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AstronomyCalc: A python toolkit for teaching Astronomical Calculations and Data Analysis methods

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Software

- Review
- Repository
- Archive

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Summary

Understanding astrophysical and cosmological processes can be challenging due to their complexity and the lack of simple, everyday analogies. To address this, we present `AstronomyCalc`, a user-friendly Python package designed to facilitate the learning of these processes and help develop insights based on the variation theory of learning (Ling Lo, 2012; Lo & Marton, 2011).

`AstronomyCalc` enables students and educators to engage with key astrophysical and cosmological calculations, such as solving the Friedmann equations, which are fundamental to modeling the dynamics of the universe. The package allows users to construct and explore various cosmological models, including the de Sitter and Einstein-de Sitter universes (see Ryden, 2017 for more examples), by adjusting key parameters such as matter density and the Hubble constant. This interactive approach helps users intuitively grasp how variations in these parameters affect properties like expansion rates and cosmic time evolution. This package written in such as manner that it can be easily expanded with more astronomical caluclations that is required in a course. The package is designed to be easily expanded with additional astronomical calculations as needed for a course.

Moreover, `AstronomyCalc` includes modules for generating synthetic astronomical data or accessing publicly available datasets. In its current version, users can generate synthetic Type Ia supernova measurements of cosmological distances (VanderPlas et al., 2012) or utilize the publicly available Pantheon+ dataset (Brout et al., 2022). Additionally, the package supports the download and analysis of the SPARC dataset, which contains galaxy rotation curves for 175 disk galaxies (Lelli et al., 2016).

The datasets provided in the package can be analyzed within the package to test cosmological and astrophysical models, offering a hands-on experience that mirrors the scientific research process in astronomy. `AstronomyCalc` implements simplified versions of advanced data analysis algorithms, such as the Importance sampling (Tokdar & Kass, 2010) and Metropolis-Hastings algorithm (Robert & Casella, 2004) for Monte Carlo Markov chain sampling or statistical data interpretation, to explain the fundamental workings of these methods. By integrating theoretical concepts with observational data analysis, `AstronomyCalc` not only aids in conceptual learning but also provides insights into the empirical methods used in the field.

Statement of Need

The field of astronomy and cosmology requires a deep understanding of complex processes that are often difficult to visualize or grasp through traditional learning methods. `AstronomyCalc` addresses this challenge by offering an interactive, user-friendly tool that bridges the gap between theoretical knowledge and practical application.

Designed with the variation theory of learning in mind, this package enables students and educators to experiment with and explore key astrophysical and cosmological models in an intuitive manner. By varying parameters and observing the resulting changes, users can develop a more profound understanding of the underlying physical processes.

Furthermore, `AstronomyCalc` equips users with the tools needed to analyze real or simulated astronomical data, thereby providing a comprehensive learning experience that reflects the true nature of scientific inquiry in astronomy. This makes `AstronomyCalc` an invaluable resource for education in astronomy and cosmology, enhancing both the depth and quality of learning in these fields.

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References

Brout, D., Scolnic, D., Popovic, B., Riess, A. G., Carr, A., Zuntz, J., Kessler, R., Davis, T. M., Hinton, S., Jones, D., & others. (2022). The pantheon+ analysis: Cosmological constraints. *The Astrophysical Journal*, *938*(2), 110. https://doi.org/10.3847/1538-4357/ac8e04

Lelli, F., McGaugh, S. S., & Schombert, J. M. (2016). SPARC: Mass models for 175 disk galaxies with spitzer photometry and accurate rotation curves. *The Astronomical Journal*, *152*(6), 157. https://doi.org/10.3847/0004-6256/152/6/157

Ling Lo, M. (2012). *Variation theory and the improvement of teaching and learning*. Göteborg: Acta Universitatis Gothoburgensis.

Lo, M. L., & Marton, F. (2011). Towards a science of the art of teaching: Using variation theory as a guiding principle of pedagogical design. *International Journal for Lesson and Learning Studies*, *1*(1), 7–22. https://doi.org/10.1108/20468251211179678

Robert, Christian P., & Casella, G. (2004). The metropolis—hastings algorithm. In *Monte carlo statistical methods* (pp. 267–320). Springer New York. https://doi.org/10.1007/978-1-4757-4145-2_7

Ryden, B. (2017). *Introduction to cosmology*. Cambridge University Press.

Tokdar, S. T., & Kass, R. E. (2010). Importance sampling: A review. *Wiley Interdisciplinary Reviews: Computational Statistics*, *2*(1), 54–60.

VanderPlas, J., Connolly, A. J., Ivezić, Ž., & Gray, A. (2012). Introduction to astroML: Machine learning for astrophysics. *2012 Conference on Intelligent Data Understanding*, 47–54. https://doi.org/10.1109/CIDU.2012.6382200