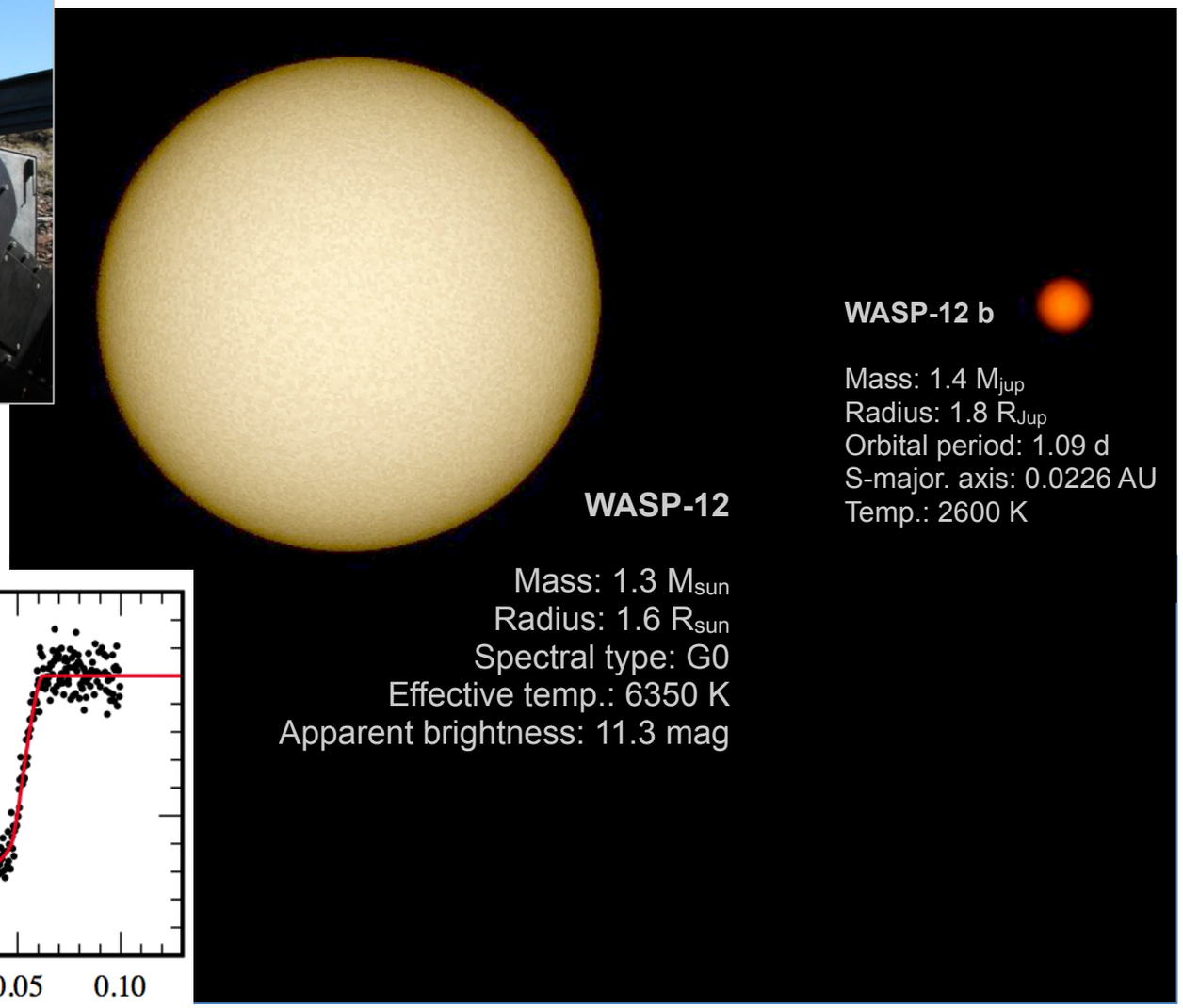
Planet-star tidal interactions with precise transit timing

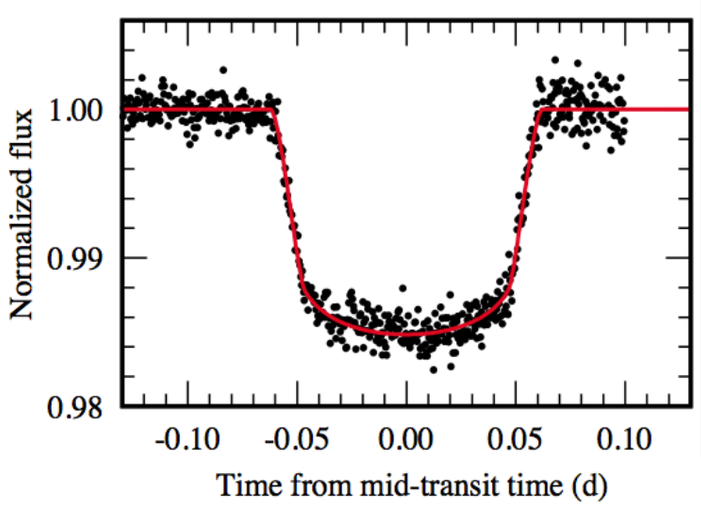
Gracjan Maciejewski
Centre for Astronomy, Nicolaus Copernicus University

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

The WASP-12 system

SuperWASP
(Wide Angle Search for Planets)

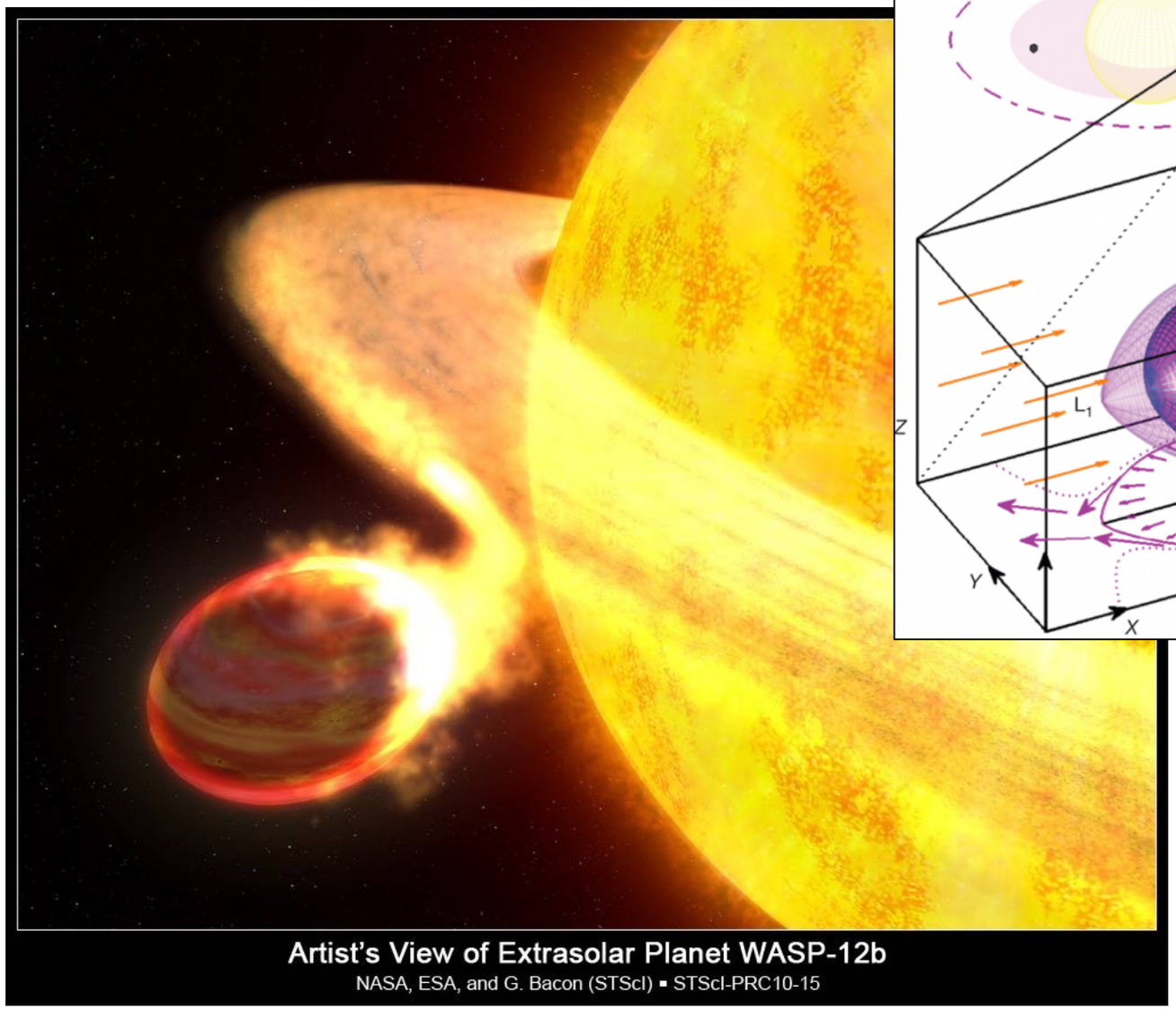


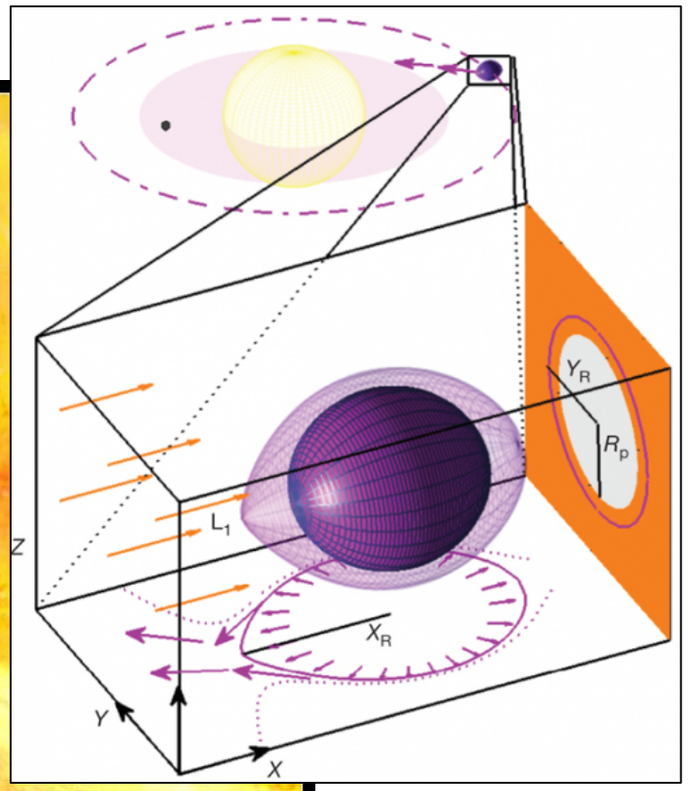


Hebb et al. 2009, ApJ, 693, 1920

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

The WASP-12 system

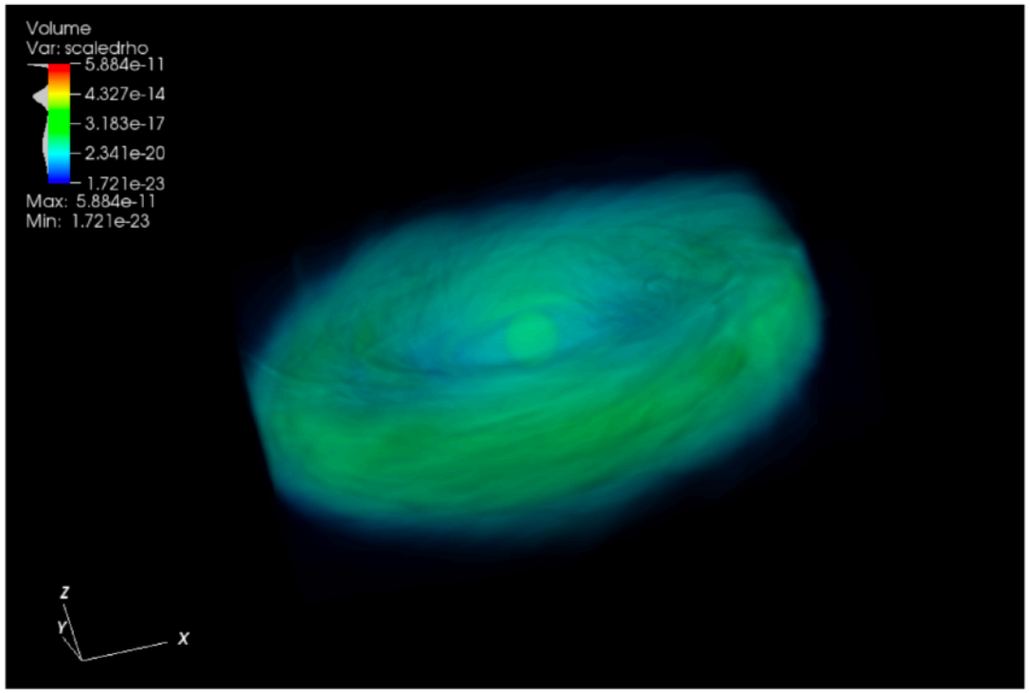


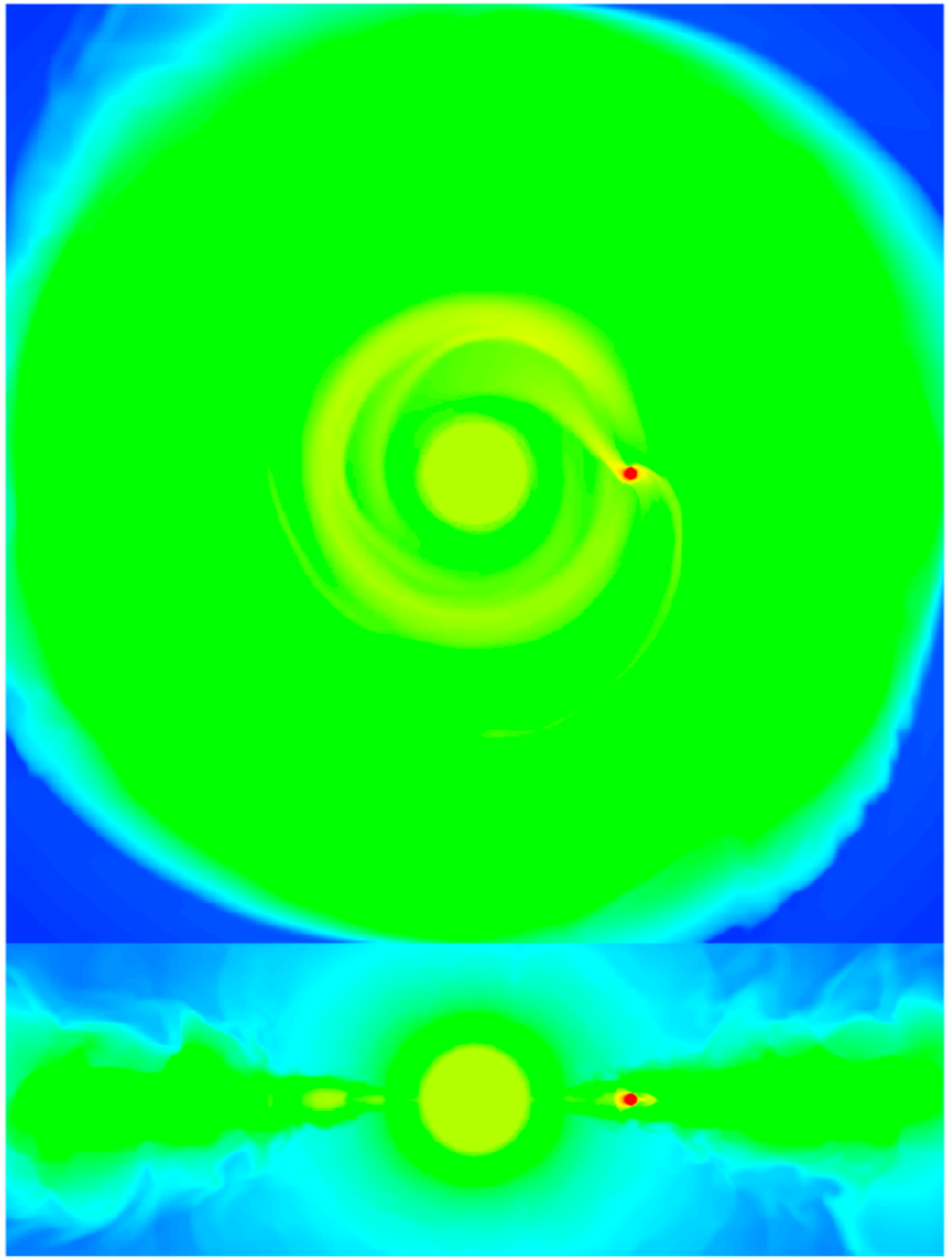


Li et al. 2010, Nature, 463, 1054

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

The WASP-12 system



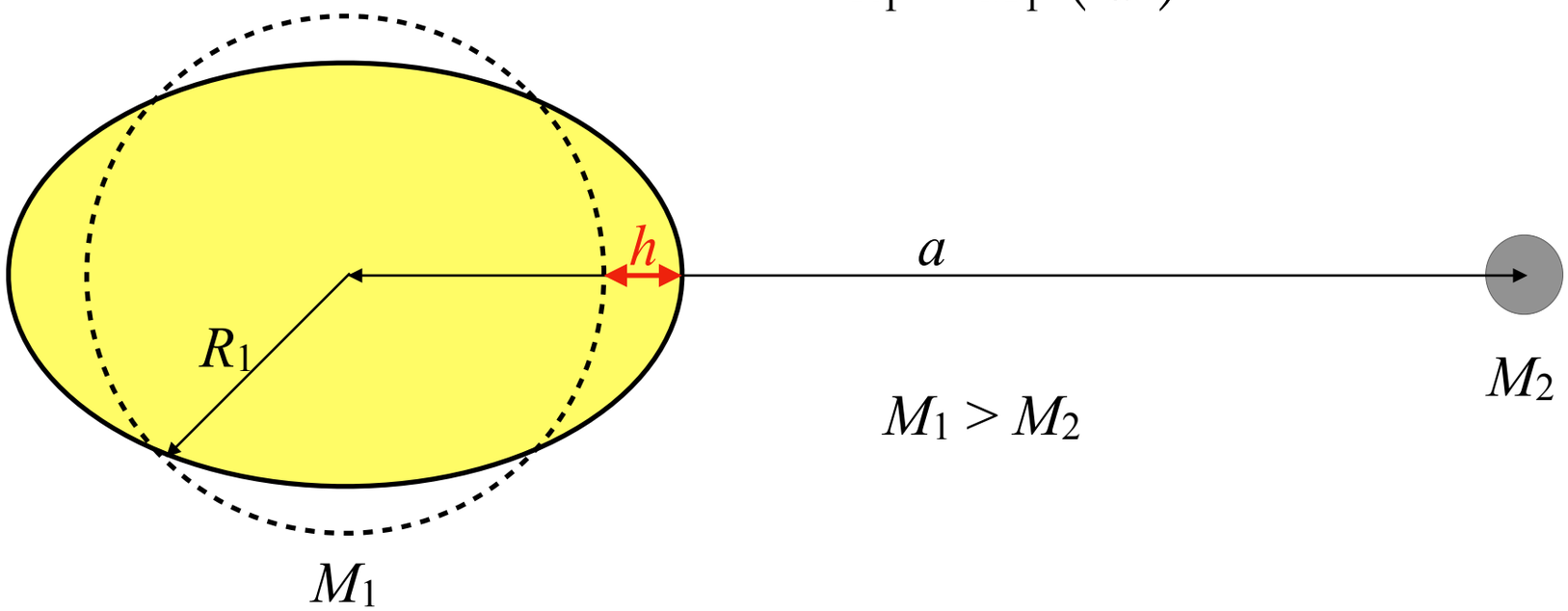


Debrecht et al. 2018

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

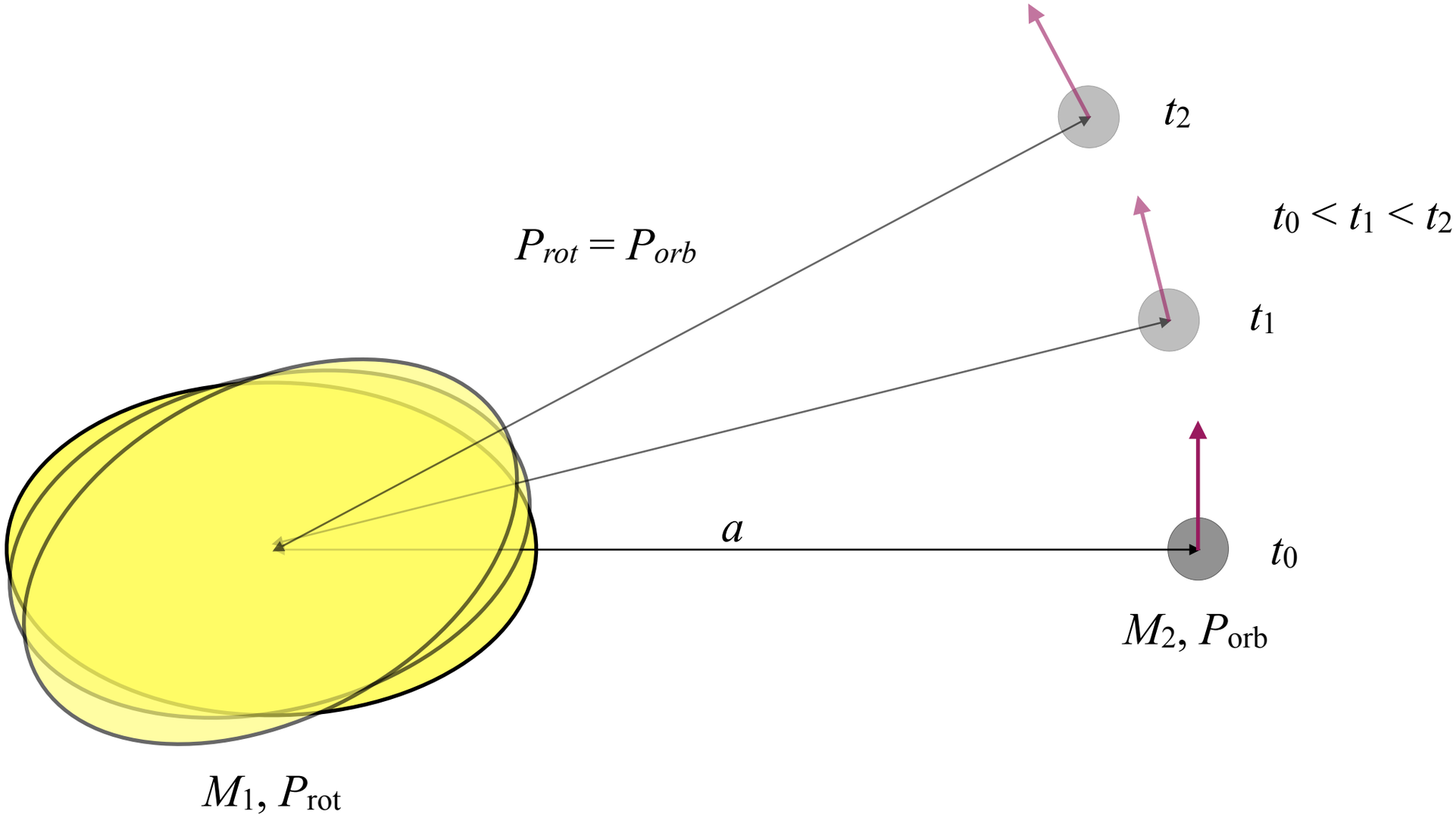
Tidal interactions

$$\frac{h}{R_1} = \frac{M_2}{M_1}\left(\frac{R_1}{a}\right)^3$$



This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

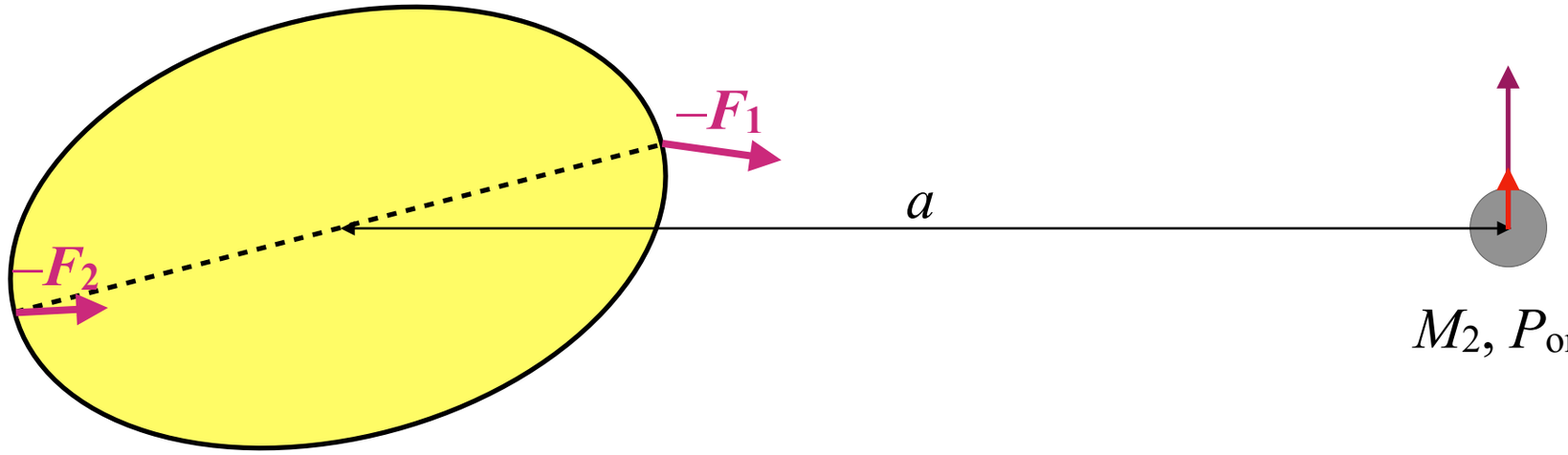
Tidal interactions



This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Tidal interactions

$$P_{rot} < P_{orb}$$

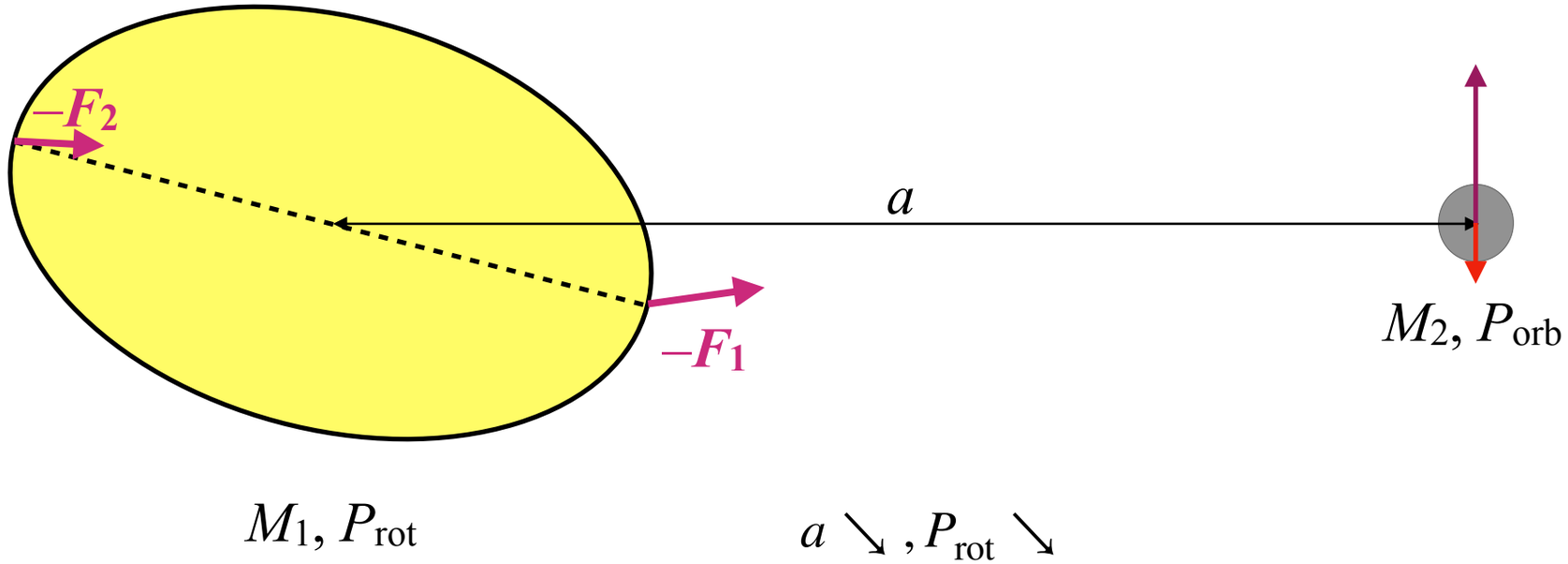


$a \nearrow , P_{\mathrm{rot}} \nearrow$

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Tidal interactions

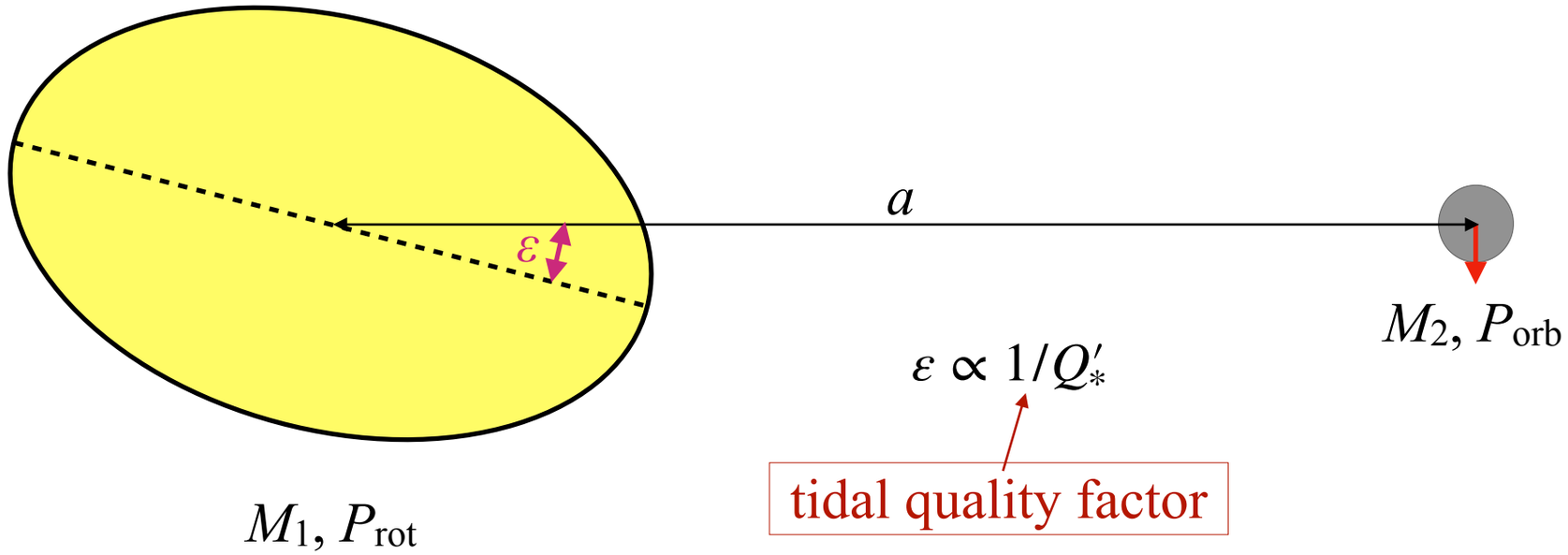
$$P_{rot} > P_{orb}$$



This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Tidal interactions

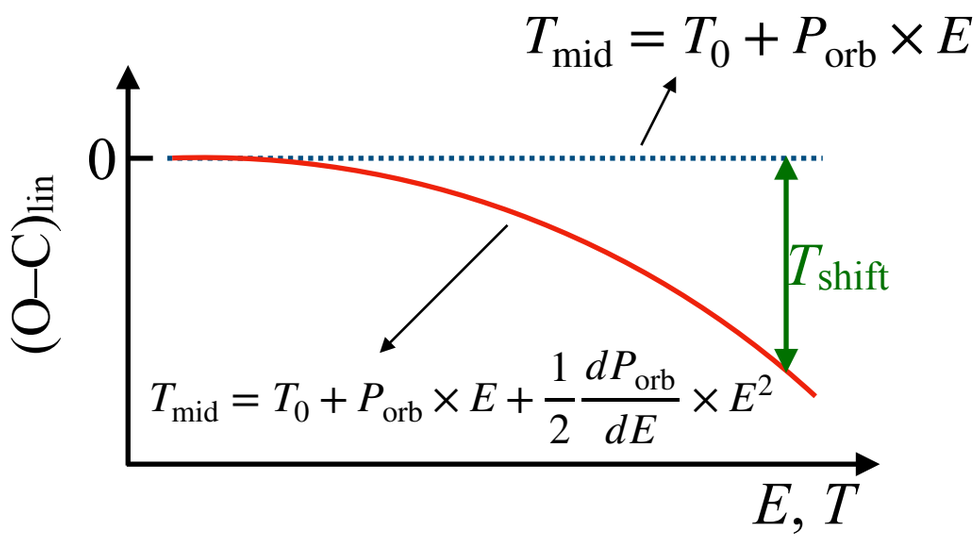
$$P_{rot} > P_{orb}$$



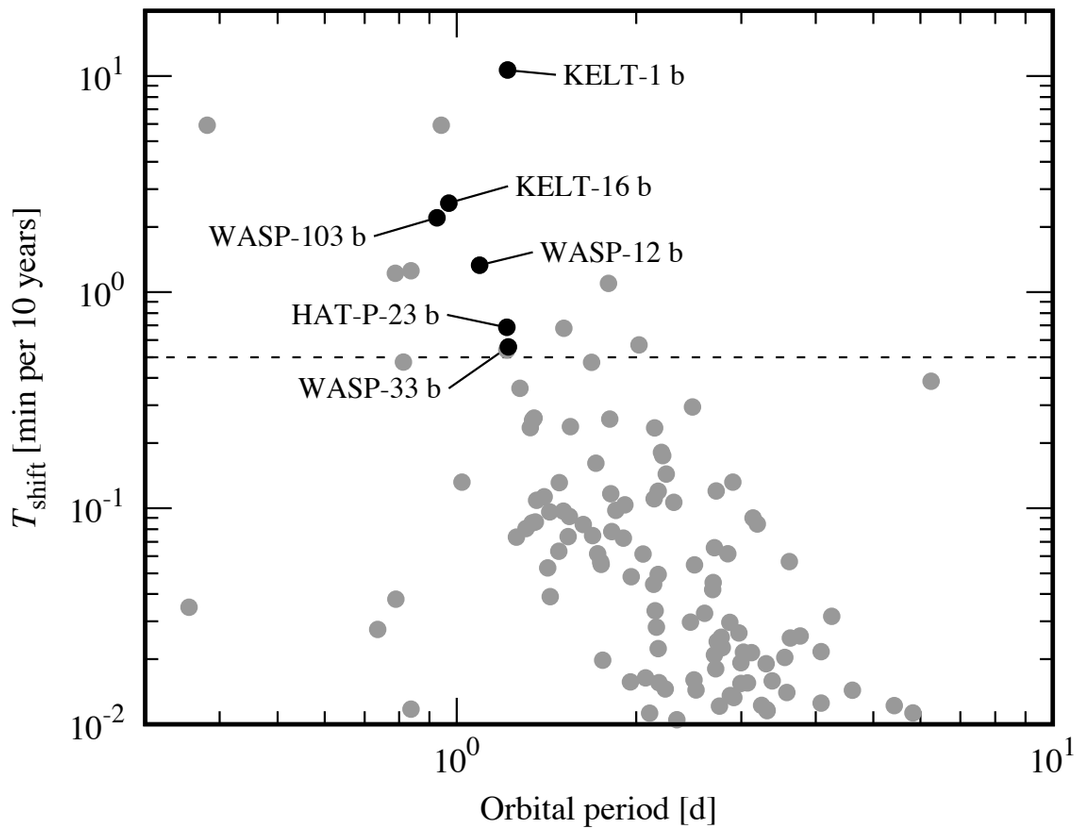
$$Q' \propto \frac{\text{maximum energy stored in the distortion}}{\text{energy dissipated in one cycle}} \in [10^5, 10^9]$$

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Search for orbital decay due to tides



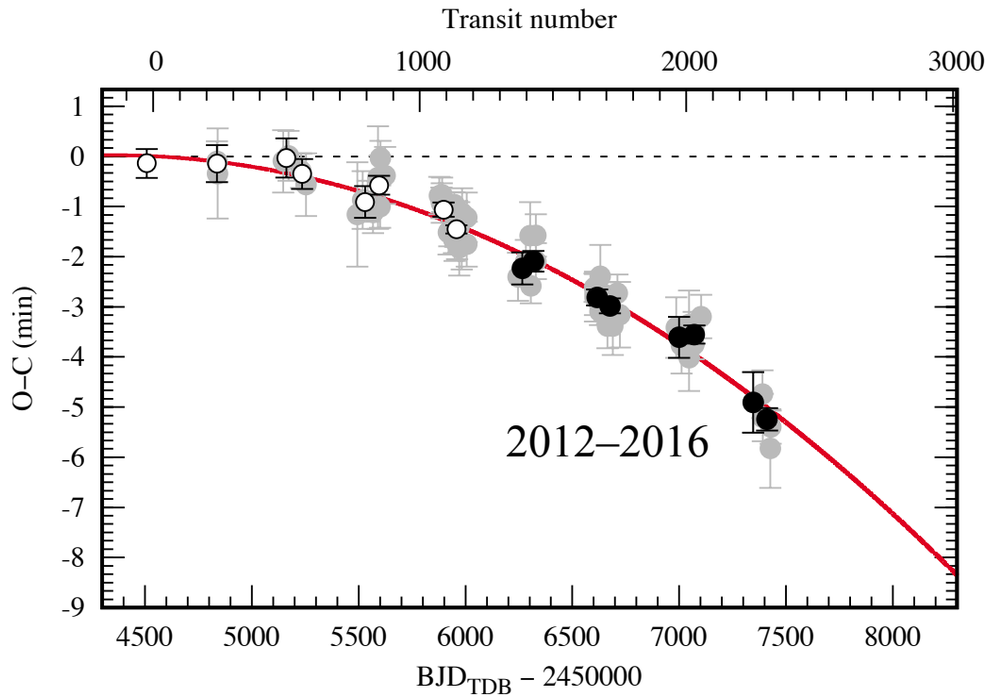
$$T_{\rm shift} = -\frac{27}{4}\frac{\pi}{Q'_*}\left(\frac{M_p}{M_*}\right)\left(\frac{R_*}{a}\right)^5 \frac{1}{P_{\rm orb}} T^2$$



Maciejewski *et al*. 2018, submitted

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

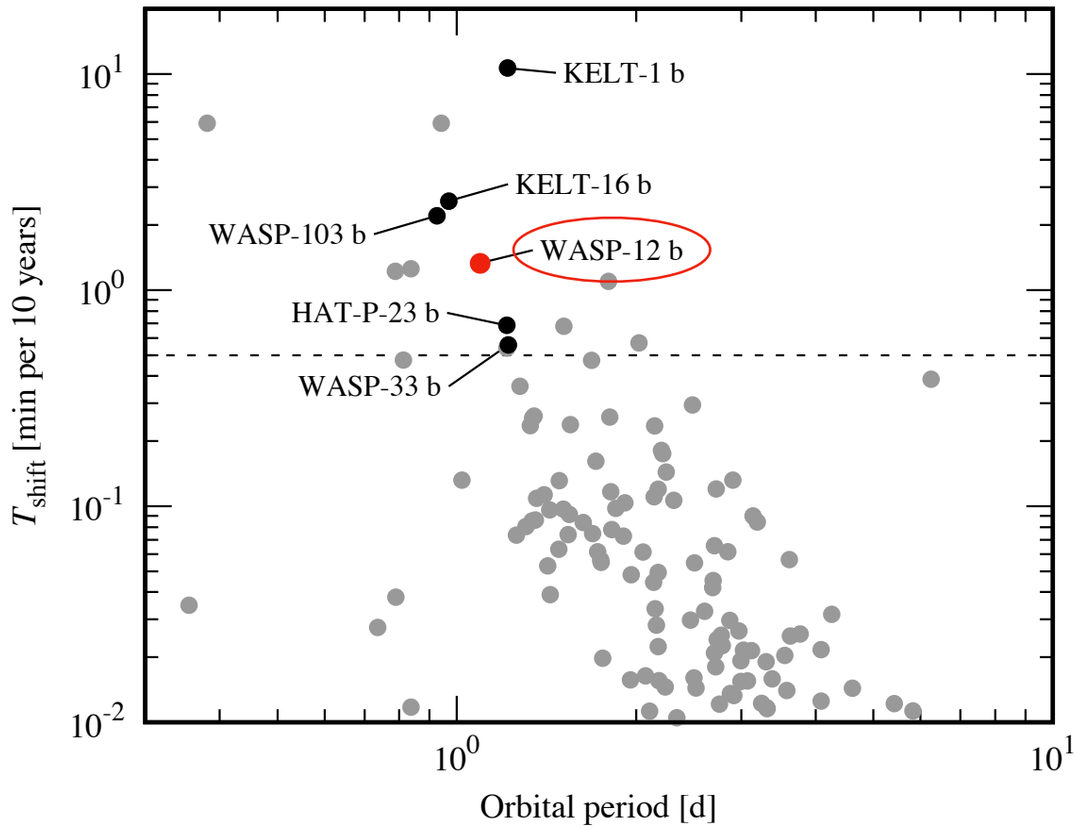
Search for orbital decay due to tides – WASP-12



Maciejewski et al. 2016, A&A, 588, L6

Orbital decay

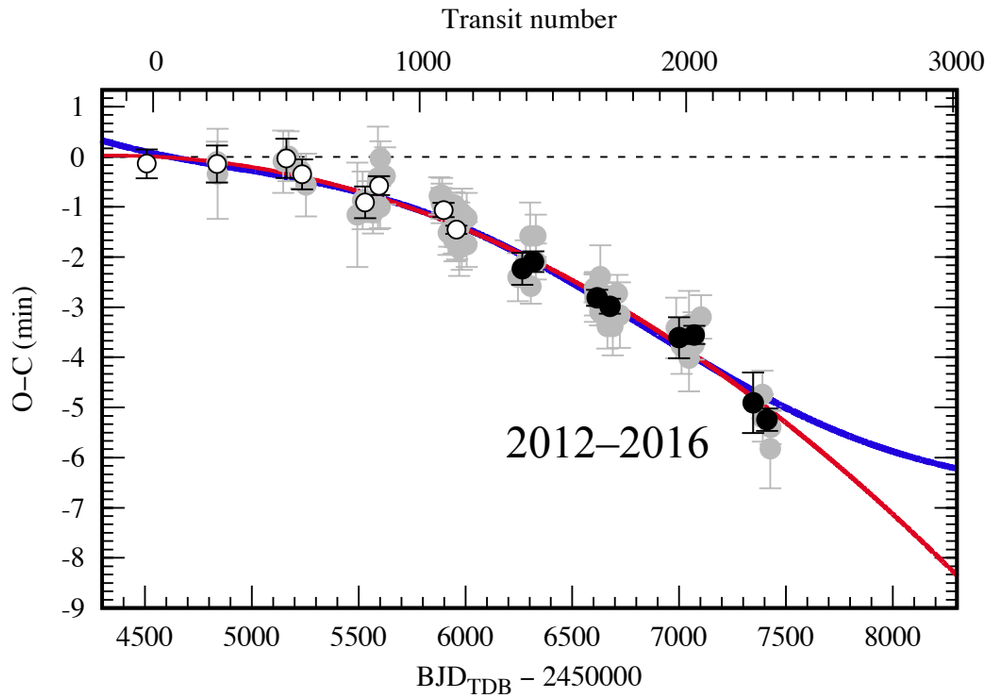
- P_{orb} decreases by **26 milliseconds per year**
- the orbital distance shrinks by **600 meters a year**
- the planet will fall onto the host star in less than **10^6 yr**



Maciejewski *et al*. 2018, submitted

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Search for orbital decay due to tides – WASP-12



Maciejewski et al. 2016, A&A, 588, L6

Apsidal precession of slightly eccentric orbit
(precession of the orbit due to the nonpoint-mass component of the gravitational field)

- e_{orb} of about **0.001**
- period of precession of about **10 yr**

Apsidal precession might be caused by:

- tidal deformations of the star and planet

$$\dot{\omega}_{\rm tidal} = \dot{\omega}_{\rm tidal,*} + \dot{\omega}_{\rm tidal,p} = \frac{15}{2} k_{2*} \left(\frac{R_*}{a}\right)^5 \frac{M_p}{M_*} f_2(e) n + \frac{15}{2} k_{2p} \left(\frac{R_p}{a}\right)^5 \frac{M_*}{M_p} f_2(e) n,$$

- rotation bulges

$$\dot{\omega}_{\rm rot} = \dot{\omega}_{\rm rot,*} + \dot{\omega}_{\rm rot,p} = \frac{k_{2*}}{2} \left(\frac{R_*}{a}\right)^5 \frac{v_*^2 a^3}{G M_*} g_2(e) n + \frac{k_{2p}}{2} \left(\frac{R_p}{a}\right)^5 \frac{v_p^2 a^3}{G M_p} g_2(e) n,$$

- general relativity

$$\dot{\omega}_{GR} = \frac{3 G M_* n}{a c^2 (1 - e^2)}.$$

The total apsidal rotation is

$$\dot{\omega}_{\rm tot} = \dot{\omega}_{\rm tid,p} + \dot{\omega}_{\rm GR} + \dot{\omega}_{\rm rot,p} + \dot{\omega}_{\rm rot,*} + \dot{\omega}_{\rm tid,*}.$$

For typical very hot Jupiters

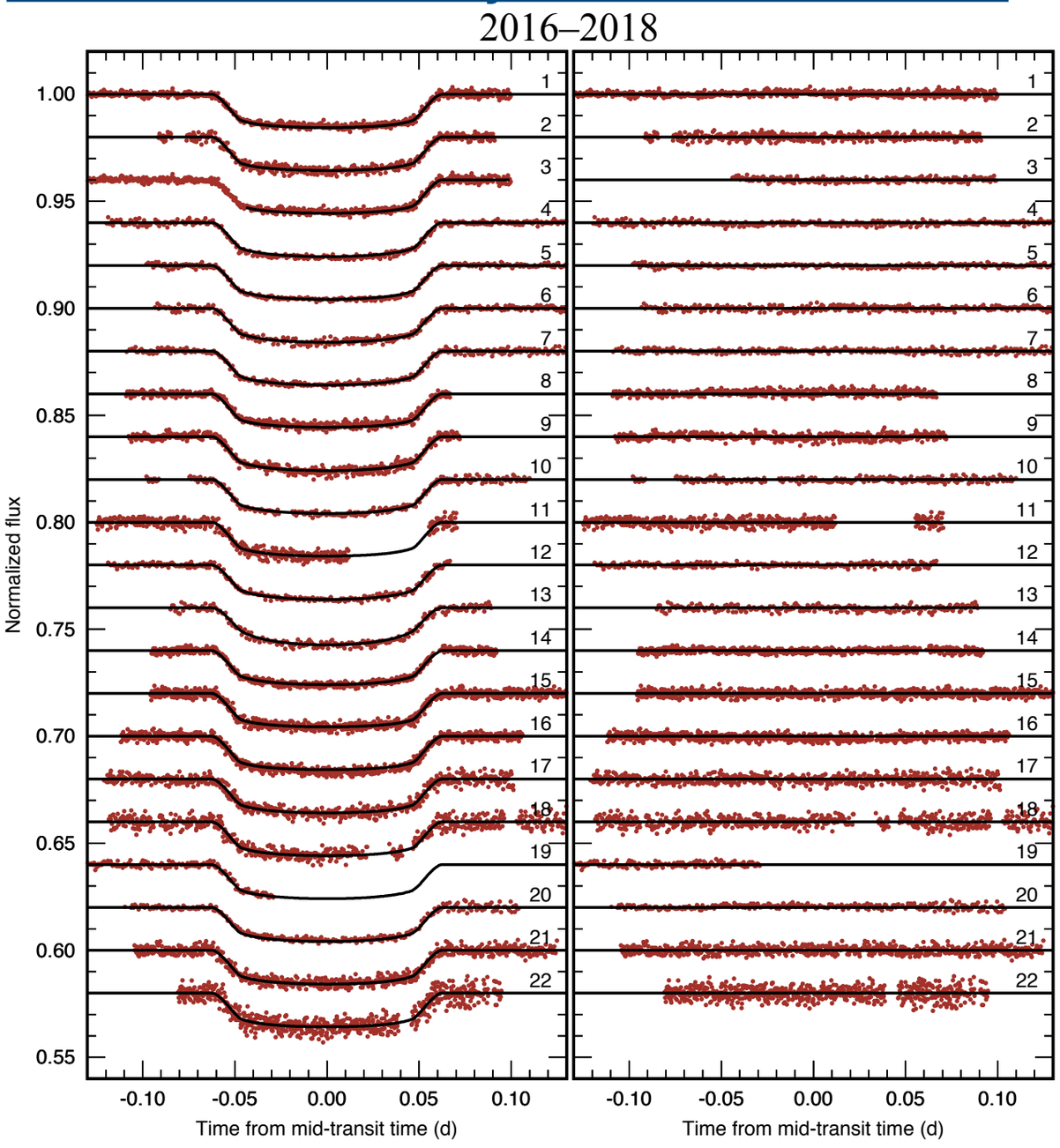
$$\dot{\omega}_{tot} \approx \dot{\omega}_{tidal,p}$$

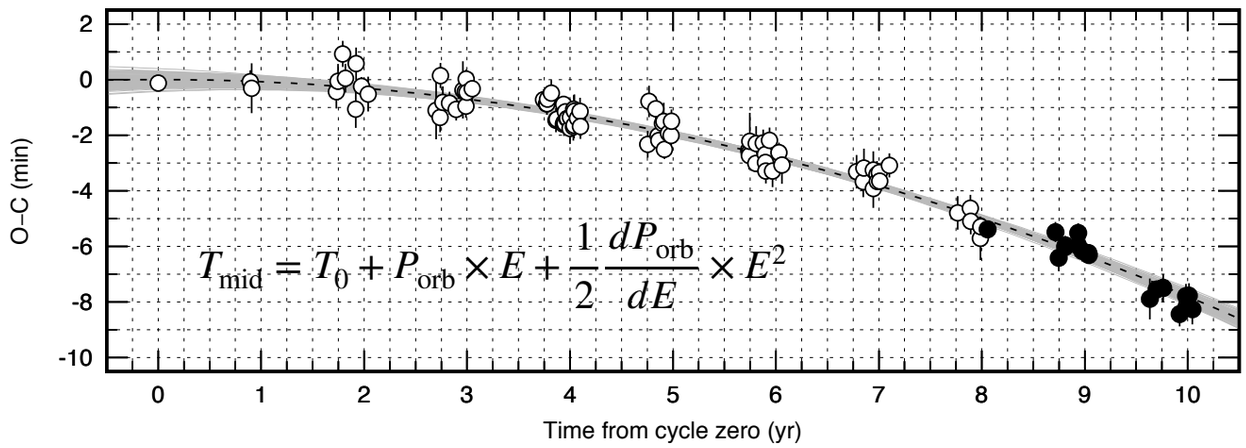
so the planetary Love number k_{2p} would be accessible *via* observations

Ragozzine & Wolf 2009, ApJ, 698, 1778

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Search for orbital decay due to tides – WASP-12





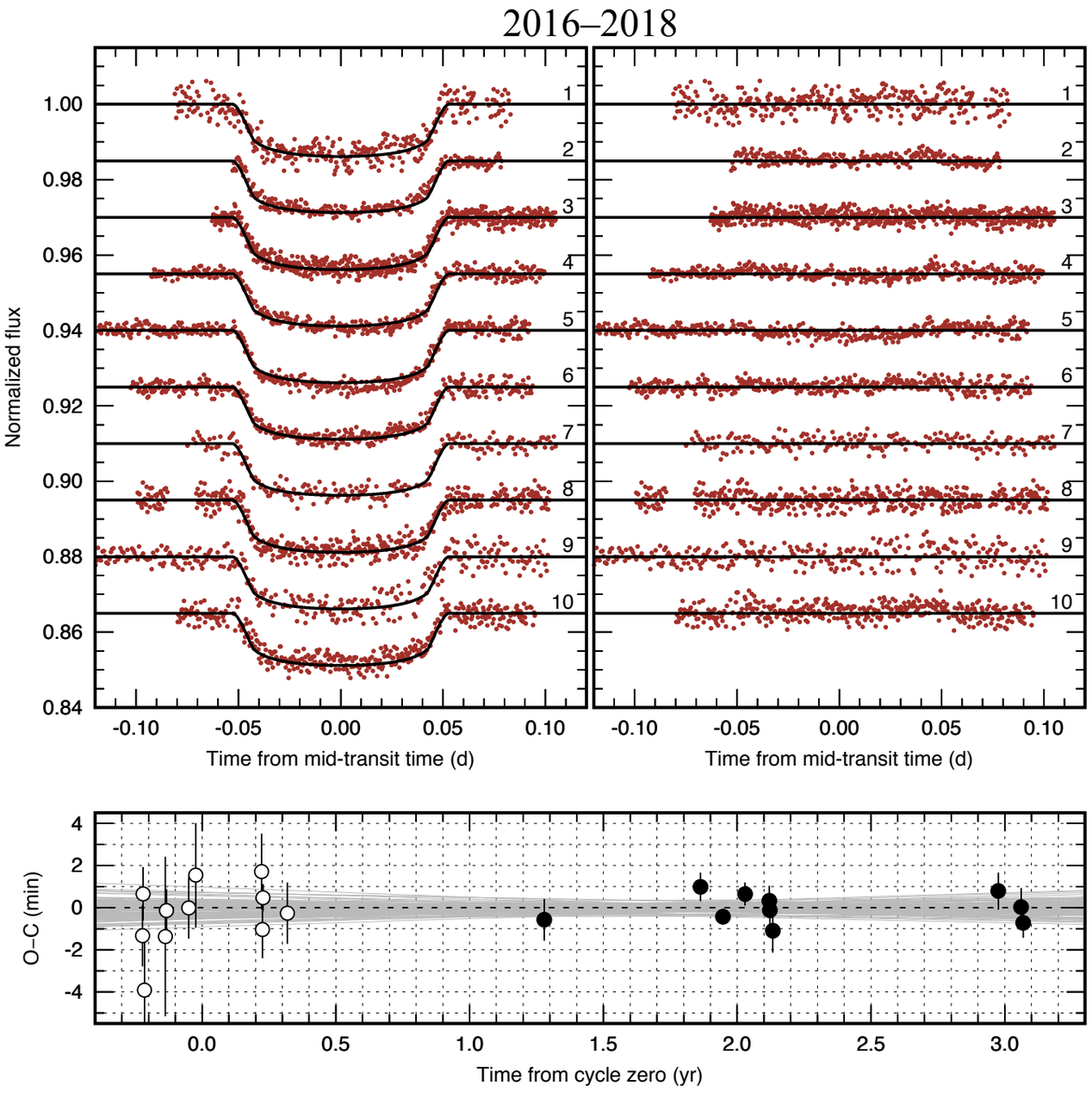
$$Q'_* = -\frac{27}{2}\pi \left(\frac{M_p}{M_*}\right)\left(\frac{a}{R_*}\right)^{-5}\left(\frac{dP_{\rm orb}}{dE}\right)^{-1} P_{\rm orb}$$

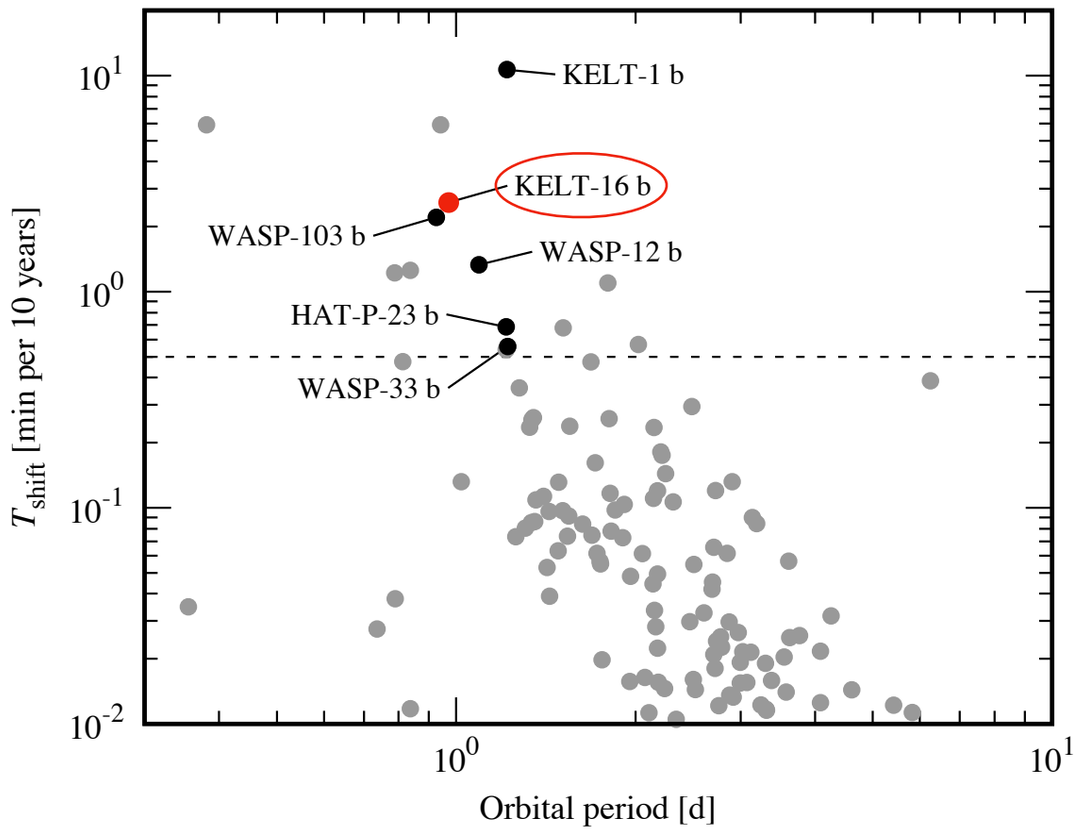
$$Q'_* = (1.82 \pm 0.32) \times 10^5$$

Maciejewski *et al*. 2018, submitted

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Search for orbital decay due to tides – KELT-16



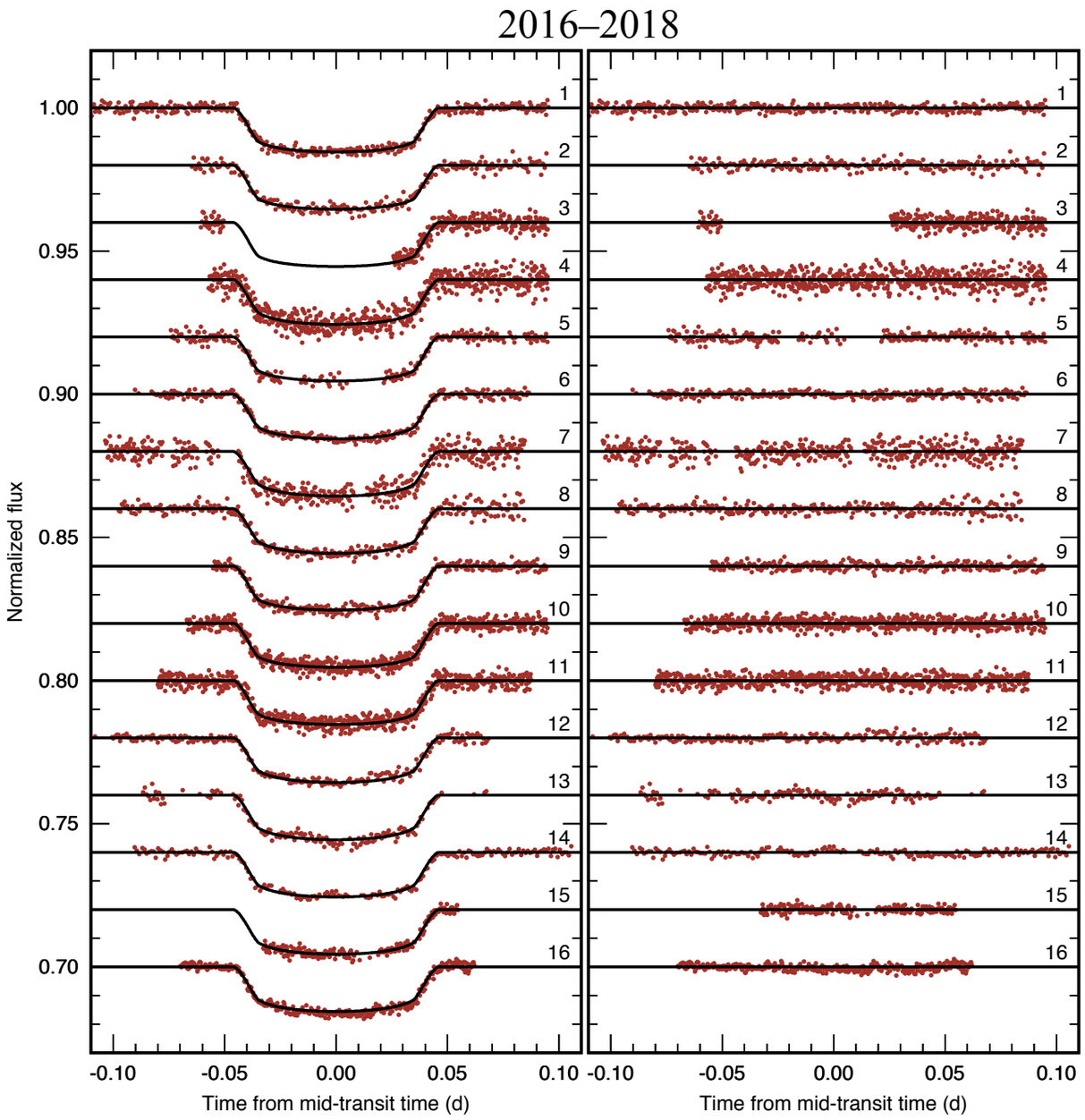


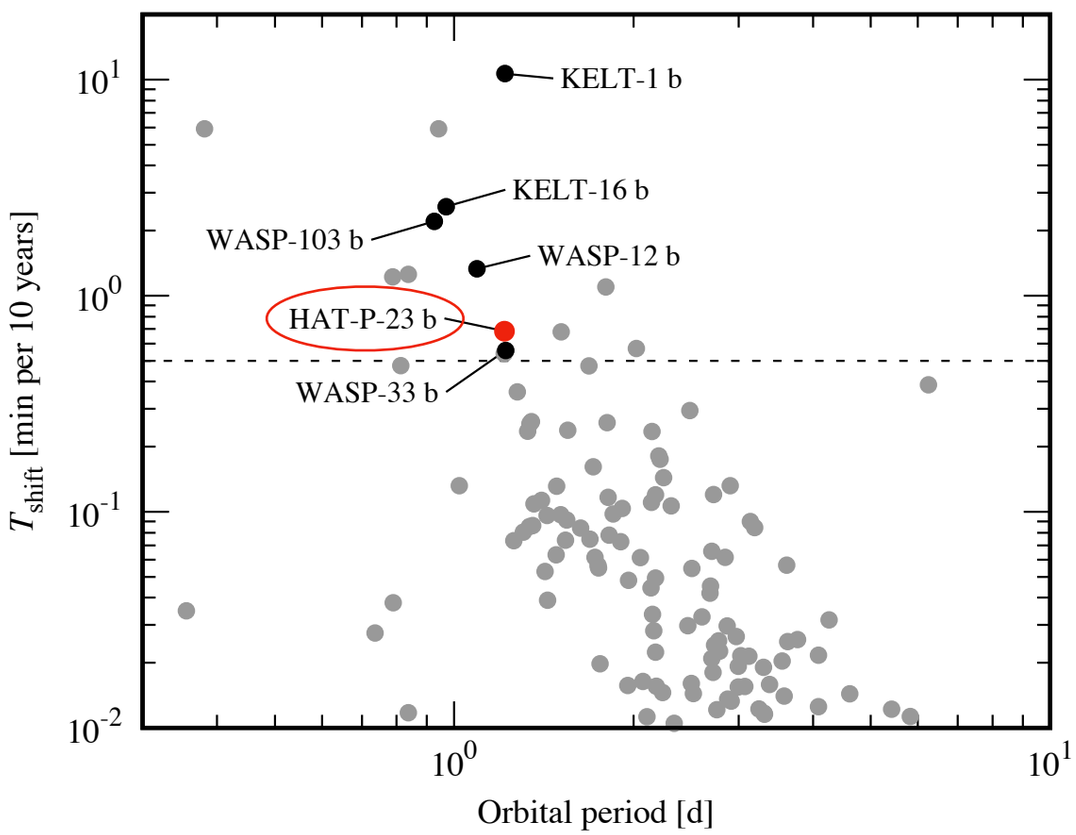
$Q'_* > 6.2 \times 10^4$ at the 95 % confidence level

Maciejewski *et al*. 2018, submitted

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Search for orbital decay due to tides – HAT-P-23

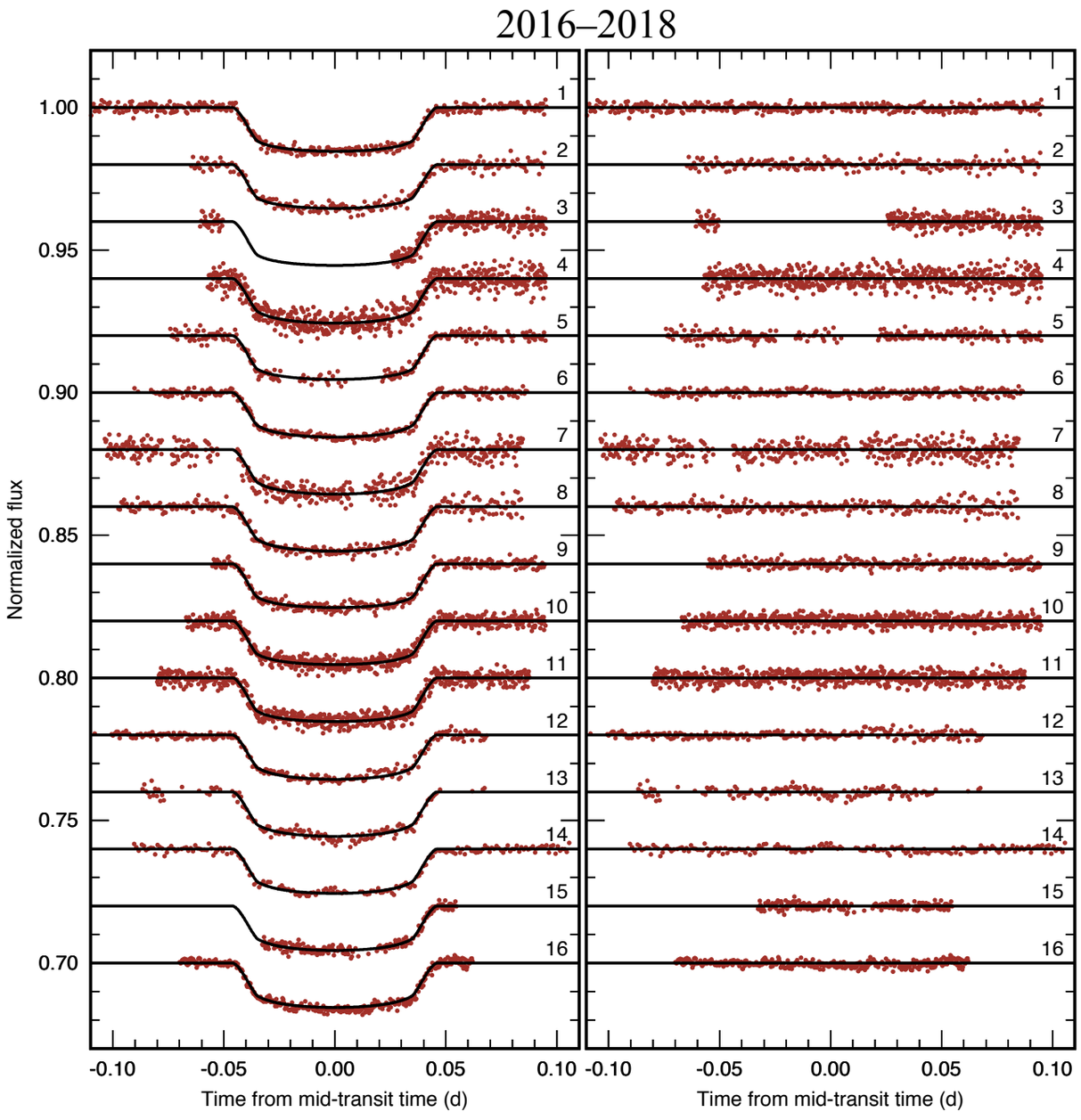


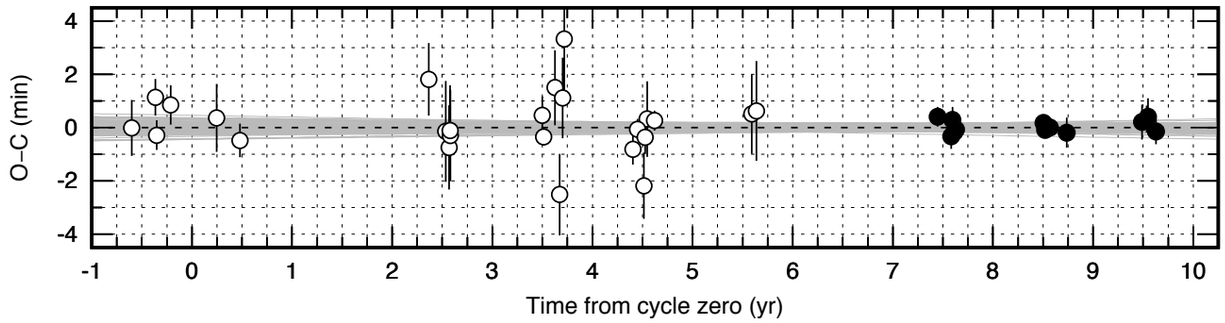


Maciejewski *et al*. 2018, submitted

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Search for orbital decay due to tides – HAT-P-23



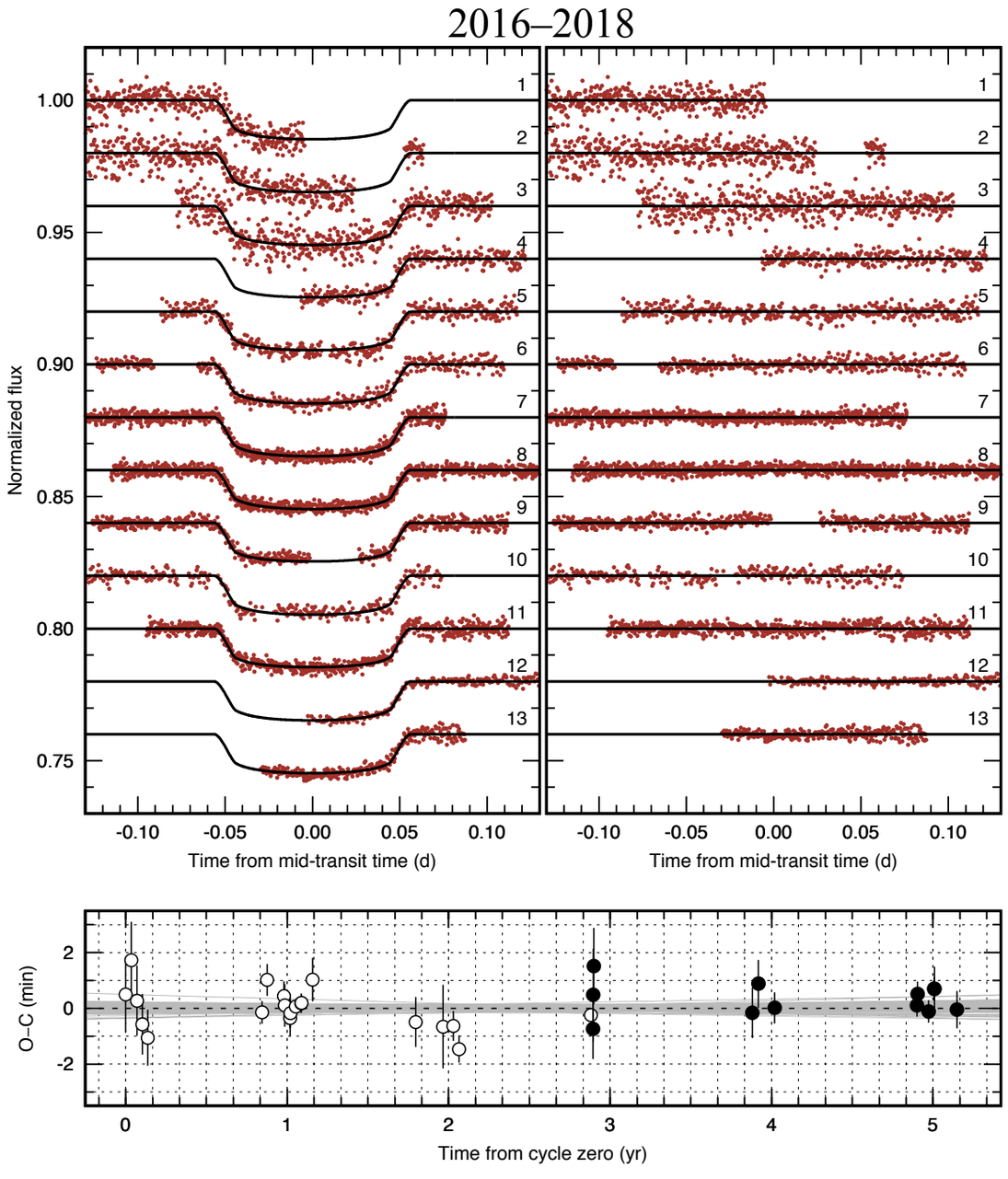


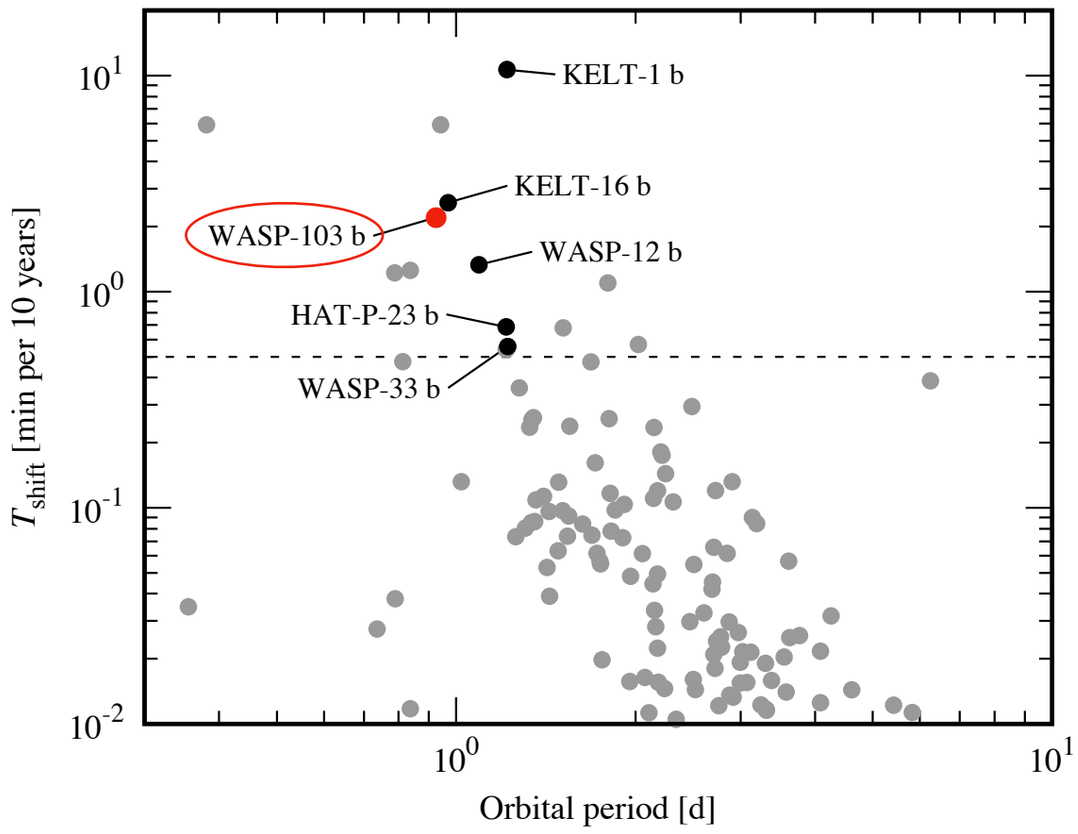
$Q'_* > 5.6 \times 10^5$ at the 95 % confidence level

Maciejewski *et al*. 2018, submitted

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Search for orbital decay due to tides – WASP-103



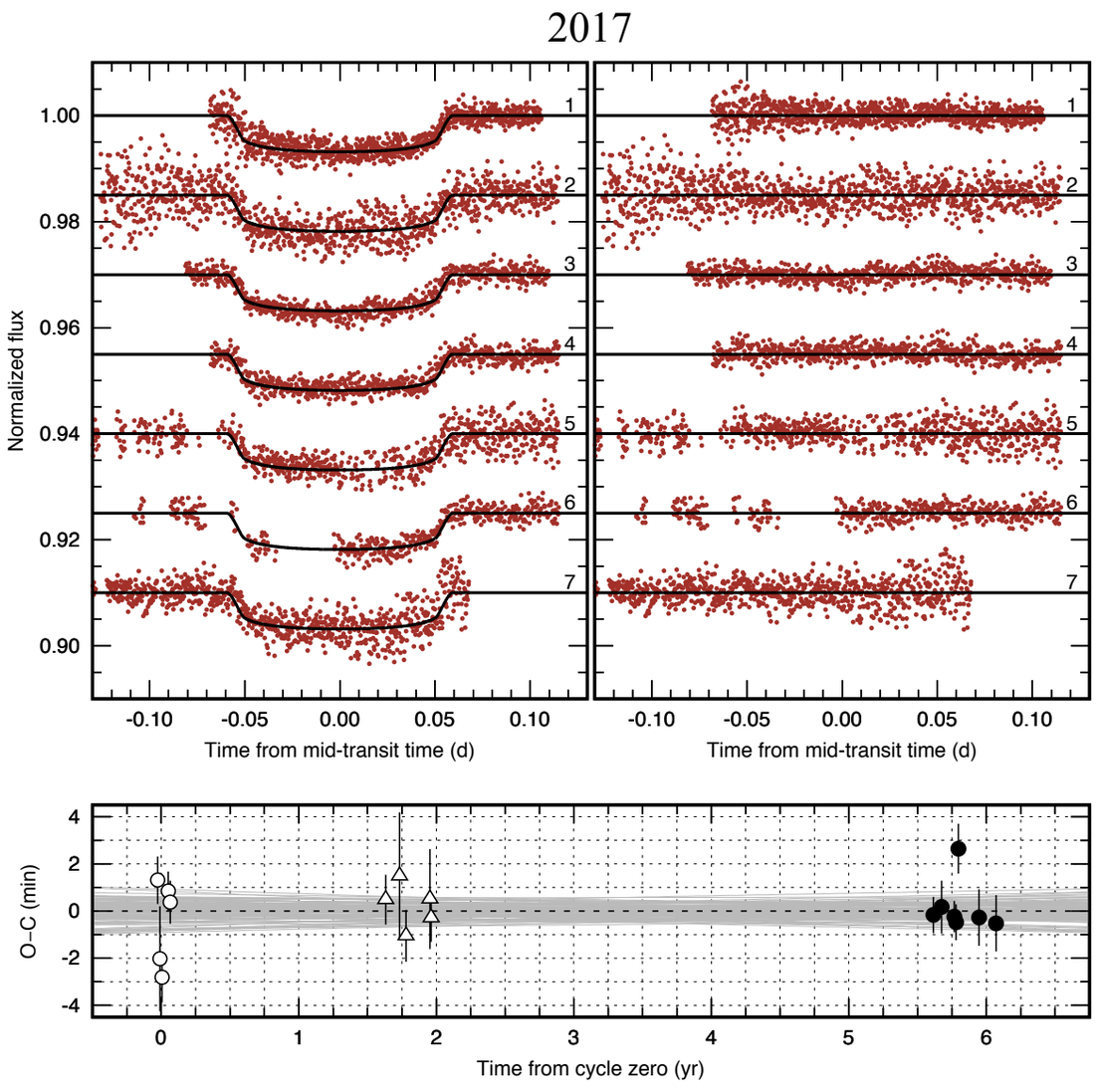


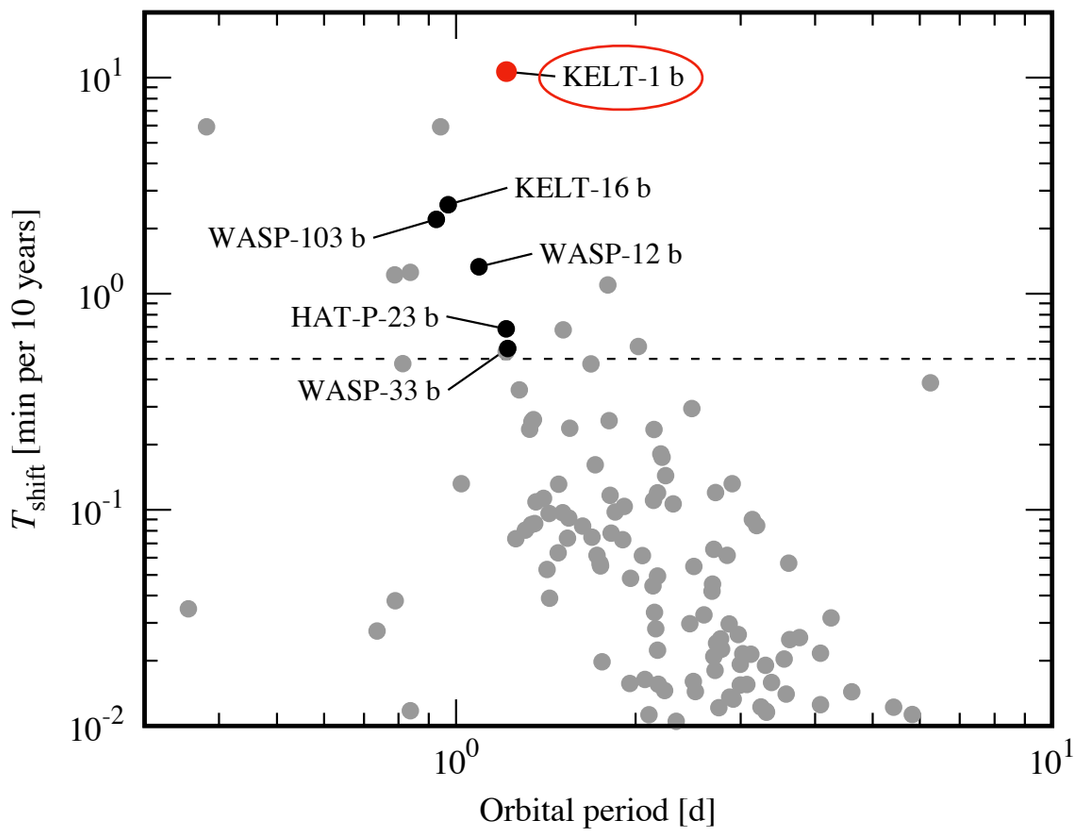
$Q'_* > 10^6$ at the 99.97 % confidence level

Maciejewski *et al*. 2018, submitted

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Search for orbital decay due to tides – KELT-1



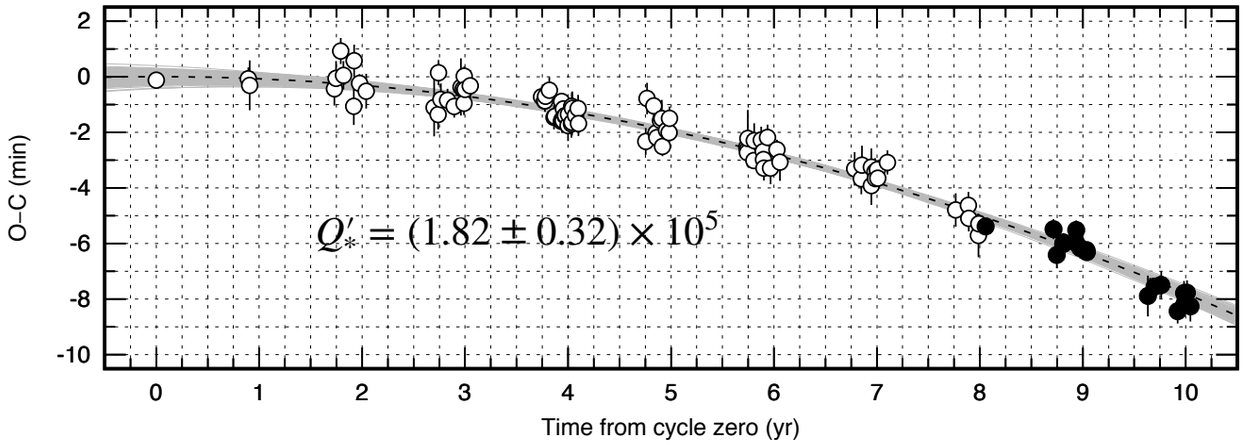


$Q'_* > 7.4 \times 10^5$ at the 95 % confidence level

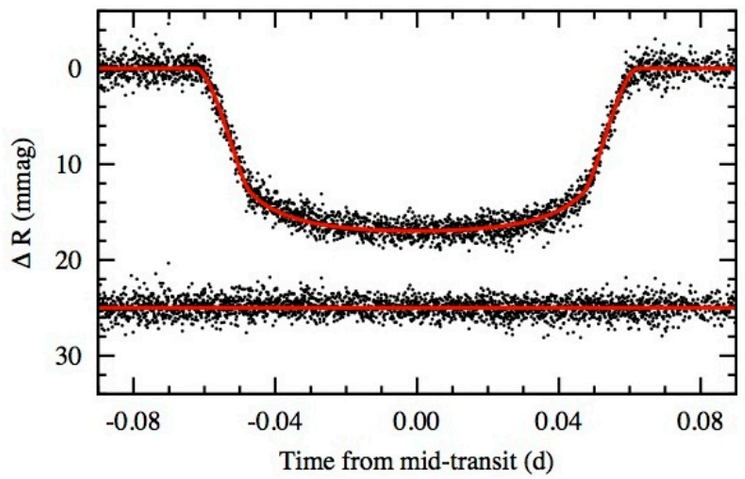
Maciejewski *et al*. 2018, submitted

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Search for orbital decay due to tides – WASP-12

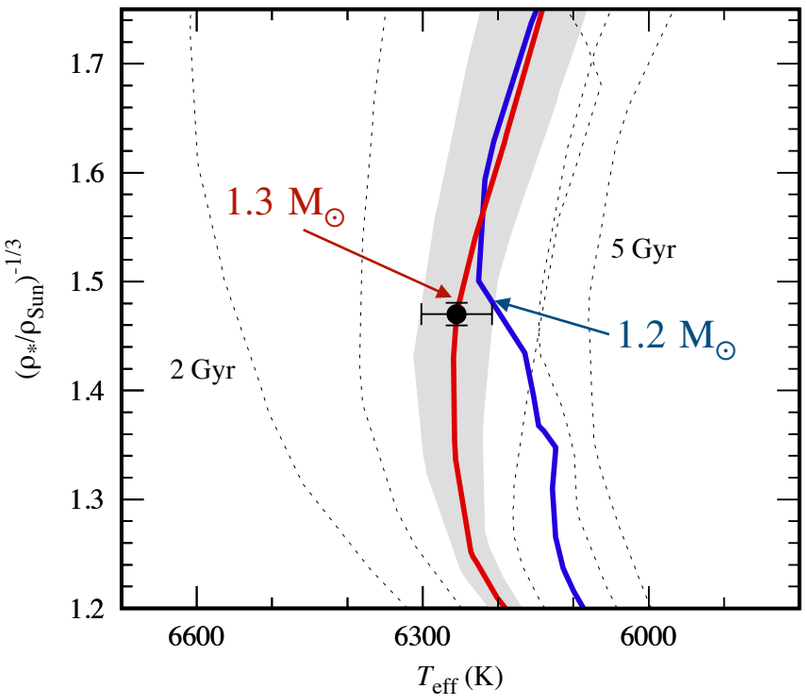


Maciejewski *et al*. 2018, submitted



Maciejewski *et al*. 2013, A&A, 551, 108

$$\rho_* = \frac{3\pi}{GP_b^2}\left(\frac{a_b}{R_*}\right)^3$$



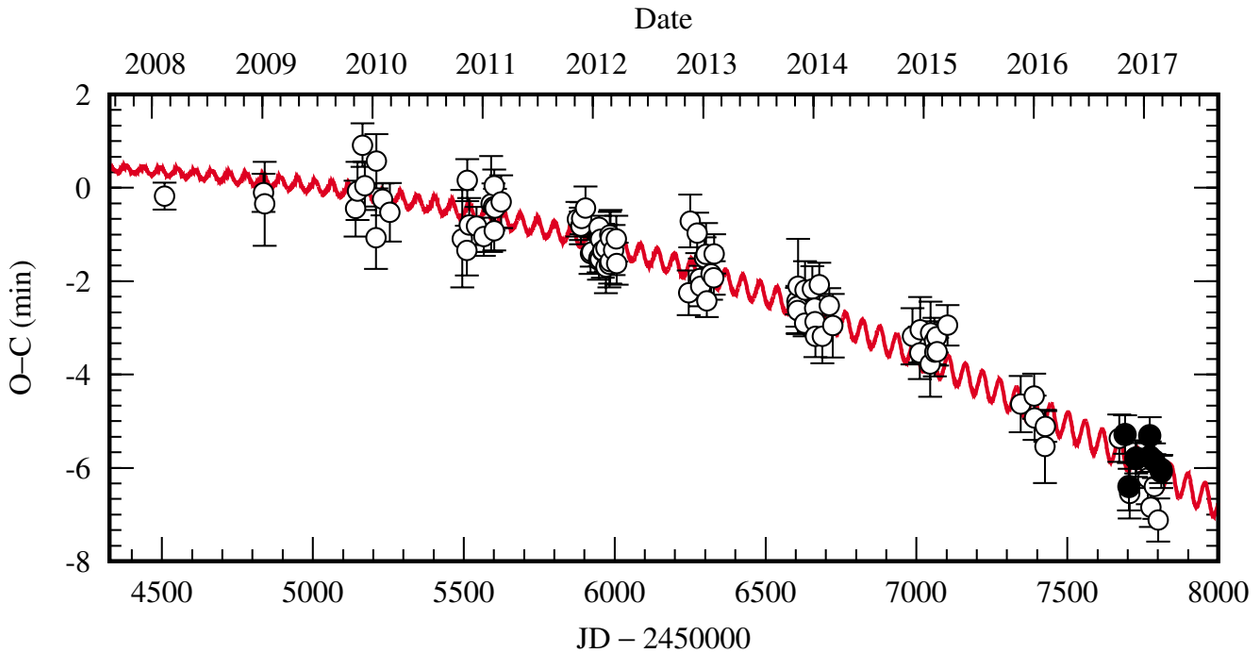
Maciejewski *et al*., in prep.

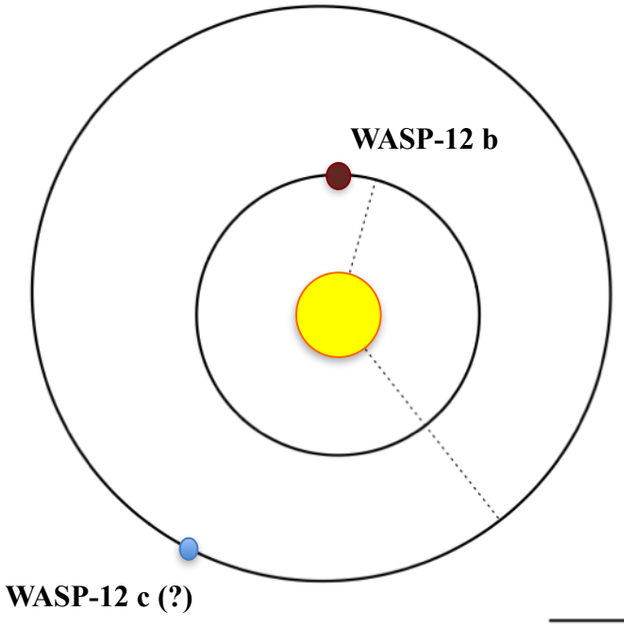
If WASP-12 is a subgiant star then theoretical models predict

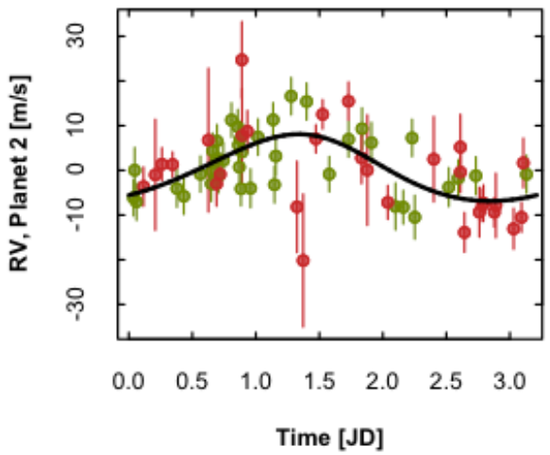
$$Q'_* \approx 1.9 \times 10^5$$

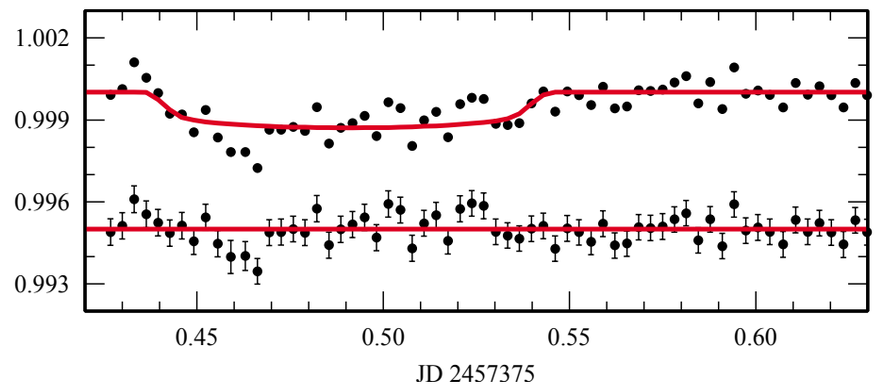
This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

WASP-12 b – transit time variations of the perturbative nature





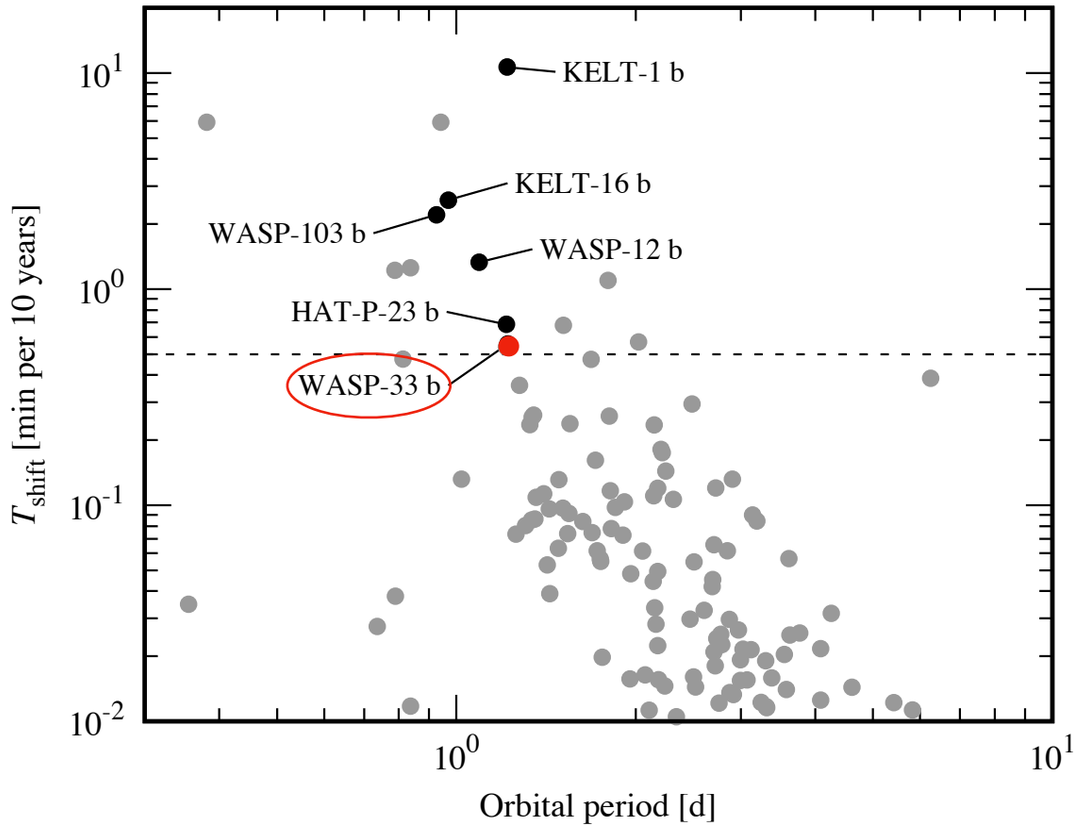




Maciejewski G., 2018, Proceedings of the Polish Astronomical Society, Vol. 7, p.113

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

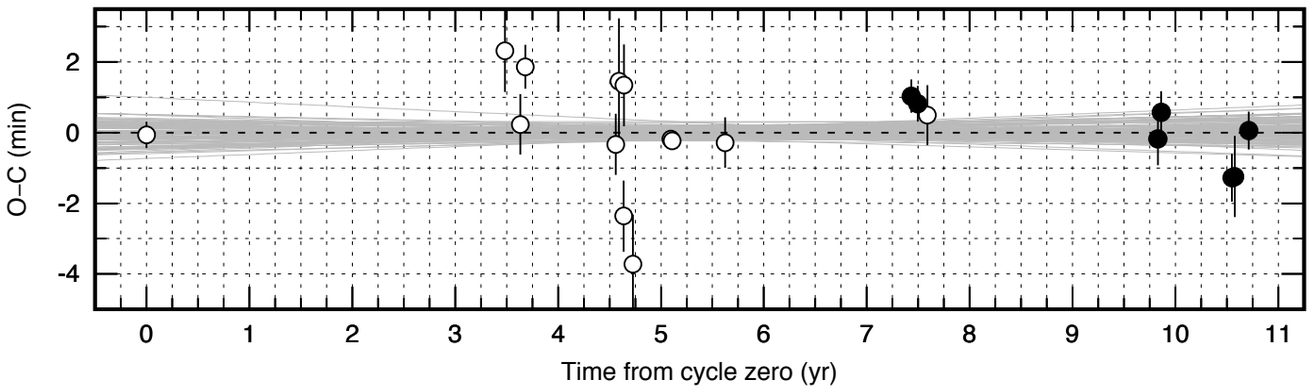
Search for orbital decay due to tides – WASP-33



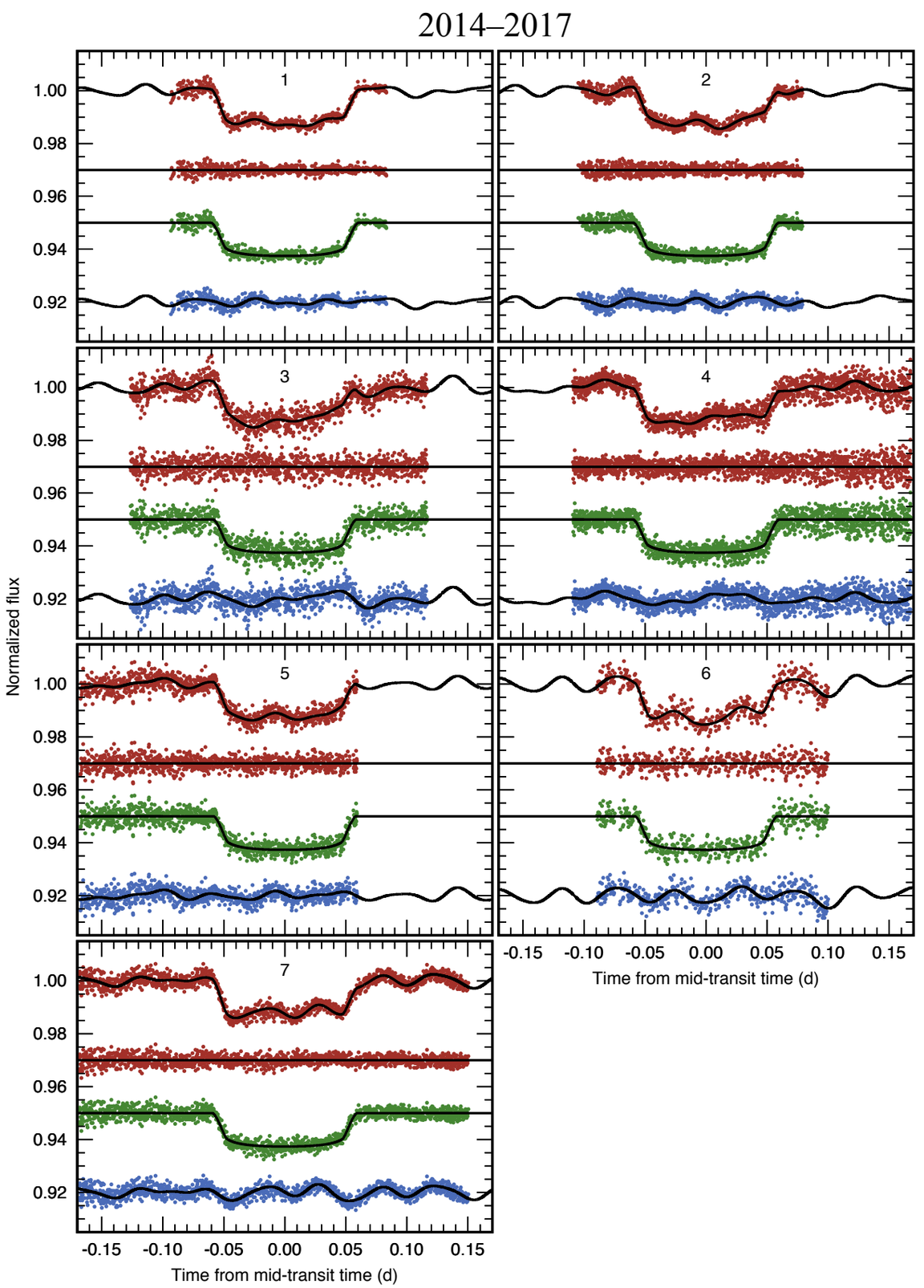
Maciejewski *et al*. 2018, submitted

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

Search for orbital decay due to tides – WASP-33



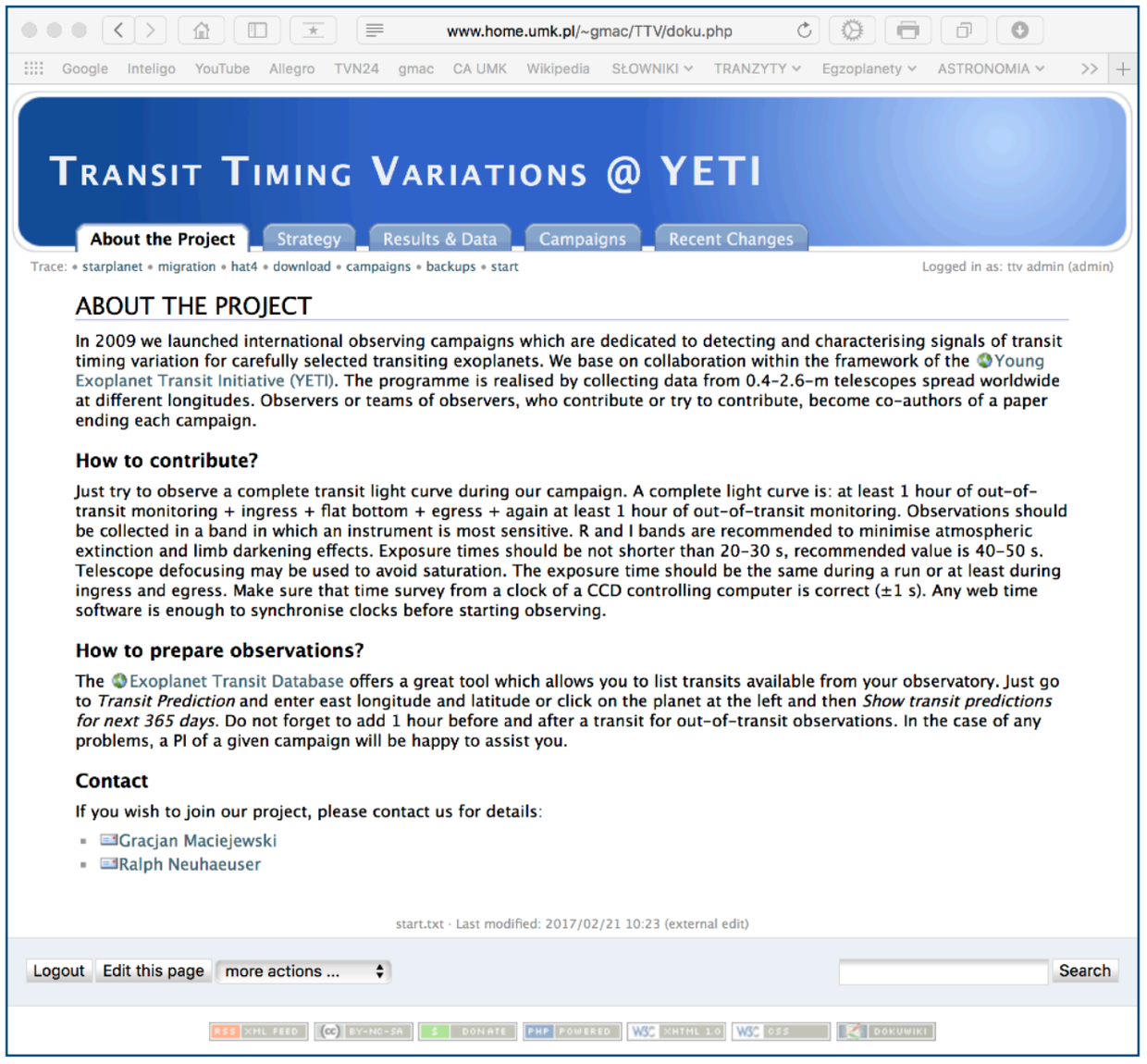
$Q'_* > 5.0 \times 10^5$ at the 95 % confidence level



Maciejewski *et al*. 2018, submitted

This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.

http://www.home.umk.pl/~gmac/TTV



This research has been supported by the National Science Centre, Poland through grant no. 2016/23/B/ST9/00579.