Estimating the transient detection efficiency using **iPTF**

Predicting Supernova Rates

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Motivation

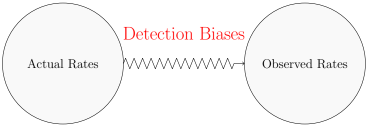
Rate estimates require recovery efficiency!

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

↓

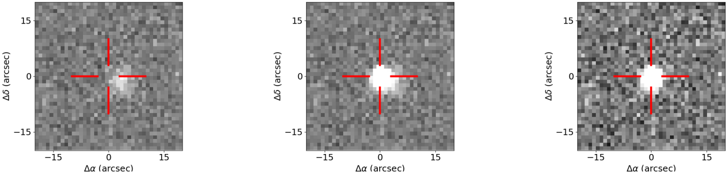
Step 2

Lightcurve ensemble

Consider transient lightcurve morphology
Instrument cadence

Single-epoch recovery

Fake Transients



(a) Original (b) Fake transient (c) Subtraction

- 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.

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

Transient Detectability

- Intrinsic properties:
  - Apparent magnitude, m
  - Host galaxy surface brightness, S_{gal}

    ⋮
- Observing conditions:
  - Limiting magnitude, m_{lim}
  - Sky brightness, F_{sky}
  - Image quality, Φ_{IQ}

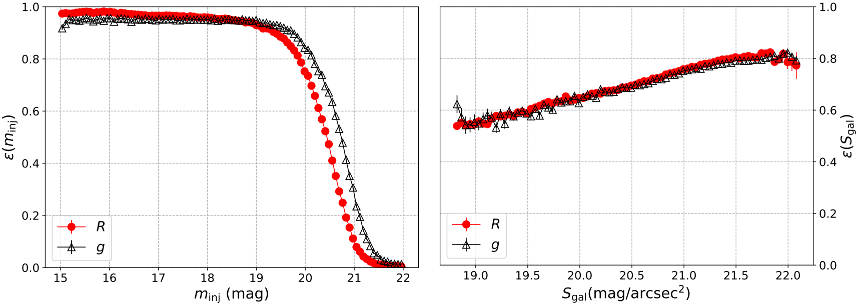
    ⋮

$$\boldsymbol{\lambda} = \{\underbrace{m, S_{\mathrm{gal}}, \ldots,}_{\text{intrinsic properties}} \overbrace{F_{\mathrm{sky}}, \Phi_{\mathrm{IQ}}, m_{\mathrm{lim}}, \ldots}^{\text{observing conditions}}\}$$

$$\varepsilon(\boldsymbol{\lambda}) = \frac{N_{\mathrm{rec}}(\boldsymbol{\lambda})}{N_{\mathrm{tot}}(\boldsymbol{\lambda})}$$

Results

Single Epoch Efficiencies



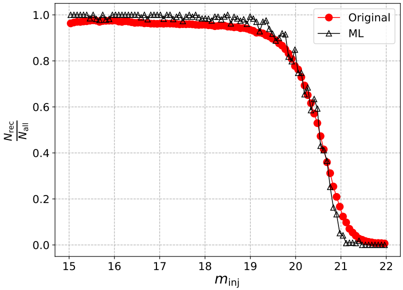
Detectability & Supervised Learning

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.

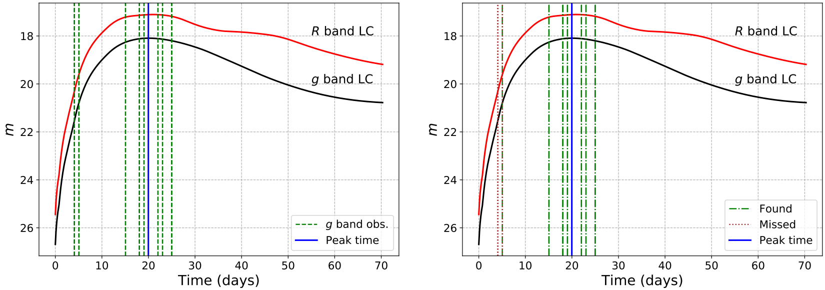
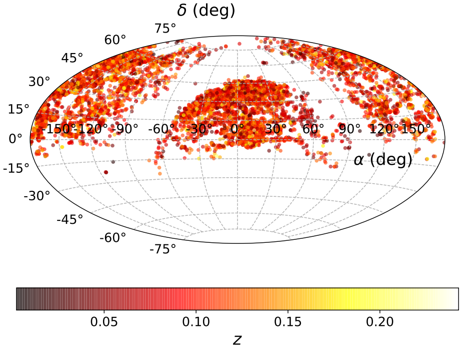
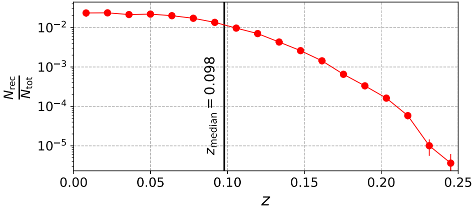


Figure: Example SNIa @ $z = 0.01,\ M_B = -19.05, (\alpha, \delta) = (16.6^\circ, 39.9^\circ)$

SN Ia Detectability





- $\approx 5 \times 10^6$ SNIas
- Observability from observing schedule.
- Detectability from single-epoch classifier

Spacetime Volume Sensitivity

Mean observable number count:

$$\lambda_{\rm SNIa} = \underbrace{R_{\rm SNIa}}_{\text{Rate in } \rm Mpc^{-3}yr^{-1}} \times \overbrace{\langle VT \rangle_{\rm SNIa}}^{\text{Sensitivity in } \rm Mpc^{3}yr}$$

In Monte-Carlo style:

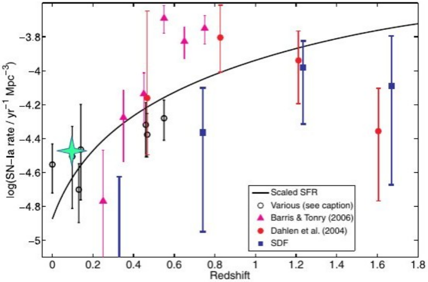
$$\begin{aligned} \langle VT \rangle_{\rm SNIa} &\approx \frac{\#\text{SNIa}_{\text{detected}}}{\#\text{SNIa}_{\text{total}}} \langle VT \rangle^{\text{max}} \\ &= 2.93 \pm 0.03 \times 10^{7} \rm Mpc^{3}yr \end{aligned}$$

Spacetime volume of simulations, $\langle VT \rangle^{\text{max}}$ up to $z_{\rm max} \sim 0.3$

SNIa Rate

Work in Progress, ballpark numbers

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.

Extra Slides

- 1035 objects tagged as SNIa in iPTF.
- $R_{\rm SNIa}^{\rm SDSS2} \sim 2.9^{+1.07}_{-0.75} \times 10^{-5} {\rm Mpc}^{-3} {\rm yr}^{-1}$ @ $z \approx 0.1$ [Dilday et al., 2008]
- Using our $\langle VT \rangle_{\rm SNIa}$, expected count $\sim 630 - 1160.$ SNIa in iPTF.

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