Estimating the transient detection efficiency using iPTF
Predicting Supernova Rates

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Motivation

Rate estimates require recovery efficiency!

Why rates?

- Track evolution of the universe, star formation history.
- Constrain progenitor models.
- Abundance of elements.

Many transients are missed!

- Intrinsically dim, high sky brightness, low cadence
- Need efficiency folding in intrinsic properties, observing conditions and cadence.
Intermediate Palomar Transient Factory

Figure: Palomar 48 inch.
Credits: https://www.ptf.caltech.edu/images

- Optical telescope mounted at Palomar Observatory.
- Survey operations 2013 – 2016, now replaced by ZTF.
- Confirmed $\sim 1900$ SNe of different types.
- SNIa rates are well studied.
  - Good case study before moving on to interesting transients
Methodology

Consider in two steps

**Step 1**

Single epoch recovery

Transient detection, given it was in field of view

**Step 2**

Lightcurve ensemble

Consider transient lightcurve morphology

Instrument cadence
Single-epoch recovery
Fake Transients

- Control the transient brightness, place them in different galaxy types covering the **intrinsic properties**.
- Perform injections into original images covering the **observing conditions**. ¹
- Run image subtraction to determine missed/found injections.

¹Similar technique for PTF [Frohmaier et al., 2017].
Transient Detectability

- **Intrinsic properties:**
  - Apparent magnitude, $m$
  - Host galaxy surface brightness, $S_{\text{gal}}$
  - ...

- **Observing conditions:**
  - Limiting magnitude, $m_{\text{lim}}$
  - Sky brightness, $F_{\text{sky}}$
  - Image quality, $\Phi_{\text{IQ}}$
  - ...

\[
\lambda = \left\{ m, S_{\text{gal}}, \ldots, F_{\text{sky}}, \Phi_{\text{IQ}}, m_{\text{lim}}, \ldots \right\}
\]

\[
\varepsilon(\lambda) = \frac{N_{\text{rec}}(\lambda)}{N_{\text{tot}}(\lambda)}
\]
Results

Single Epoch Efficiencies

![Graph showing single epoch efficiencies for various magnitudes and galactic surface brightnesses.](image-url)
Detectability & Supervised Learning

Was the transient detected?

- Need joint detectability for arbitrary conditions.
- Restrict to parameters which capture maximum variability:
  \[ \beta = \{ m, S_{\text{gal}}, F_{\text{sky}}, \Phi_{\text{IQ}}, m_{\text{lim}} \} \]
- Multi-dimensional problem, sparsely populated, traditional binning is difficult.
- Treat problem as binary classification: Found/Not found.
- Nearest Neighbor algorithm from scikit-learn library.
Supernova (SN) Ia lightcurves

- We use SALT2 model SNIa lightcurves [Guy et al., 2007].
- Phenomenological model based on observations by SDSS and SNLS surveys.

Figure: Example SNIa @ $z = 0.01$, $M_B = -19.05$, $(\alpha, \delta) = (16.6^\circ, 39.9^\circ)$
SN Ia Detectability

- \( \approx 5 \times 10^6 \) SNIas
- Observability from observing schedule.
- Detectability from single-epoch classifier
Mean observable number count:

\[ \lambda_{\text{SNIa}} = R_{\text{SNIa}} \times \langle VT \rangle_{\text{SNIa}} \]

Sensitivity in Mpc\(^3\)yr

Rate in Mpc\(^{-3}\)yr\(^{-1}\)

In Monte-Carlo style:

\[ \langle VT \rangle_{\text{SNIa}} \approx \frac{\#_{\text{SNIa detected}}}{\#_{\text{SNIa total}}} \langle VT \rangle_{\text{max}} \]

\[ = 2.93 \pm 0.03 \times 10^7 \text{Mpc}^3\text{yr} \]

Spacetime volume of simulations, \(\langle VT \rangle_{\text{max}}\) up to \(z_{\text{max}} \sim 0.3\)
Consistent with Subaru results [Poznanski et al., 2007]

Takeaway
The single-epoch classifier could be used for $\langle VT \rangle$ calculation of any general transient.
• 1035 objects tagged as SNIIa in iPTF.
• $R_{\text{SNIIa}}^{\text{SDSS2}} \sim 2.9^{+1.07}_{-0.75} \times 10^{-5}\text{Mpc}^{-3}\text{yr}^{-1} \ @ \ z \approx 0.1$ [Dilday et al., 2008]
• Using our $\langle VT \rangle_{\text{SNIIa}}$, expected count $\sim 630 - 1160$. SNIIa in iPTF.

A measurement of the rate of type Ia supernovae at redshift $z \approx 0.1$ from the first season of the SDSS-II supernova survey. *The Astrophysical Journal, 682*(1):262–282.

Real-time recovery efficiencies and performance of the palomar transient factory's transient discovery pipeline.


Salt2: using distant supernovae to improve the use of type ia supernovae as distance indicators.

*Astronomy & Astrophysics, 466(1):11–21.*


Supernovae in the Subaru deep field: an initial sample and type ia rate out to redshift 1.6.