SF2A 2025
A. Siebert, K. Baillié, M. Béthermin, F. Cantalloube, E. Josselin, N. Lagarde, J. Malzac, J. Richard, L. Selliez, O. Venot (eds)

ENHANCED ASTEROSEISMIC CHARACTERIZATION OF RED GIANTS WITH PYTADACS-S: APPLICATION TO TESS LIGHT CURVES

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Abstract. NASA's Transiting Exoplanet Survey Satellite (TESS) mission, launched in 2018, was designed to survey nearly the entire sky in search of transiting exoplanets around bright, nearby stars. In addition to its primary exoplanet objectives, TESS has proved to be a powerful tool for asteroseismology, enabling the study of stellar oscillations across the HR diagram. However, the extraction of asteroseismic stellar parameters from TESS photometric light curves is often perturbed by instrumental artifacts. In particular, light curves from TESS suffer from regular discontinuities, stray light contamination from the Sun and Moon, and various instrumental systematics. These issues significantly affect the power spectral density and may lead to unreliable asteroseismic properties. The `PyTADACS` library implements tools meant for the calibration and correction of TESS light curves to perform seismic and rotational analysis. In this work, we present `PyTADACS-S`, tuned to automatically deliver high-quality light curves of subgiants and red giants for asteroseismology. After describing the tools, we show preliminary results on a sample of 311 000 stars, enabling robust estimation of global seismic parameters regardless of the length of the observations beyond the continuous viewing zones and opening the study of the two long PLATO pointing by TESS.

Keywords: asteroseismology, stars: oscillations, methods: data analysis

1 Introduction

`PyTADaCS-S` (Python TESS Automated Data Correction and Analysis Software for Seismology) (García et al., in prep.) is an automated Python pipeline tailored for large-scale asteroseismic analysis on TESS (Ricker et al. 2014) data. The package includes functions that process stars simultaneously, performing both light curve calibration and the estimation of global seismic parameters (e.g. ν_{max} and $\Delta\nu$ using PyA2Z, (Liagre et al., in prep.), and FliPer (Bugnet et al. 2018).

Rather than aiming for exhaustive correction of each individual star, `PyTADaCS-S` concentrates on mitigating the principal systematics to a level that ensures the robust extraction of global seismic parameters. This approach allows a balance between processing time and good data quality in the corrected light curve, making large-scale analysis feasible on a standard laptop computer.

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2 PyTADaCS-S : overview and first results

We chose to use the QLP SAP_FLUX for our analysis rather than KSPSAP_FLUX. KSPSAP_FLUX is optimized for exoplanet detection, with a high-pass filter that suppresses long-timescale variability, including stellar oscillations (Hon et al. 2021; Kunimoto et al. 2022). As a result, the power spectral density (PSD) is filtered, and it is not possible to measure seismic power below $\sim 25\,\mu$Hz. Thus, KSPSAP_FLUX is not optimal for asteroseismic studies of solar-like stars, for which maintaining the low-frequency variability is essential.

PyTADaCS-S processes a list of TIC IDs, resampling the flux to 30-minute or 200-s cadence. For 200-s cadence, only sectors originally sampled at a minimum of 200-s (Sector>56) are retained. Regularly occurring data gaps significantly degrade asteroseismic analyses by inducing power leakage toward higher frequencies and by convolving the intrinsic signal with a complex window function. This distortion modifies the inferred background parameters and increases the difficulty of accurately characterizing asteroseismic signals. To mitigate these effects, the code can fill gaps shorter than a predefined size using a multi-scale discrete cosine transform following inpainting methods (García et al. 2014; Pires et al. 2015). Moreover, gaps longer than 3 sectors can be removed. Sector-to-sector flux variations, even for contiguous observations, introduce significant spectral noise. To correct this effect, PyTADaCS-S applies total mean stitching: each sector's flux is adjusted to a common baseline by subtracting its mean value. This method eliminates artificial offsets while reducing overall noise for stars with $\nu_{max} > 0.5\,\mu$Hz.

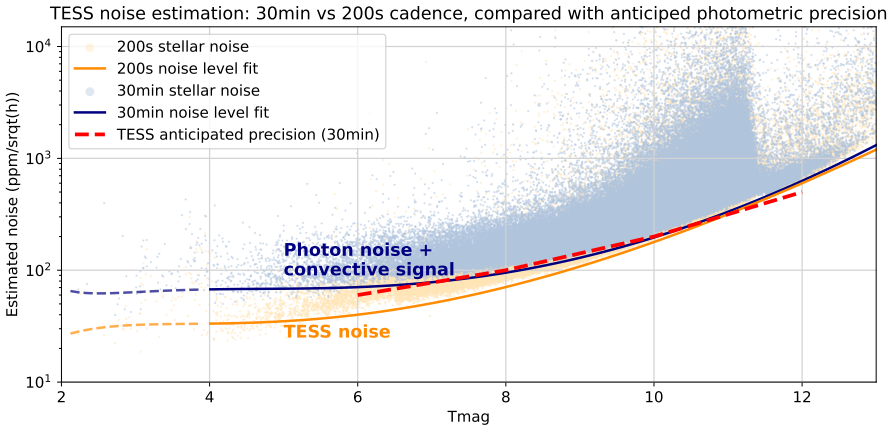

Fig. 1. Median noise as a function of TESS magnitude (T_{mag}) on processed stars at 200-s cadence (orange) and 30-min cadence (blue). Noise is estimated from median power above $f_{\rm Nyquist} - 10\,\mu$Hz. Polynomial fits of the noise level (bottom envelope) on both cadences are shown in blue and orange solid lines. Red line is the anticipated TESS noise as presented in Schlieder (2017). Dashed lines for $T_{mag} < 4$ highlight the uncertainty due to sparse data.

We applied PyTADaCS to a sample of 311 000 red giants observed with a 30-min and 200-s cadence. Fig. 1 shows the evolution of the photon noise with the TESS magnitude: the lower envelope reflects the minimum background noise reachable at each magnitude, which is a good proxy of TESS noise, that matches the expected noise level at 30-min cadence. Beyond magnitude 11, the noise levels of both cadences converge, indicating that TESS noise dominates in these magnitudes. For brighter stars ($T_{mag} < 11$), the difference is due to stellar signal.

3 Conclusions

PyTADaCS allows a fast, automated calibration of TESS light curves, optimized for large-scale asteroseismic analysis on a laptop. A first run on 311 000 stars was completed in less than 3 days on a M1 MBP, from which a noise model as a function of magnitude was derived. Global seismic parameters (ν_{max}, FliPer) are reliably estimated from the calibrated light curves. We are currently training a random forest model to directly predict surface gravity ($log(g)$) for the ensemble of stars. This pipeline is being applied to TESS subgiants located in the PLATO (Planetary transits and oscillations of stars, Rauer et al. 2025) field, with the goal of pre-characterizing these stars before PLATO's launch.

We acknowledge the support from the PLATO Centre National D'Études Spatiales grant. We acknowledge the use of TESS High Level Science Products (HLSP) produced by the Quick-Look Pipeline (QLP) at the TESS Science Office at MIT, which are publicly available from the Mikulski Archive for Space Telescopes (MAST). Funding for the TESS mission is provided by NASA's Science Mission directorate.

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