The Journal of Open Source Software

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

Attila Bódi [1,2]

1 HUN-REN CSFK Konkoly Observatory, Konkoly Thege M. út 15-17, Budapest, 1121, Hungary **2** Department of Astrophysical Sciences, Princeton University, 4 Ivy Lane, Princeton, NJ 08544, USA

DOI: 10.xxxxxx/draft

Software

- Review
- Repository
- Archive

Editor: Warrick Ball

Reviewers:

- @keatonb
- @darthoctopus

Submitted: 06 August 2024
Published: unpublished

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 tool 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 star, 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).

Several techniques have been developed to search for periodicities of the light curves and also for any deviation from the 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

The purpose of `seismolab` is sixfold. It is able to combine *Gaia* data with the 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). Different modules are implemented to extract the Fourier coefficients and Fourier parameters of light curves, and to derive the temporal variation of the amplitude, phase and zero point of the dominant variation (Benkő et al., 2023). One can extract the minimum or maximum times and derive an O-C diagram (Sterken, 2005). The package can be use to fill gaps in time series data using the method of inpainting Sandrine Pires et al. (2015). There is also a module that provides different transformation methods for time-frequency analysis (Kolláth & Buchler, 1997).

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

Acknowledgements

This project has been supported by the KKP-137523 'SeismoLab' Élvonal grant of the Hungarian Research, Development and Innovation Office (NKFIH).

References

Bailer-Jones, C. A. L., Rybizki, J., Fouesneau, M., Demleitner, M., & Andrae, R. (2021). Estimating Distances from Parallaxes. V. Geometric and Photogeometric Distances to 1.47 Billion Stars in Gaia Early Data Release 3. *161*(3), 147. https://doi.org/10.3847/1538-3881/abd806

Benkő, J. M., Plachy, E., Netzel, H., Bódi, A., Molnár, L., & Pál, A. (2023). Time series analysis of bright TESS RRc stars: additional modes, phase variations, and more. *521*(1), 443–462. https://doi.org/10.1093/mnras/stad556

Bovy, J., Rix, H.-W., Green, G. M., Schlafly, E. F., & Finkbeiner, D. P. (2016). On Galactic Density Modeling in the Presence of Dust Extinction. *818*(2), 130. https://doi.org/10.3847/0004-637X/818/2/130

Kolláth, Z., & Buchler, J. R. (1997). Time-Frequency Analysis of Variable Star Light Curves. *Annals of the New York Academy of Sciences*, *808*, 116. https://doi.org/10.1111/j.1749-6632.1997.tb51656.x

Molnár, L., Bódi, A., Pál, A., Bhardwaj, A., Hambsch, F.-J., Benkő, J. M., Derekas, A., Ebadi, M., Joyce, M., Hasanzadeh, A., Kolenberg, K., Lund, M. B., Nemec, J. M., Netzel, H., Ngeow, C.-C., Pepper, J., Plachy, E., Prudil, Z., Siverd, R. J., … Ricker, G. R. (2022). First Results on RR Lyrae Stars with the TESS Space Telescope: Untangling the Connections between Mode Content, Colors, and Distances. *258*(1), 8. https://doi.org/10.3847/1538-4365/ac2ee2

Pires, Sandrine, Mathur, S., García, R. A., Ballot, J., Stello, D., & Sato, K. (2015). Gap interpolation by inpainting methods: Application to ground and space-based asteroseismic data. *574*, A18. https://doi.org/10.1051/0004-6361/201322361

Pires, S., Starck, J.-L., Amara, A., Teyssier, R., Réfrégier, A., & Fadili, J. (2009). FAst STatistics for weak Lensing (FASTLens): fast method for weak lensing statistics and map making. *395*(3), 1265–1279. https://doi.org/10.1111/j.1365-2966.2009.14625.x

Plachy, E., Pál, A., Bódi, A., Szabó, P., Molnár, L., Szabados, L., Benkő, J. M., Anderson, R. I., Bellinger, E. P., Bhardwaj, A., Ebadi, M., Gazeas, K., Hambsch, F.-J., Hasanzadeh, A., Jurkovic, M. I., Kalaee, M. J., Kervella, P., Kolenberg, K., Mikołajczyk, P., … Vanderspek, R. (2021). TESS Observations of Cepheid Stars: First Light Results. *253*(1), 11. https://doi.org/10.3847/1538-4365/abd4e3

Sterken, C. (2005). The O-C Diagram: Basic Procedures. In C. Sterken (Ed.), *The light-time effect in astrophysics: Causes and cures of the o-c diagram* (Vol. 335, p. 3).

Tarczay-Nehéz, D., Molnár, L., Bódi, A., & Szabó, R. (2023). Testing ultralow amplitude Cepheid candidates in the Galactic disk by TESS and Gaia. *676*, A28. https://doi.org/10.1051/0004-6361/202346094

Wenger, M., Ochsenbein, F., Egret, D., Dubois, P., Bonnarel, F., Borde, S., Genova, F., Jasniewicz, G., Laloë, S., Lesteven, S., & Monier, R. (2000). The SIMBAD astronomical database. The CDS reference database for astronomical objects. *143*, 9–22. https://doi.org/10.1051/aas:2000332