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seismolab: A Python package for analyzing space-based observations of variable stars

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Summary

Classical pulsating stars are characterized by periodic or multi-periodic brightness variations from several hundredths to a few tenths of relative magnitudes. The observation of these variable stars is essential for testing pulsation and stellar evolution models. The different forms of frequency spectra are powerful tools for comparing observations and theoretical models. Long-term period changes can reveal information about the motion of the variable star in a binary system (Plachy et al., 2021). Proper classification of variable stars, which usually requires rigorous analysis, is crucial to studying the properties of clear samples (Tarczay-Nehéz et al., 2023).

Upon entering the era of photometric space missions, the launch of the NASA *Kepler* and *TESS* missions have brought a new opportunity to expand the science of variable stars, enabling the characterization of short-term variability and the detection of millimagnitude-level variations. The latest generation of large photometric and astrometric surveys has greatly expanded the number of known, observed and classified variable stars. Mining these large data sets has led to new discoveries and more detailed analysis in this field (Benkő et al., 2023; Molnár et al., 2022; Plachy et al., 2021).

Several techniques have been developed to search for periodicity in light curves and also for any deviation from strictly periodic behavior. We have developed a Python package, `seismolab`, which implements various methods for downloading, analyzing, and visualizing data of variable stars from space-based surveys. The framework is primary intended to be used with data obtained by the *Kepler*, *TESS* and *Gaia* surveys, but can also be used by other similar existing and future surveys. Some modules are also useful for analyzing ground-based observations.

Statement of need

`seismolab` is a fully Python-based, open-source package, built on top of popular Python packages such as NumPy (Harris et al., 2020), SciPy (Virtanen et al., 2020), PyMC (Salvatier et al., 2016) and Astropy (Astropy Collaboration et al., 2013, 2018, 2022). The framework contains the main analysis tools for the astronomical community working on the light curves of variable stars, primarily, but not exclusively, from space-based surveys. `seismolab` is a modular library that allows users to select the best methods for their particular science problem. It has six main modules which implement common operations often used by the variable star community, but available in limited or no form in other popular codes.

The *Gaia* module facilitates the derivation of basic stellar parameters (such as distance and corrected-brightnesses) by combining Bailer-Jones distance catalog (Bailer-Jones et al., 2021), galactic extinction maps (Bovy et al., 2016) and magnitudes from the Simbad catalog (Wenger et al., 2000) using different methods. The *fourier* module extends the standard Fourier analysis with easily available visualization tools and instant estimation of Fourier parameters. The *template* and *OC* modules provide a flexible and automated version of commonly used methods for extracting the temporal variation of the amplitude, phase and zero-point of the dominant variation (Benkő et al., 2023; Sterken, 2005). The *inpainting* module helps to eliminate the artifacts seen in the Fourier- and time-frequency analysis caused by gaps and uneven sampling using the method of inpainting (Pires et al., 2009, 2015). The *tfa* module implements various techniques not available in other popular python packages to characterize light curves in the two-dimensional time-frequency plane (Kolláth & Buchler, 1997).

The documentation of `seismolab` consists of pages describing the various available functions, as well as tutorial notebooks.

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