Tidal Interactions in WASP-12 and Resulting Orbital Decay

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Introduction

Hot Jupiters serve as an important laboratory for understanding tidal interactions and planetary evolution due to their close orbits around host stars. Gravitational forces between the planet and star induce perturbations in their internal structures. In a non-synchronized system ($\omega_* \neq \Omega_p$), these interactions cause the planet's orbit to shrink over time, ultimately leading to the planet spiraling into its host star and being destroyed.

WASP-12b, a giant planet ($1.47M_j$ & $1.9R_j$) orbiting a host star ($1.43M_\odot$ & $1.65R_\odot$) (Collins et al. 2017a) that is believed to be at the end of its main sequence phase is one of the most significant objects in the study of orbital decay, since it remains one of the several objects for which the orbital decay characteristics has been detected through several studies (Maciejewski et al. 2016, Kutluay et al. 2023).

Within this study, we present an up-to date TTV analysis of WASP-12b using light curve measurements from ETD, TESS and literature sources. Additionally, we add two new light curves coming from TUG T100 telescope and AUKR T80 telescope (Figure 1). In order to compare our findings from TTV analysis, we obtained a stellar evolutionary model of WASP-12 using MESA (Paxton et al. 2011), then we calculated the tidal response and dissipation inside the star.

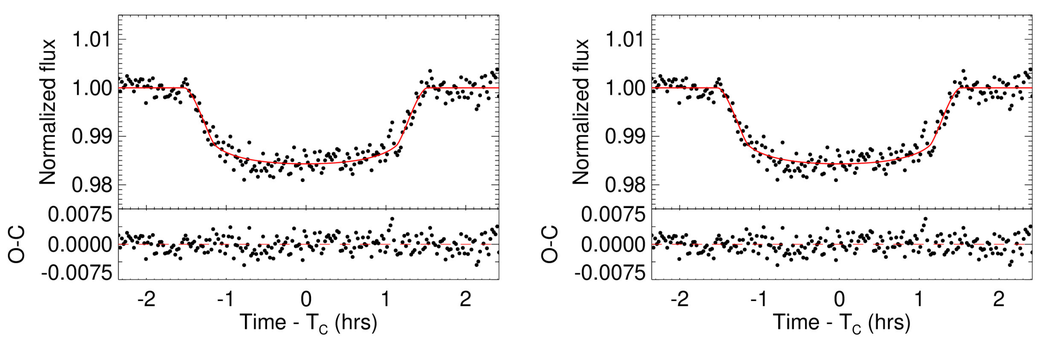


Figure 1: Transit light curves of WASP-12b conducted within this study. (left) At TUG Observatory (T100 telescope), in 02.02.2025 (right) At Ankara University Kreiken Observatory (T80 telescope), in 03.10.2025. The bottom panels represents the residuals from transit models.

Data and Methods

In this study, we homogeneously analyzed 233 light curves using AstroImageJ (Collins et al. 2017a) and EXOFAST (Eastman et al. 2013). We constructed the TTV diagram with the ephemeris used in Kutluay et al. (2023), and then we implemented two models to our long-term transit data (Eq.1 & 2) using Python's PYMC module. The linear model states the orbital period remains constant over time, whereas the quadratic model states that orbital period changes secularly over time.

$$T(E) = T_0 + P \times E \tag{1}$$

$$T(E) = T_0 + P \times E + \frac{1}{2}\frac{dP}{dE} \times E^2 \tag{2}$$

After obtaining the quadratic coefficient $\frac{1}{2}\frac{dP}{dE}$, we measured the efficiency of the tidal interactions, with a parameter so-called tidal quality factor, defined as (Patra et al. 2017)

$$Q'_\star = -\frac{27\pi}{2}\left(\frac{M_p}{M_\star}\right)\left(\frac{R_\star}{a}\right)^5 \dot{P} \tag{3}$$

To test the accuracy of the orbital period change and tidal quality factor obtained from the quadratic model, we first obtained the stellar parameters related to the surface and internal structure in a star-age-dependent manner using the evolutionary model of the host-star through MESA (Paxton et al. 2011). Then, using the specified formulation (see Barker 2020), we measured how the energy resulting from tidal interactions could be dissipated by the following mechanisms: equilibrium tides, inertial waves or internal gravity waves. Internal waves have already been eliminated since $P_{rot} = 37.93$ days $> P_{orb} = 1.09$ days.

Results

According to the fit statistics of WASP-12b's TTV diagram (Figure 2), it is found that $\Delta BIC = -186.25$, meaning that quadratic models favors the long-term transit dataset. Also, from the model, it is found that orbital period of WASP-12b has been decreasing with $\frac{dP}{dt} = -29.4 \pm 0.4$ ms/yr. The corresponding tidal decay timescale is calculated as $\tau = P/|\dot{P}| = 3.21 \pm 0.04$ Gyr. Utilizing Eq. 3, we found that $Q'_* = (1.7 \pm 0.4) \times 10^5$.

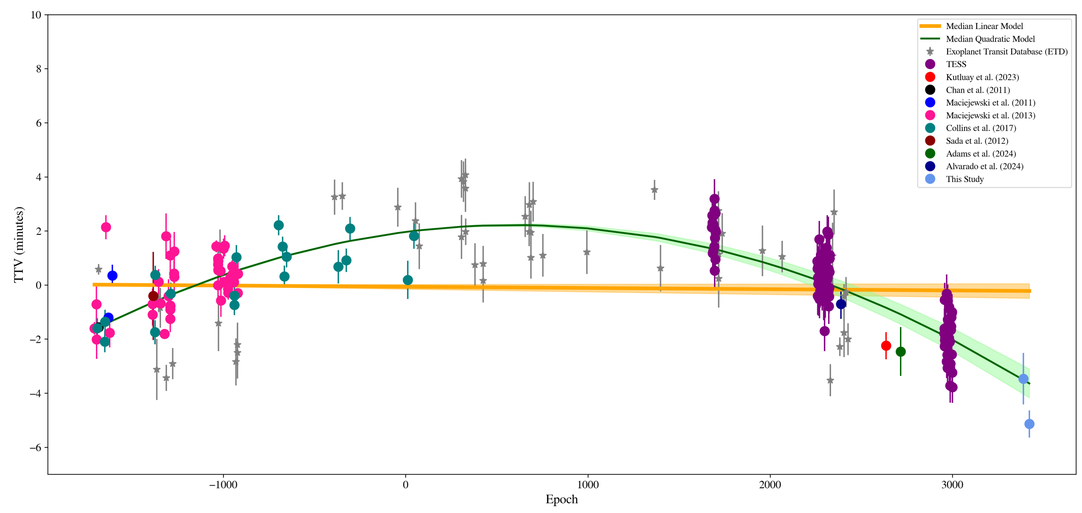


Figure 2: TTV diagram of WASP-12b. Orange line represents the median linear model, whereas the green parabola represents the median quadratic model. Shaded regions with the same color is limited by $\pm 3\sigma$ of the median models.

By MESA, we modeled the host star's evolution until the sub-giant branch using $M_* \in (1.30, 1.35, 1.434)$ and $[Fe/H] \in (0.10, 0.20, 0.30)$, therefore obtaining inner-structure parameters over time. For the rotational and diffusional parameters, we took advantage of MIST models for solar-like stars (Choi et al. 2016) These parameters were used to analyze the effiency of tidal interactions in radiation and convection zones, revealing its link to stellar age and mass. From Figure-3, the efficieny of these mechanisms can be seen for 9 different models.

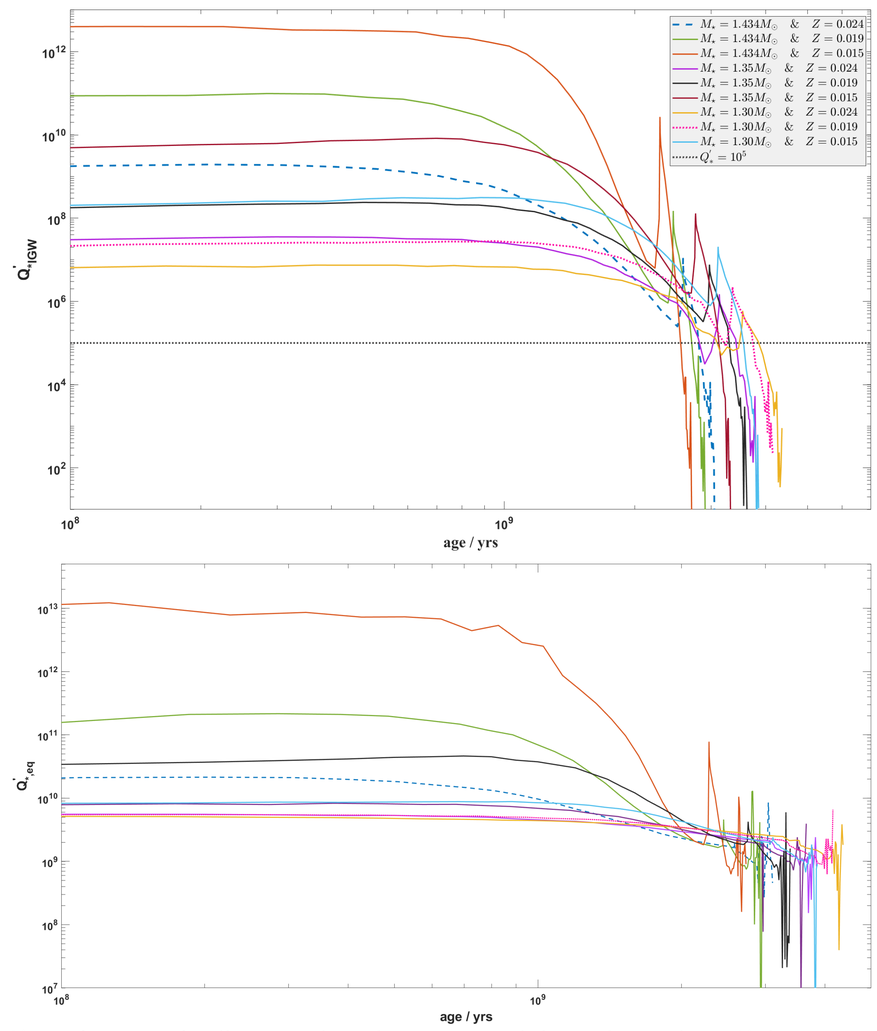


Figure 3: $Q'_\star$ as a function of stellar age, where the upper panel shows the resulting $Q'_\star$ due to internal gravity waves, while the bottom panel shows that due to equilibrium tides.

Figure-3 shows that equilibrium tides cannot be the dominant mechanism for the observed $Q'_\star$. Rather, internal gravity waves is likely to be the ruling mechanism, if the star is in the subgiant phase. This matter is still under debate, as the constraints on age are not well defined in global models.

References

You can access references from the QR Code.

Acknowledgments

This research was undertaken text is derived from sections 1.10.33 of Cicero's De finibus bonorum et malorumtext is derived from sections 1.10.33 of Cicero's De finibus bonorum et malorumtext is derived from sections 1.10.33 of Cicero's De finibus bonorum et malorum.