The Journal of Open Source Software

SkyPy: A package for modelling the Universe

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DOI: 10.21105/joss.03056

Software

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Editor: Arfon Smith

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Submitted: 15 February 2021
Published: 10 September 2021

Summary

SkyPy is an open-source Python package for simulating the astrophysical sky. It comprises a library of physical and empirical models across a range of observables and a command line script to run end-to-end simulations. The library provides functions that sample realisations of sources and their associated properties from probability distributions. Simulation pipelines are constructed from these models using a YAML-based configuration syntax, while task scheduling and data dependencies are handled internally and the modular design allows users to interface with external software. SkyPy is developed and maintained by a diverse community of domain experts with a focus on software sustainability and interoperability. By fostering co-development, it provides a framework for correlated simulations of a range of cosmological probes including galaxy populations, large scale structure, the cosmic microwave background, supernovae and gravitational waves.

Version 0.4 implements functions that model various properties of galaxies including luminosity functions, redshift distributions and optical photometry from spectral energy distribution templates. Future releases will provide additional modules, for example to simulate populations of dark matter halos and model the galaxy-halo connection, making use of existing software packages from the astrophysics community where appropriate.

Statement of need

An open-data revolution in astronomy led by past, ongoing, and future legacy surveys such as *Euclid* (Laureijs et al., 2011), the Rubin Observatory Legacy Survey of Space and Time (Ivezić et al., 2019), *Planck* (Planck Collaboration, 2020) and the Laser Interferometer Gravitational-Wave Observatory (LIGO Scientific Collaboration, 2015) means access to data is no longer the

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primary barrier to research. Instead, access to increasingly sophisticated analysis methods is becoming a significant challenge. Researchers frequently need to model multiple astronomical probes and systematics to perform a statistically rigorous analysis that fully exploits the available data. In particular, forward modelling and machine learning have emerged as important techniques for the next generation of surveys and both depend on realistic simulations. However, existing software is frequently closed-source, outdated, unmaintained or developed for specific projects and surveys making it unsuitable for the wider research community. As a consequence astronomers routinely expend significant effort replicating or re-developing existing code. The growing need for skill development and knowledge sharing in astronomy is evidenced by a number of open initiatives focused on software, statistics and machine learning e.g., Astropy (Astropy Collaboration, 2018, 2013), OpenAstronomy (https://openastronomy.org), Dark Machines (http://darkmachines.org), The Deep Skies Lab (https://deepskieslab.com), and the Cosmo-Statistics Initiative (https://cosmostatistics-initiative.org). Recently, the research community has developed a number of important open-source python packages that address individual aspects of modelling astronomical surveys e.g. `GalSim` (Rowe et al., 2015), `Halotools` (Hearin et al., 2017) and `popsynth` (Burgess & Capel, 2021). `SkyPy` was established as a part of this software ecosystem to meet the need for realistic end-to-end simulations and enable forward modelling and machine learning applications.

Acknowledgements

AA and PS acknowledge support from a Royal Society Wolfson Fellowship grant. LFB, SB, IH, and RPR acknowledge support from the European Research Council in the form of a Consolidator Grant with number 681431. IH also acknowledges support from the Beecroft Trust. JPC acknowledges support granted by Agencia Nacional de Investigación y Desarrollo (ANID) DOCTORADO BECAS CHILE/2016 - 72170279. GF acknowledges financial support from the SNF 175751 "Cosmology with 3D maps of the Universe" research grant. AL and ARW thanks the STFC for support through the grant ST/S000550/1. LKN thanks the UKRI Future Leaders Fellowship for support through the grant MR/T01881X/1. This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

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