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extrabol: A Python Package for Estimating Bolometric Light Curves of Thermal Transients

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Abstract

We introduce a new, open-source, Python-based package, extrabol, for inferring the bolometric light curve evolution of extragalactic thermal transients. extrabol uses non-parametric Gaussian Process regression for light curve estimation that requires minimal user interaction. extrabol is available via GitHub.

← **Previous** article in issue

Next article in issue →

1. Introduction and Rationale

Inferring the time-evolving bolometric luminosity of an extragalactic transient is essential for understanding their underlying power sources and progenitors. If one can obtain a spectrum with sufficient wavelength coverage and resolution, the bolometric luminosity can be directly calculated by integrating over all wavelengths. Unfortunately, such data is not typically available. Instead, broadband photometry sampled at discrete wavelengths is often used to estimate the time-variable bolometric luminosity. Given the deluge of discoveries enabled by the upcoming Vera C. Rubin Observatory, expected to discover over a million supernovae annually (LSST Science Collaboration et al. 2009; Ivezić et al. 2019), automated and data-driven methods for inferring the bolometric light curves of transients are essential to enable population-level analysis.

Here, we introduce a new open-source, Python-based code for estimating the *bol*ometric light curves of *ex*tragalactic *tra*nsients, extrabol. Given a multiband light curve, extrabol uses a non-parametric model to infer the underlying broadband light curves. Then, assuming a blackbody spectral energy distribution, extrabol estimates the time-evolving bolometric luminosity, temperature and radius. extrabol is easily parallelizable and designed to work with minimal user interaction. This is in contrast to superbol (Nicholl 2018), a Python-based package which also computes bolometric light curves from broadband observations. Unlike extrabol, superbol uses deterministic interpolation methods (e.g., polynomial fits) and requires a degree of user interactivity in order to fit each object.

extrabol is available GitHub [5] and PyPI; a copy has also been placed on Zenodo (Thornton et al. 2024).

2. Methodology

The main functionality of extrabol and be summarized in three steps.

First, the data is read-in and pre-processed. The user must provide a data file including observational times, magnitudes, uncertainties and filters used to conduct the observation. Each filter must have a corresponding ID in the Spanish Virtual Observatory (Gutiérrez et al. 2006). After reading in all data from a user-generated text file, extrabol corrects for redshift and extinction due to galactic dust using the extinction model presented in Fitzpatrick & Massa (2007). The user can optionally correct the light curve for host galaxy reddening. Data points are culled based on a minimum signal-to-noise ratio and a desired temporal window specified by the user.

Next, extrabol uses Gaussian Process regression (GPR) to estimate the full evolution of the multiband light curves, based on the measured magnitudes. GPR is a non-parametric method which models the covariance between pairs of photometric points (see e.g., Aigrain & Foreman-Mackey 2023 for a recent review). We utilize a 2D kernel that incorporates the covariance across time and wavelength. We optimize the kernel parameters using the open-source code george (Foreman-Mackey 2015) via the minimize function from scipy (Virtanen et al. 2020), which uses a gradient descent optimizer. In the presence of large temporal gaps between data points, it is possible that the GP will yield an unrealistic interpolation near the mean function. For this reason, we additionally provide a series of SN templates to optionally use as GP mean functions. Specifically, the user may select from a set of Type Ia, Type Ib/c, Type IIL and Type IIP templates originally provided online. [6]

With a densely sampled interpolation, extrabol finally fits a series of blackbodies to the light curves, giving estimates of the bolometric luminosity, radius, and temperature over time. The user can specify whether a gradient descent method (using the curve_fit method in scipy) or a Markov

Chain Monte Carlo (emcee; Foreman-Mackey et al. 2019) is used in this step. While the gradient descent option is significantly quicker, a Markov Chain Monte Carlo (with a flat prior) may be desirable for better error estimation.

Finally, extrabol produces several output files, including the blackbody temperature, radius and luminosity as a function of time. Figure 1 shows an example of three output plots from extrabol.

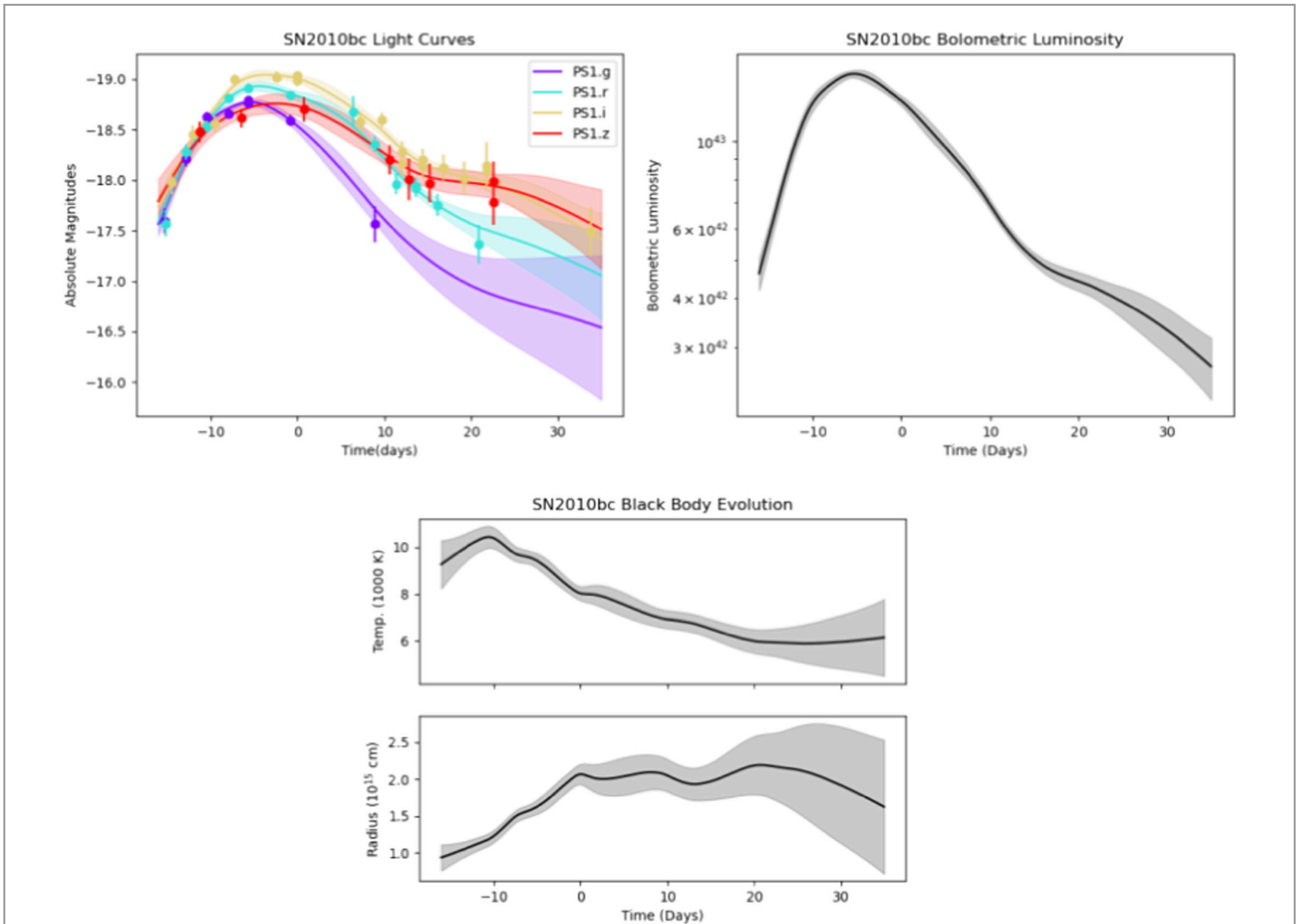

Figure 1. Example output plots of extrabol for SN 2010bc (data originally from Villar et al. 2020). Upper left: multiband Pan-STARRS Medium Deep Survey *griz* light curve (points). The GPR estimate is marked as solid lines, with 1σ uncertainty ranges given by shaded regions. Upper right: bolometric light curve estimate. Lower: estimated blackbody temperature and radius estimate over time. These estimates are used to generate the bolometric light curve.

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Footnotes

5 https://github.com/villrv/extrabol

6 https://c3.lbl.gov/nugent/nugent_templates.html
