Measure the spin-up of hot Jupiters due to tides

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SUMMARY

Tidal interaction between a star and a close-in exoplanet leads to shrinkage of the planetary orbit and eventual tidal disruption of the planet. For some of the known exoplanets the expected orbital period variation due to tides is observable over 10 years and they are expected to have measurable tidal decay by now. **We analyze TESS data for two targets known to host close-in hot Jupiters: WASP-18 and WASP-4.** We aim to measure the current limits on tidal decay which will provide new constrains on the modified tidal quality factor Q'_* . We fit the transit parameters for each target using all TESS data available and use the updated parameters to fit the mid-transit times of each individual transit. We use previously published timings with our results to find the change in period with a quadratic ephemerides model and verify the presence of orbital decay. **We obtain a new value for Q'_* for WASP-4b and we update the minimum Q'_* for WASP-18b.** We observe a clear period change in WASP-4b and an indication of decreasing period in WASP-18b, but we still do not have enough precision to constrain Q'_* significantly on the latter.

TESS TARGETS

WASP-18b

- Hot Jupiter with 10 M_{Jup} orbiting a F6V dwarf.
- Period of 0.94 days.
- Discovered by Hellier et al. (2009).
- Observed in 4 TESS sectors:
  - 2 + 3: August-October 2018
  - 29 + 30: August-October 2020

WASP-4b

- Smaller hot Jupiter with 1.2 M_{Jup}.
- Period of 1.34 days.
- Discovered by Wilson et al. (2008).
- Observed in 3 TESS sectors:
  - 2: August-September 2018
  - 28 + 29: July-September 2020

METHODS

Transits

- Transit analysis with the model from the *batman* Python code (Kreidberg, 2015).
- We split the transits in isolated light curves and fit for transit parameters.
- We then use the best fit parameters as initial values with Gaussian priors to fit the mid-transit times of each individual transit.
- Limb-darkening was modelled with a quadratic law.

Orbital Decay

We assume a quadratic ephemerides with a constant variation of period over time:

$$T_{mid} = T_0 + P \times E + \frac{1}{2}\dot{P} \times P \times E^2$$

where T_0 is the reference transit ephemerides, P is the orbital period, E is the epoch number counted from the reference ephemerides and $\dot{P} = dP/dT$ is the change in orbital period over time.

The rate of change of the orbital period can then be related to the star tidal quality factor Q'_* by the following expression.

$$Q'_* = -\frac{27}{2}\pi\left(\frac{M_p}{M_\star}\right)\left(\frac{a}{R_\star}\right)^{-5}\dot{P}^{-1}$$

MCMC Fits

- MCMC analysis with the *emcee* Python code (Foreman-Mackey et al., 2013)
- First fit for the transit parameters using the phase-folded light curves.
- Fit the individual transits to find each transit time.
- With the mid transit times, we fit for the value of $\dot{P}$ as well as T_0 and P.

RESULTS

WASP-18b

Parameter	This work	Shporer et al. (2019)	Maciejewski et al. (2020)
$r_p/R_\star$	$0.098568^{+0.000167}_{-0.000166}$	$0.09716^{+0.00014}_{-0.00013}$	$0.09776^{+0.00028}_{-0.00027}$
$a/R_\star$	$3.4522^{+0.0160}_{-0.0157}$	$3.562^{+0.022}_{-0.023}$	$3.492^{+0.024}_{-0.025}$
i (°)	$83.555^{+0.240}_{-0.228}$	$84.88^{+0.33}_{-0.38}$	$84.04^{+0.36}_{-0.38}$
u_1	0.2987 ± 0.0203	0.2192*	0.296 ± 0.034
u_2	$0.1608^{+0.0369}_{-0.0364}$	0.3127*	$0.158^{+0.061}_{-0.060}$

* from Claret (2017).

Table 1. Transit parameters for WASP-18b. Comparison with results from other studies including Sectors 2 and 3 data from TESS by Shporer et al. (2019) and Maciejewski et al. (2020).

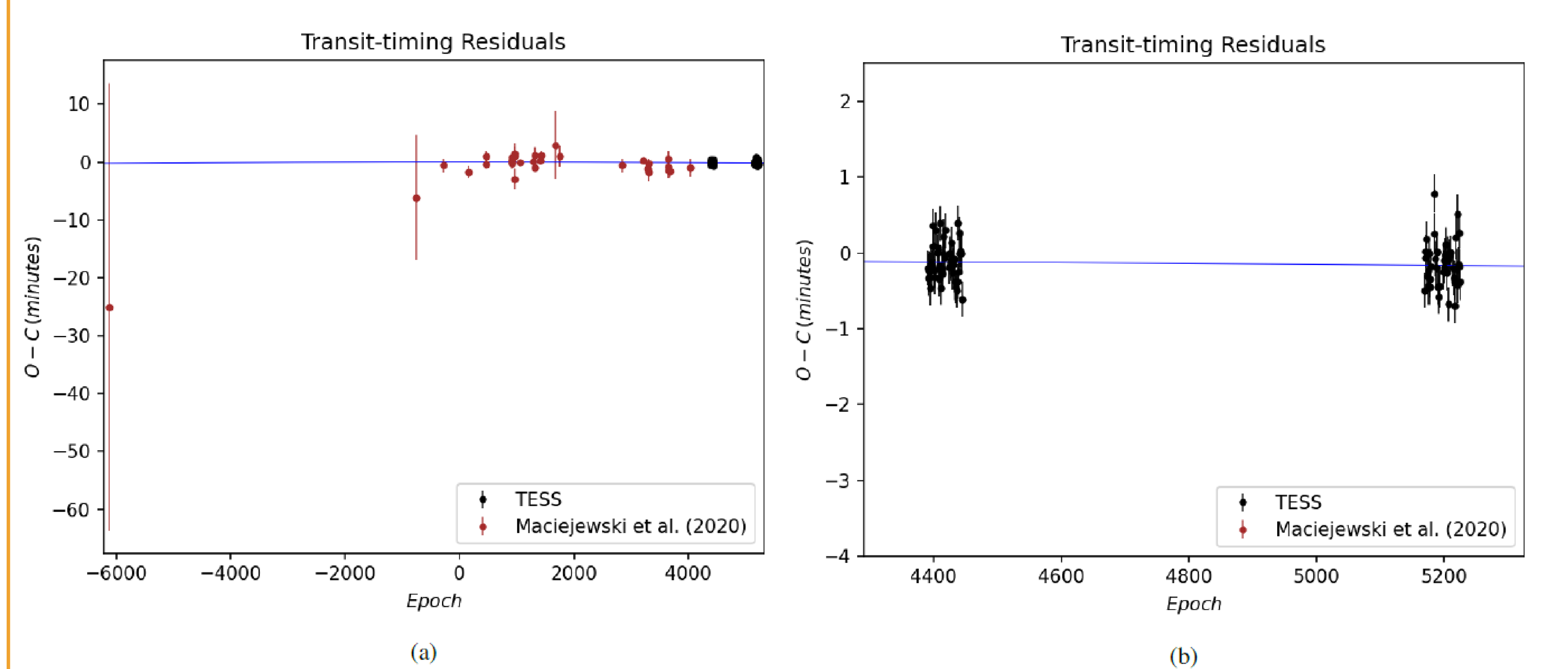

Figure 1: Transit difference (O-C) against the epoch, counted from the initial reference time for WASP-18b. (a) Complete view of all the transits used in the fit. (b) Zoom of the TESS transits.

As $\dot{P}$ is indistinguishable from zero at 3σ, we obtain a minimum value for Q'_* at 99.7% confidence level: $\boldsymbol{Q'_* > 8.04 \times 10^6}$

WASP-4b

Parameter	This work	Bouma et al. (2019)
$r_p/R_\star$	$0.151972^{+0.001204}_{-0.000937}$	$0.15201^{+0.00040}_{-0.00033}$
$a/R_\star$	$5.4132^{+0.0552}_{-0.0741}$	$5.451^{+0.023}_{-0.052}$
i (°)	$88.131^{+1.140}_{-0.890}$	$89.06^{+0.65}_{-0.84}$
u_1	$0.3583^{+0.0346}_{-0.0335}$	0.382*
u_2	$0.2205^{+0.0788}_{-0.0832}$	0.210*

* fixed value.

Table 2: Transit parameters for WASP-4b. Comparison with results from a previous work with Sector 2 data from TESS by Bouma et al. (2019).

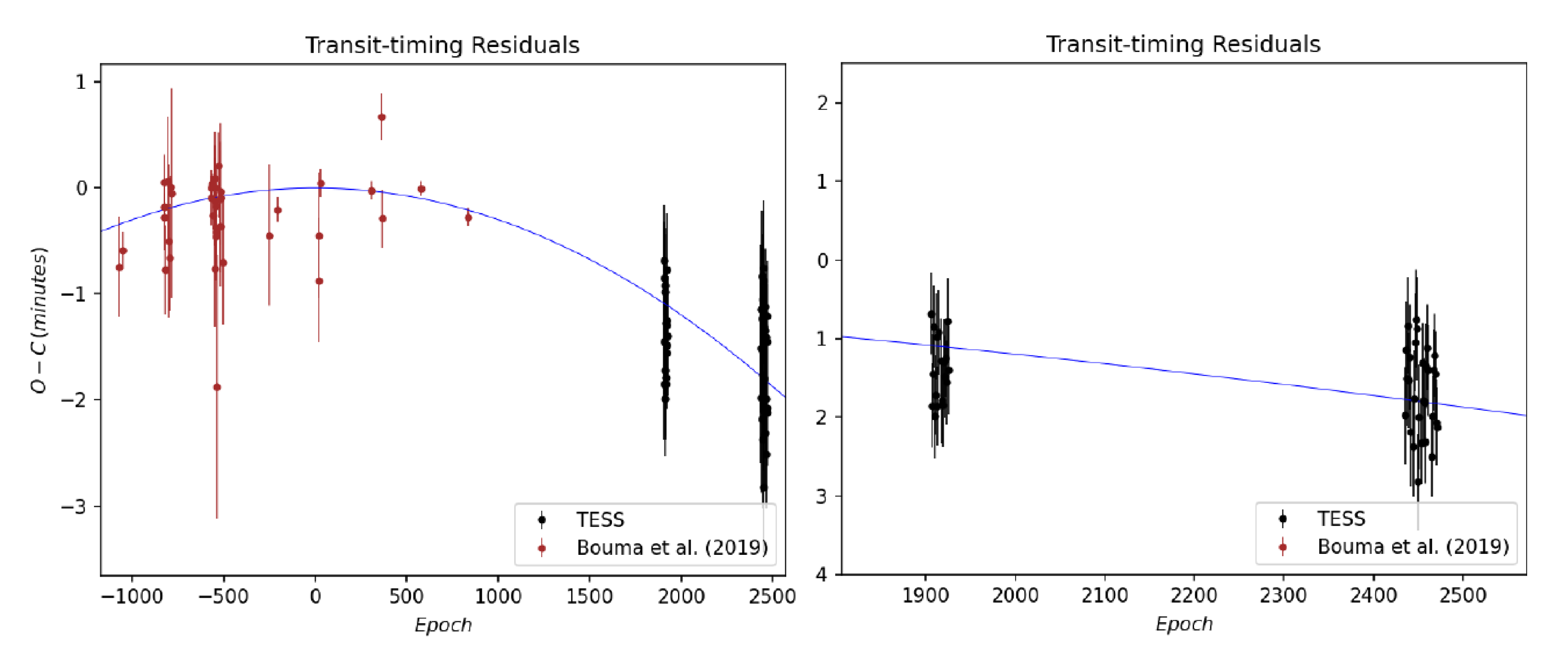

Figure 2: Transit difference (O-C) against the epoch, counted from the initial reference time for WASP-4b. (a) Complete view of all the transits used in the fit. (b) Zoom of the TESS transits.

We obtain an updated value for $\dot{P}$ and Q'_*:

$$\boldsymbol{\dot{P} = (-3.121 \pm 0.287) \times 10^{-10}}$$

$$\boldsymbol{Q'_* = (3.49 \pm 0.38) \times 10^{-6}}$$

CONCLUSIONS

- We find **strong** statistical evidence of orbital decay on **WASP-4b** at a confidence level of 99.7%.
- While tidal interaction is a strong candidate to be causing the infalling, the timescale we obtain is shorter than predicted by current tidal interaction models.
- On **WASP-18b**, we still **don't find** a statistically significant evidence of period change.
- Since the in-fall timescale is larger, we need more observations at a later date to confirm the change in period.

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