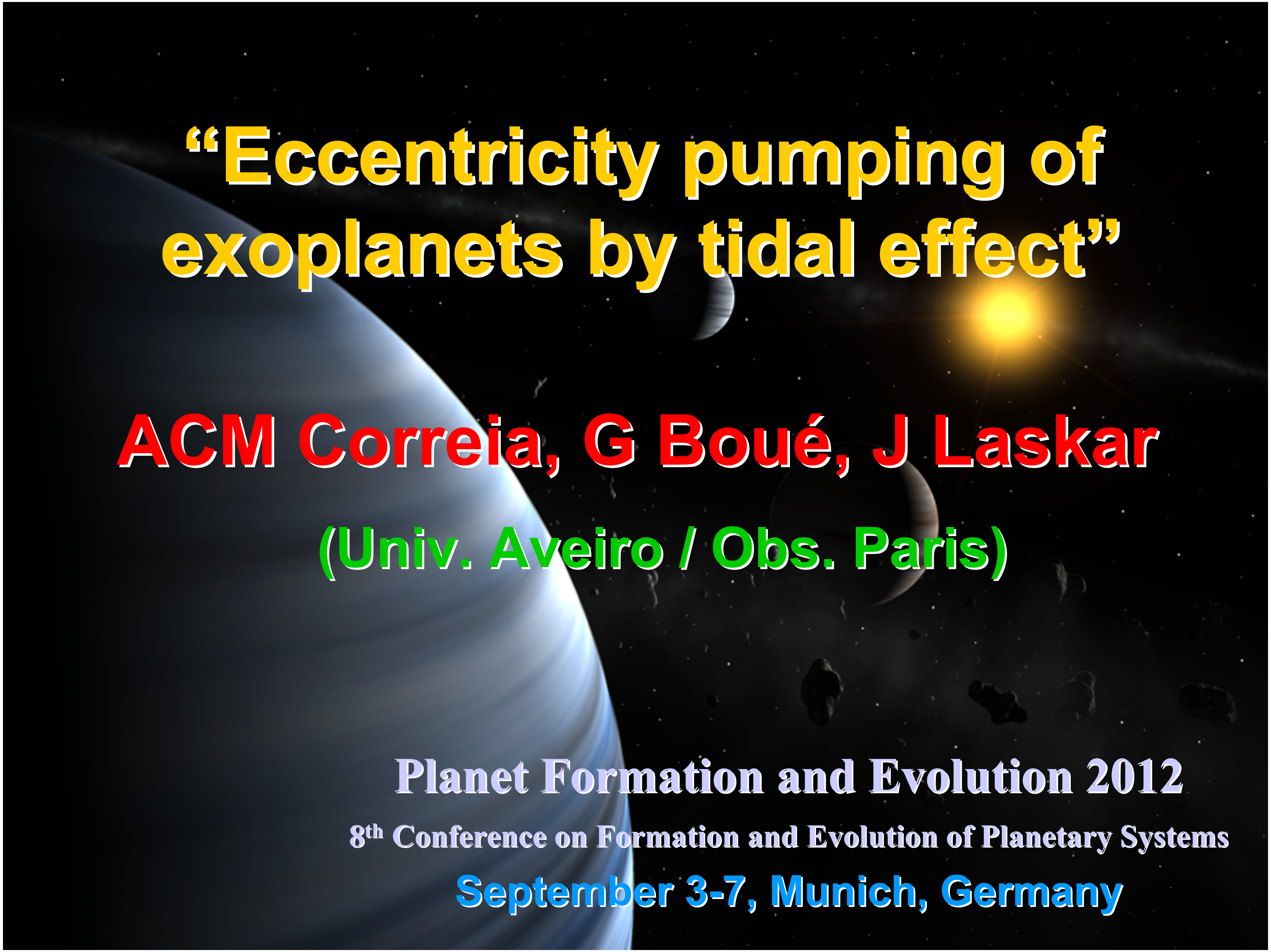
"Eccentricity pumping of exoplanets by tidal effect"
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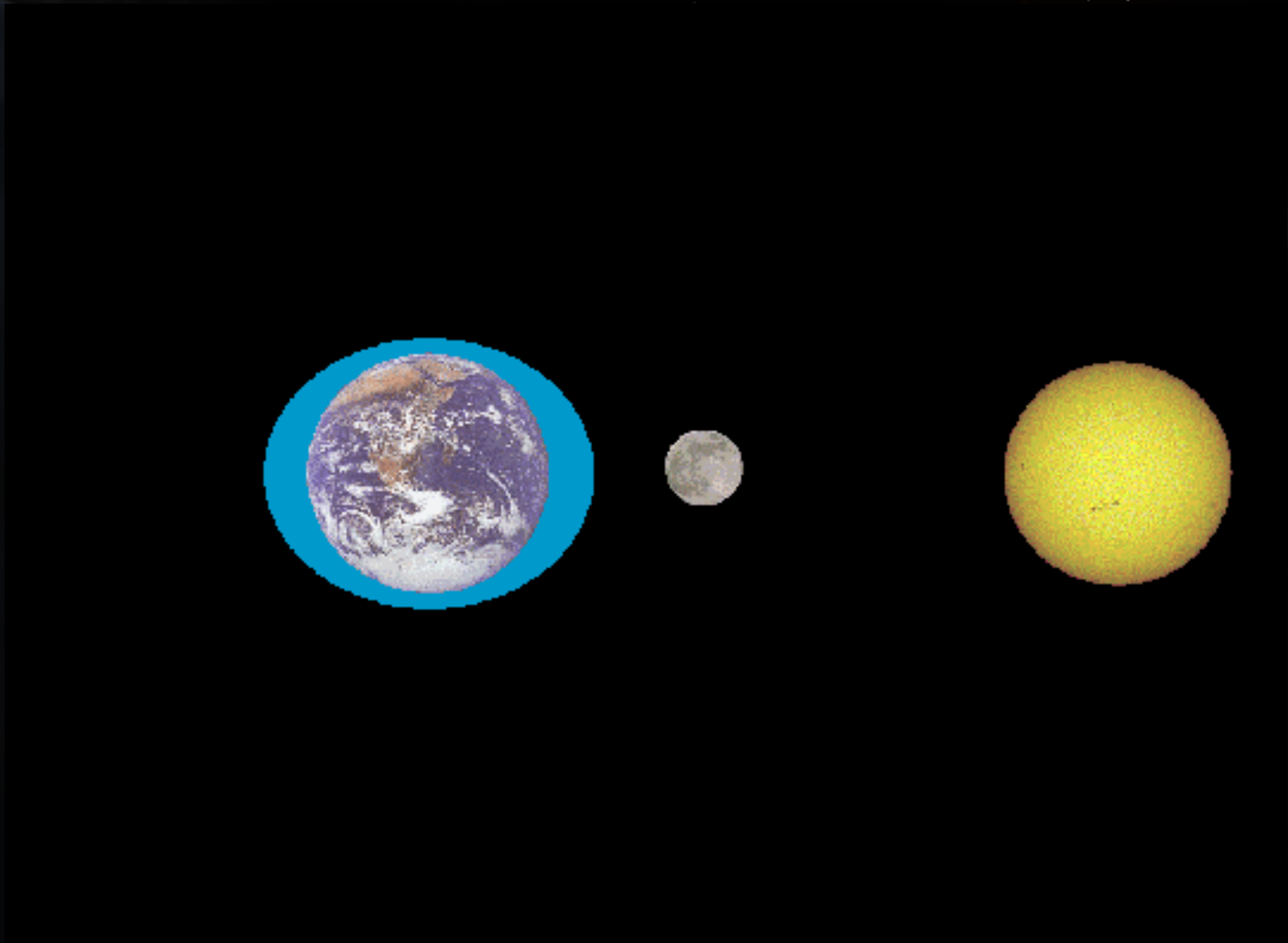
Tidal effects



moderate close-in planets

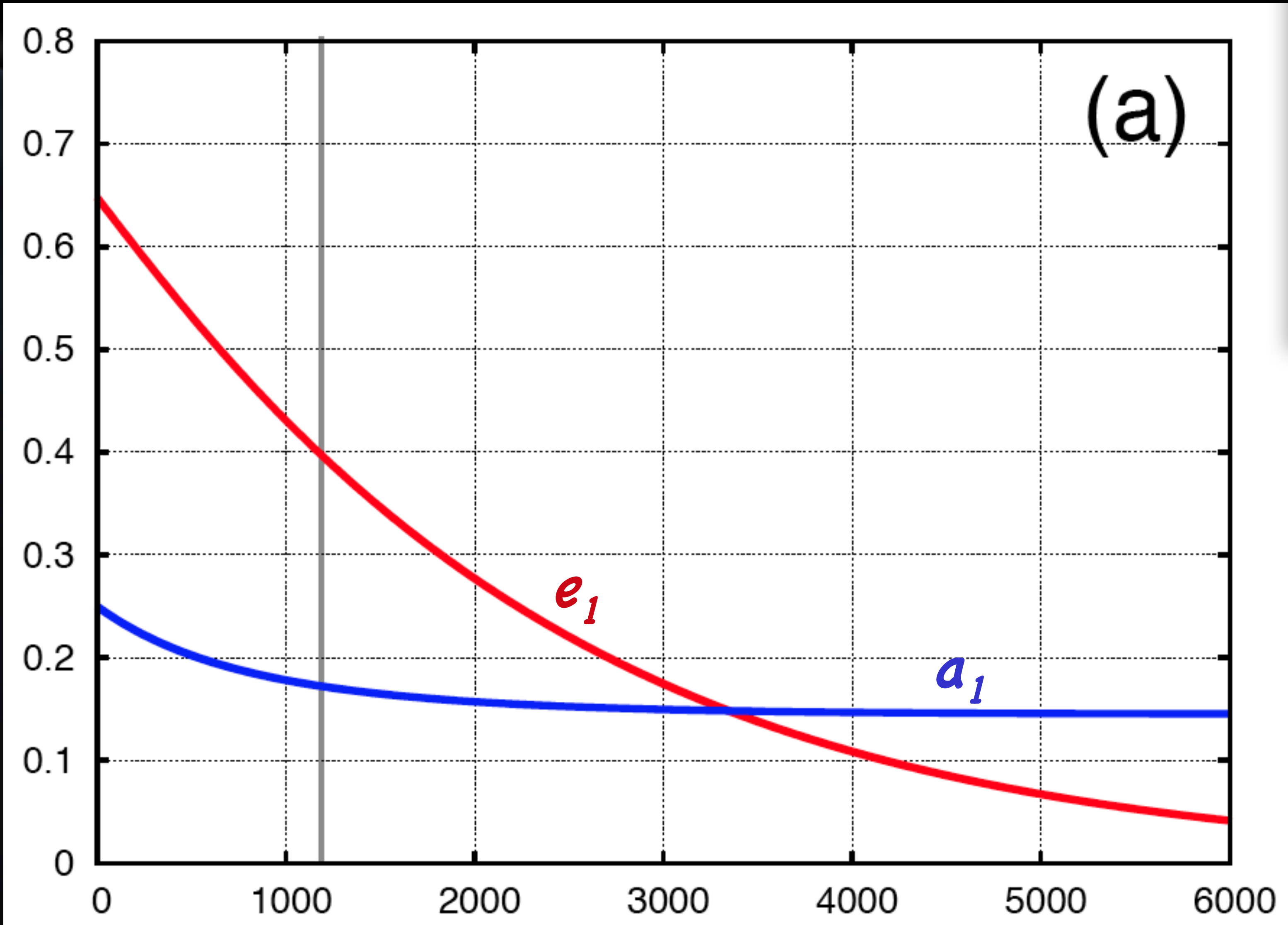
Table 1

Single Planetary Systems with $0.1 < a_1 < 0.3$ and $e_1 > 0.3$

Star (Name)	a_1 (AU)	e_1	m_1 (M_J)	m_0 ($M_\odot$)	Age (Gyr)	τ (Gyr)
HD 108147	0.102	0.53	0.26	1.19	2.0	0.01
CoRoT-10	0.105	0.53	2.75	0.89	3.0	0.24
HD 33283	0.145	0.48	0.33	1.24	3.2	0.34
HD 17156	0.163	0.68	3.19	1.28	3.4	0.44
HIP 57050	0.164	0.31	0.30	0.34	...	39.4
HD 117618	0.176	0.42	0.18	1.05	3.9	2.06
HD 45652	0.228	0.38	0.47	0.83	...	93.3
HD 90156	0.250	0.31	0.06	0.84	4.4	35.8
HD 37605	0.260	0.74	2.84	0.80	10.7	10.6
HD 3651	0.284	0.63	0.20	0.79	5.1	15.5

eccentricity damping

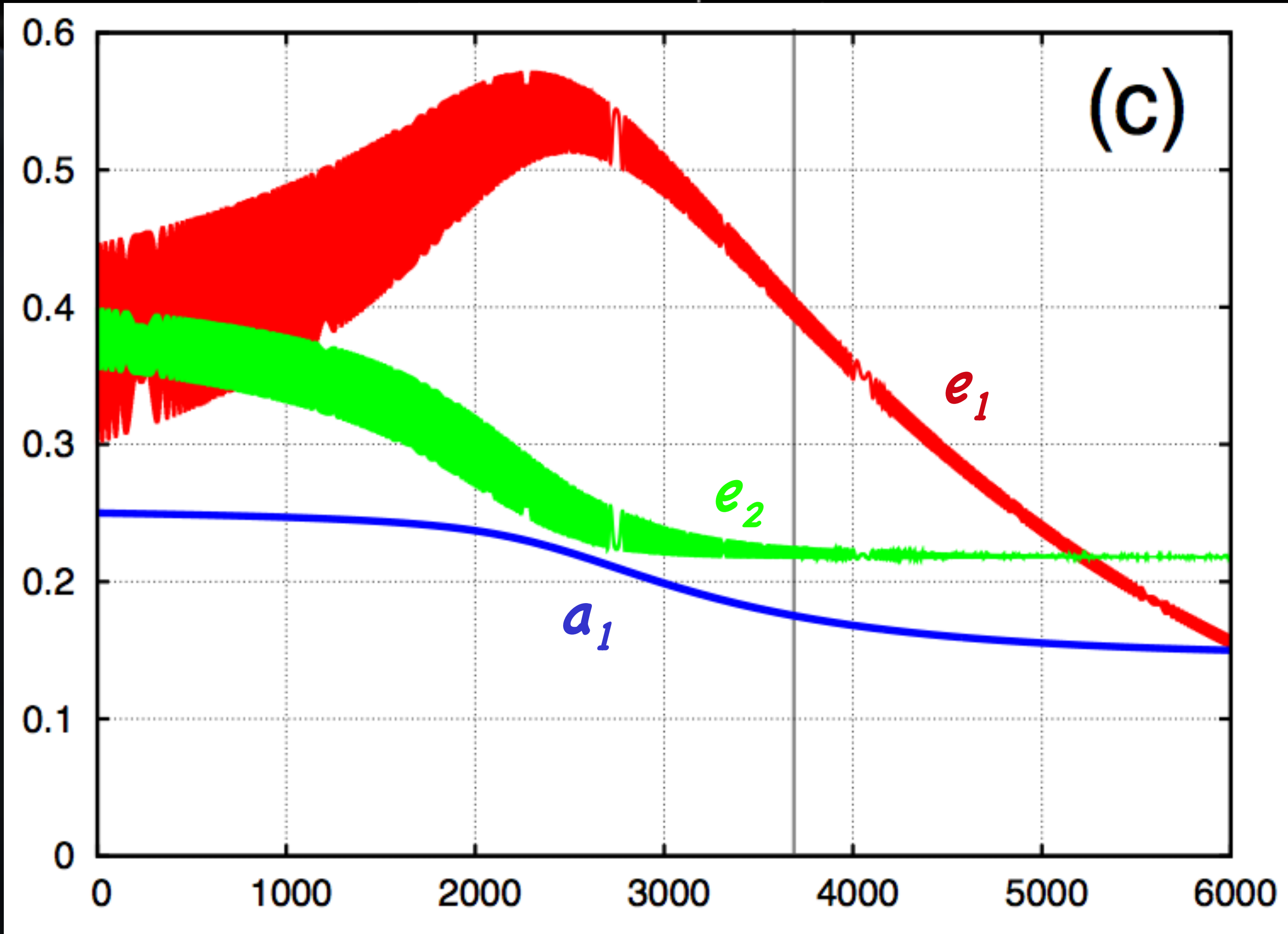
HD 117618 b



Correia, Boué & Laskar, *ApJ Lett* (2012)

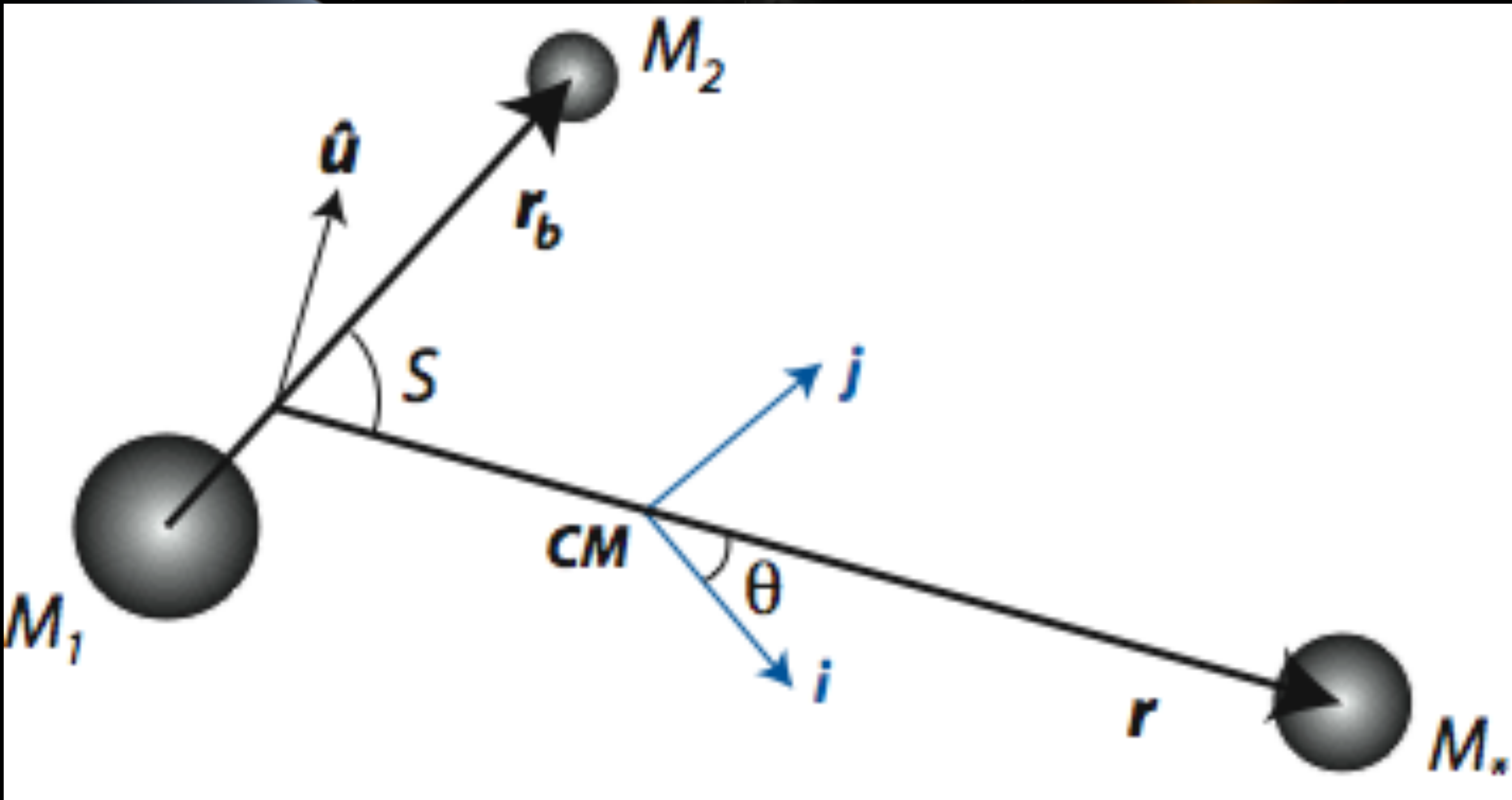
eccentricity pumping

HD 117618 b



Correia, Boué & Laskar, *ApJ Lett* (2012)

planar 3-body problem
(not restricted + octupolar approx.)



Conservative energy

relativity + spin + octupolar approx.

$$U = -C_0 \left(1 - e^2\right)^{-1/2} \ldots C_1 \left(1 - e^2\right)^{-3/2}$$

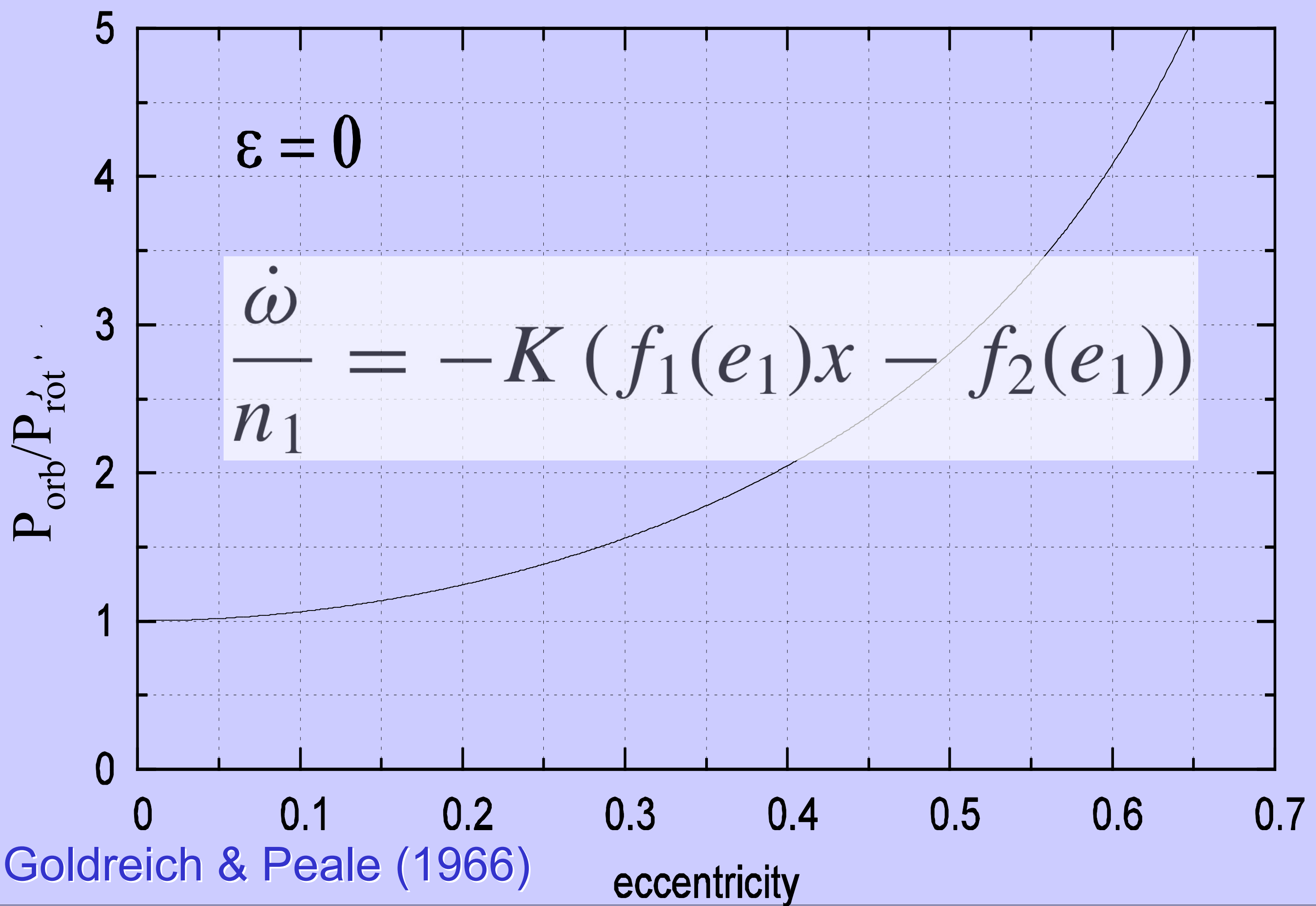
$$- C \ldots \cos \varpi,$$

$$J_2 = k_2 \frac{\omega^2 R^3}{3 G m_1}$$

$$C_0 = \frac{3\beta_1 G^2 (m_0 + m_1)^2}{a_1^2 c^2}, \qquad C_1 = \frac{G m_0 m_1 J_2 R^2}{2 a_1^3},$$

$$C_2 = \frac{G \beta_1 m_2 a_1^2}{4 a_2^3}, \qquad C_3 = \frac{15 G \beta_1 m_2 a_1^3}{16 a_2^4} \frac{(m_0 - m_1)}{m_0 + m_1},$$

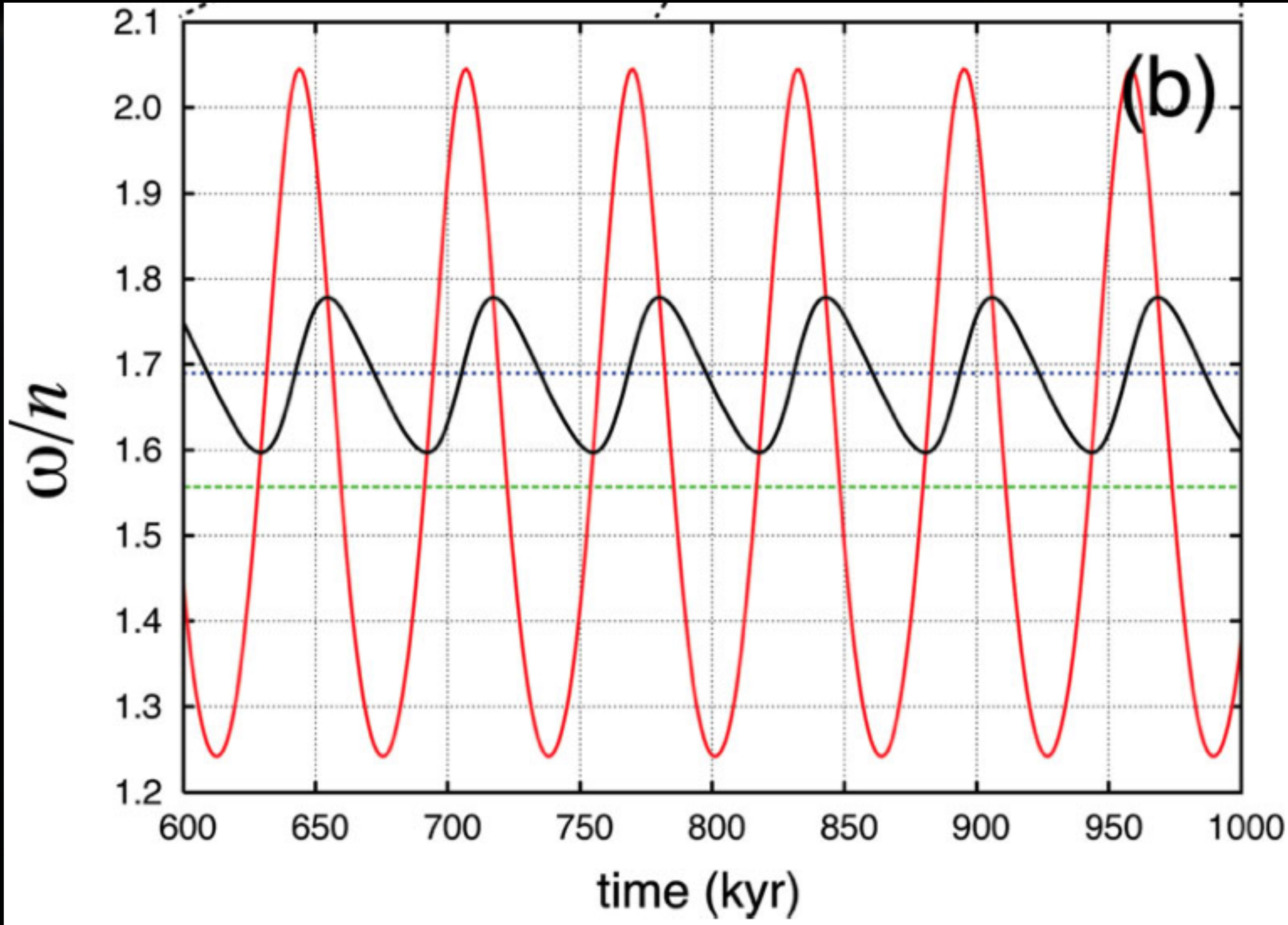
Intermediate evolution:
$\omega_{eq} / n = f_2/f_1(e)$



Goldreich & Peale (1966)

Rotation tidal wobble

Jupiter-size planets



Equations of motion

$$\dot{e}_1 = -\nu_{31} \frac{e_2 \left(1 + 3/4 e_1^2\right) \sqrt{1 - e_1^2}}{\left(1 - e_2^2\right)^{5/2}} \sin \varpi$$

$$\dot{\varpi} = \frac{\nu_0}{\left(1 - e_1^2\right)} + \frac{\nu_1 x^2}{\left(1 - e_1^2\right)^2}$$

$$+ \nu_{21} \frac{\sqrt{1 - e_1^2}}{\left(1 - e_2^2\right)^{3/2}} - \nu_{22} \frac{\left(1 + \frac{3}{2} e_1^2\right)}{(1 - e_2^2)^2}$$

$$x = \omega / n_1$$

$$\frac{\dot{\omega}}{n_1} = -K \left(f_1(e_1) x - f_2(e_1) \right)$$

linearized system

$$\delta \dot{e}_1 = -A \sin \varpi ,$$

$$\delta e_1 = \Delta e \cos(gt + \varpi_0)$$

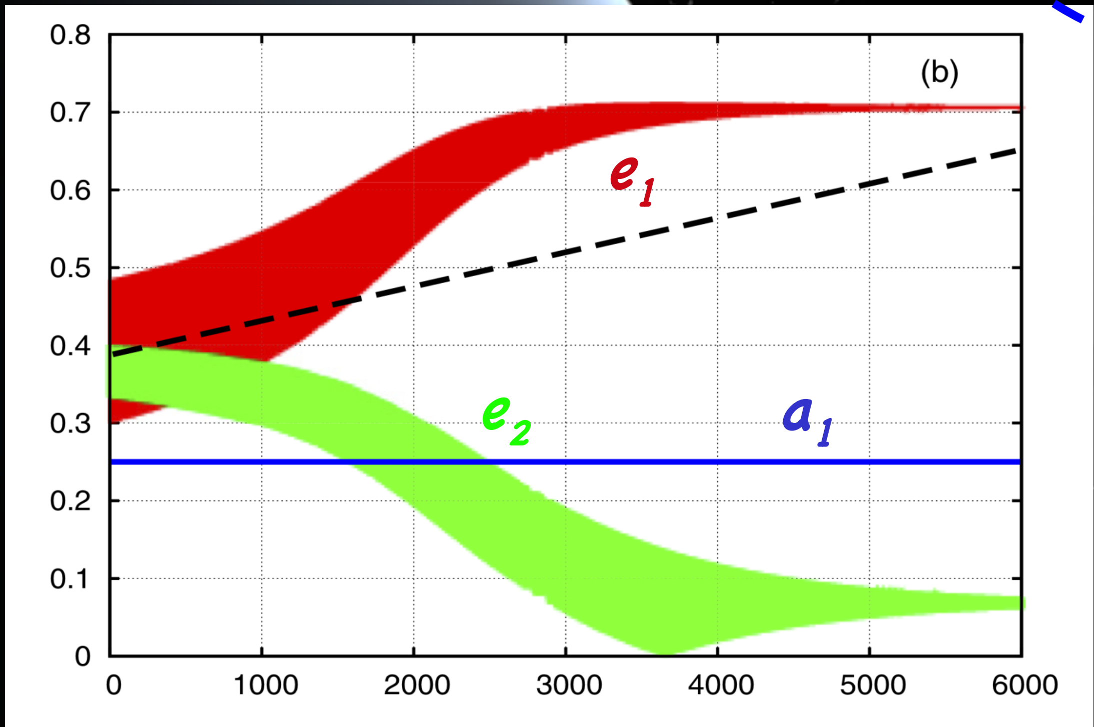
$$\dot{\varpi} = g$$

$$\delta x = \Delta x \cos(gt + \varpi_0 - \phi)$$

$$\delta \dot{x} = -\nu_x \delta x + \nu_e \delta e_1 ,$$

drift on the eccentricity

$$\delta \dot{e}_1 = -A\sin(gt + \varpi_0) - \frac{g_x A}{2g}\Delta x \sin(2gt + 2\varpi_0 - \phi) - \frac{g_e A}{2g}\Delta e \sin(2gt + 2\varpi_0) + \frac{g_x A}{2g}\Delta x \sin\phi .$$



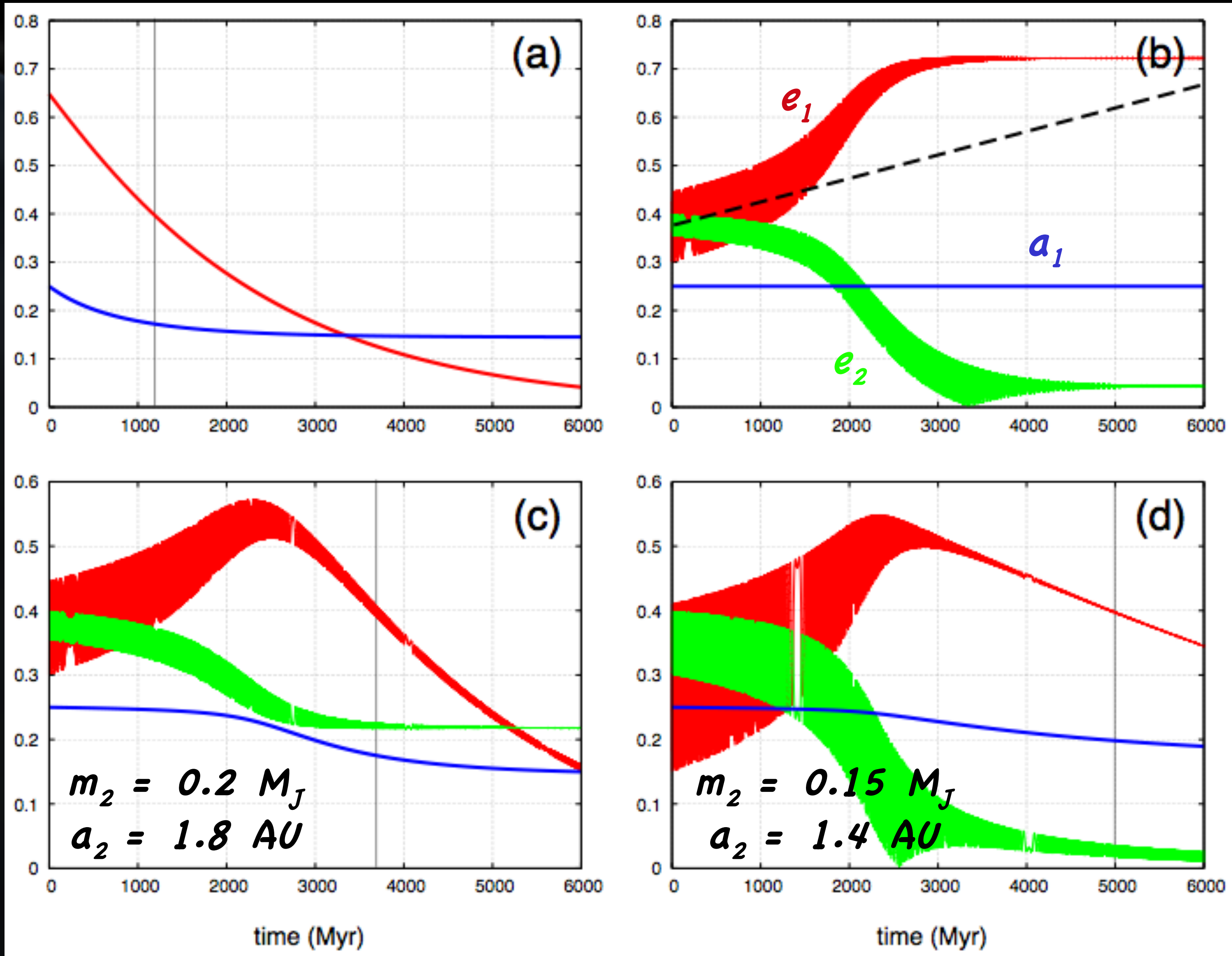
full tidal evolution

$$\frac{\dot{a}_1}{a_1} = -7K' f_6(e_1) e_1^2,$$

$$\dot{e}_1 = -\frac{7}{2} K' f_6(e_1) \left(1 - e_1^2\right) e_1$$

eccentricity pumping

HD 117618 b



Correia, Boué & Laskar, *ApJ Lett* (2012)

Conclusions

- Tidal effects are responsible for a slow secular evolution of the spins and orbits of close-in exoplanets.
- Tidal effects alone align the spin axis, synchronize the rotation and orbital periods, and damp the eccentricity of the orbit.
- Tidal effects combined with planetary perturbations may present unexpected behaviors such as the *pumping of the eccentricity*.
- The pumping effect is more effective for planets where the spin fully damped by tides, but the orbit is only slowly modified.