




OrbDot: A Python package for studying the secular evolution of exoplanet orbits

Simone R. Hagey¹ and Aaron Boley¹

¹ Department of Physics and Astronomy, The University of British Columbia, 6224 Agricultural Road Vancouver, BC, V6T 1Z1, Canada

DOI: [10.21105/joss.08550](https://doi.org/10.21105/joss.08550)

Software

- [Review](#) 
- [Repository](#) 
- [Archive](#) 

Editor: [Warrick Ball](#) 

Reviewers:

- [@soichiro-hattori](#)
- [@j-faria](#)

Submitted: 06 May 2025

Published: 03 September 2025

License

Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License ([CC BY 4.0](#)).

In partnership with



AMERICAN
ASTRONOMICAL
SOCIETY

This article and software are linked with research article DOI [10.3847/1538-3881/aded15](https://doi.org/10.3847/1538-3881/aded15), published in the *Astronomical Journal*.

Summary

Gradual changes in exoplanet orbits, known as secular variations, can be detected through observations of transits, eclipses, and radial velocities that span multiple decades in time. Their detection and characterization enable the study of a wide range of dynamical phenomena, such as orbital decay and precession, which operate on timescales of millions of years. Under certain conditions, measurements of secular variations can even probe the interior structure of exoplanets, providing a unique tool for understanding exoplanet formation and evolution.

The necessity to search over many orbital epochs coupled with an ever-growing archive of exoplanet observations creates a need for fast and flexible open-source software that can reliably detect gradual changes in exoplanet orbits. OrbDot addresses this need by offering robust tools for fitting secular evolution models to exoplanet transit and eclipse mid-times, transit durations, and radial velocity data.

A key advantage of OrbDot is its ability to fit multiple types of data simultaneously, which can help to break parameter degeneracies. It also excels at assisting in result interpretation by generating reports on model comparisons and assessments of various physical effects in the context of the models and their corresponding theory. For example, analysis reports could determine key parameters for assessing tidal energy dissipation, apsidal precession mechanisms, variations due to systemic proper motion, and the dynamical effects of non-resonant companion objects, depending on the applied models.

OrbDot remains highly efficient with multiple data types and a high number of free parameters, as it utilizes powerful nested sampling algorithms of the `nestle` ([Barbary, 2021](#); [Skilling, 2006](#)) and `PyMultiNest` ([Buchner et al., 2014](#); [Feroz et al., 2009](#)) packages. The intricacies of the implementation are abstracted such that the OrbDot input files are simple and the method calls require only a list of free parameters, along with the desired model for fitting.

Extensive documentation, including examples, is hosted on [ReadTheDocs](#).

The examples demonstrate that OrbDot can quickly reproduce literature results using only a few lines of code. Readers may be especially interested in the OrbDot example analysis of the transit and eclipse mid-times of Hot Jupiter WASP-12 b, which is well-known for showing strong evidence for orbital decay.

A complementary case study of TrES-1 b ([Hagey et al., 2025](#)) illustrates the full capabilities of OrbDot, placing it in a broader scientific context. Moreover, an early version of this code was used for the orbital analysis of the Hot Neptune LTT-9779 b, published in Edwards et al. ([2023](#)).

Statement of need

Many exoplanet systems now have transit and radial velocity data spanning over a decade, enabling studies of secular variations. While tools for analyzing short-term transit variations exist, there is a lack of open-source software dedicated to long-term orbital evolution. This does not, however, reflect a lack of interest, as the number of such studies is growing rapidly.

OrbDot lowers the barrier to entry for researchers at all levels, including undergraduates, by making advanced statistical methods accessible without requiring extensive computational experience. Despite its ease of use, OrbDot is not intended to be a black box. Rather, with extensive documentation, examples, and accessible source code, it is presented to the community with transparency that lends itself to community contributions and independent verification of results. It is designed to be easily extended, as the nested sampling framework supports custom log-likelihood models with free parameters that are part of the OrbDot ecosystem. This ensures that the software may evolve to meet the needs of the research community.

Similar software

Some existing tools have features that overlap with OrbDot's functionality, but none provides its full suite of capabilities. The most similar codes, Susie (Barker et al., 2024; Barker & Kirk, 2025) and PdotQuest (Wang et al., 2024), which are not fully packaged software, are designed to fit secular evolution models to transit and eclipse timing data, but not to radial velocities. OrbDot also has greater flexibility in model fitting than Susie and PdotQuest. For example, Susie employs simple least-squares fitting, and while PdotQuest (Wang et al., 2024) uses MCMC, it currently supports only the orbital decay model, making both codes narrower in scope than OrbDot. Moreover, OrbDot includes tools for theoretical interpretation.

The well-known package TTVFast (Deck et al., 2014) is highly robust and capable of modeling both transit and radial velocity data, but it is focused on short-term timing variations driven by multi-planet dynamics near mean-motion resonances. OrbDot, in contrast, explores long-term secular models. Similarly, general-purpose frameworks such as juliet (Espinoza et al., 2019), exoplanet (Foreman-Mackey et al., 2021), EXOFAST (Eastman et al., 2019), ExoStriker (Trifonov, 2019), and allesfitter (Günther & Daylan, 2021) can jointly model transit and RV data, but their TTV models are also restricted to short-term variations, with an emphasis on transit light curve fitting rather than directly using transit and eclipse mid-times to constrain models.

The RV-focused packages RadVel (Fulton et al., 2018) and Kima (Faria et al., 2018) provide flexible modeling of radial velocity datasets, but do not have a framework for incorporating transit and eclipse data into the modeling. The codes also have limited options for studying long-term trends. For example, RadVel (Fulton et al., 2018) includes linear and quadratic RV terms, which OrbDot also supports, but it does not model evolving orbital elements. Kima (Faria et al., 2018) incorporates an apsidal precession model, but only for circumbinary planets – a niche application.

In summary, OrbDot is a fully packaged, documented, and maintained software suite designed specifically for studies of secular orbital evolution. It unifies transit, eclipse, and RV data, bypasses light-curve fitting to focus directly on timing measurements, implements robust Bayesian inference with nested sampling, and provides a flexible framework for selecting models, priors, and parameterizations. In addition, it integrates tools for theoretical analysis, making OrbDot the first software to systematically support data-driven, comprehensive studies of long-term exoplanet orbital dynamics.

Acknowledgements

This work was supported, in part, by an NSERC Discovery Grant (DG-2020-04635) and the University of British Columbia. SH's contribution was further supported, in part, by an NSERC PGS-D and a Li Tze Fong Fellowship.

References

- Barbary, K. (2021). *nestle: Nested sampling algorithms for evaluating Bayesian evidence*. <https://ascl.net/2103.022>
- Barker, M., Jackson, B., Huchmala, R., Adams, E., & Kirk, A. (2024). Susie Transiting Exoplanet Ephemeris Package. *56th Annual Meeting of the Division for Planetary Sciences*, 56, 402.02. <https://doi.org/10.3847/25c2cf6b.64cecc52>
- Barker, M., & Kirk, A. (2025). The Susie Python package. In *GitHub repository*. <https://github.com/BoiseStatePlanetary/susie>; GitHub.
- Buchner, J., Georgakakis, A., Nandra, K., Hsu, L., Rangel, C., Brightman, M., Merloni, A., Salvato, M., Donley, J., & Kocevski, D. (2014). X-ray spectral modelling of the AGN obscuring region in the CDFS: Bayesian model selection and catalogue. *Astronomy & Astrophysics*, 564, A125. <https://doi.org/10.1051/0004-6361/201322971>
- Deck, K. M., Agol, E., Holman, M. J., & Nesvorný, D. (2014). TTVFast: An efficient and accurate code for transit timing inversion problems. *The Astrophysical Journal*, 787(2), 132. <https://doi.org/10.1088/0004-637X/787/2/132>
- Eastman, J. D., Rodriguez, J. E., Agol, E., Stassun, K. G., Beatty, T. G., Vanderburg, A., Gaudi, B. S., Collins, K. A., & Luger, R. (2019). EXOFASTv2: A public, generalized, publication-quality exoplanet modeling code. *arXiv e-Prints*, arXiv:1907.09480. <https://doi.org/10.48550/arXiv.1907.09480>
- Edwards, B., Changeat, Q., Tsiraras, A., Allan, A., Behr, P., Hagey, S. R., Himes, M. D., Ma, S., Stassun, K. G., Thomas, L., Thompson, A., Boley, A., Booth, L., Bouwman, J., France, K., Lowson, N., Meech, A., Phillips, C. L., Vidotto, A. A., ... Ward-Thompson, D. (2023). Characterizing a world within the hot-Neptune desert: Transit observations of LTT 9779 b with the Hubble Space Telescope/WFC3. *The Astronomical Journal*, 166(4), 158. <https://doi.org/10.3847/1538-3881/ace777>
- Espinoza, N., Kossakowski, D., & Brahm, R. (2019). juliet: A versatile modelling tool for transiting and non-transiting exoplanetary systems. *Monthly Notices of the Royal Astronomical Society*, 490(2), 2262–2283. <https://doi.org/10.1093/mnras/stz2688>
- Faria, J. P., Santos, N. C., Figueira, P., & Brewer, B. J. (2018). kima: Exoplanet detection in radial velocities. *Journal of Open Source Software*, 3(26), 487. <https://doi.org/10.21105/joss.00487>
- Feroz, F., Hobson, M. P., & Bridges, M. (2009). MULTINEST: An efficient and robust Bayesian inference tool for cosmology and particle physics. *Monthly Notices of the Royal Astronomical Society*, 398(4), 1601–1614. <https://doi.org/10.1111/j.1365-2966.2009.14548.x>
- Foreman-Mackey, D., Luger, R., Agol, E., Barclay, T., Bouma, L., Brandt, T., Czekala, I., David, T., Dong, J., Gilbert, E., Gordon, T., Hedges, C., Hey, D., Morris, B., Price-Whelan, A., & Savel, A. (2021). exoplanet: Gradient-based probabilistic inference for exoplanet data & other astronomical time series. *Journal of Open Source Software*, 6(62), 3285. <https://doi.org/10.21105/joss.03285>
- Fulton, B. J., Petigura, E. A., Blunt, S., & Sinukoff, E. (2018). RadVel: The radial velocity modeling toolkit. *Publications of the Astronomical Society of the Pacific*, 130(986), 044504.

<https://doi.org/10.1088/1538-3873/aaaaa8>

Günther, M. N., & Daylan, T. (2021). Allesfitter: Flexible star and exoplanet inference from photometry and radial velocity. *The Astrophysical Journal Supplement Series*, 254(1), 13. <https://doi.org/10.3847/1538-4365/abe70e>

Hagey, S. R., Edwards, B., Tsiaras, A., Boley, A. C., Kokori, A., Narita, N., Sada, P. V., Walter, F., Zellem, R. T., A-thano, N., Alton, K. B., Álava Amat, M. Á., Benni, P., Besson, E., Brandebourg, P., Bretton, M., Caló, M., Crow, M. V., Dalouzy, J.-C., ... Trnka, J. (2025). TrES-1 b: A case study in detecting secular evolution of exoplanet orbits. *The Astronomical Journal*, 170(4), 197. <https://doi.org/10.3847/1538-3881/aded15>

Skilling, J. (2006). Nested sampling for general Bayesian computation. *Bayesian Analysis*, 1(4), 833–859. <https://doi.org/10.1214/06-BA127>

Trifonov, T. (2019). *The Exo-Striker: Transit and radial velocity interactive fitting tool for orbital analysis and N-body simulations*. Astrophysics Source Code Library, record ascl:1906.004. <http://ascl.net/1906.004>

Wang, W., Zhang, Z., Chen, Z., Wang, Y., Yu, C., & Ma, B. (2024). Long-term variations in the orbital period of hot Jupiters from transit-timing analysis using TESS survey data. *The Astrophysical Journal Supplement Series*, 270(1), 14. <https://doi.org/10.3847/1538-4365/ad0847>