EPSC Abstracts
Vol. 18, EPSC-DPS2025-1287, 2025, updated on 24 Nov 2025
https://doi.org/10.5194/epsc-dps2025-1287
EPSC-DPS Joint Meeting 2025
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Probing Transit Timing Variations Amid Heteroscedasticity: Lessons from HAT-P-7b and TrES-2b

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It has been more than 25 years since the first light curve of a planetary transit has been published (Charbonneau et al. 2000). Since then, thousands of light curves have been published for many of the discovered planets. Although photometric observation of a planetary transit is conceptually straightforward, variations in data reduction, modeling approaches, and analysis tools have introduced significant heteroscedasticity into the resulting light curves — and consequently into the derived parameters. Among these, the timing of mid-transit is particularly sensitive, as its measurement and associated uncertainty are highly model-dependent. Yet mid-transit times form the backbone of Transit Timing Variation (TTV) analyses, through which one can probe the presence of additional planetary companions, tidal interactions with the host star, apsidal precession, and magnetic activity.

Properly addressing the sources of heteroscedasticity in TTV datasets is essential for disentangling genuine physical signals from observational systematics. In practice, this manifests in TTV diagrams as short-term scatter exceeding the quoted timing uncertainties — particularly between datasets acquired with different instruments, reduction pipelines, or modeling techniques.

We have been monitoring a sample of hot Jupiter systems (Basturk et al. 2020, 2022, 2023; Yalcinkaya et al. 2024), some of which are candidates for orbital decay due to strong tidal interactions. To date, definitive evidence for orbital decay has been reported in only two systems: WASP-12b (Yee et al. 2020) and WASP-4b (Basturk et al. 2025, and references therein). To systematically investigate the heteroscedasticity issue in TTV data, we focused on two well-observed systems, HAT-P-7 and TrES-2. Both were continuously monitored by the Kepler spacecraft during its primary mission, supplemented by numerous ground-based observations and, more recently, multiple sectors of TESS photometry.

We compiled all available transit light curves for these systems, modeled them uniformly using the EXOFAST suite (Eastman et al. 2013), and derived mid-transit times to construct homogeneous TTV datasets for each planet. Our analysis revealed significant variance discrepancies between different data subsets — often exceeding the reported timing uncertainties. In this study, we present our methodology for addressing this issue and discuss the implications for interpreting the observed TTV signals in the context of tidal interaction theory.