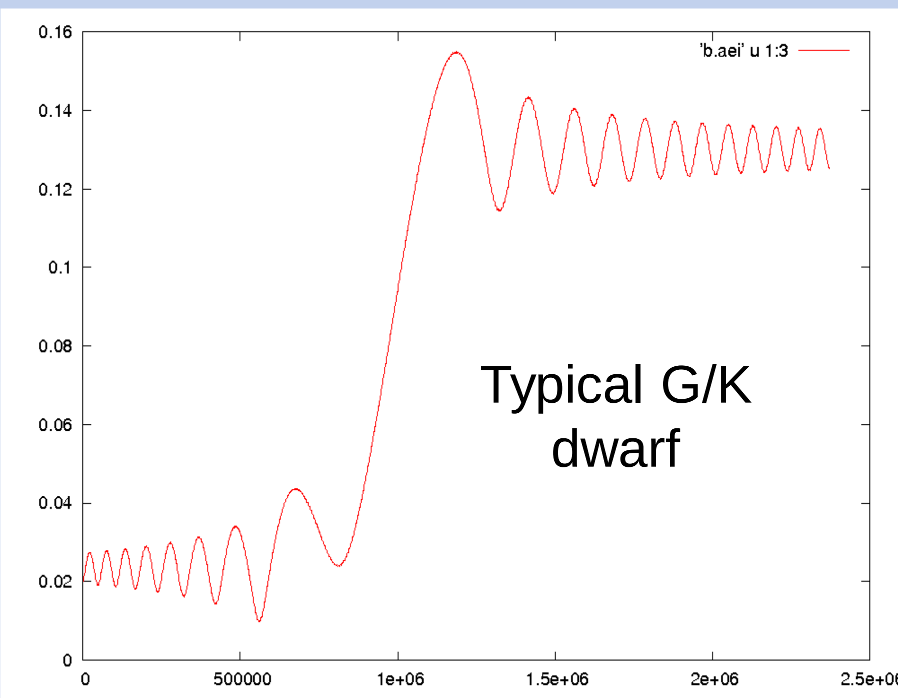


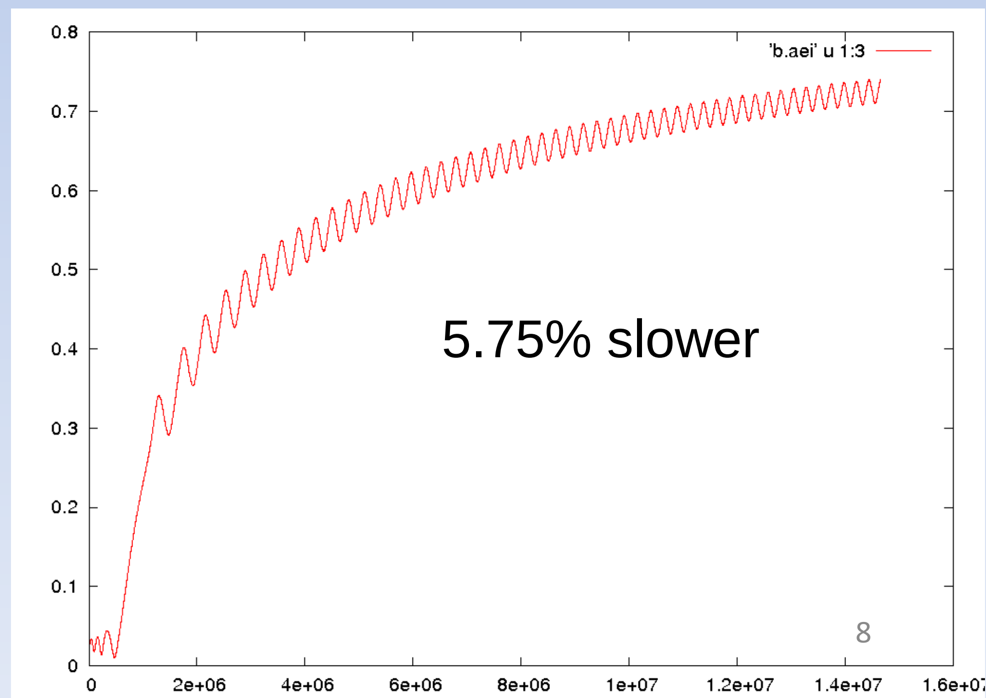
'c.aei' u 1:3
'd.aei' u 1:3
'x.aei' u 1:3
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2e+06
4e+06
6e+06
8e+06
1e+07

Sweeping Sec. Resonances / Stellar Spin-down

- Consider GR and J2 effects
- The magnetised wind remove angular momentum from rotating star

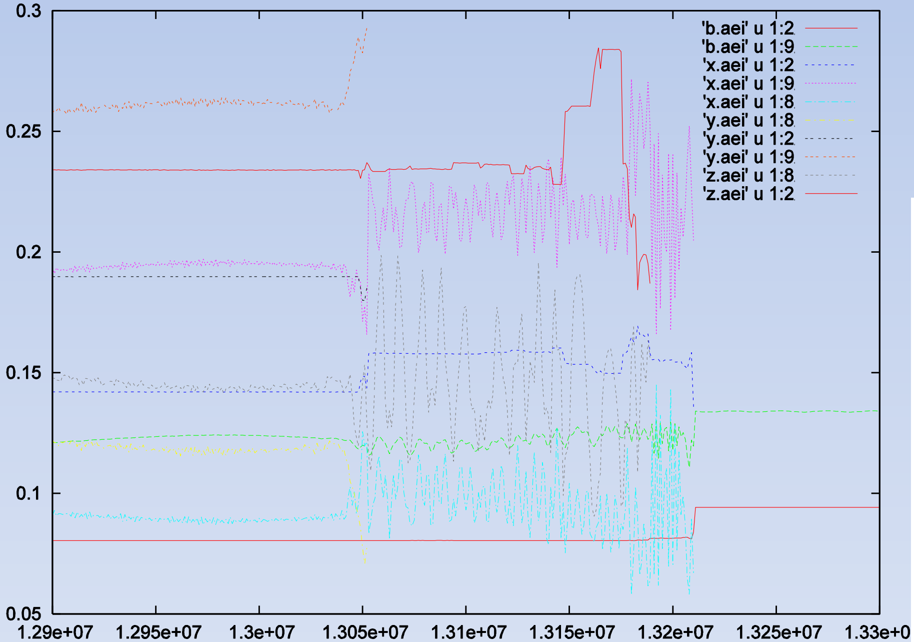


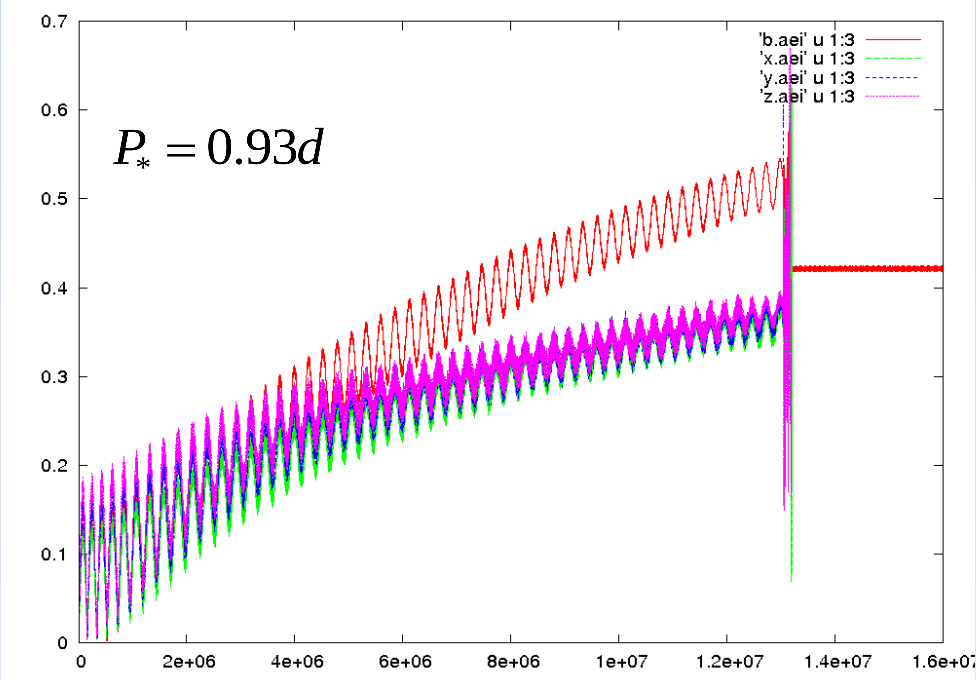




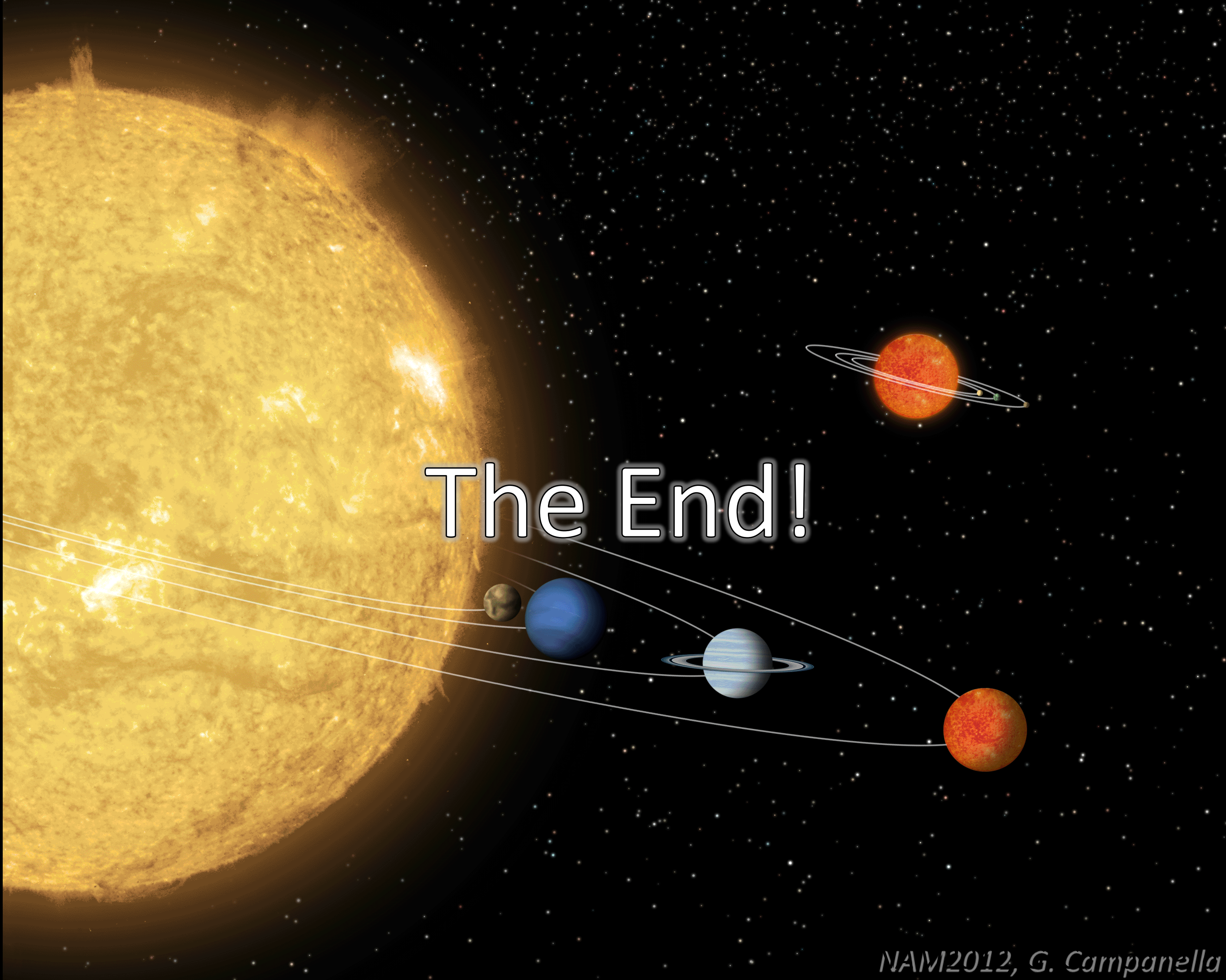
Stellar Spin-down

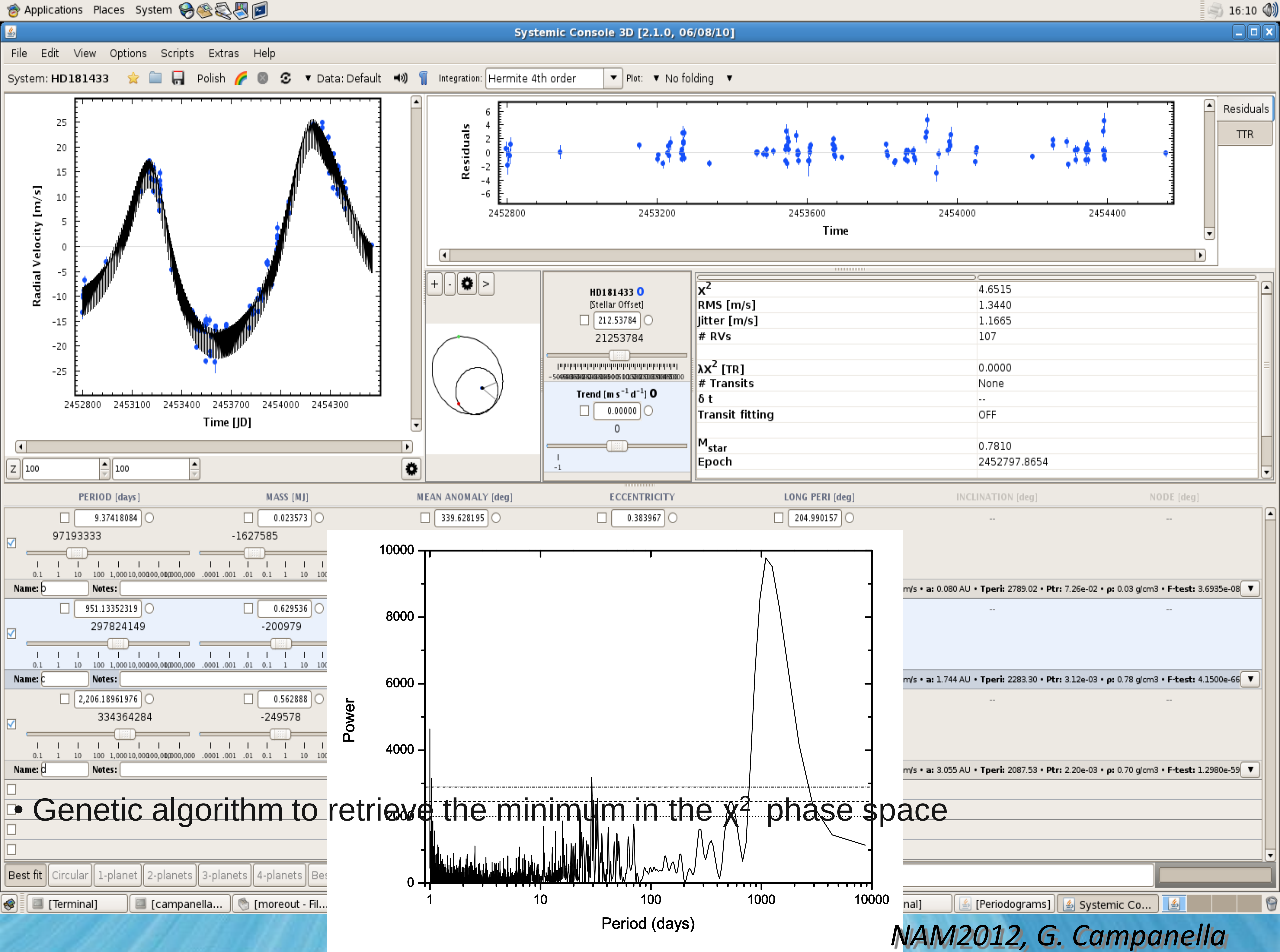
- Model to test:
  - 3 terrestrial planets external to b
  - instabilities must be generated while e is increasing
  - b is released from the resonance
  - 3 planets removed or moved out leaving b with the present e



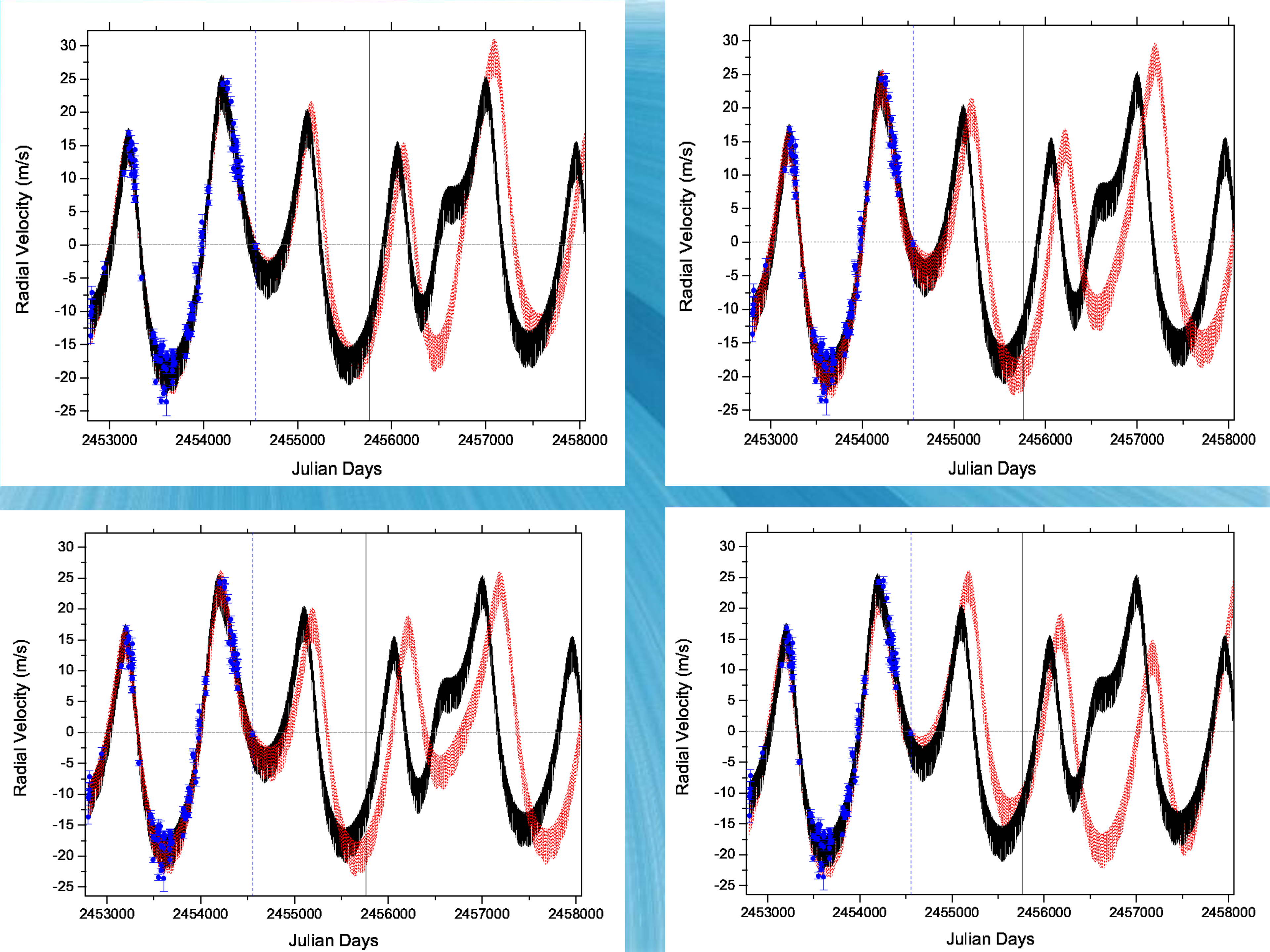


NAM2012, G. Campanella

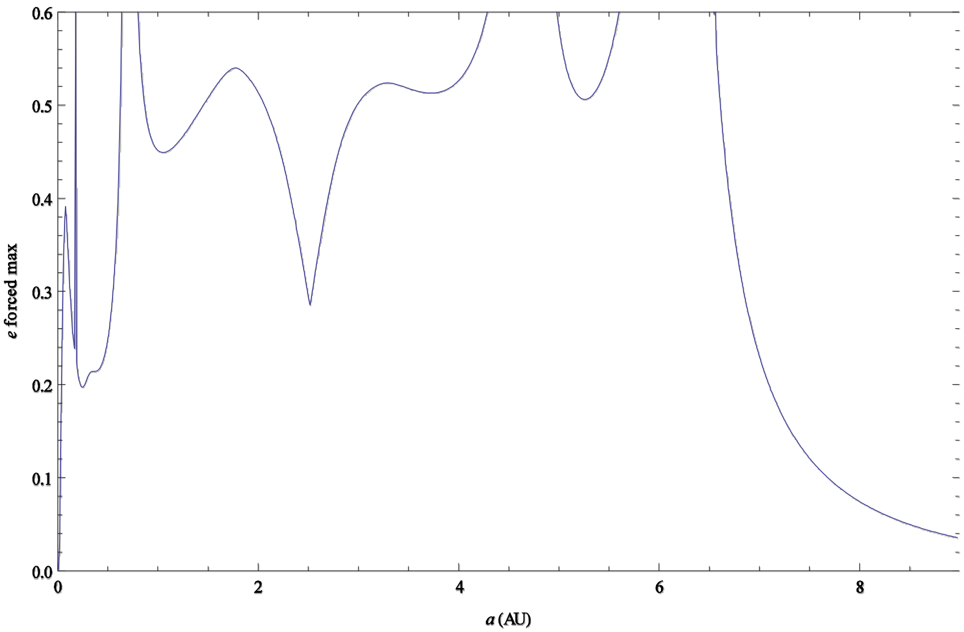

The End!
NAM2012, G. Campanella

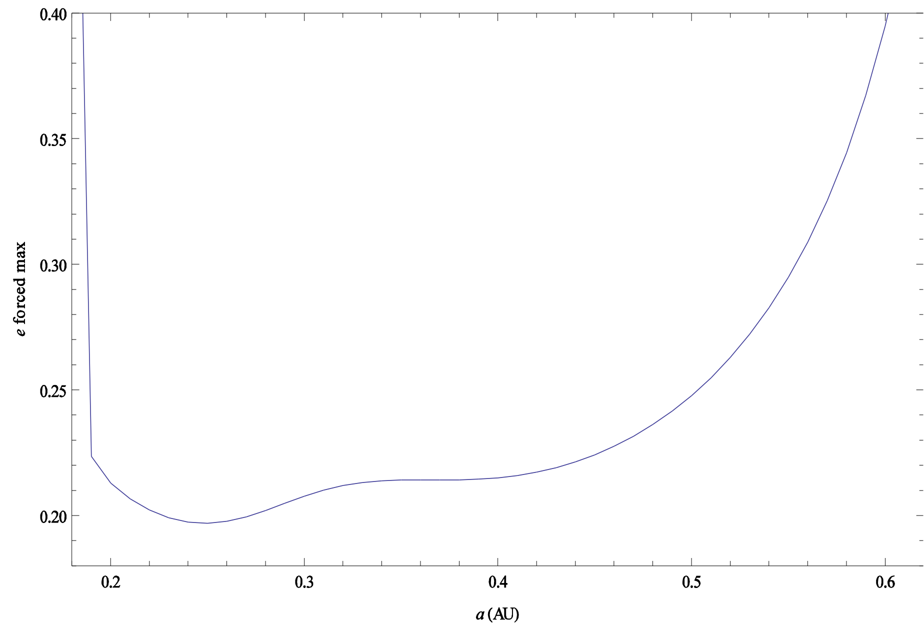


- Genetic algorithm to retrieve the minimum in the χ^2 phase space


Radial Velocity (m/s)
Julian Days
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
2453000
2454000
2455000
2456000
2457000
2458000

Additional planets?





Campanella et al. in prep.

- Habitable Zone orbital distance $a_{hab} = \sqrt{L_* / L_\odot} = 0.55AU$
- Stable region at around 0.2 - 0.6 AU, confirmed by numerical simulations
- With a super-Earth in the HZ the fit improves. Signal would be at the noise level (F-test ~ 30%)

- The existence of this planet would support the "packed planetary systems" hypothesis

Barnes & Raymond 2004

Scattering

- Consider GR effects
- Planets have a physical size
- Scenario: terrestrial planet (1-10 $M_\oplus$) at 2.5-5 $R_{H,m}$ from b

$$R_{H,m} = 0.5(a_1 + a_2)\left[(M_1 + M_2)/3M_*\right]^{1/3}$$

- Collisions, no ejections:

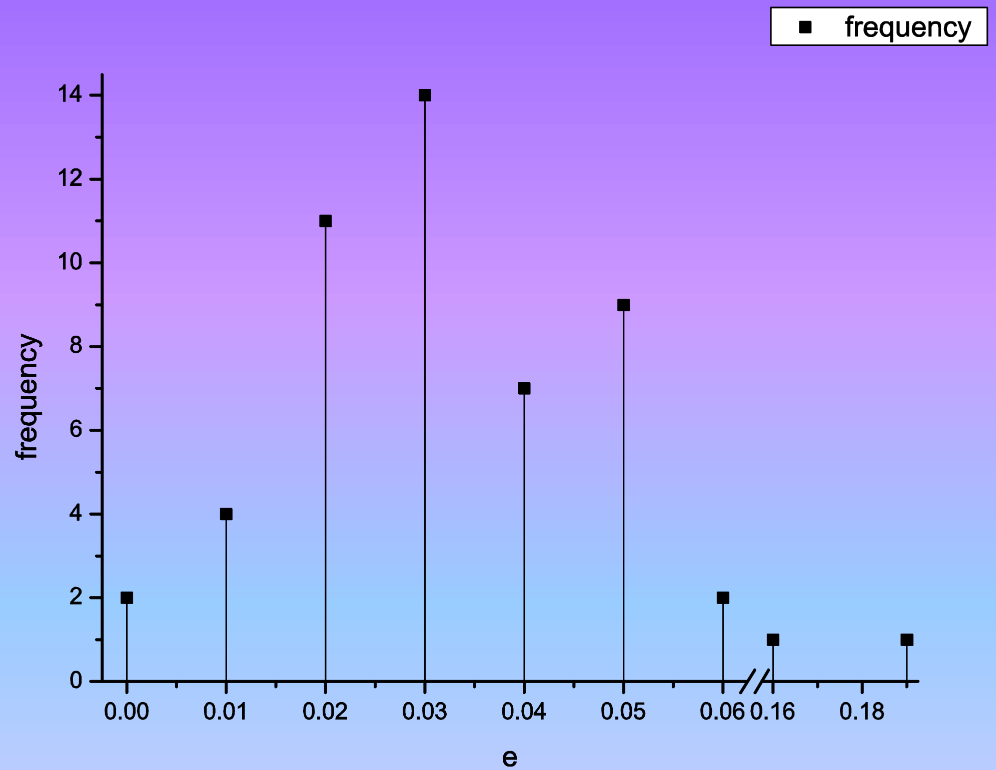
$$v_{orb,b} = \sqrt{GM_*/a_b} = 88 Km/s$$

- Max kick from a 1 $M_\oplus$

$$v_{esc,\oplus} = \sqrt{2Gm_\oplus/r_\oplus} \approx 11 Km/s$$

$$v_{esc,*} = \sqrt{2GM_*/a_*} \approx 124 Km/s$$

$$e = v_{esc,\oplus}/v_{orb,b} \approx 0.13$$



Scattering

- Engineered construction:
  - planet x excites the others, then removed

energy to remove x provided by moving inwards c and d

- how massive x needs to be to generate e_b? $e = v_{esc,x} / v_{orb,b} \approx 0.39$

m_x= 0.22 M_{JUP} $(\rho_x = \rho_{JUP})$

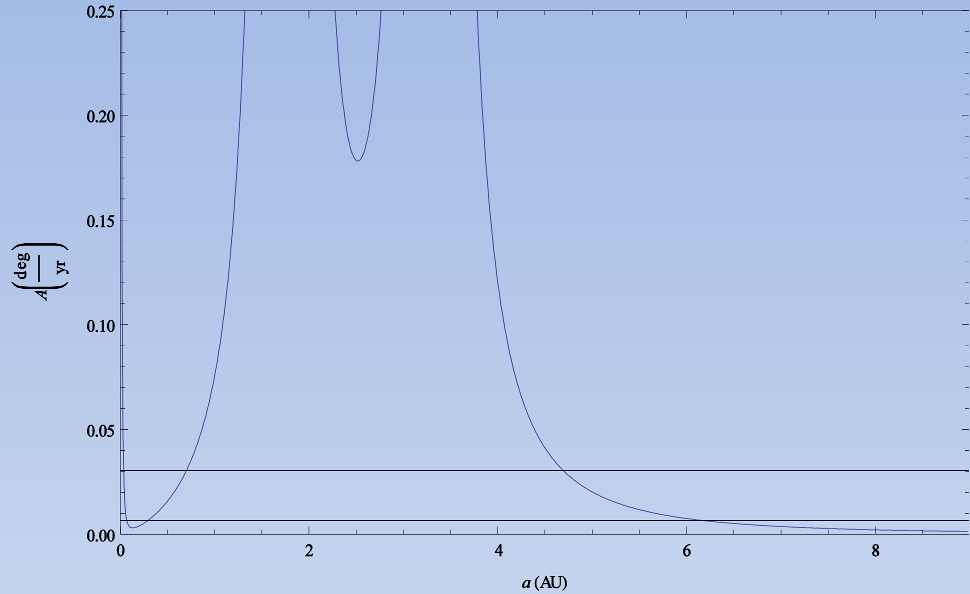
$$E_i = -\frac{GM_*}{2}\left(\frac{m_c}{a_{c,i}} + \frac{m_d}{a_{d,i}}\right) \qquad E_f = -\frac{GM_*}{2}\left(\frac{m_c}{a_{c,f}} + \frac{m_d}{a_{d,f}}\right)$$

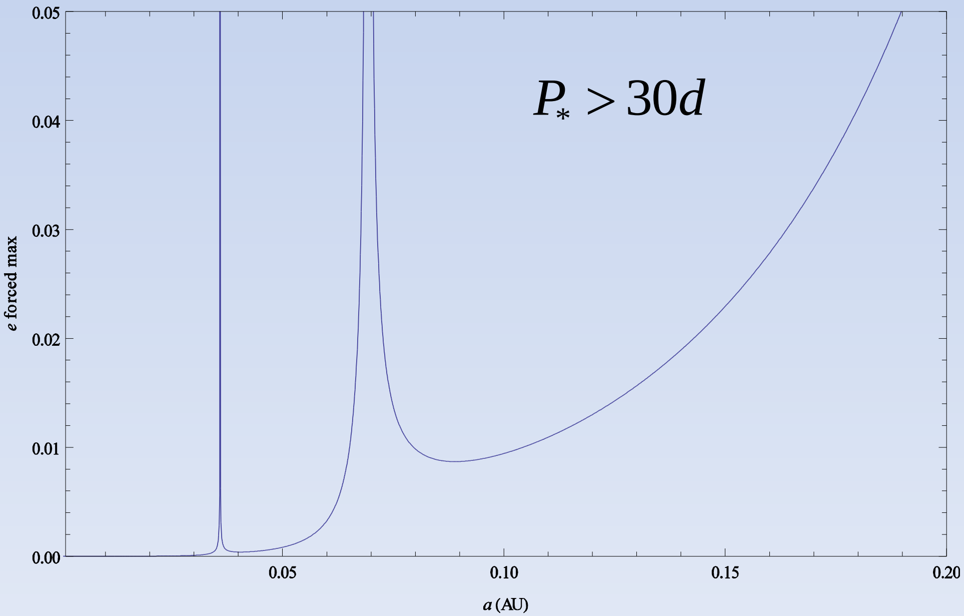
$$\Delta E = \frac{GM_*}{2}\frac{m_x}{a_{x,i}} \qquad \Delta E = E_i - E_f$$

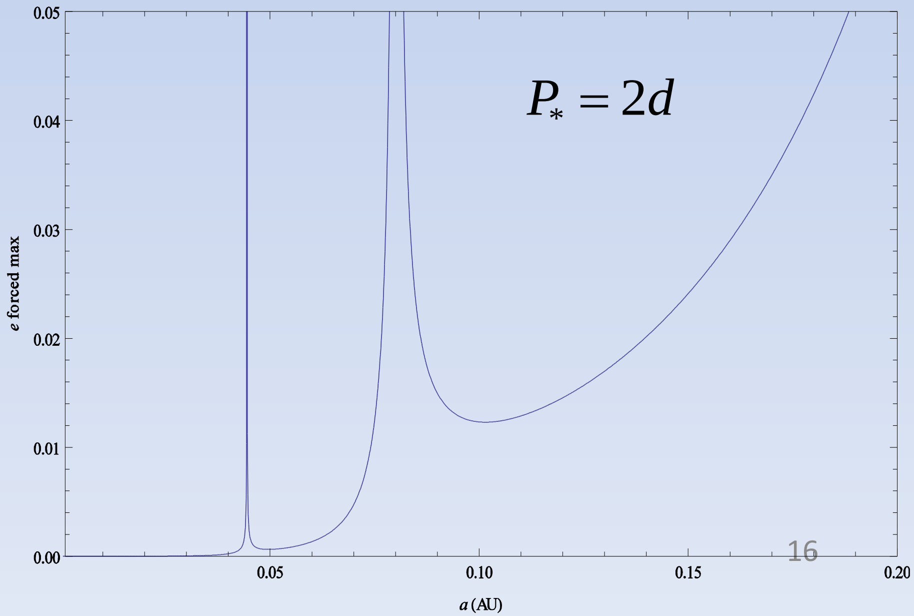
- $a_{c,i}$= 1.8 AU x: 2-5 $R_{H,m}$ outside d's orbit

Sweeping Secular Resonances

- Consider GR and J2 effects   Treat planet b as a test particle







Stellar Spin-down

- The magnetised outflowing wind remove angular momentum from rotating star:

For a G or K dwarf

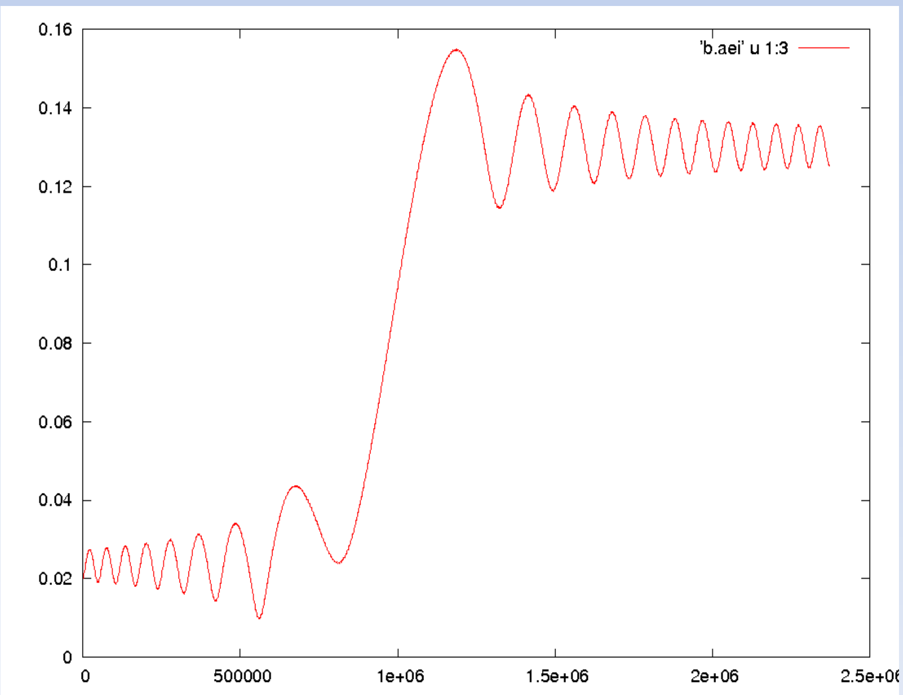
$$\frac{d\Omega}{dt} = -\alpha\Omega^3$$

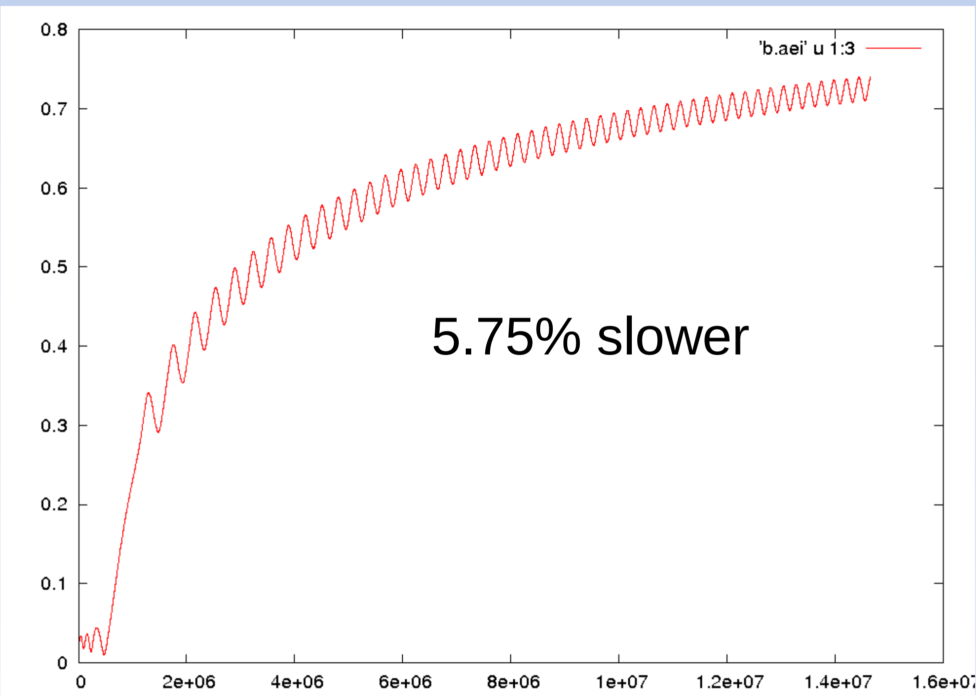
$$\alpha = 1.5\times10^{-14}\, yrs$$

Verbunt & Zwaan 1981
Dobbs-Dixon et al. 2004

$\Omega \propto t^{-1/2}$ empirical relation for solar-type stars

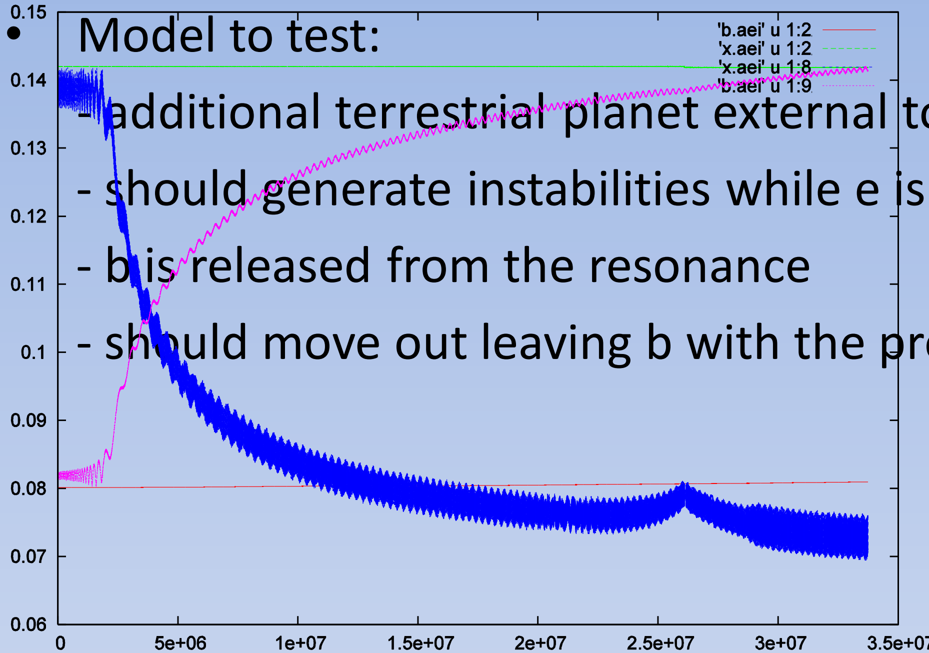
Skumanich 1972

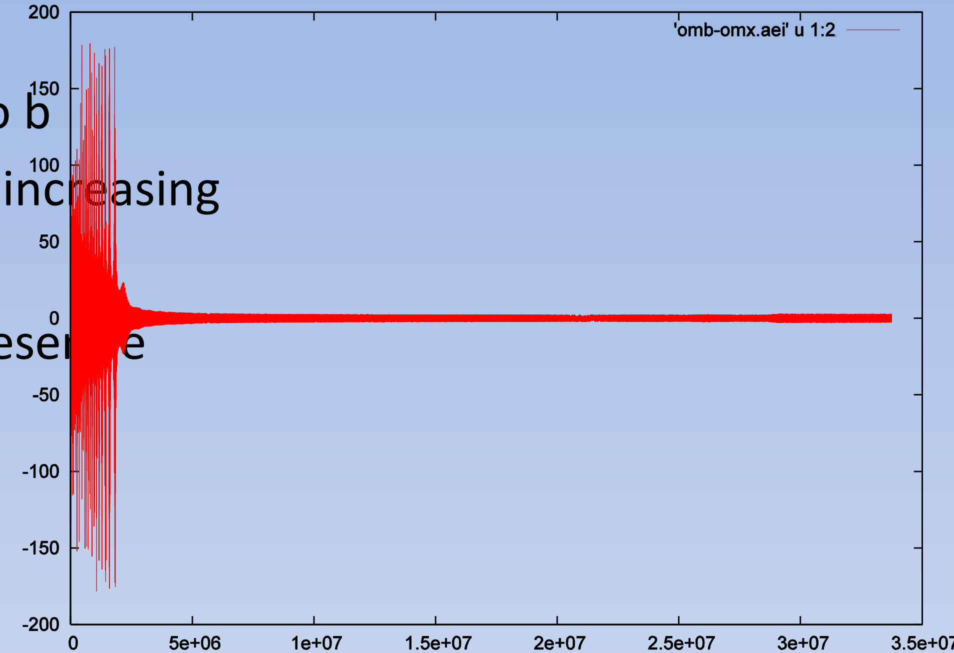


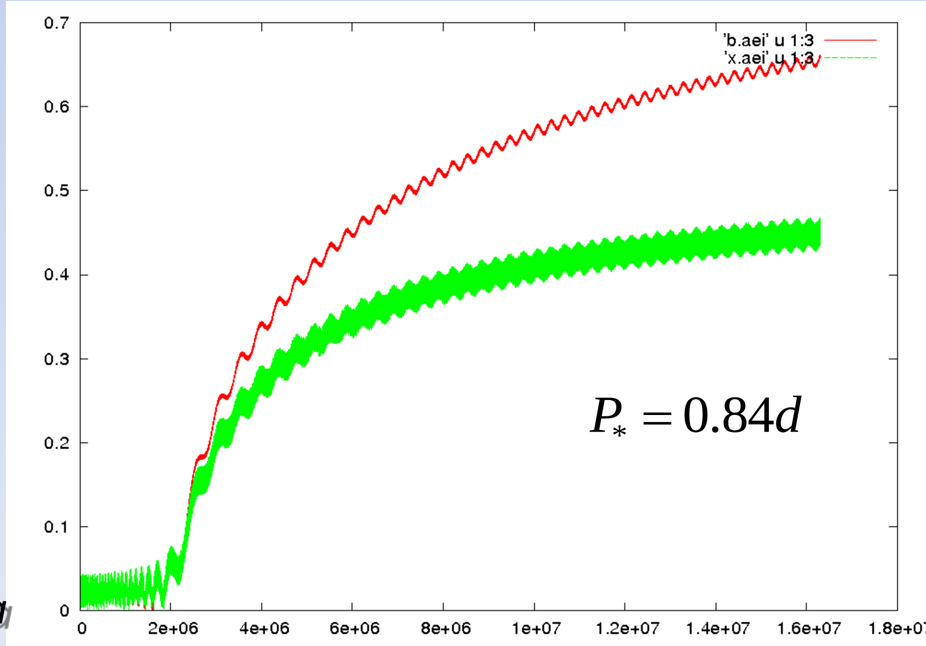


Stellar Spin-down

- Model to test:
  - additional terrestrial planet external to b
  - should generate instabilities while e is increasing
  - b is released from the resonance
  - should move out leaving b with the presence







Conclusions

• Around 100 planetary systems are known
• A broad range of properties need to be interpreted

• Dynamical stability used as an additional observable when considering RV data

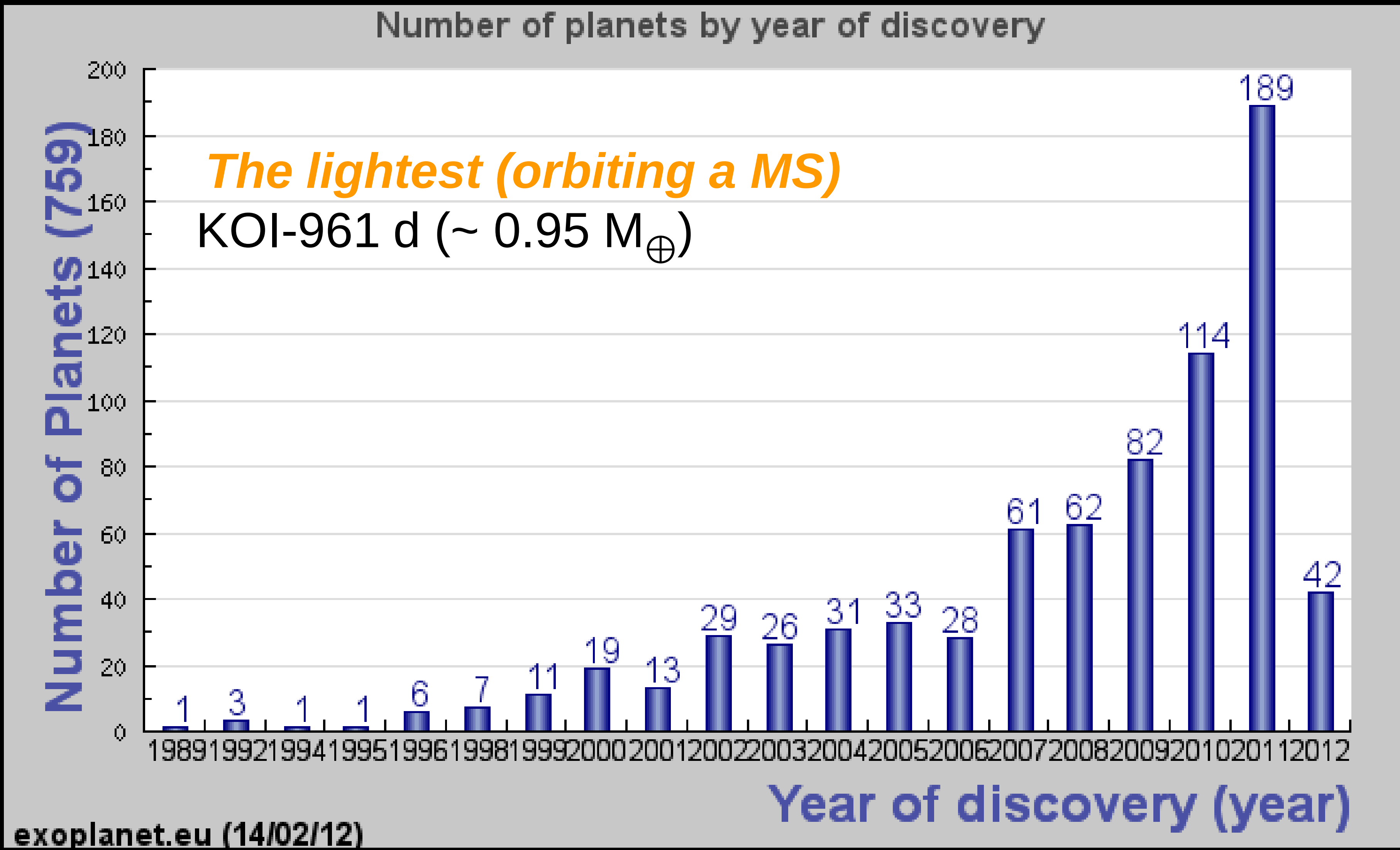
• Planet-planet scattering can generate large eccentricity and throw planets into MMRs
• Sweeping secular resonances during an earlier stage of stellar evolution can generate large eccentricities

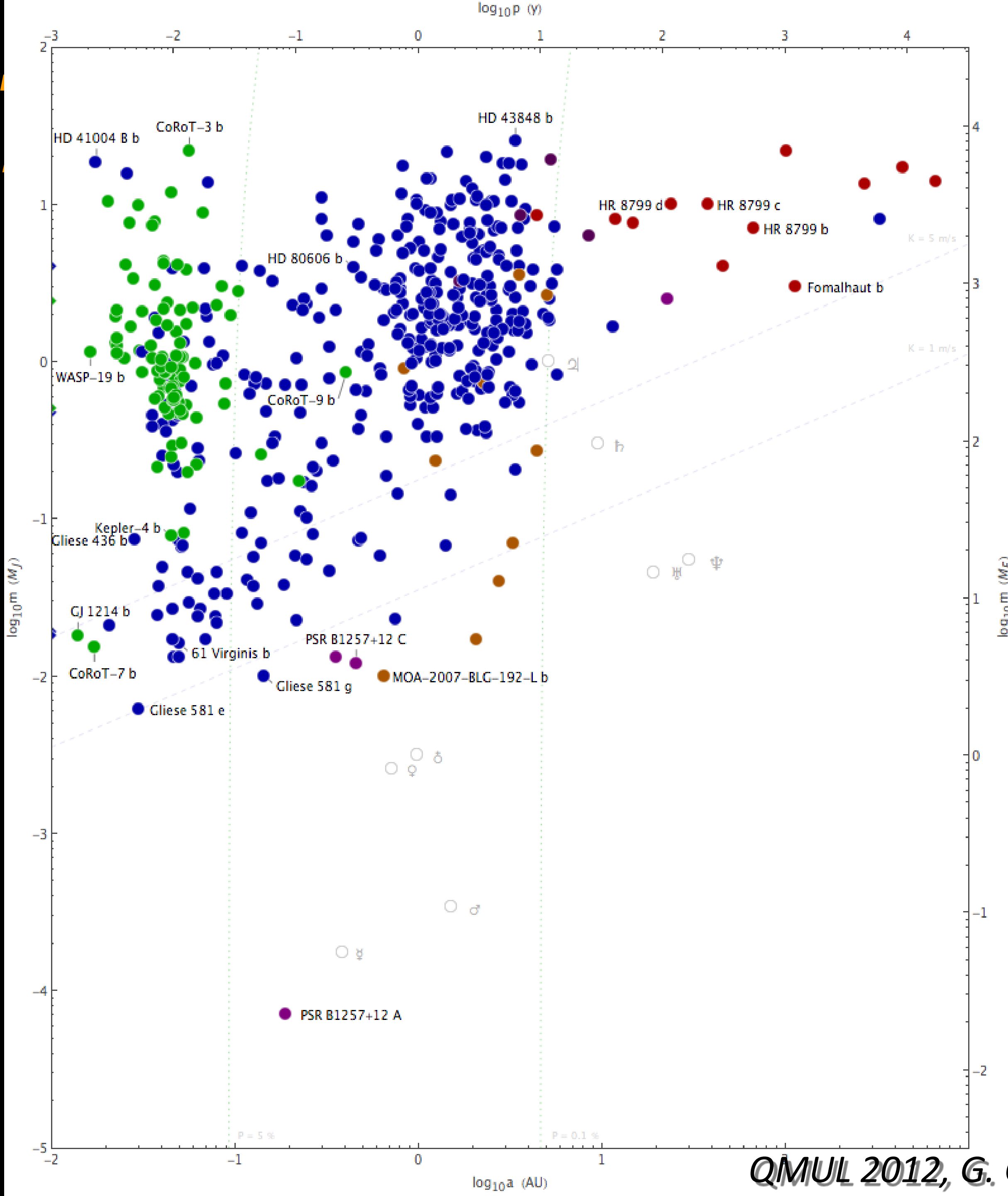
• The present state of the system HD 181433 may have been generated by scattering of giant and rocky planets while the star was a fast rotator

760 Extrasolar planets

The lightest (orbiting a MS)

KOI-961 d (~ 0.95 $M_{\oplus}$)





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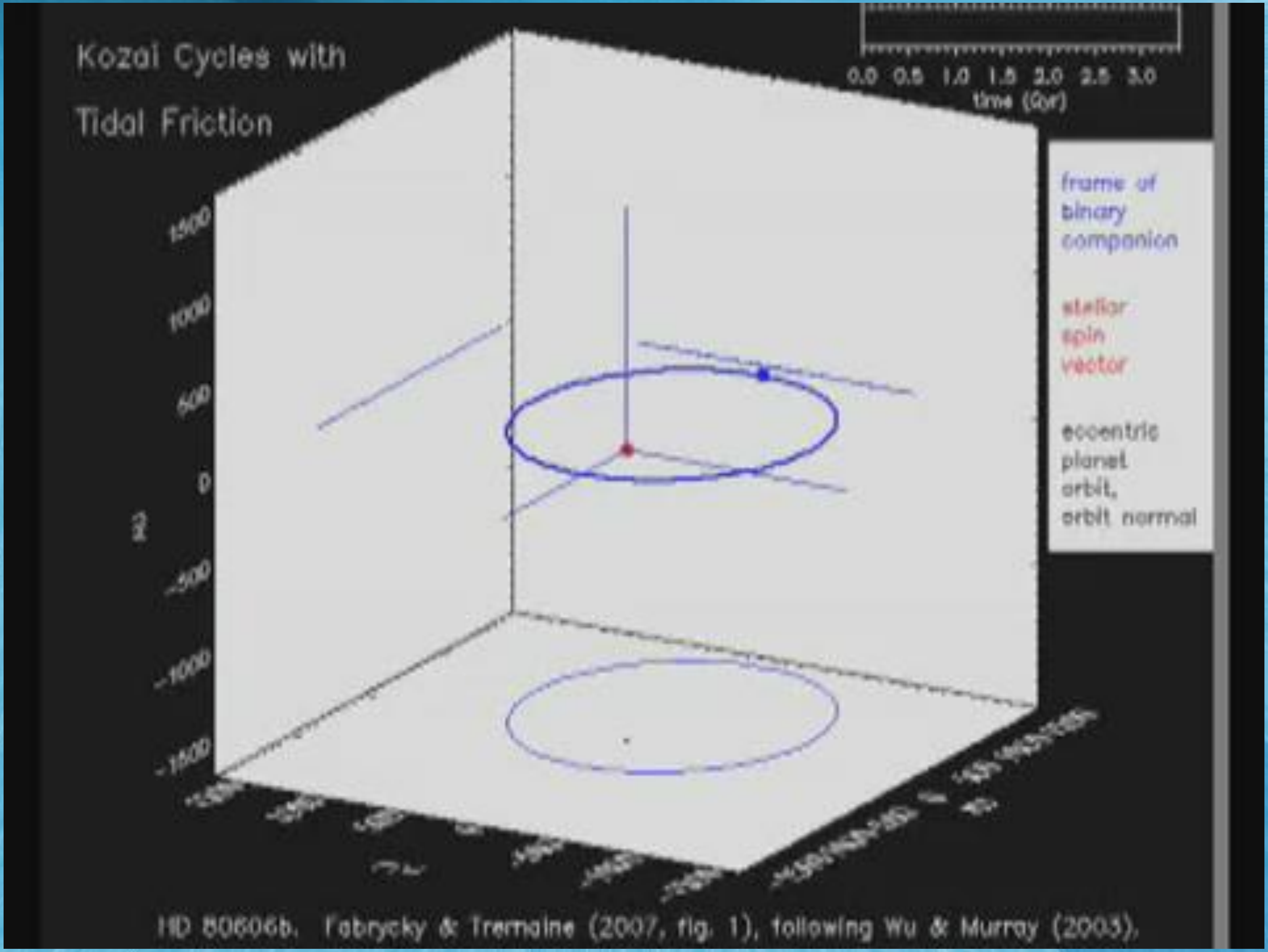
The Ultimate Fate of HD 80606 b



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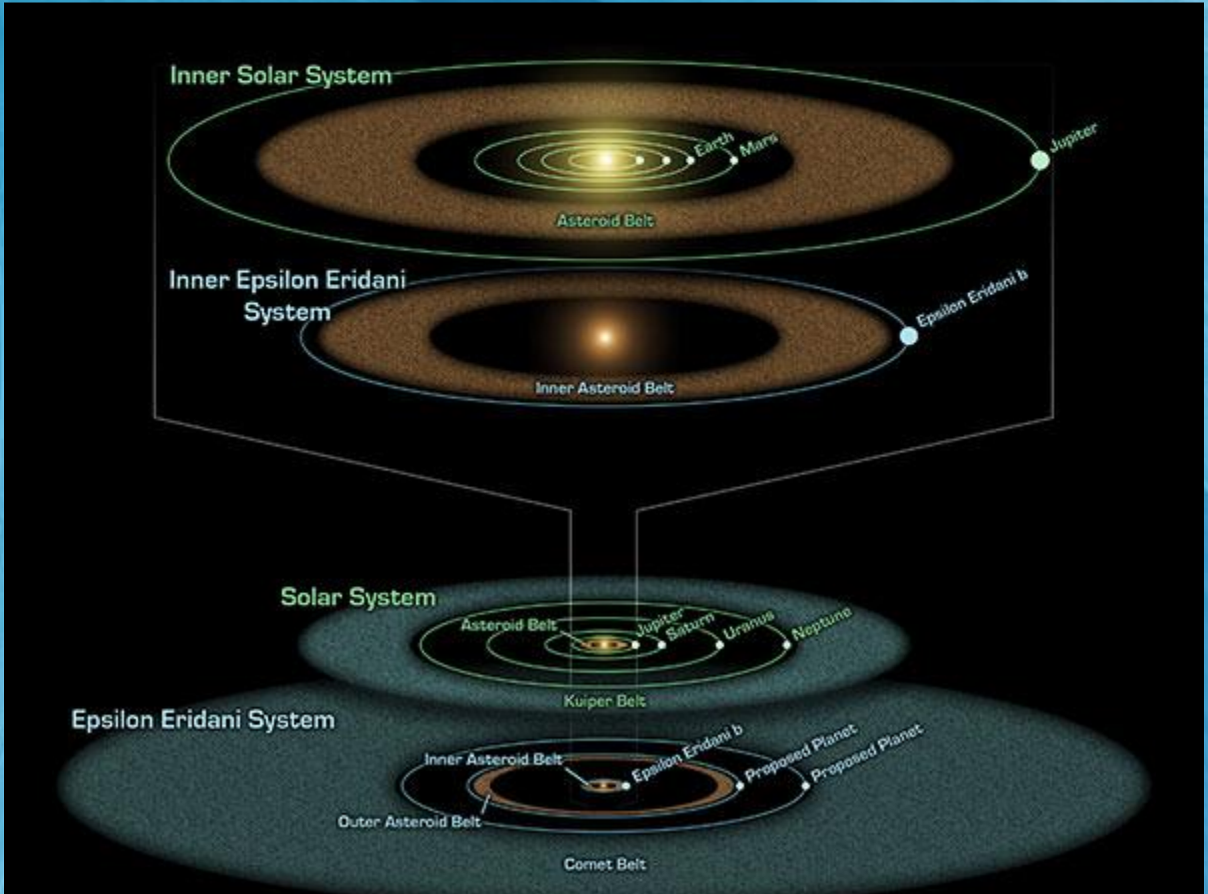
The Nearest Planetary System: Epsilon Eridani

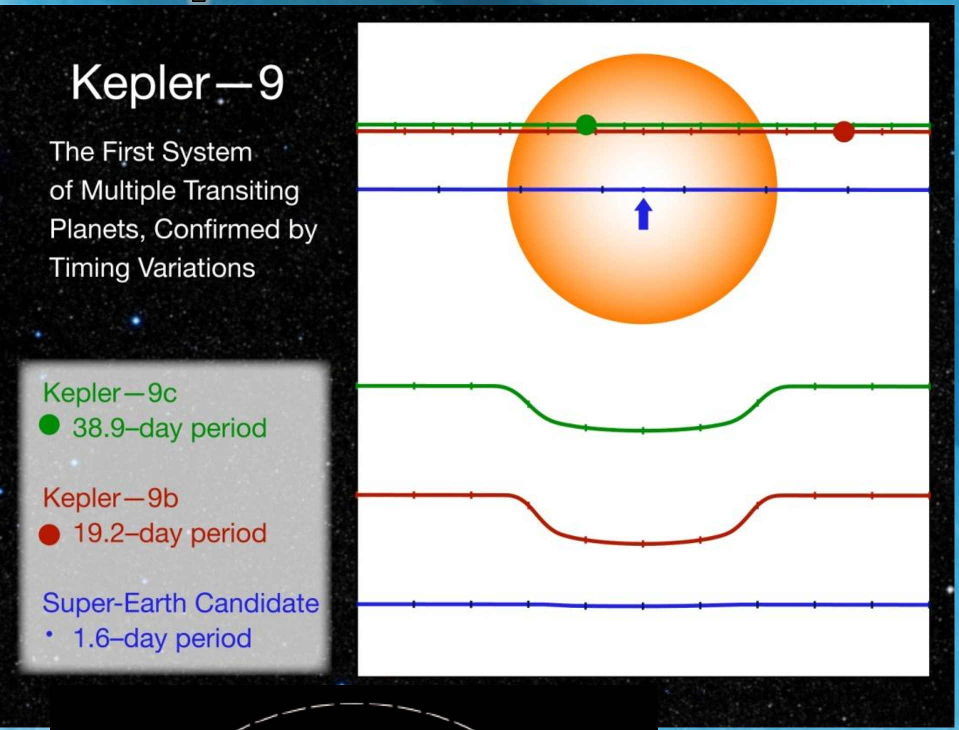
- ~ 10 light years away
- two asteroid belts

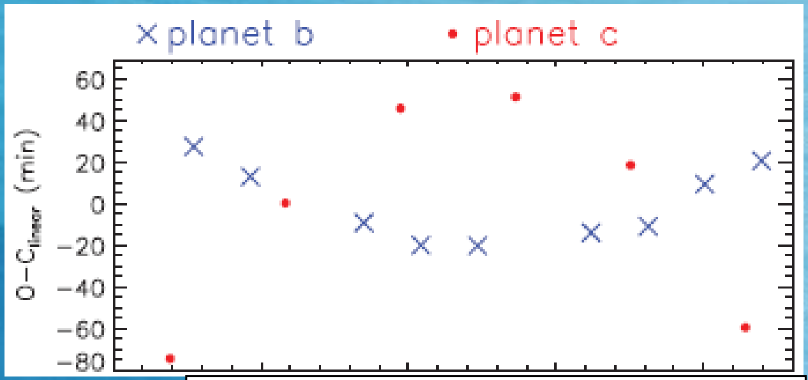


1 light-year = 10 000 billion km

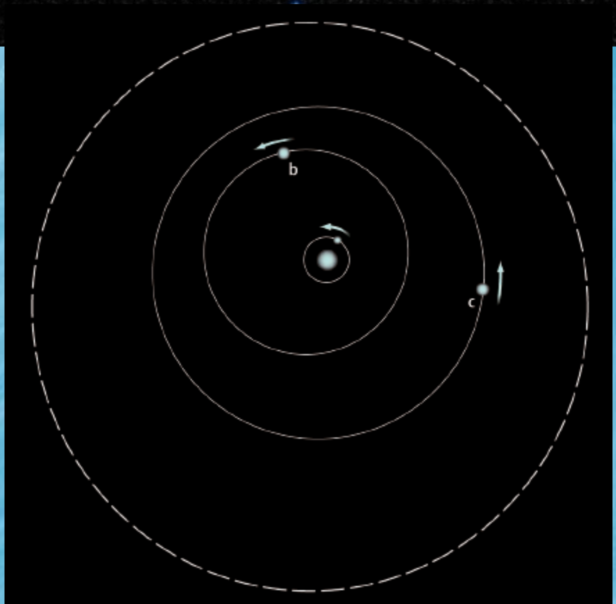
17 Kepler's Transiting Planet Systems

Kepler-9: A System with 3 Transiting Planets

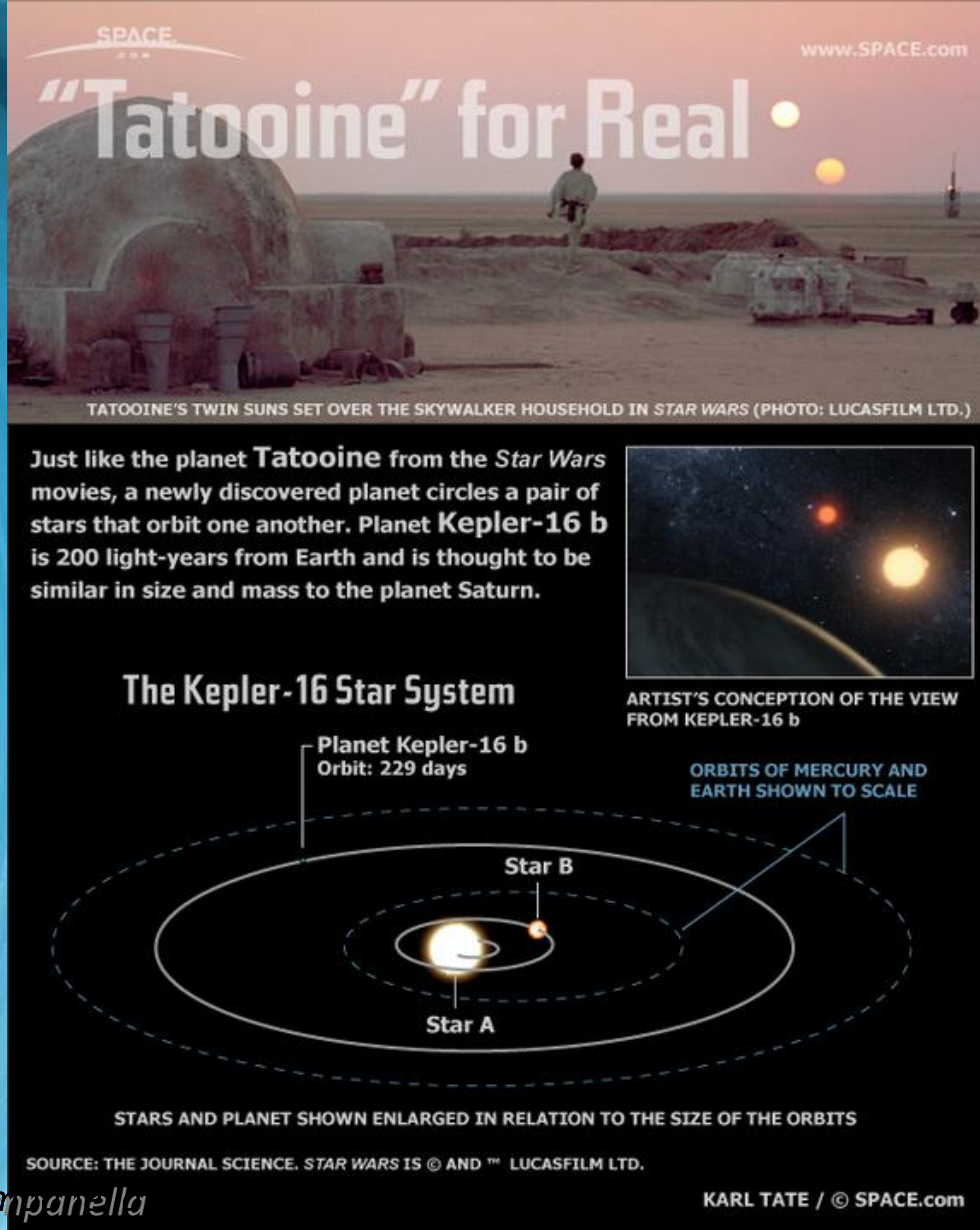




Holman et al. 2010



	Kepler-9 d	Kepler-9 b	Kepler-9 c
Mass	7 $M_{\oplus}$	0.25 M_{Jup}	0.17 M_{Jup}
Radius	1.6 $R_{\oplus}$	0.84 R_{Jup}	0.82 R_{Jup}
P (days)	1.6	19.2	38.9



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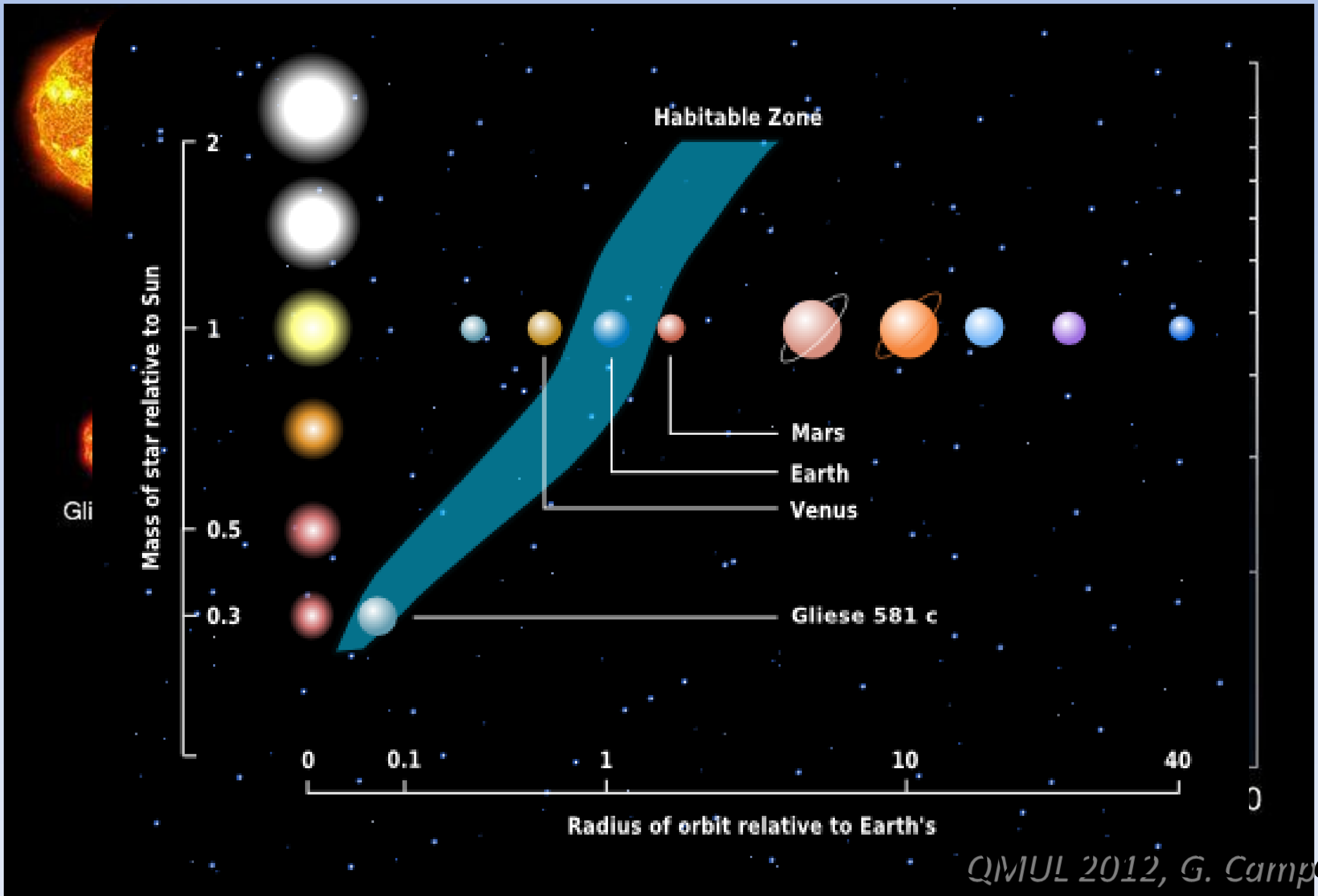
"Tatooine" for Real
TATOOINE'S TWIN SUNS SET OVER THE SKYWALKER HOUSEHOLD IN STAR WARS (PHOTO: LUCASFILM LTD.)
Just like the planet Tatooine from the Star Wars movies, a newly discovered planet circles a pair of stars that orbit one another. Planet Kepler-16 b is 200 light-years from Earth and is thought to be similar in size and mass to the planet Saturn.
ARTIST'S CONCEPTION OF THE VIEW FROM KEPLER-16 b
The Kepler-16 Star System
Planet Kepler-16 b
Orbit: 229 days
ORBITS OF MERCURY AND EARTH SHOWN TO SCALE
Star B
Star A
STARS AND PLANET SHOWN ENLARGED IN RELATION TO THE SIZE OF THE ORBITS
SOURCE: THE JOURNAL SCIENCE. STAR WARS IS © AND ™ LUCASFILM LTD.
KARL TATE / © SPACE.com

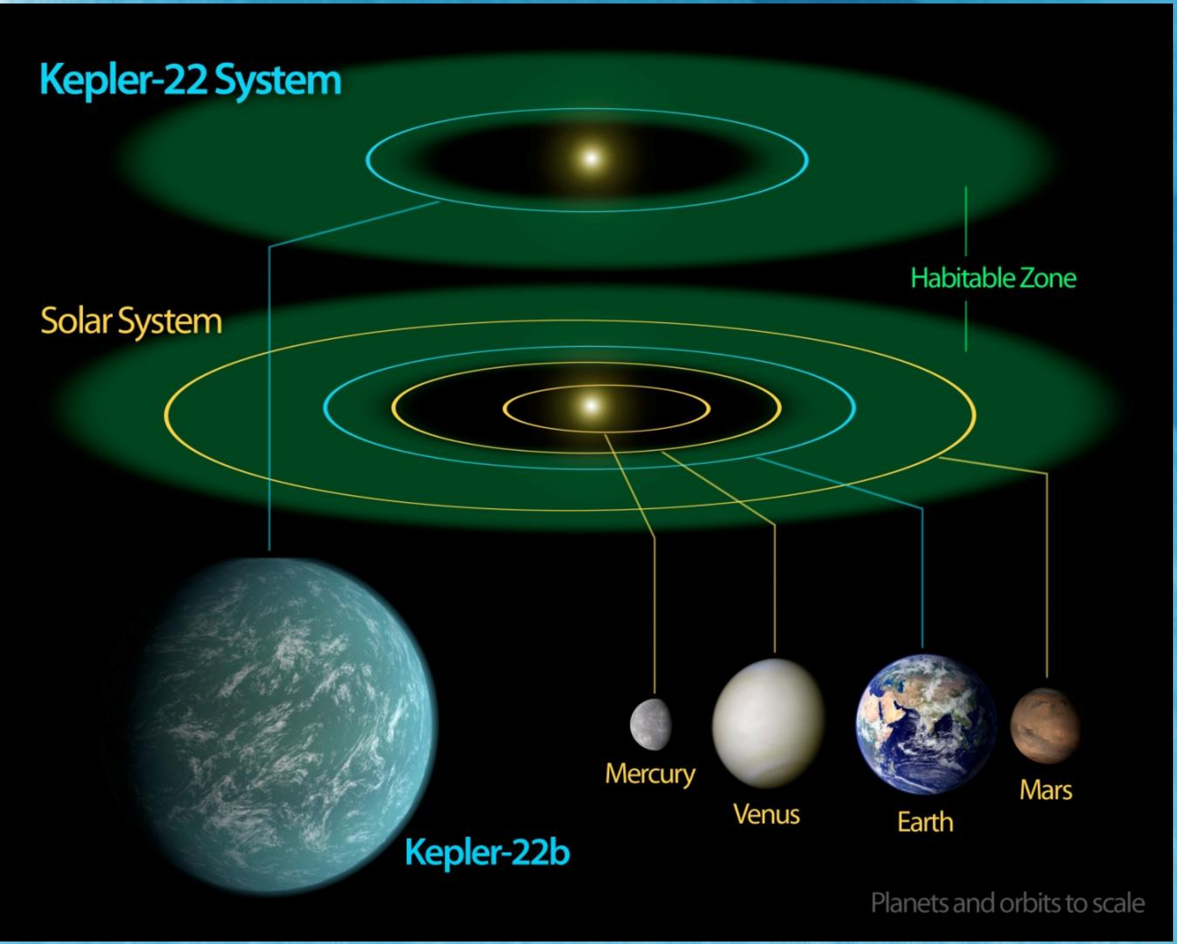
The Habitable Zone

- *Habitable Zone (HZ):* the region around a star within which an Earth-like planet can sustain **liquid water** on its surface.
- Planets inside the HZ are not necessarily habitable.



Kepler-22

- Smallest planet known to orbit in the middle of the HZ of a sun-like star



	Kepler-22 b
Mass	$< 35\ M_{\oplus}$
Radius	$2.4\ R_{\oplus}$
P (days)	290

Borucki et al. 2012

699 *Candidates detected by RV*