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stingray: A modern Python library for spectral timing

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Software

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Summary

Many celestial objects vary in brightness on timescales of milliseconds to centuries. These "light curves"–variations of brightness of an object as a function of time–often encode interesting physical processes that can help us learn about the nature of the celestial bodies that produced them. In stars like our sun, typical time scales tell us about stellar rotation, starspots and internal physics like convection. In remnants of stellar explosions like neutron stars, we can use time series to learn about the densest matter known in the universe. Finally, variations in brightness of radiation emitted by gas falling into a black hole give important clues to the nature of gravity and allow us to test General Relativity to high precision. Unravelling the underlying physical processes requires sophisticated statistical and signal processing methods, largely based on Fourier analysis, now well-established in this field.

Stingray is an Astropy-affiliated (Astropy Collaboration, 2013, p. @astropy2) Python package, making a large range of routinely used time series analysis methods available to the astronomy community. It is based on existing implementations of Fourier-space methods in Numpy (Millman & Aivazis, 2011) and Scipy (Jones, Oliphant, Peterson, & others, n.d.), but conveniently wraps them in classes and functions that allow easy application on astronomical data sets, especially from X-ray timing telescopes like the Rossi X-ray Timing Explorer (RXTE) (Bradt, Rothschild, & Swank, 1993), the Nuclear Spectroscopic Telescope Array (NuSTAR)(Harrison et al., 2013) and the Neutron Star Interior Composition Explorer (NICER) (Gendreau et al., 2016).
Stingray is a modular, class-based library aiming to allow users to build custom workflows for their particular data set and science problem, and implements common operations such as periodograms with standard normalizations, cross spectra and coherence, auto- and cross-correlations, as well as higher-order Fourier products such as bispectra and spectral-timing methods like covariance spectra. The latter consider both time and wavelength of the arriving radiation simultaneously and allows for more comprehensive studies of the underlying physical system. Stingray also implements submodules that allow efficient parametric modelling of periodograms, simulations of realistic time series, and specialized tools to study pulsars.

Stingray was designed with a flexible and extensible API to be end-user friendly, but also lies at

the core of two other packages: HENDRICS (Bachetti, 2018), which implements end-to-end versions of standard data analysis workflows, and DAVE, a graphical user interface designed to enable high-level exploratory data analysis on astronomical time series. A longer publication on the underlying methodology and implementation can be found in (Huppenkothen et al., n.d.), while the source code itself is available on GitHub (Huppenkothen et al., 2018) as part of a larger ecosystem including tutorials, as well as the repositories for HENDRICS and DAVE.

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