Significant TESS Timing Offsets of 31 Hot Jupiters

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DDE Meeting, University of Coimbra, Portugal

July 7-11, 2025

Abstract

A precise transit ephemeris serves as the premise for follow-up exoplanet observations. We compare TESS Object of Interest (TOI) transit timings of 262 hot Jupiters with the archival ephemeris and find 31 of them having TOI timing offsets, among which WASP-161b shows the most significant offset of −203.7 ± 4.1 minutes. The median value of these offsets is 17.8 minutes, equivalent to 3.6σ. We generate TESS timings in each sector for these 31 hot Jupiters, using a self-generated pipeline. The pipeline performs photometric measurements to TESS images and produces transit timings by fitting the light curves. We refine and update the previous ephemeris, based on these TESS timings (uncertainty~1 minute) and a long timing baseline (~10 yr). Our refined ephemeris gives the transit timing at a median precision of 0.82 minutes until 2025 and 1.21 minutes until 2030. We regard the timing offsets to mainly originate from the underestimated ephemeris uncertainty. All the targets with timing offset larger than 10σ present earlier timings than the prediction, which cannot be due to underestimated ephemeris uncertainty, apsidal precession, or Rømer effect as those effects should be unsigned. For some particular targets, timing offsets are likely due to tidal dissipation. Our sample leads to the detection of period-decaying candidates of WASP-161b, XO-3b and K2-237b.

Introduction

Transit ephemeris is crucial for exoplanet follow-up investigations. The observed transit timing could deviate from the ephemeris's prediction due to either the underestimation of ephemeris uncertainties, or physical processes (transit-timing variation, TTV). The TTV could originate from tidal dissipation, apsidal precession, Rømer effect, mass loss, and multiple planets. Hot Jupiters likely form beyond the ice line and migrate inward to their observed close-in orbits, predominantly via disk migration or high-eccentricity tidal pathways. The TTV can provide direct evidence of hot Jupiter migration. To search the TTV, we compare TESS timings and archival ephemeris predictions, and report transit-timing offsets of 31 hot Jupiters in this work.

Sample and Method

We filter from 421 hot Jupiters in the NASA Exoplanet Archive, with a selection criteria of an orbital period of fewer than 10 days, a planet mass larger than 0.5 M_J, and a planet radius larger than 0.5 R_J. 262 hot Jupiters have TESS photometry by crossmatching this sample and the TESS Objects of Interest (TOI) Catalog. 31 hot Jupiters show significant transit timing offsets by comparing TOI times with the predicted times from previous ephemeris.

We independently reducing the TESS image data of the 31 hot Jupiters in a grained-refine manner. The pipeline includes two parts, a photometric pipeline to obtain the transit light curve and transit modeling. The photometric includes astrometry checking, aperture photometry, deblending of the nearby contamination, and light-curve detrending modules. The light curve is fitted with a planet transit model by applying Markov Chain Monte Carlo (MCMC). We apply the transit model to both the light curve of a single epoch and the light curve folded from one TESS sector (examples as shown in Figure 1). The folding is based on the archival ephemeris and we evaluate the fitting parameter bias if folding an inappropriate period . For one TESS sector, the timing bias is~4 minutes if the period is biased at 0.0004 days. Such a large period bias would cause significant TESS timing offsets when compared to ephemeris prediction and thereby is flagged.

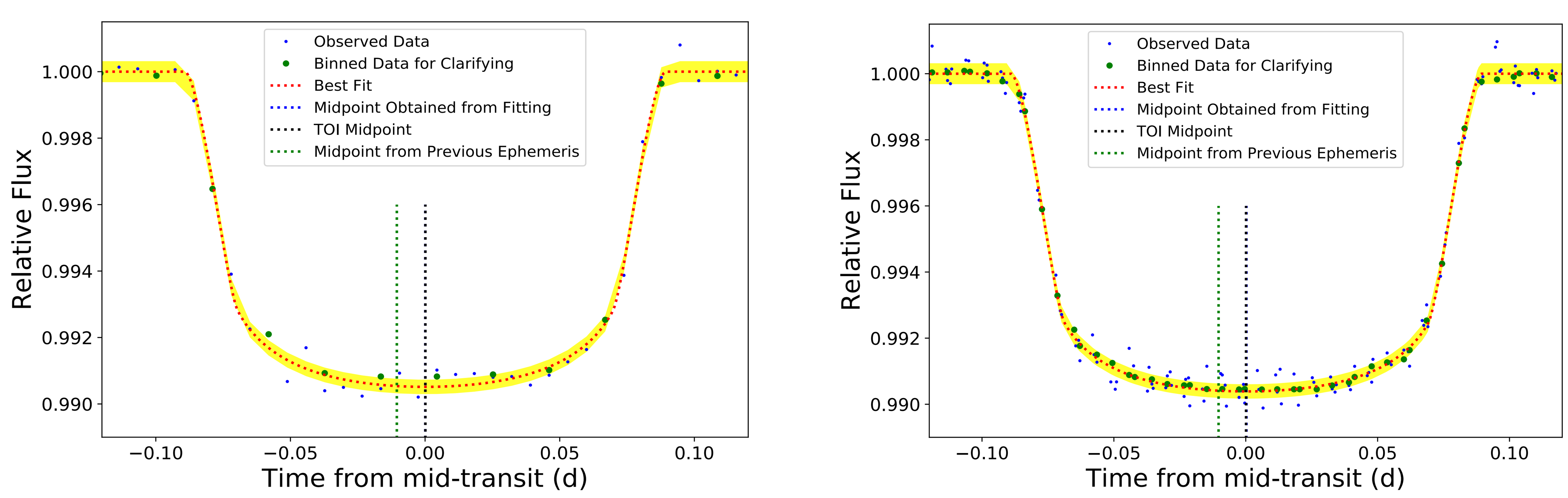

Figure 1. Light curves of KELT-19Ab as an example: a single epoch around TOI timing (left panel), folded multiple visits at a reference epoch (right panel). The blue points present observations (10 minute cadence) while the green points are bins of every three points for clarity. The red line gives the transit model fit with the yellow region indicating the 1σ confidence region. The vertical blue line gives the fitted timing; the black vertical line, TOI timing; the green vertical line, previous ephemeris prediction. The timings from single epoch fitting (folded-epoch fitting) are only 0.14 minutes earlier (0.20 minutes later) than TOI, corresponding to a negligible difference as shown in the image (overlapped blue and black lines). The observed TESS timings show an offset of~15 minutes, compared to the previous ephemeris prediction as shown in the vertical green line. The fitting uncertainty is 0.54 minutes for a single epoch, and 0.23 minutes for folded epochs.

Results

We present the latest timings of 31 hot Jupiters from folded light curves in each TESS sector. In this sample, the median ΔT_C (TESS mid-transit time minus the predicted time from the previous ephemeris) is 17.8 minutes while the median combined uncer -tainty is 4.9 minutes. Therefore the signal-to-noise ratio (S/N) is 3.6.

We classify the sources of ephemerides into three categories, according to the pot -tential properties implied by the timings. We refine the ephemeris of the sample by jointly fitting TESS timings and archival times from previously published papers.

- Type I: Linear period fits
- Type II: Quadratic fits (indicating changing periods, e.g., orbital decay)
- Type III: may suggest complex effects (e.g., perturbations)

WASP-161b, XO-3b, and KELT-18b present timing offsets larger than 10σ. These three targets all have an earlier observed timing than the predictions from the previous ephemeris under the assumption of a constant period.

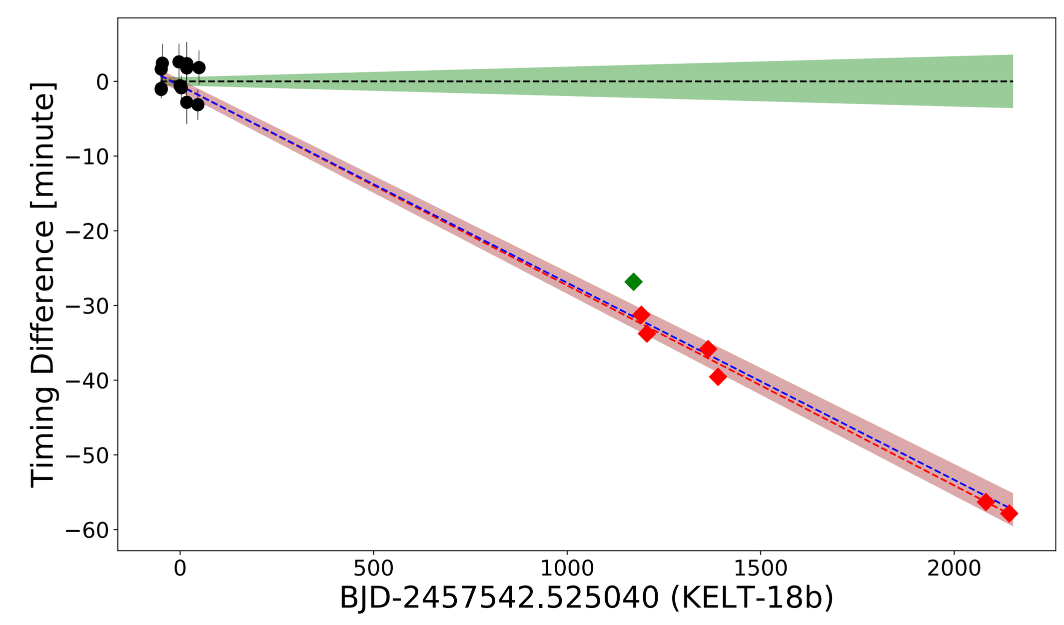

Figure 2. The timing difference of KELT-18b. The timing difference is the observed mid-transit times minus the ephemeris predictions. The red point refers to TESS timing difference; black points refer to timing differences of other observations from literature paper ; the black dashed line is reference ephemeris; blue line alternative reference ephemeris; the red line is the refined ephemeris derived by combining TESS observation; the green region is 1σ significant region of reference ephemeris; the brown region is 1σ significant region of alternative reference ephemeris. We note that our refined ephemeris overlaps the alternative reference ephemeris, indicating the consistency of the two ephemerides.

Summary

We discuss the ephemerides of 31 hot Jupiters and refine the ephemerides of the sample by jointly fitting TESS timings and archival times from previously published papers. The TESS timings are obtained by our self-generated pipeline. TESS enables high-precision timing refinement of known hot Jupiters. Follow-up research is still underway. Our team discovery that WASP-161b, XO-3b and K2-237b present evidence of period decaying. Future monitoring (CHEOPS, JWST, RV) is crucial to confirm the migration channels.

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