"Stellar wobble in triple star systems"

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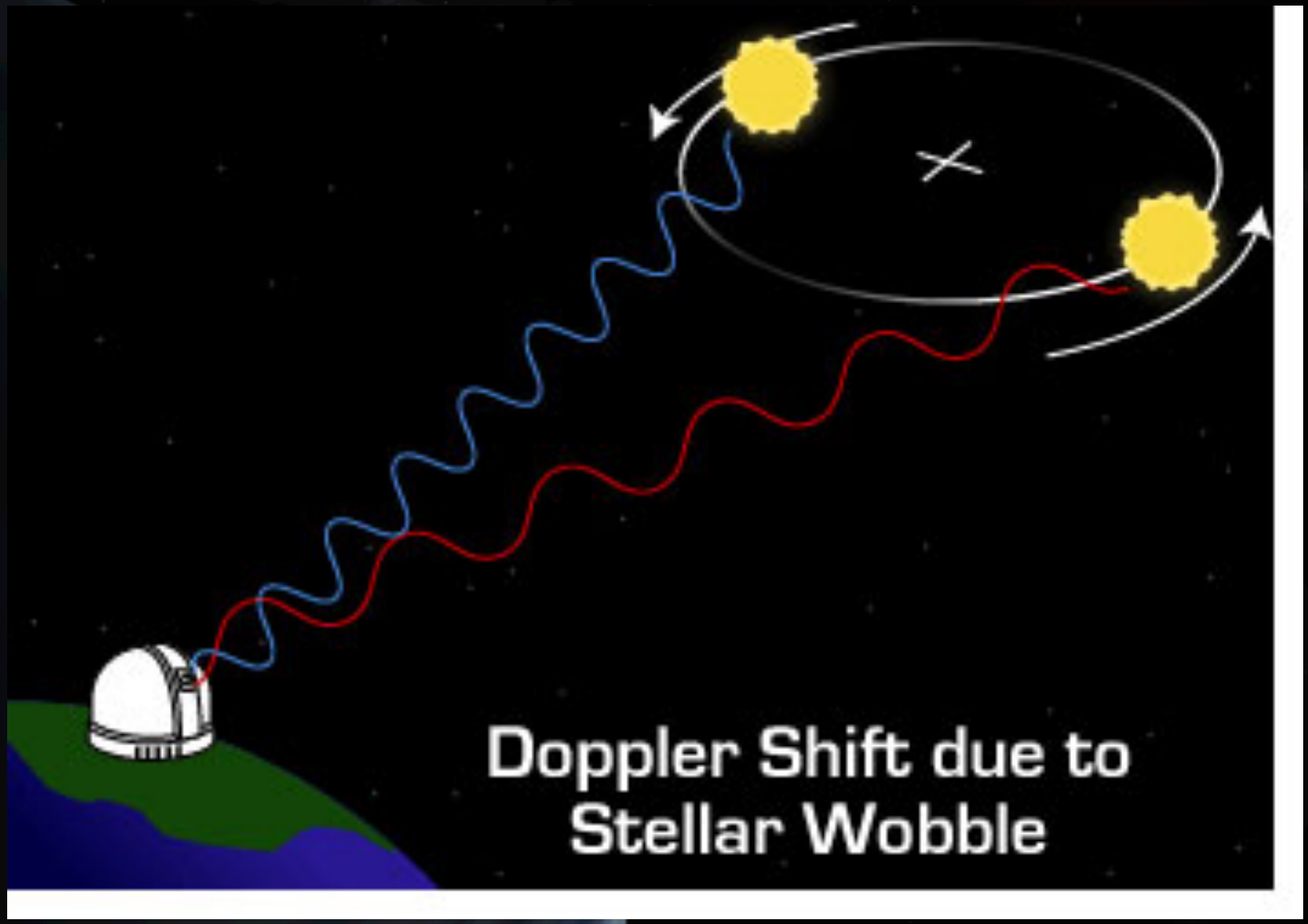
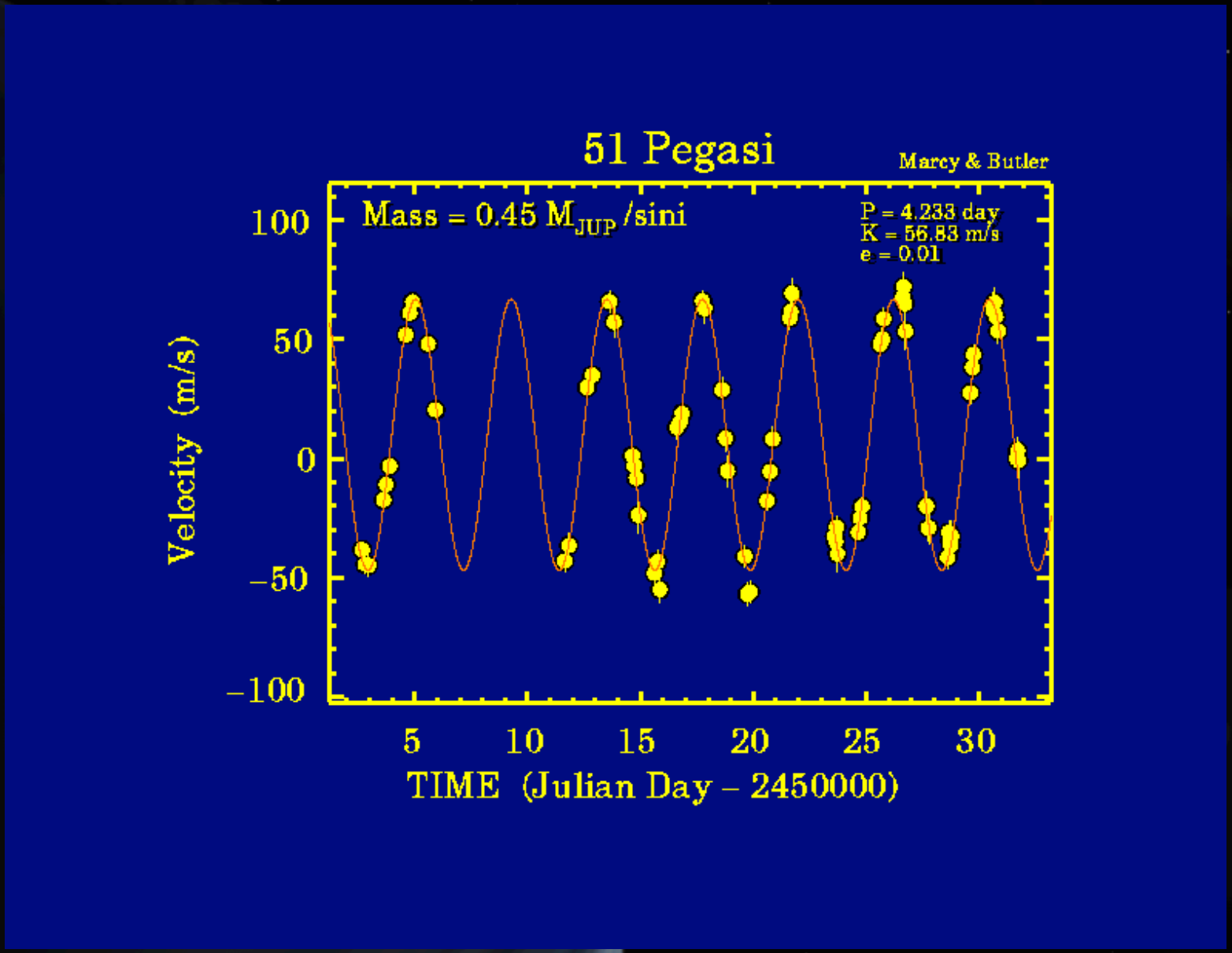
Orbital couples: "Pas de Deux"
in the Solar System and the Milky Way
Paris, 10-12 October 2011

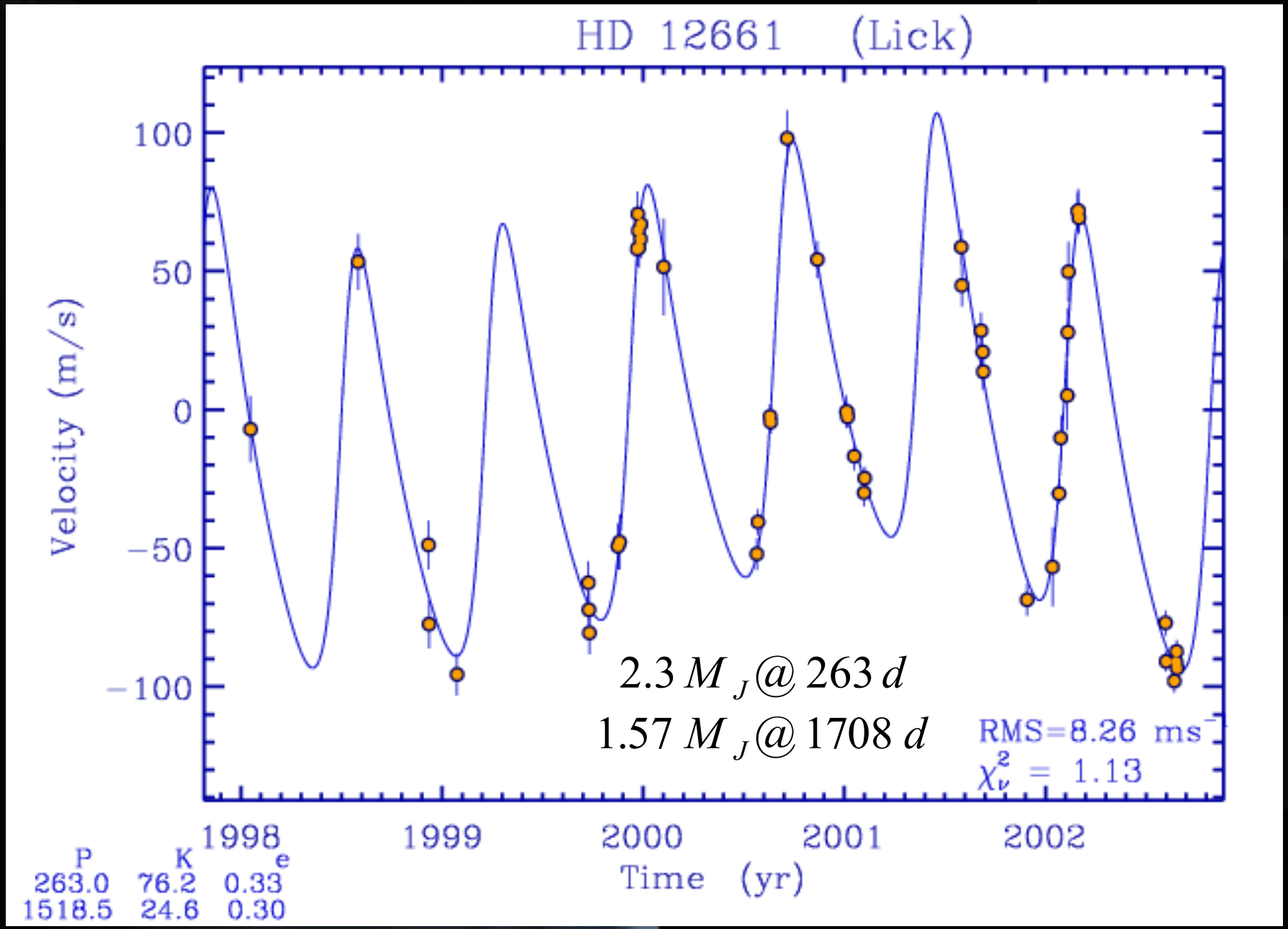
radial-velocity method



1 planet: 0.45 M_J @ 4.2 d

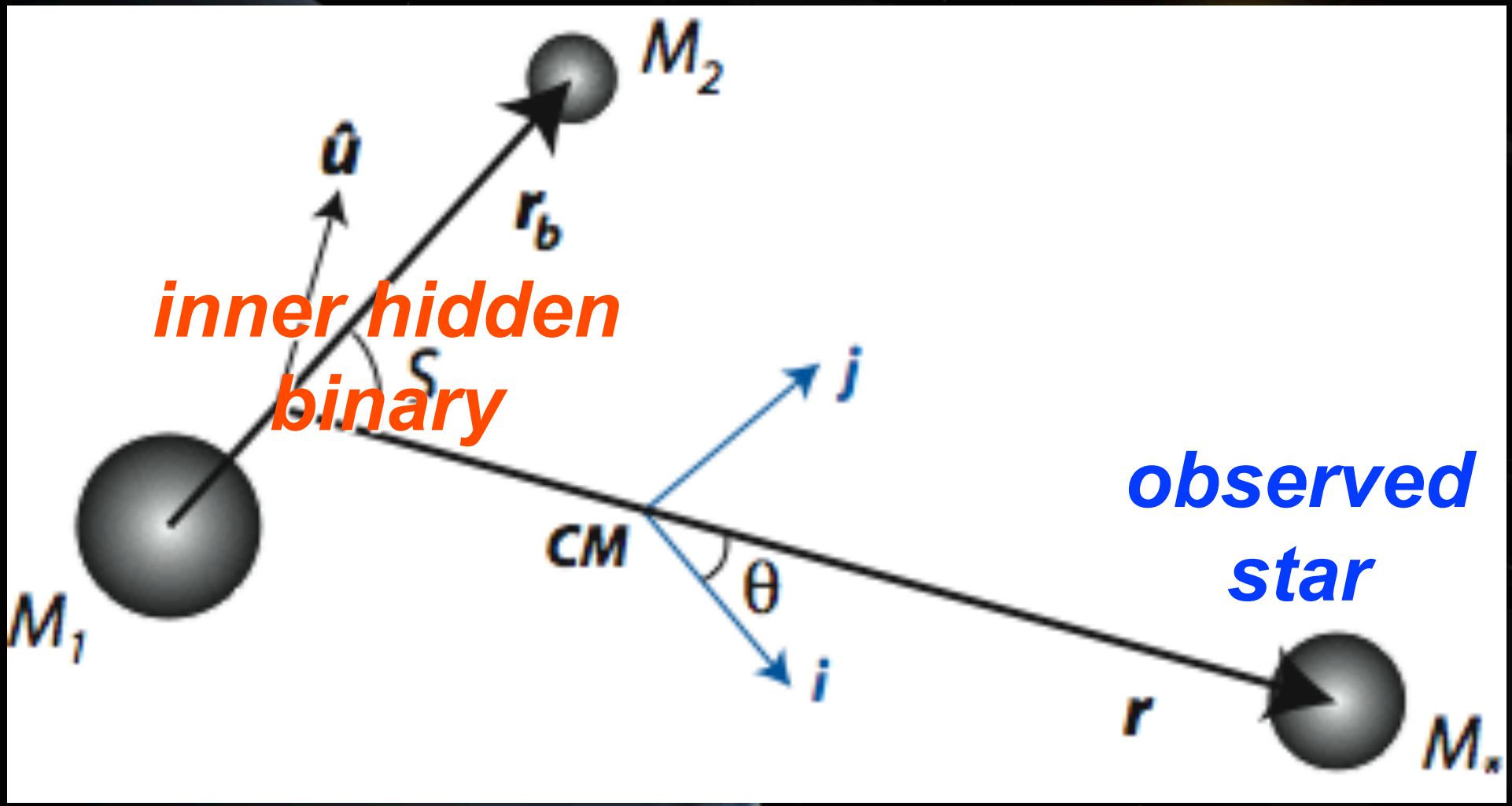


2 planets

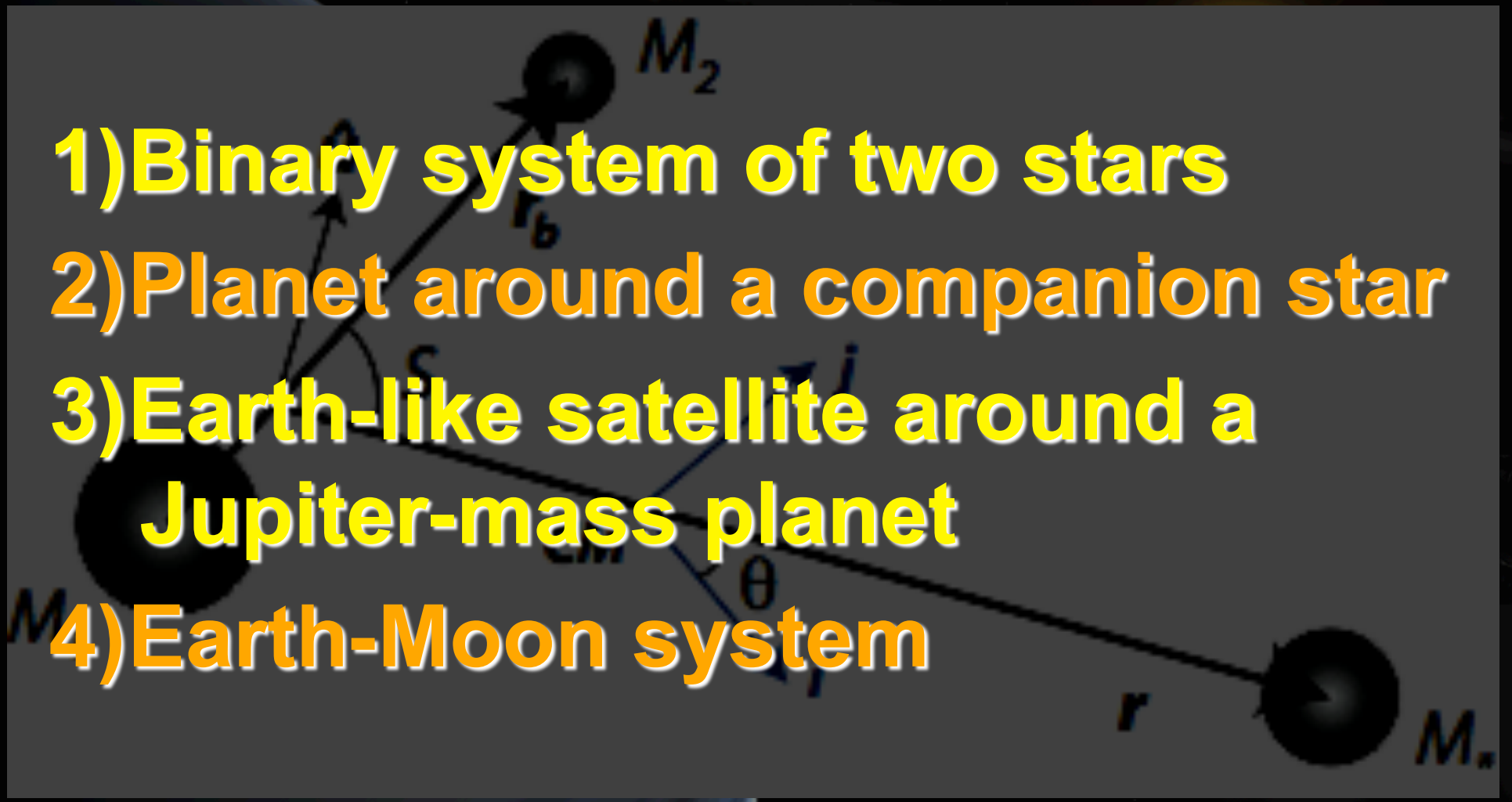

HD 12661 (Lick)
Velocity (m/s)
100
50
0
−50
−100
1998
1999
2000
2001
2002
Time (yr)
2.3 M_J@ 263 d
1.57 M_J@ 1708 d
RMS=8.26 ms⁻¹
χ^2_ν = 1.13
P K e
263.0 76.2 0.33
1518.5 24.6 0.30

3-body problem

(not restricted and $r_b/r << 1$)

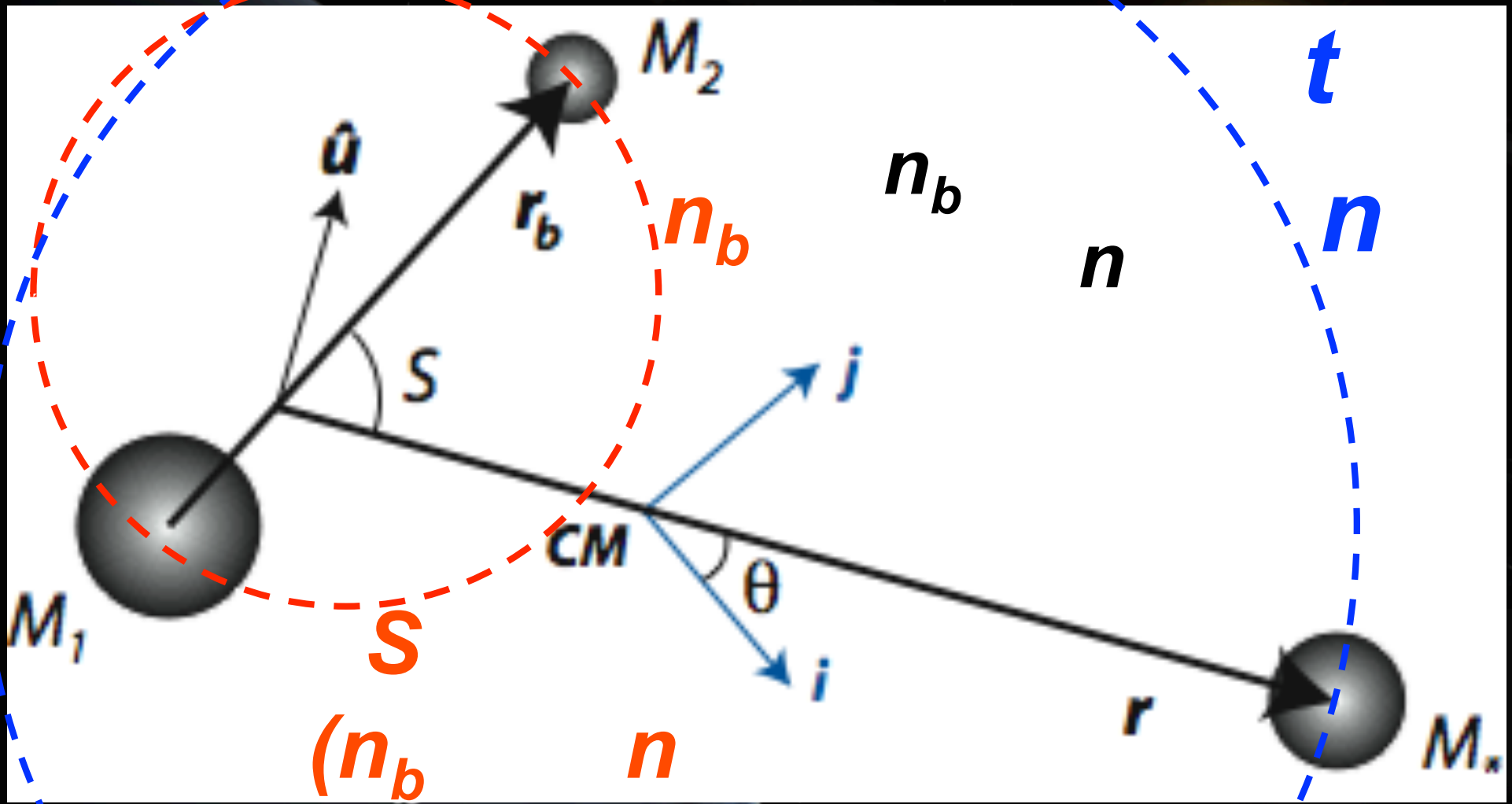


Can an hierarchical binary system mimic a planet?



1) Binary system of two stars
2) Planet around a companion star
3) Earth-like satellite around a Jupiter-mass planet
4) Earth-Moon system

Coplanar circular problem



n

t

n_b

n

n

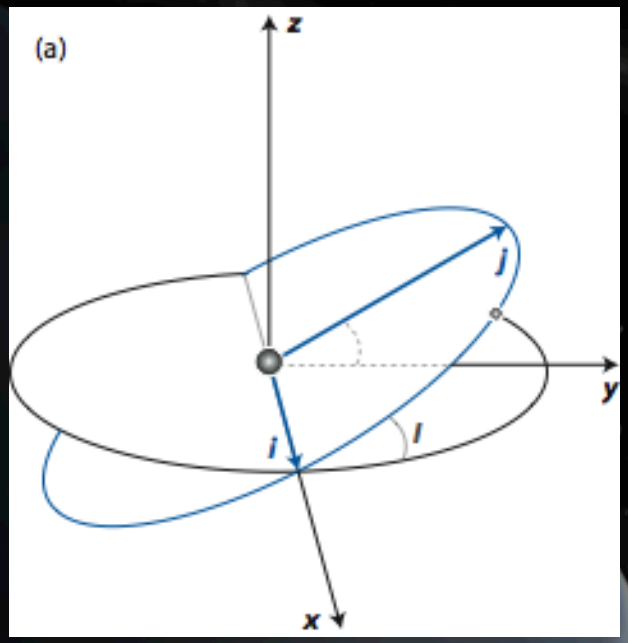
S

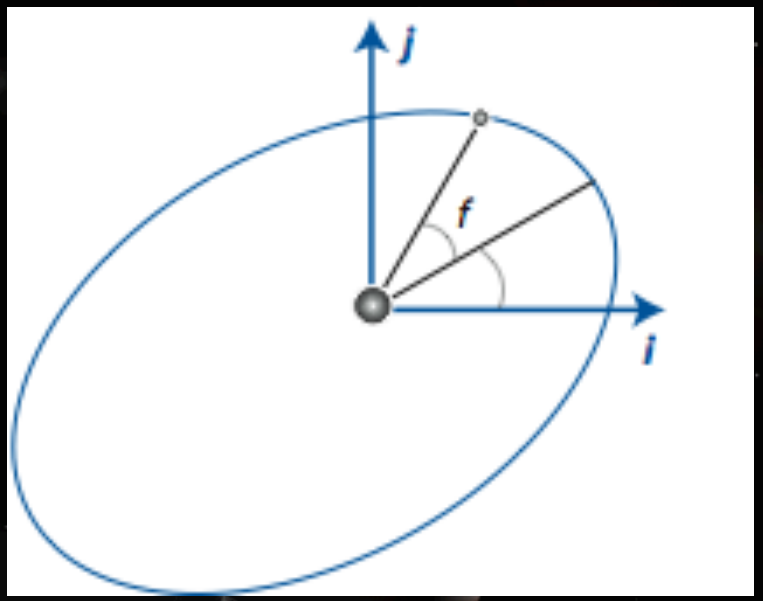
$(n_b$

n

$)t$

Radial velocity of a planet



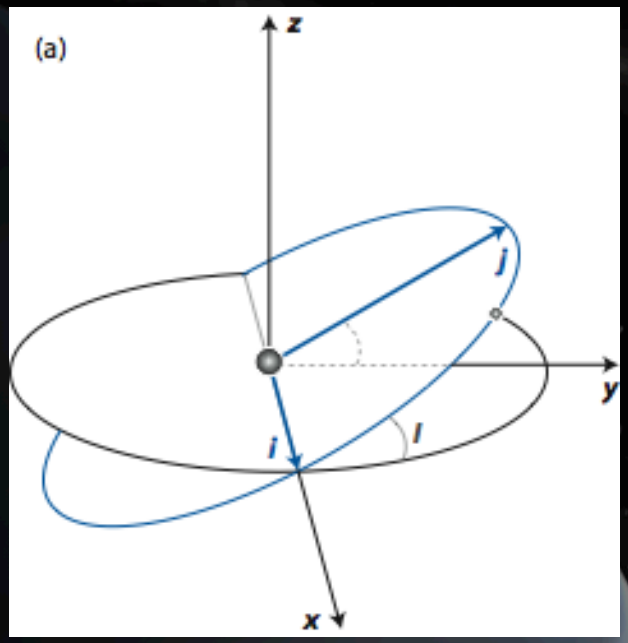


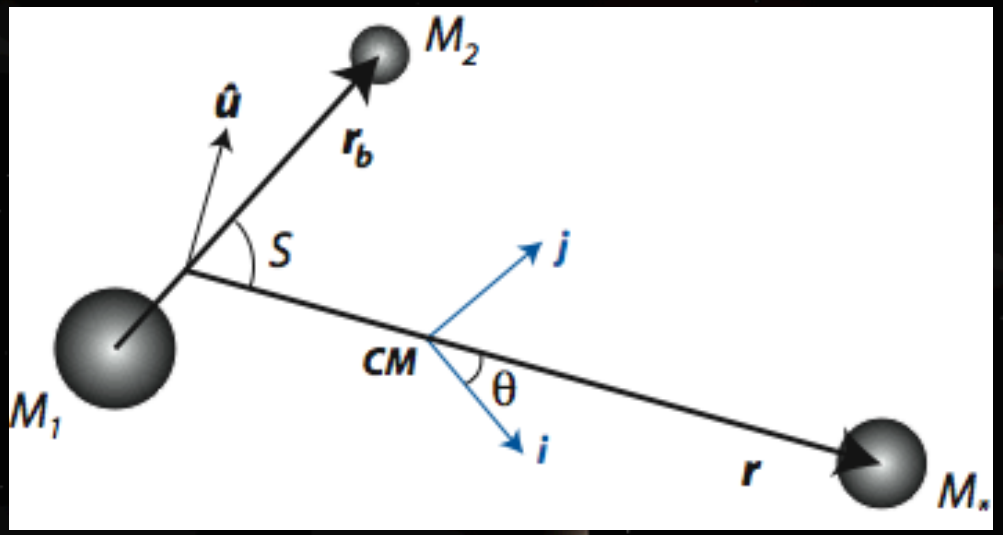
$$V_r = K\,[\cos(\quad + f) + e\cos(\quad)]$$

circular orbit)

$$V_r = K_p \cos(\quad + nt)$$

Radial velocity of a binary



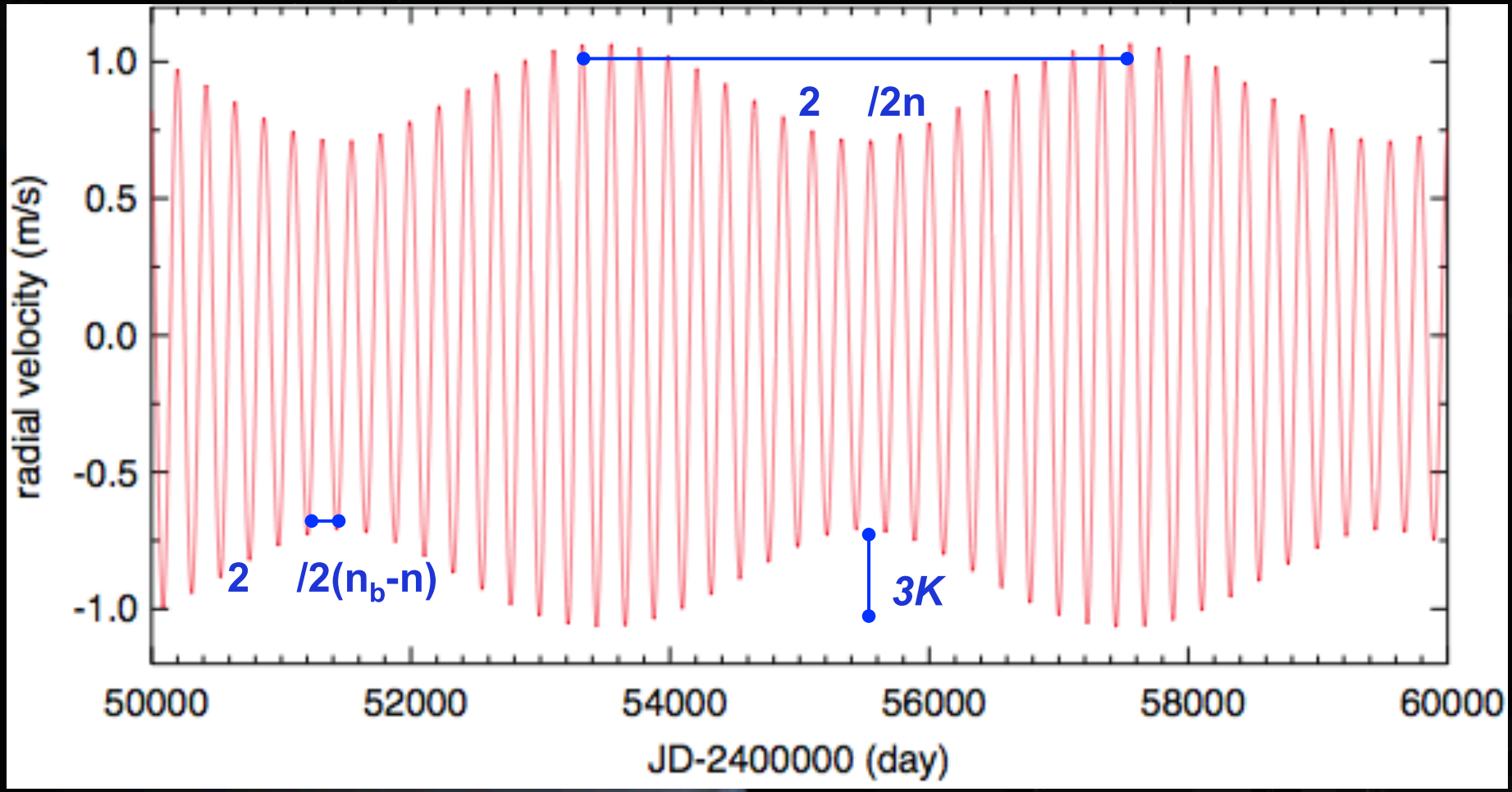


$$V_r = K_0 \cos(\quad_0 + nt) + V_b$$

binary wobble)

$$V_b = K\,[\,6\cos(2S)\cos(\quad) + 9\sin(2S)\sin(\quad)\,]$$

binary wobble



$$V_b = K [\ 6 \cos(2(n_b-n)t) \cos(nt) + 9 \sin(2(n_b-n)t) \sin(nt)\ ]$$

Can it mimic a planet?

$$V_b = K [\, 6 \cos(2(n_b - n)t) \cos(nt) + 9 \sin(2(n_b - n)t) \sin(nt) \,]$$

or…

$$V_b = \underbrace{K_1 \cos(n_1 t)}_{\text{One Planet}} + \underbrace{K_2 \cos(n_2 t)}_{\text{Two Planets !!}}$$

n_1 K_1 n_b n

n_2 K_2 n_b n


Can we distinguish between binary or two planets?
YES !!!
n_1 n_2 $|K_1|$ 5 |
n $K_2|$
n_1 r_2
K_1 n_b K_2 n_b
n n

Can we misinterpret a binary as ONE planet?

YES...

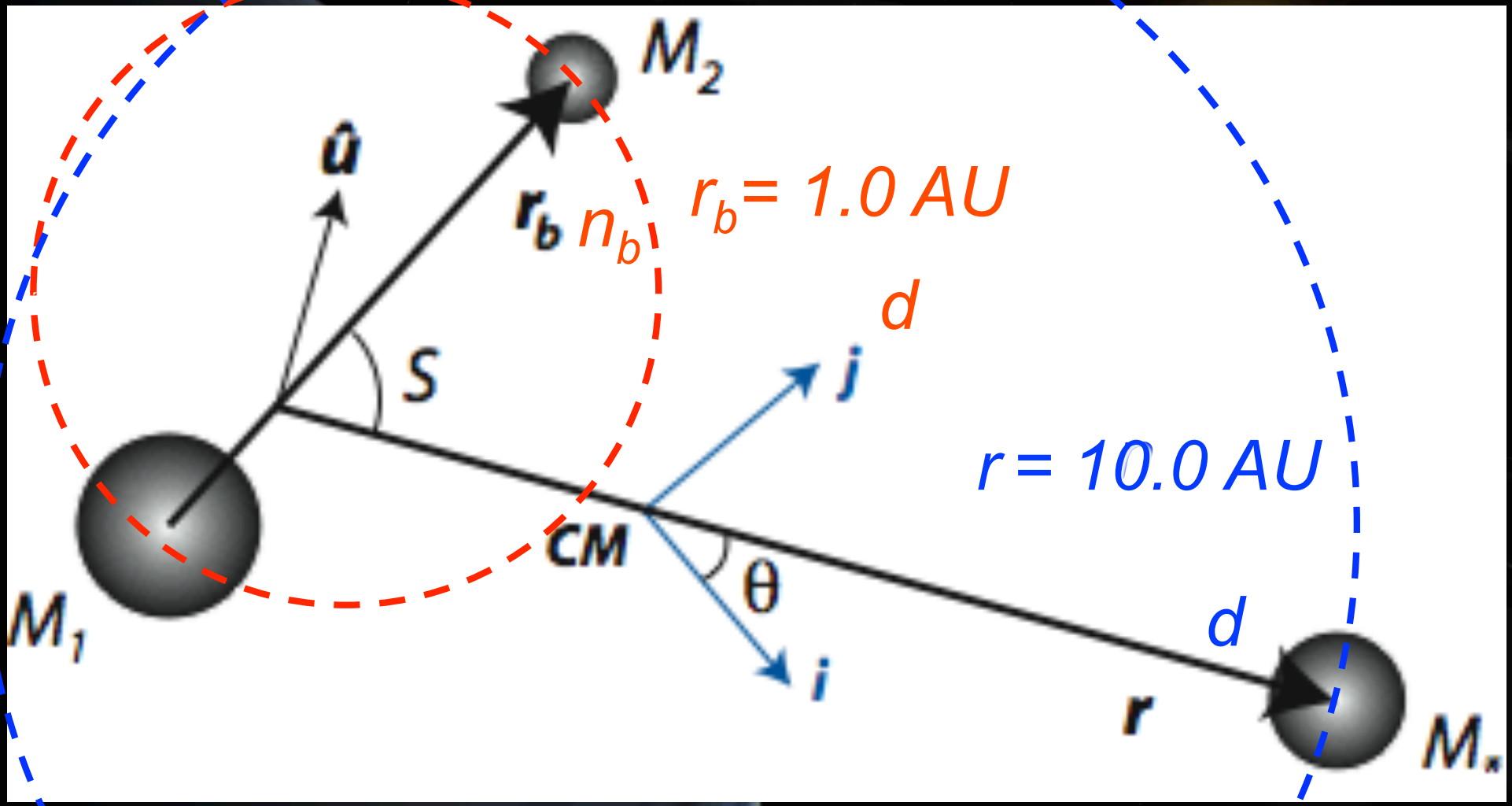
...if we do not have enough precision in the observational data to detect the second "planet".

$$a_p = \left(\frac{M}{4M_b}\right)^{1/3} a_b$$

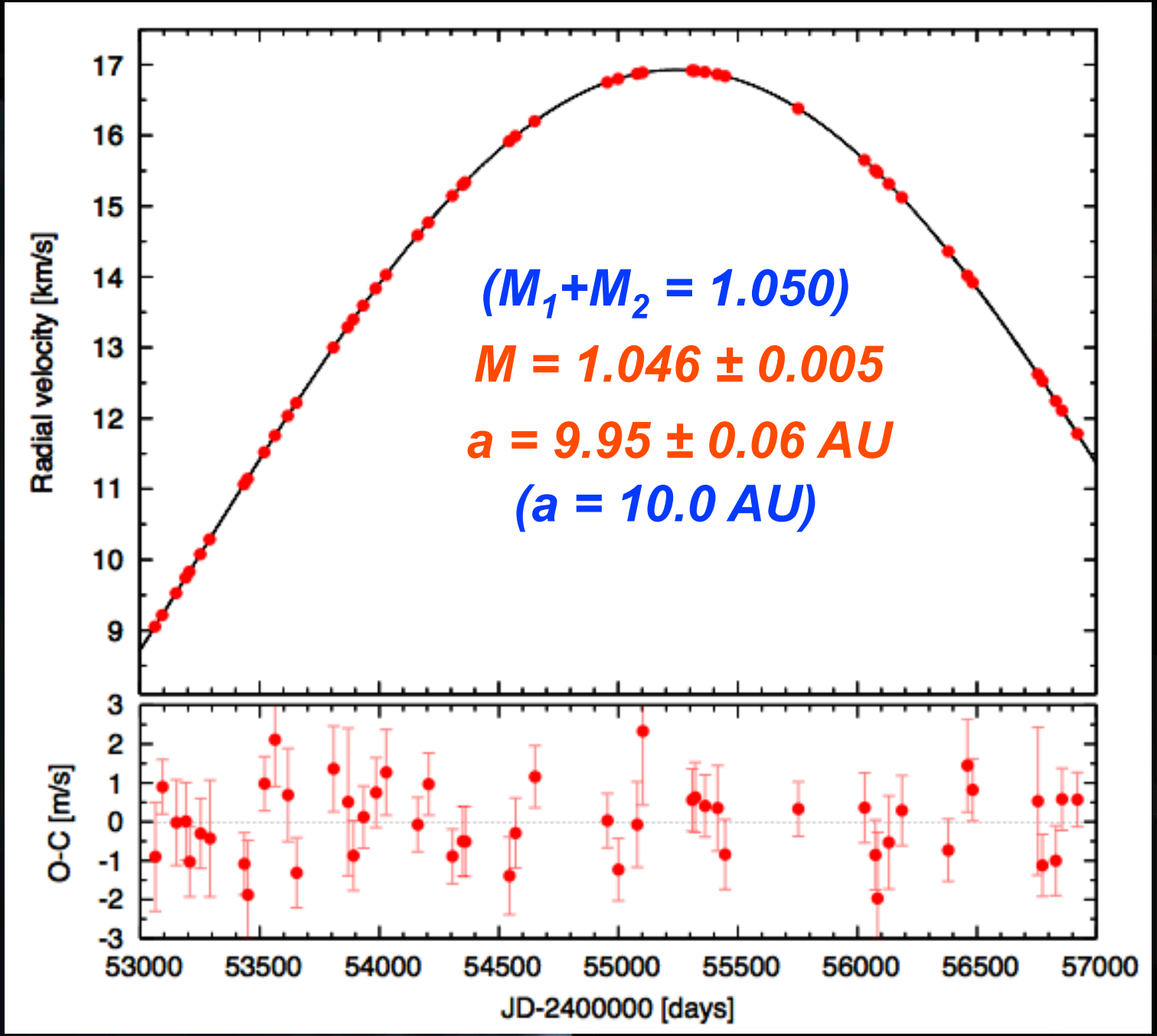
$$\frac{M_p}{M + M_b} = \frac{15}{32}\frac{\mu}{M_b}\left(\frac{a_b}{a}\right)^4 \frac{a_b}{a_p}$$

example

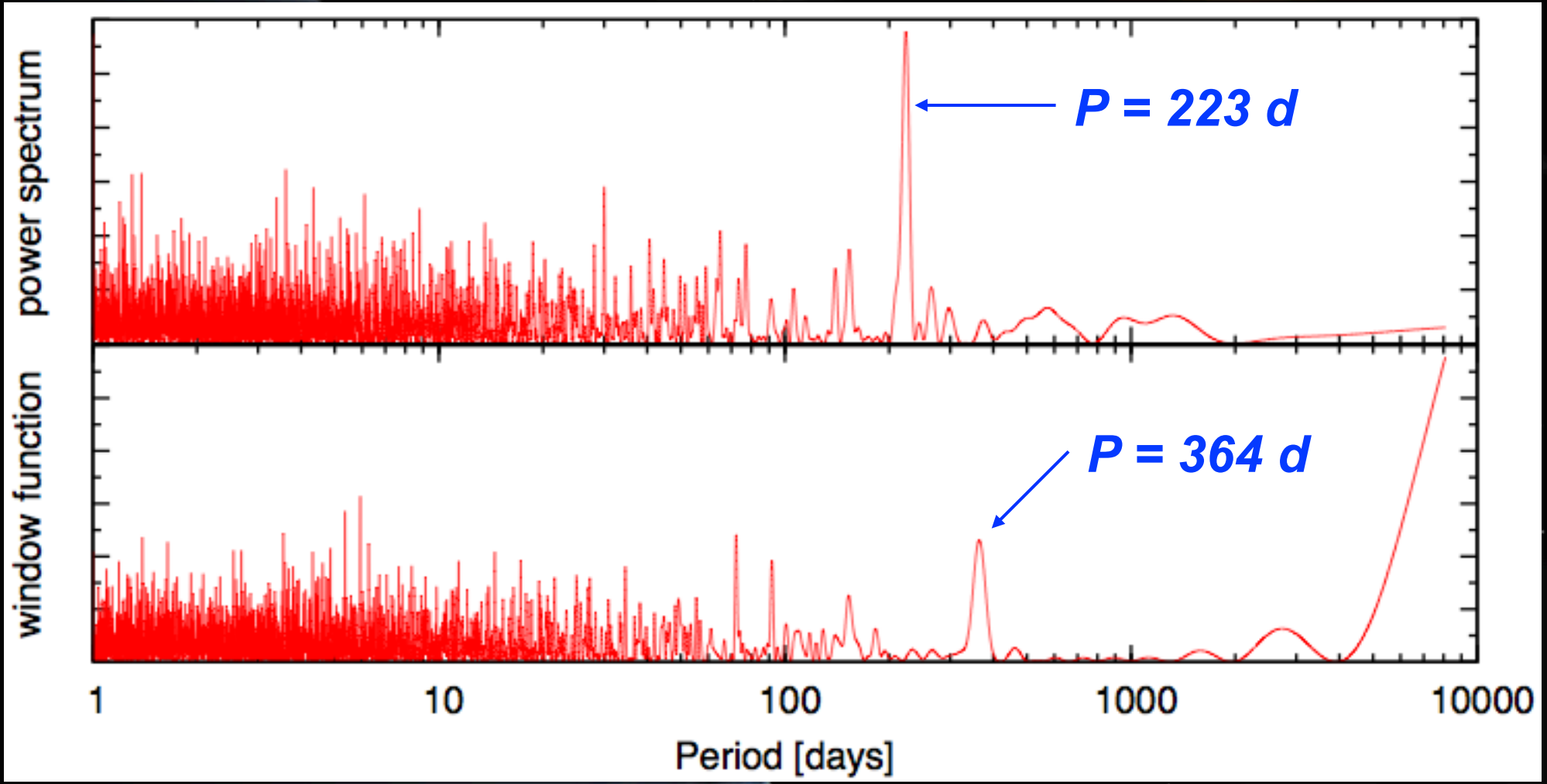
M_*=1.00; M_1=0.70; M_2=0.35



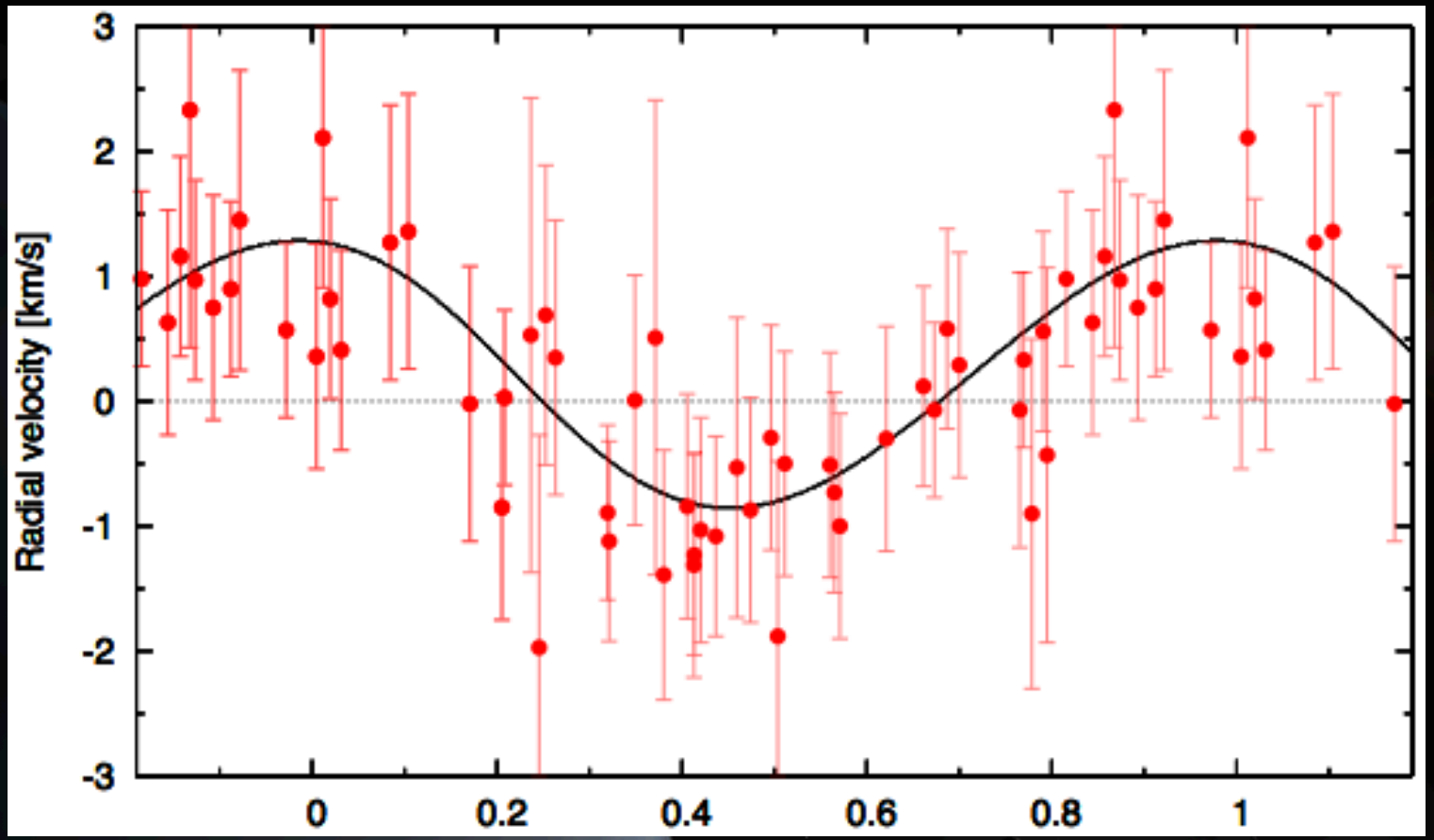
50 points with HARPS (~0.8m/s)



Residuals Fourier analysis



Residuals Phase-folded diagram



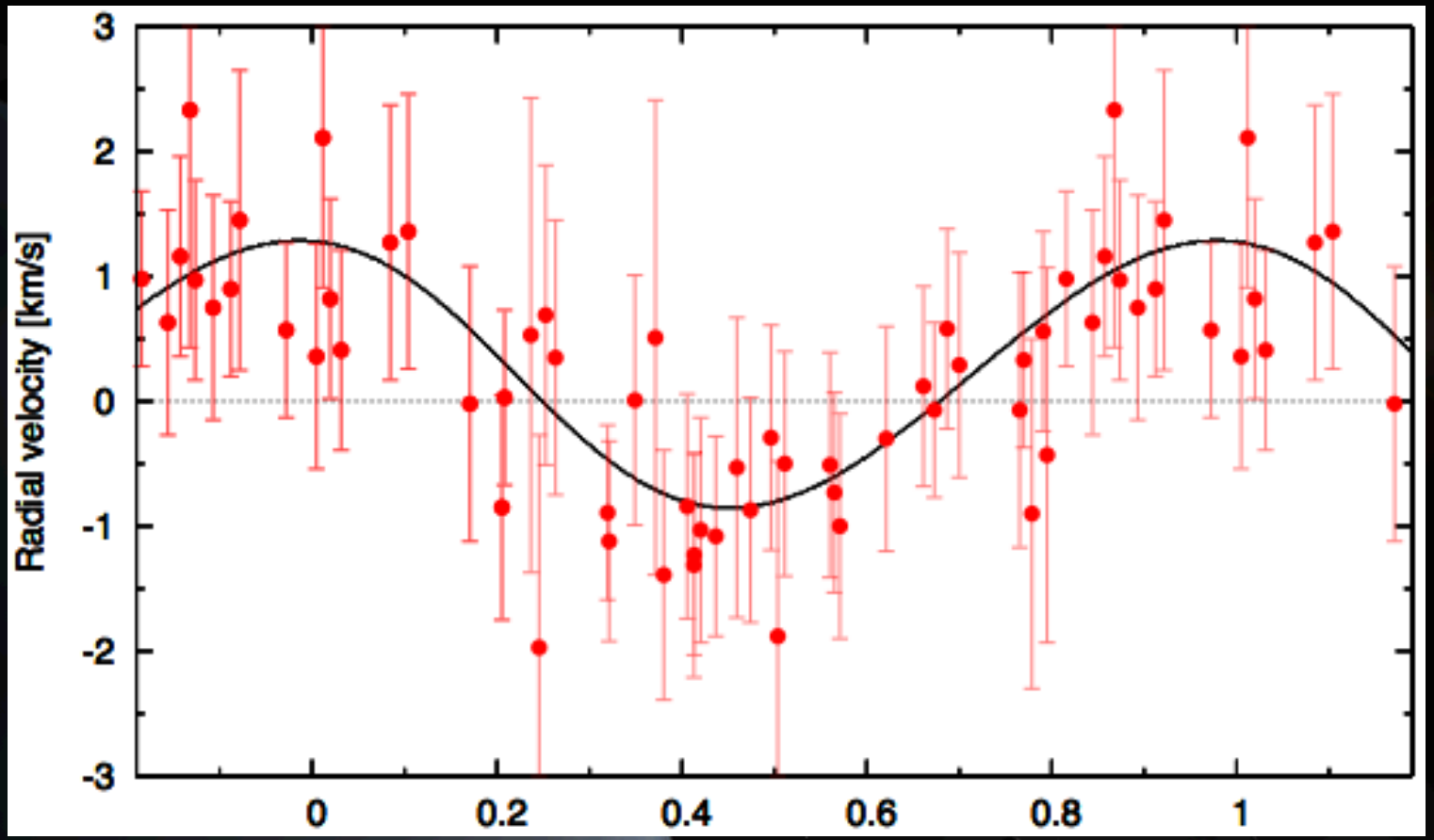
$P_1 = 222.6 \pm 1.2$ d

$K_1 = 1.07 \pm 0.19$ km/s

($n_1 = 2\, n_b$ $3n = 2$ /222.64 d)

($K_1 = 0.89$ km/s)

Residuals Phase-folded diagram



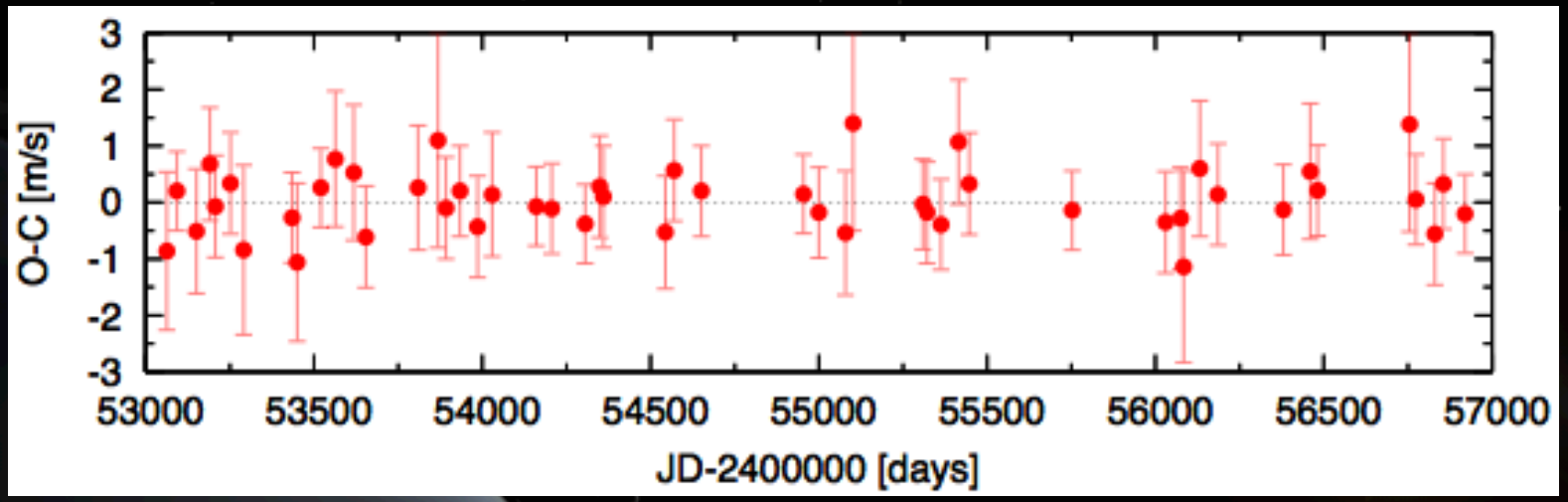
$a_p = 0.719 \pm 0.003$ AU

$M_p = 20.6 \pm 3.7\ M_{earth}$

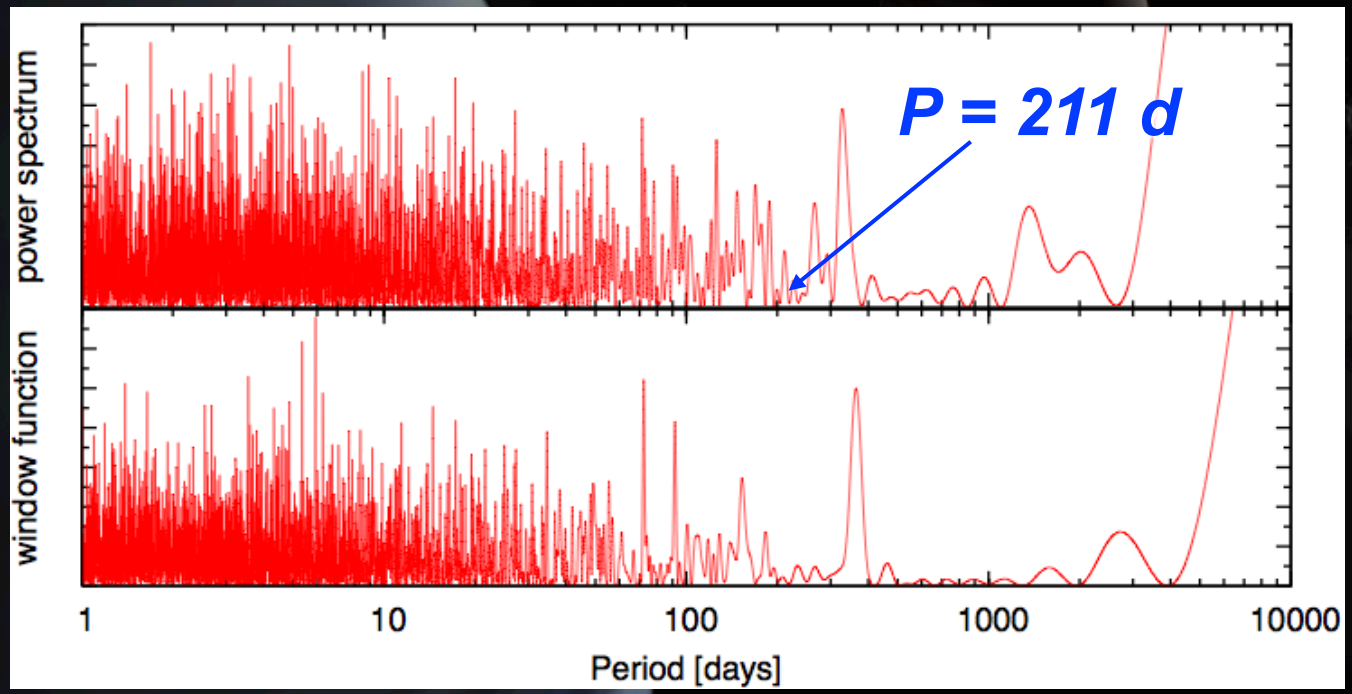
($a_p = 0.719$ AU)

($M_p = 17.3\ M_{earth}$)

Residuals of binary + planet



Fourier analysis of binary + planet

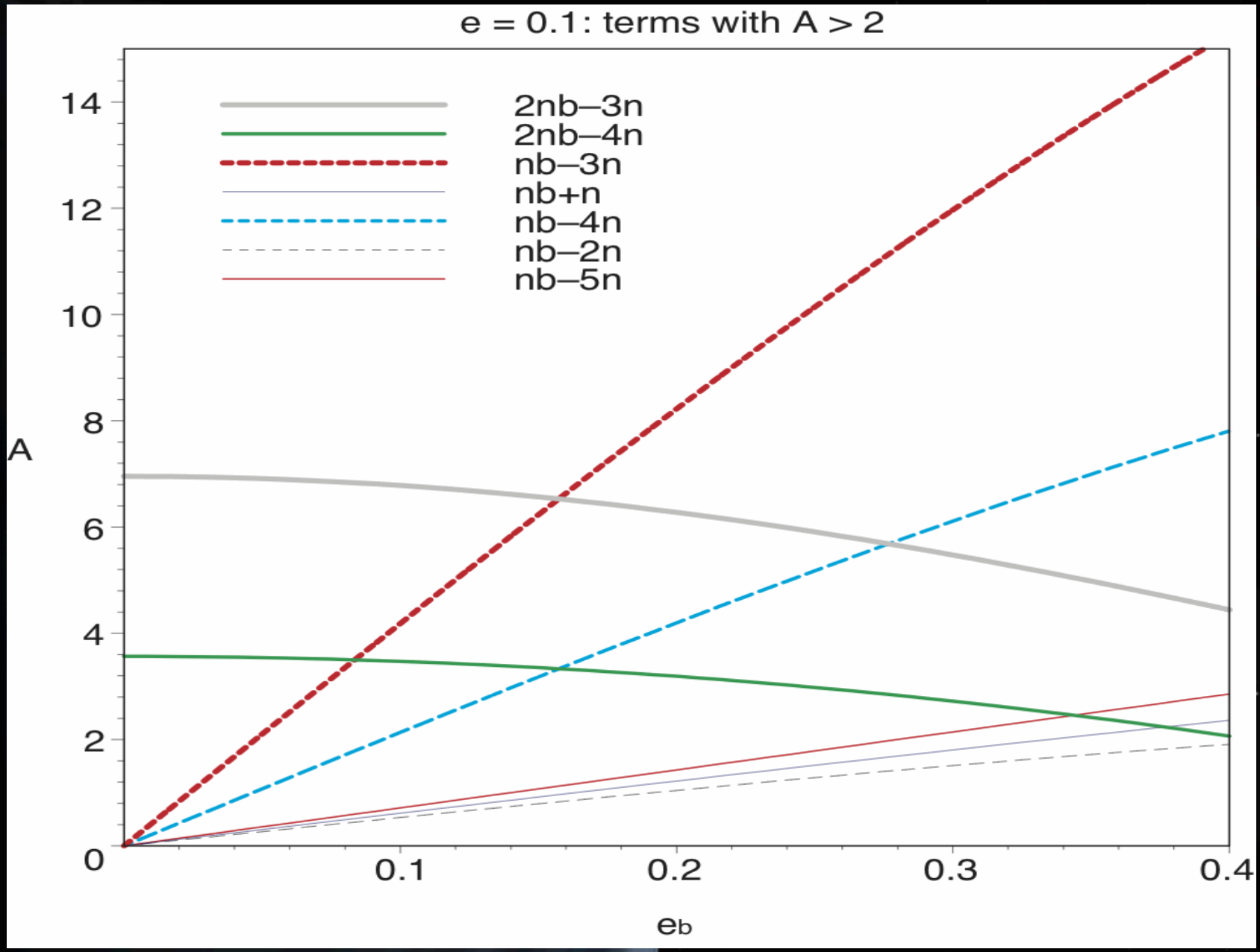


more examples ($M_* = 1$)
(circular coplanar orbits)

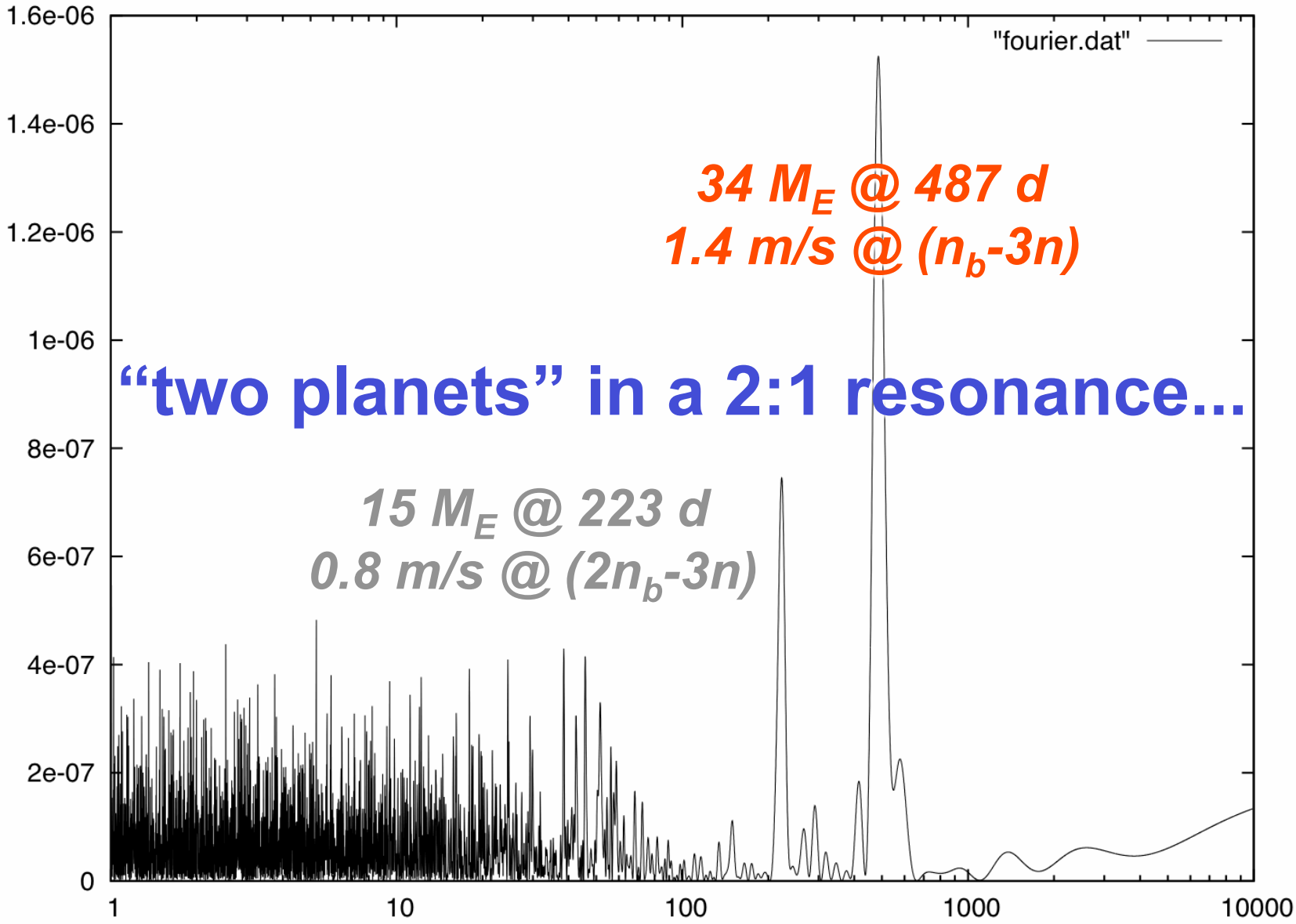
Ex.	Binary system M_1 ($M_\odot$)	M_2 ($M_\odot$)	a (AU)	a_b (AU)		Frequencies $2\pi/\Omega$ (yr)	$2\pi/n_1$ (day)	$2\pi/n_2$ (day)	Amplitudes $\lvert K_1\rvert$ (m/s)	$\lvert K_2\rvert$ (m/s)	Planet M_p ($M_\oplus$)	a_p (AU)
1	1.00	1.00	10.0	1.00	0.114	18.26	137.1	131.7	0.987	0.197	23.90	0.520
2	1.00	1.00	10.0	1.50	0.172	18.26	265.6	246.0	4.081	0.816	123.1	0.809
3	0.70	0.35	10.0	1.10	0.156	22.09	222.6	211.0	0.888	0.178	17.26	0.719
4	1.00	0.10	10.0	1.50	0.210	21.82	363.7	333.3	1.000	0.200	23.47	0.997
5	1.00	0.01	10.0	1.50	0.215	22.30	380.6	348.1	0.114	0.023	2.59	1.028
6	1.00	10^{-3}	10.0	1.50	0.216	22.36	382.5	349.7	0.012	0.002	0.26	1.031
7	10^{-3}	10^{-3}	1.00	0.01	0.114	1.00	4.23	4.13	10^{-5}	10^{-6}	10^{-4}	0.051
8	10^{-3}	10^{-6}	1.00	0.01	0.144	1.00	6.06	5.86	10^{-7}	10^{-8}	10^{-7}	0.065

what about non-coplanar eccentric orbits?...

eccentric coplanar orbits

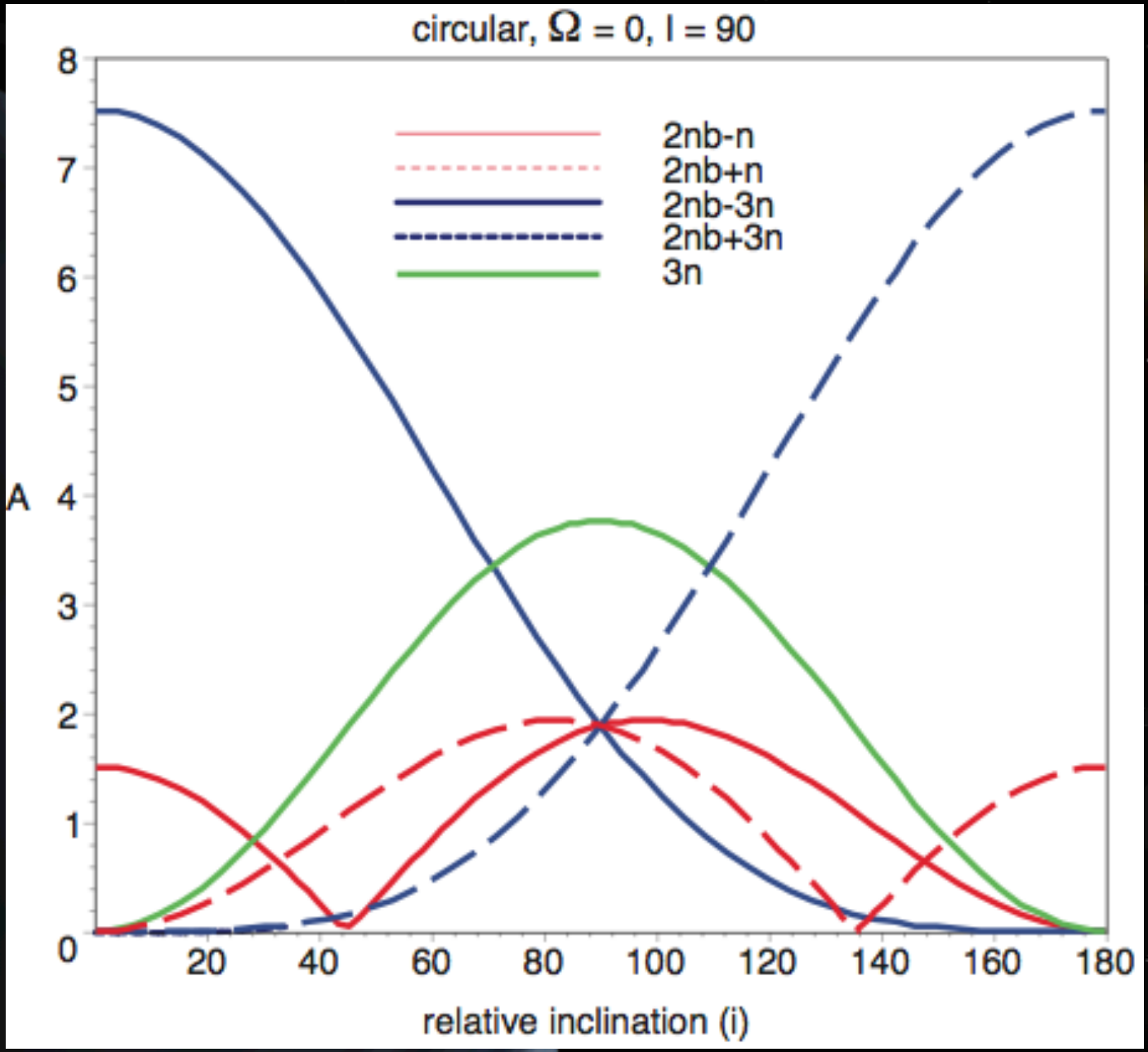


$$e = 0.1 \quad e_b = 0.2 \quad i = 0 \quad t_{obs} = 0.5T = 11\ y \quad prec = 0.8\mathrm{m}/s$$



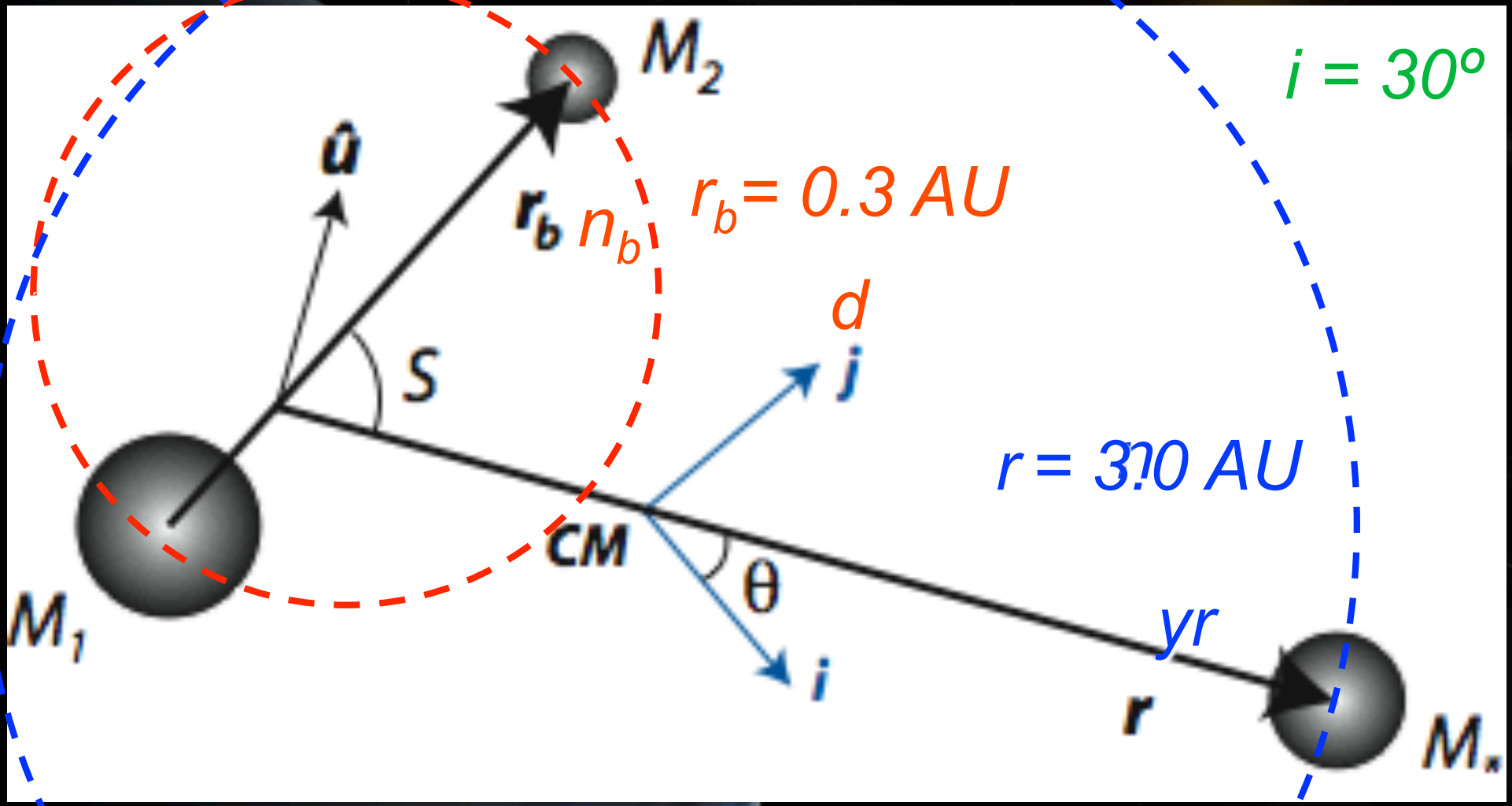
"two planets" in a 2:1 resonance...

circular inclined orbits

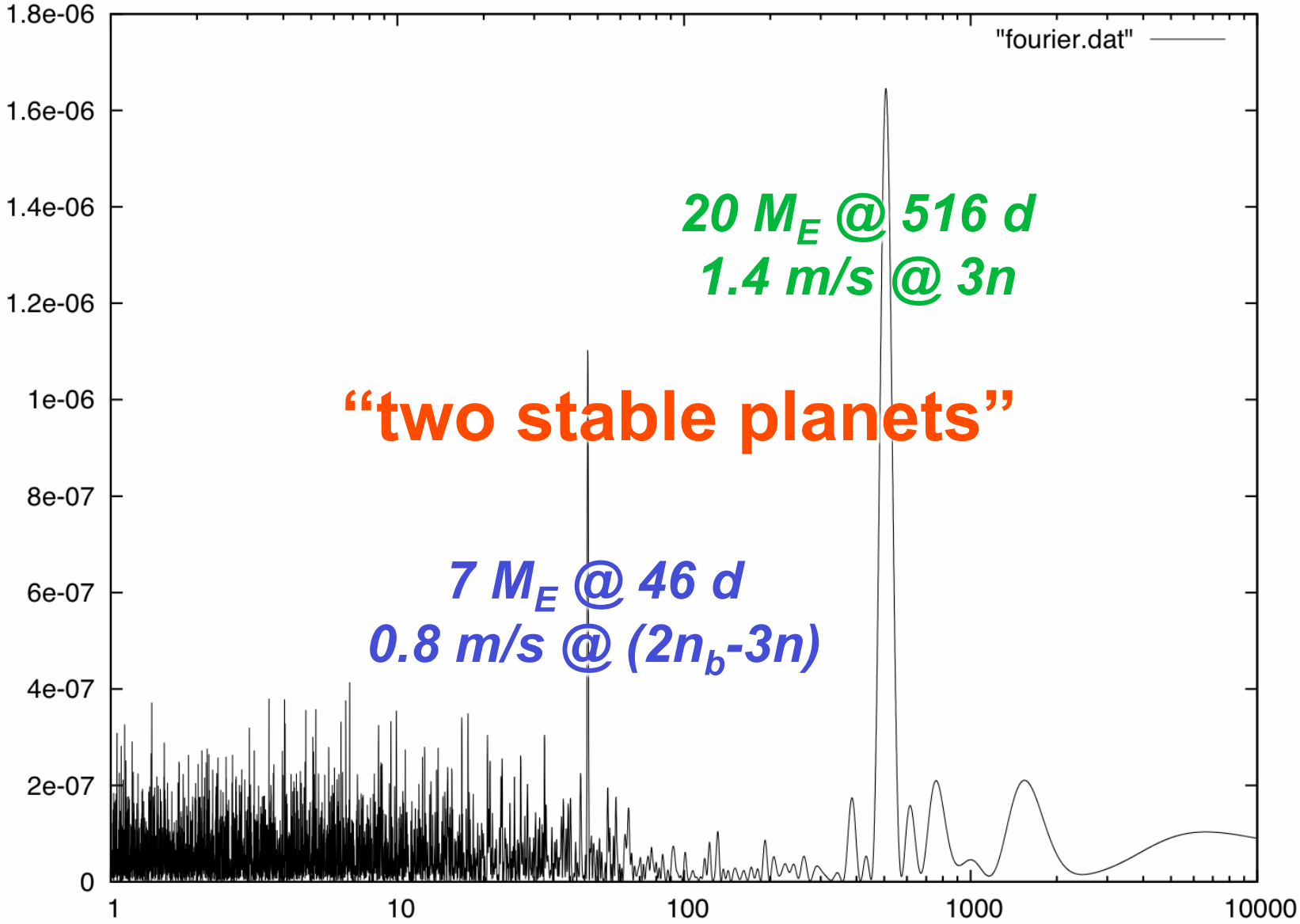


close binary, inclined orbits

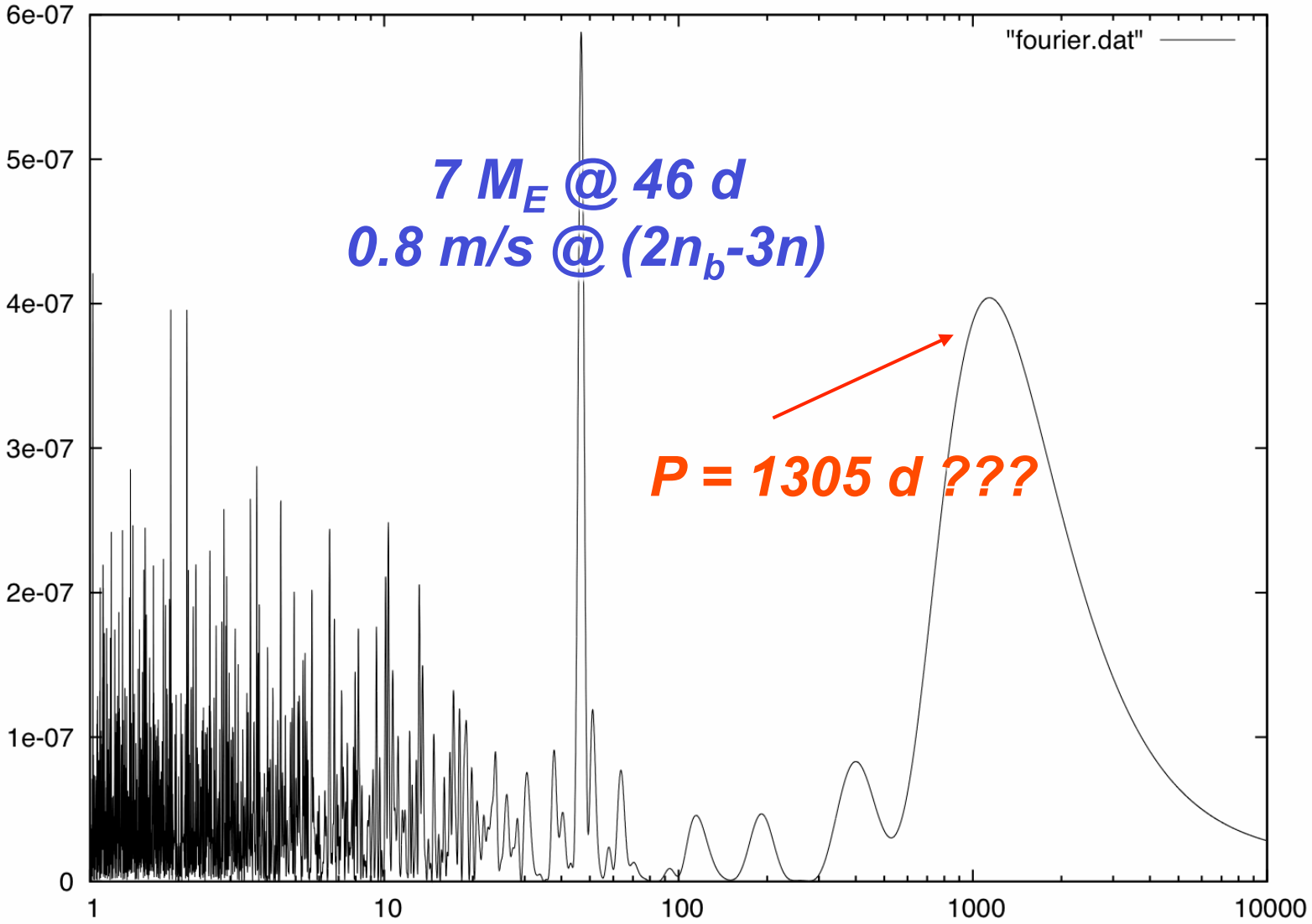
M_*=1.00; M_1=0.35; M_2=0.15



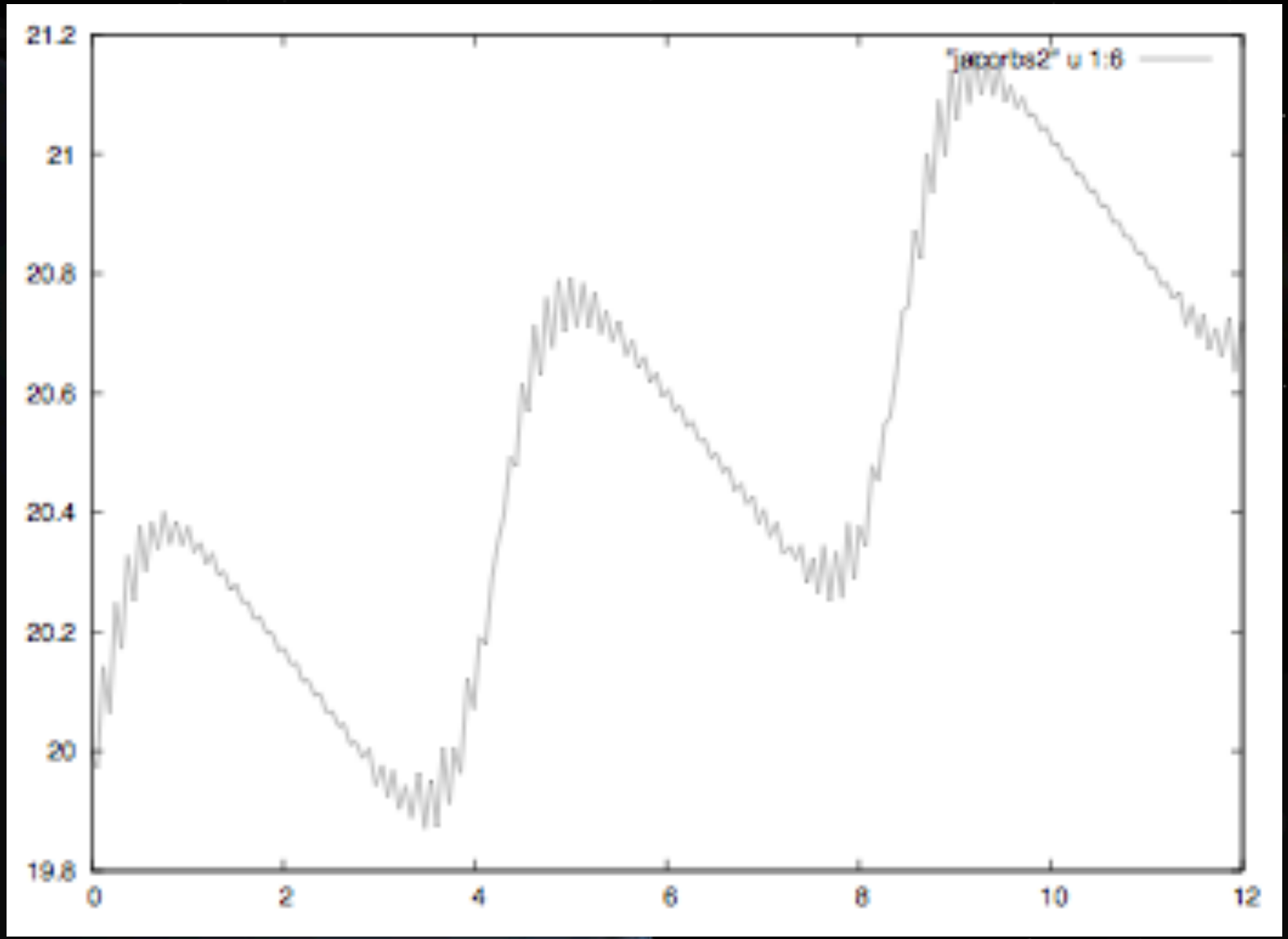
$e = e_b = 0 \quad i = 30^o \quad t_{obs} = 2.6\,T = 11\ y \quad prec = 0.7\mathrm{m}/s$



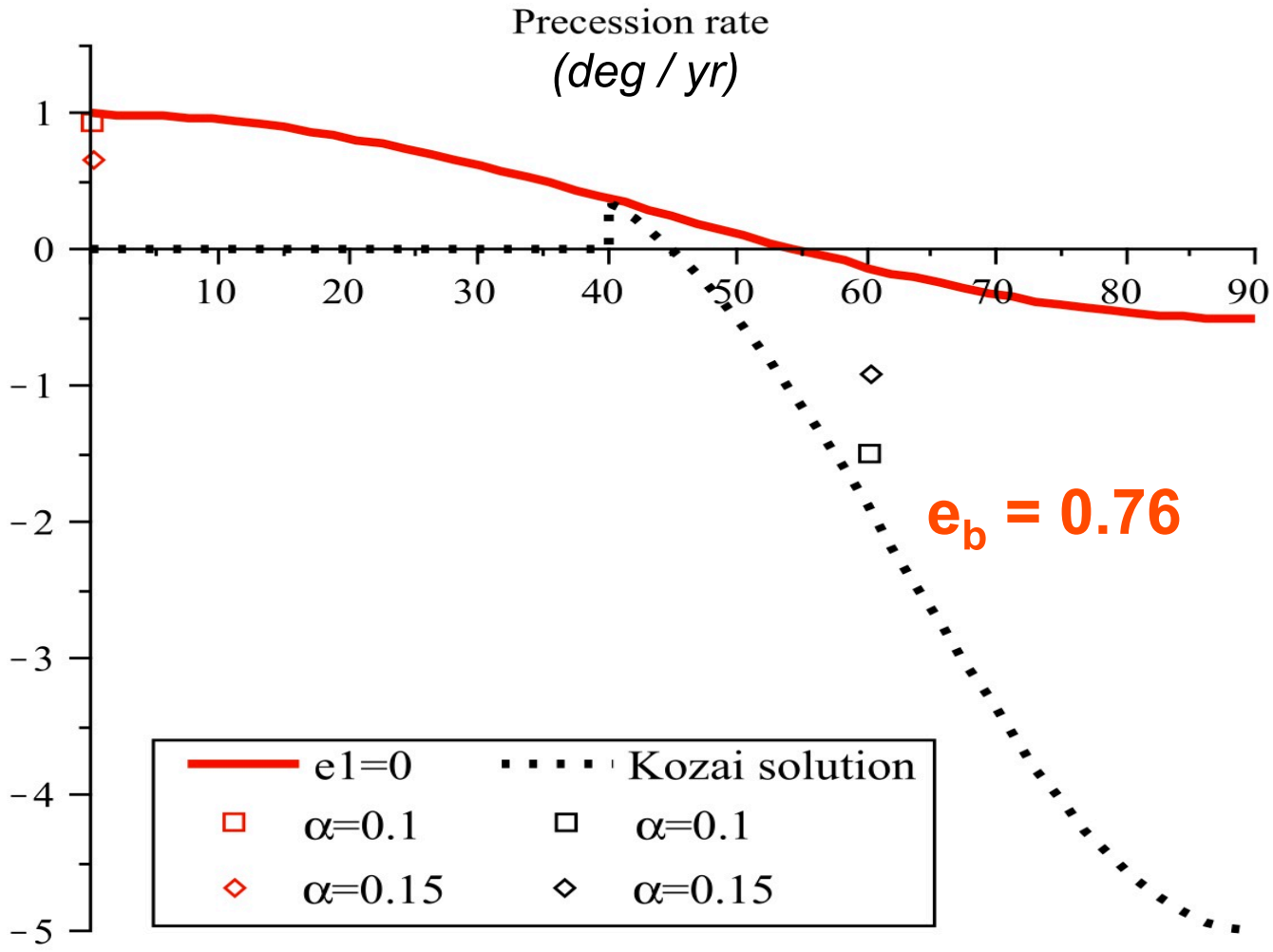
$e=0.2; \quad e_b = 0.0; \quad i = 30^o$



precession of the outer orbit



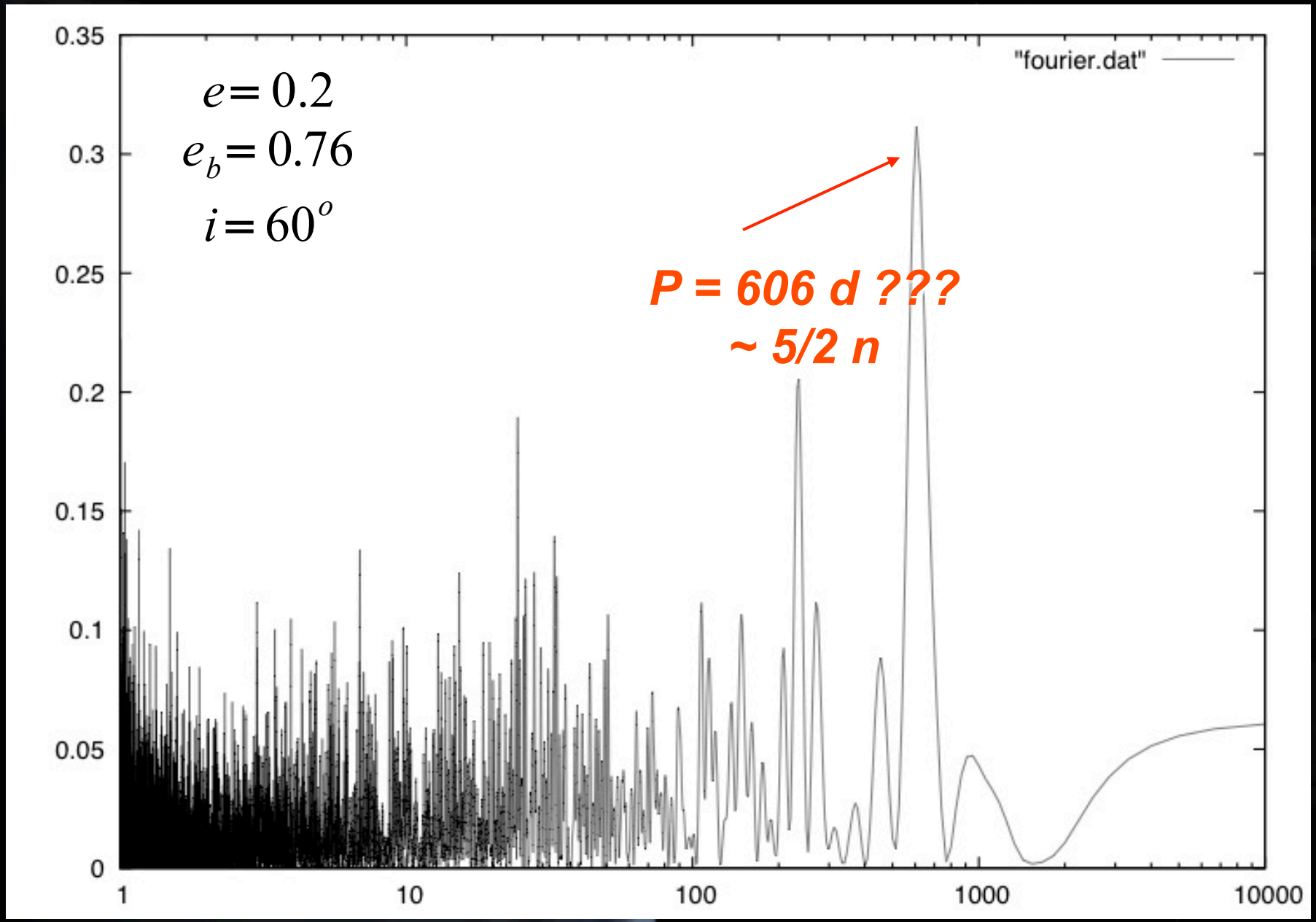
time (yr)


Precession rate
(deg / yr)
1
0
-1
-2
-3
-4
-5
10
20
30
40
50
60
70
80
90
e1=0
Kozai solution
α=0.1
α=0.1
α=0.15
α=0.15

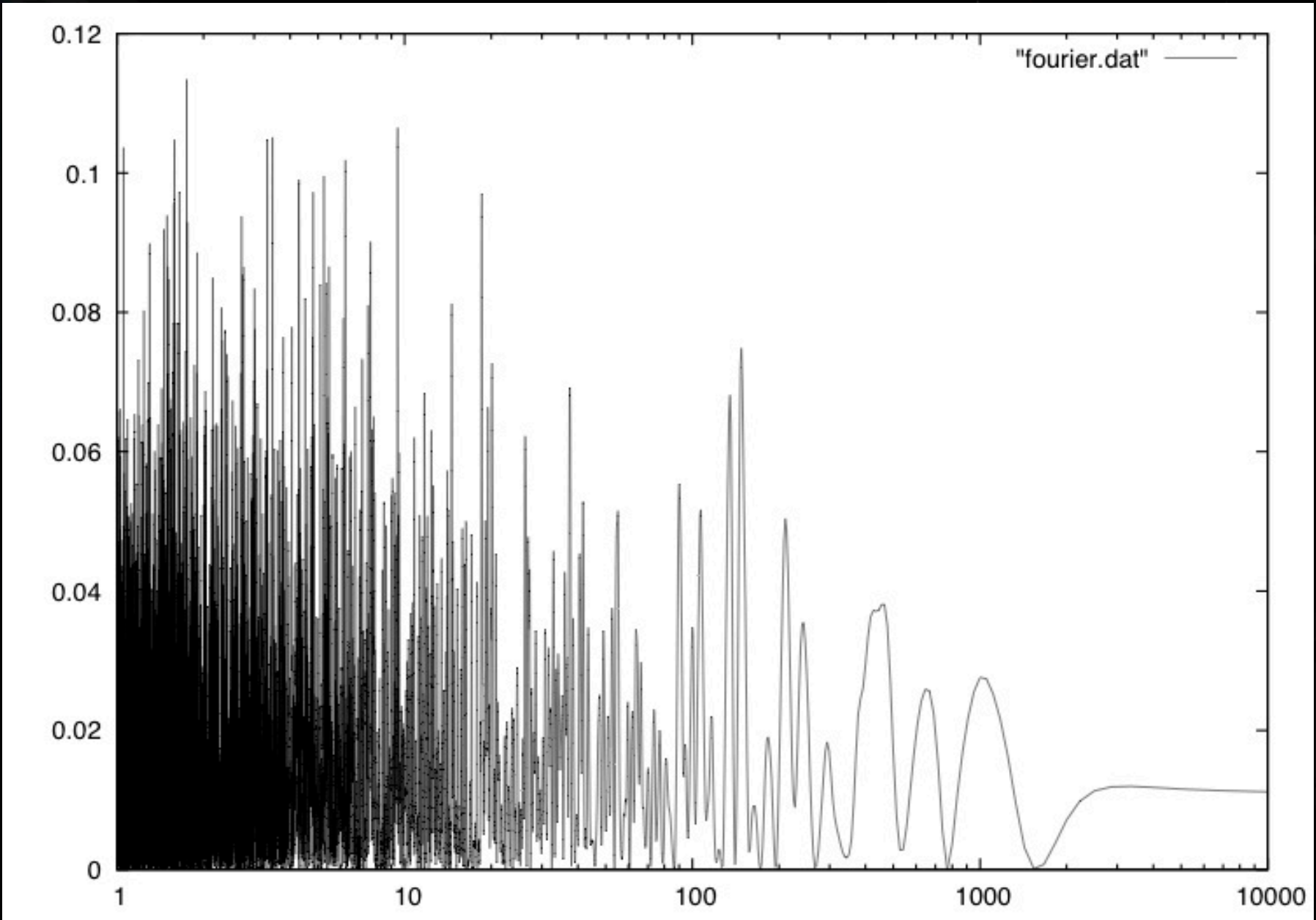
$e_b = 0.76$

e = 0.2

fixed keplerian orbit



precessing keplerian orbit



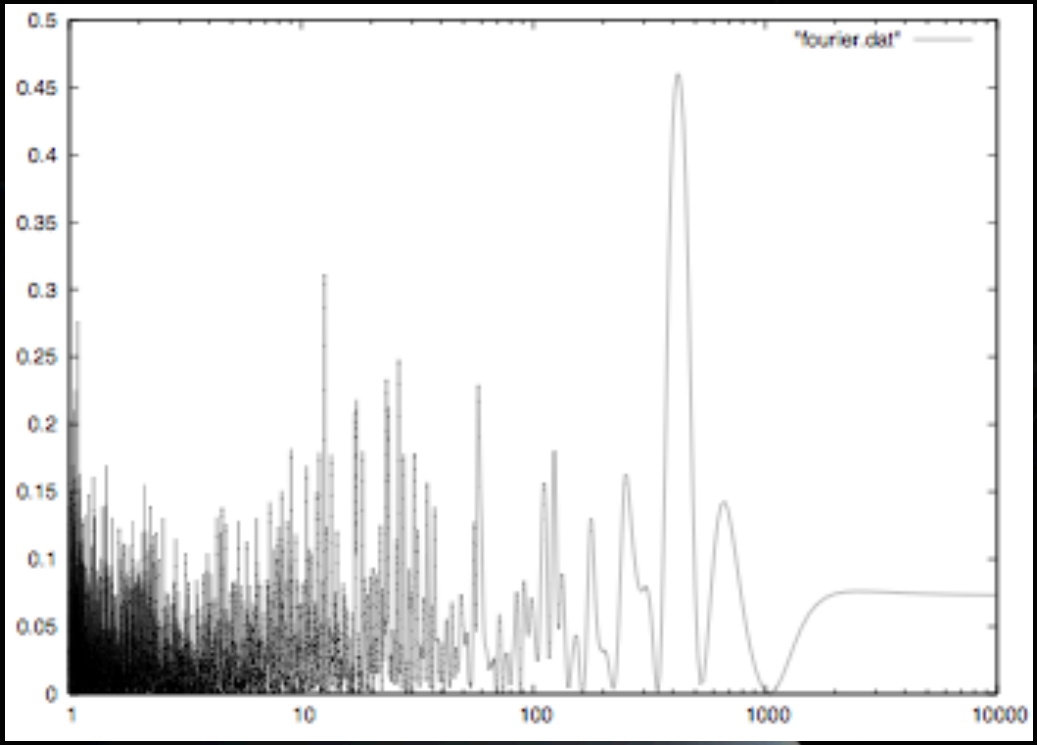
-Octantis A+B: tight binary system

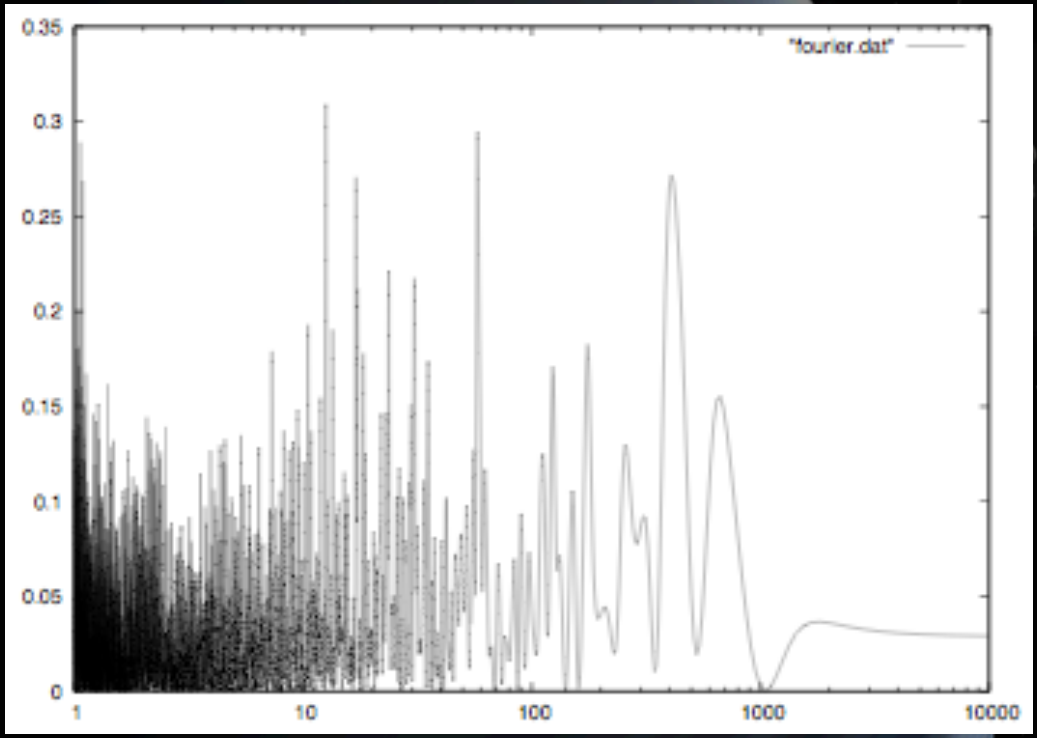
Planet around -Octantis A is about midway between the stars... The system is highly unstable!
(see Gozdziewski, Slonina & Rozenkiewicz talk tomorrow).

ν-Octantis A	
$m_A = (1.4 \pm 0.3)\, M_\odot$	
ν-Octantis B + planet	
$T_2 = (1050.11 \pm 0.13)$ day	$T_p = (417 \pm 4)$ day
$K_2 = (7032.3 \pm 2.6)$ m/s	$K_p = (51.8 \pm 1.6)$ m/s
$e_2 = 0.2359 \pm 0.0003$	$e_p = 0.123 \pm 0.037$
$\omega_2 = (75.05 \pm 0.075)^\circ$	$\omega_1 = (260 \pm 21)^\circ$
$I_2 = (70.8 \pm 0.9)^\circ$	$I_p = ?$
$\Omega_2 = (87 \pm 1)^\circ$	$\Omega_p = ?$
$m_B = (0.5 \pm 0.1)\, M_\odot$	$m_p \sin I_p = 2.5\, M_J$
$a_2 = (2.55 \pm 0.13)$ AU	$a_p = (1.2 \pm 0.1)$ AU
$\sqrt{\chi^2} = 4.2$	
$rms = 19$ m/s	

Table 4. Fitted parameters for ν-Octantis and possible planet (Ramm et al. 2009).

Could planet be artifact caused by -Octantis B being unresolved binary?





	fit	ν-Octantis
T (day)	(1)	1050.46 ± 0.03
	(0)	1050.11 ± 0.03
	(0)+pl	417 ± 1
K (m/s)	(1)	7044.24 ± 0.60
	(0)	7032.27 ± 0.68
	(0)+pl	51.83 ± 0.53
e	(1)	0.23553 ± 0.00007
	(0)	0.23589 ± 0.00009
	(0)+pl	0.124 ± 0.010
$\dot{\omega}$ (°/yr)	(1)	-0.860 ± 0.017
$\sqrt{\chi^2}$	(1)	7.3
	(0)	8.1
	(0)+pl	4.4
rms (m/s)	(1)	36.3
	(0)	39.1
	(0)+pl	22.8

What can be done to distinguish planets from a binary?

- **Be careful when annoucing planets within binary systems (companion star could be itself an unresolved binary system)!**
- **Use our expressions to predict binary parameters that mimic a given planet. Check if they are realistic!!!**
- **Perform 3-body fits with a binary and compare with planet fits to predict most likely configuration...**
- **Be aware that we may not yet have enough information to decide!!!**

Refs: Morais & Correia, *A&A* **491** (2008), *A&A* **525** (2011), *MNRAS* **sub.** (2011)