Deriving Time-Dependent Supernova Luminosity Functions via Hierarchical Bayesian Modeling

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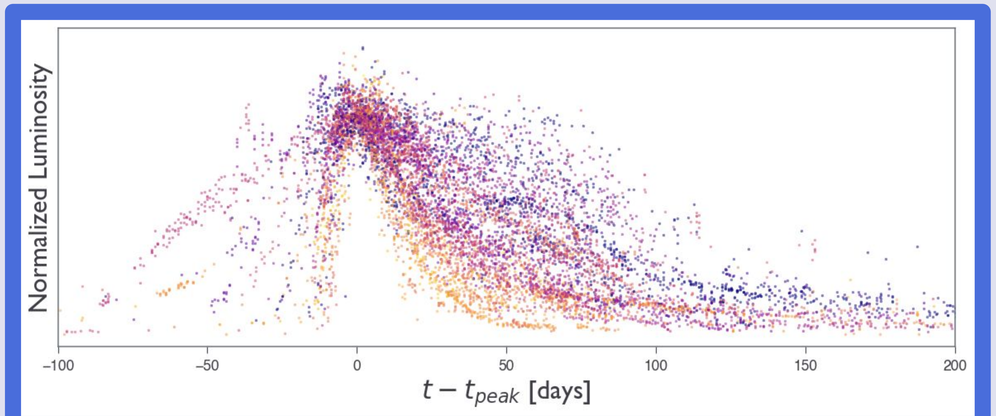
I. Background

The Bright Transient Survey (BTS)
an ideal sample for population studies

- **Magnitude-limited** survey of bright **(m < 18.5)** extragalactic transients detected in the Zwicky Transient Facility (ZTF) [1, 2]
  - High spectroscopic completeness (93% at m_peak < 18.5)
  - Sample of **>8,700 spectroscopically classified supernovae**

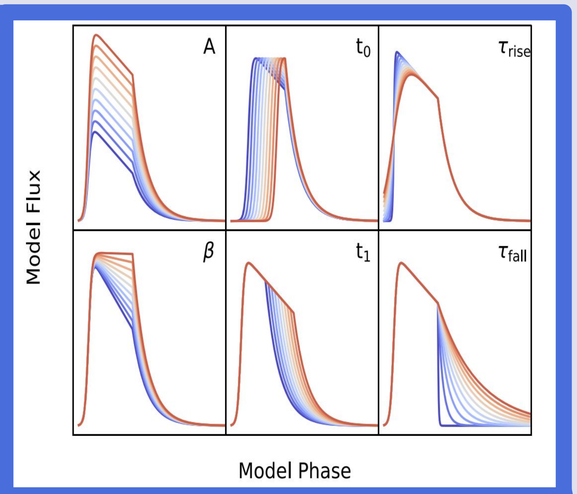


200 Type II SN light curves from BTS (only ~2.3% of the entire BTS SN sample) color-coded by fade time.

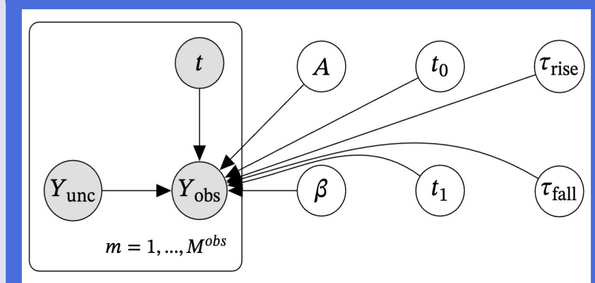
II. This Work

Parametric Light Curve Models
applied to BTS

- Villar+2019 [3] presents a model flexible enough to fit a broad range of supernova (SN) light curve shapes
- Implemented with `pymc` [4] and applied to BTS photometry
  - Fits 1 SN light curve at a time
  - **~7 min. runtime** (to fit observations of 1 SN, in 1 filter, with dense sampling)

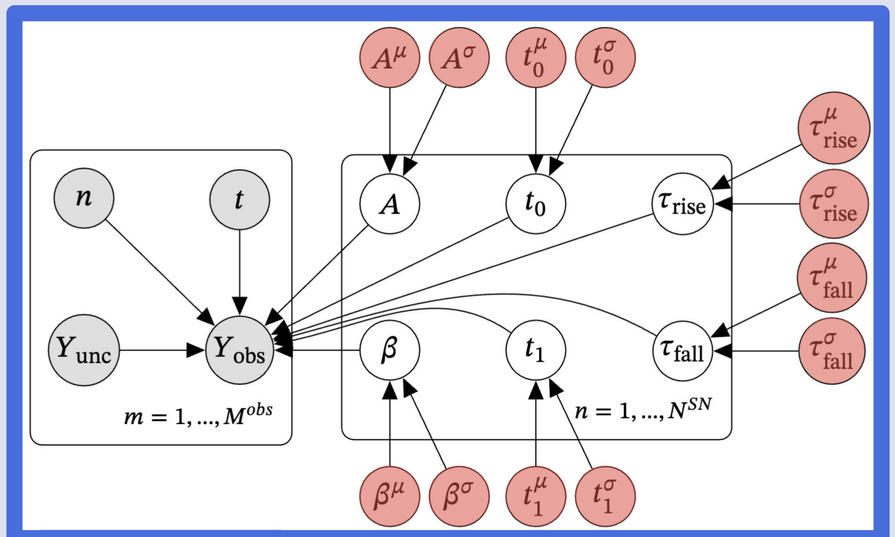


Parametric light curve model from [3]. In each panel, one parameter is varied from high (red) to low (blue) values. Figure from [3].



The model above as a probabilistic graphical model (PGM).

Going Hierarchical ★
adding hyperparameters to model a population of light curves



PGM representation of a hierarchical Bayesian model (HBM) with added hyperpriors in pink. In this example, every prior in plate *n* is taken to be Gaussian.

- `pymc` +2 hyperpriors: ~10x slower than no hyperpriors
  → Try `numpyro` [5], fast sampling method
- **`numpyro`: ~10x faster than `pymc`**
- `numpyro` +5 hyperpriors: ~2x faster than `pymc`
  → Suitable to model the entire BTS sample
- From hyperpriors, can **derive time-dependent luminosity functions**

III. Future Work

Measuring SN Rates
with the largest spectroscopic sample of SNe

Well-fitting hyperpriors
↓
Define luminosity functions
↓
Calculate SN rates

- Most recent measurement of SN rates with similar spectroscopic selection function: Li+2011a,b [6] with the Lick Observatory Supernova Search (LOSS)
  - BTS sample **more than an order of magnitude larger** than that in [6]
  - BTS detects luminous **SN subclasses entirely missed by** [6] (SNe Ibn and superluminous SNe (SLSNe))

1. C. Fremling *et al* 2020 *ApJ* 895 32
2. Eric C. Bellm *et al* 2019 *PASP* 131 018002
3. V.A. Villar *et al* 2019 *ApJ* 884 83
4. O. Abril-Plaet *et al* 2023 *PeerJ* 9 e1516
5. D. Phan and N. Pradhan 2019 *arXiv preprint* arXiv:1912.11554
6. W. Li *et al* 2011 *MNRAS* 412 3 1441–1472