A Probability Classifier for Prompt Identification of Rapid-Evolving Astronomical Transients

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Astronomical Transients

Astronomical transients, like exploding stars, accreting black holes, can have lifetimes as long as decades, or as short as hours. Although slow-evolving transients have been studied extensively, the "fast transients" are extremely difficult to discover as they brighten and fade away swiftly (Fig. 1). Identifying the fast transients from the slower ones and planning follow-up observations is a significant and challenging task.

Vera C. Rubin Observatory, with its huge field of view (~10 deg^2) and the ability to detect extremely faint objects (m~24 in magnitude), will be a powerful tool for discovering transients. It will generate about 20 TB of data that contains millions of astronomical transients each night. Identifying the fast transients from the slower ones and planning follow-up observations is a significant and challenging task.

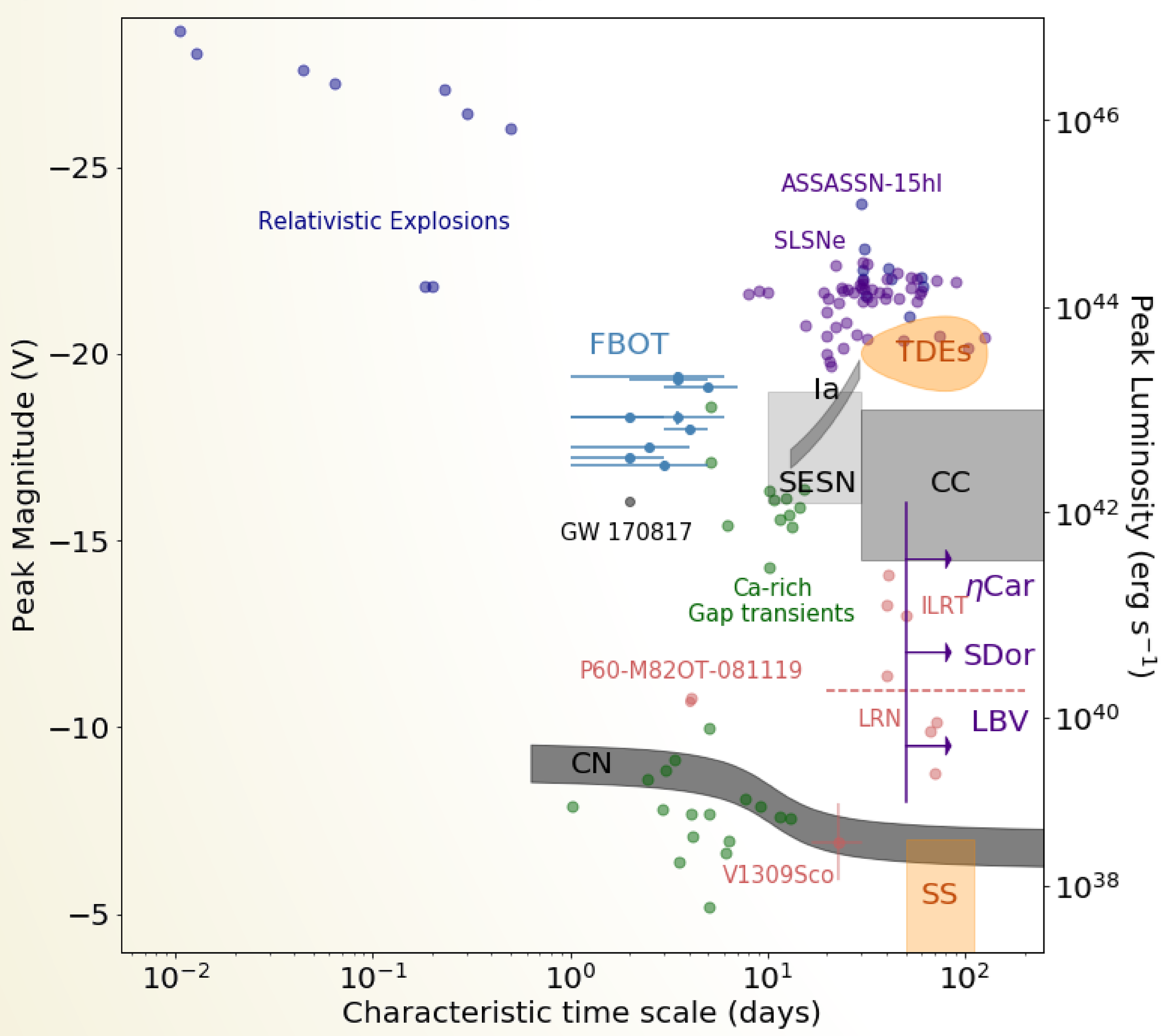

Fig. 1 The lifetimes and brightness (magnitudes) of typical astronomical transients. The lifetimes of "fast transients" are as short as a couple of days (FBOT, GW) or hours (relativistic explosions). Few examples of fast transients are know, but this may be an observational bias due to technical restrictions (Ivezić *et al*, 2019).

CC: Core-Collapse supernovae
CN: Classical Novae(MMRD)
FBOT: Fast Blue Optical Transients
Ia: thermonuclear supernovae
ILRT: Intermediate Luminous red transients
LBV: Luminous blue variables
LRN: Luminous red novae
SESN: Stripped-Envelope supernovae
SLSN: Superluminous supernovae
SS: Symbiotic Stars
TDE: Tidal Disruption Events

Presto-Color Strategy

Most classifiers for astronomical transients require full light curves (time series), but even one day after detection may be too late for planning follow-up observations. The Presto-Color observing strategy enables a prompt identification of the "fast transients" utilizing only 3 observations in a single night:

- First measurement for m_{11} in filter 1
- Second measurement for m_2 in filter 2 with time gap ΔT_1
- Third measurement for m_{12} in filter 1 with time gap ΔT_2
- **Magnitude change = $m_{11} - m_{12}$**
- **Color = $m_{11} - m_2$**

The distributions of "fast transients" and the slower ones are distinctive in the resulting phase-space diagram (Fig. 2).

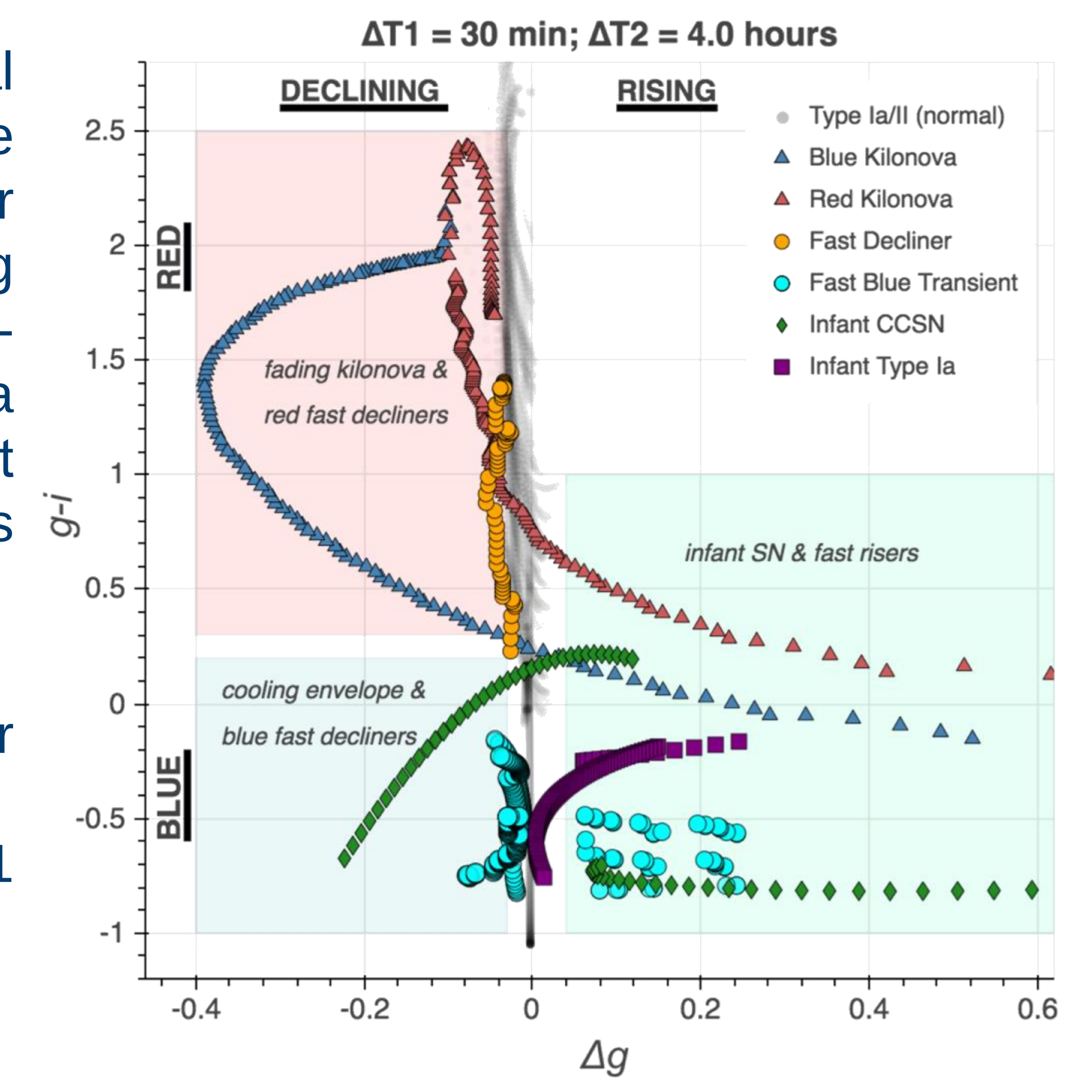

Fig. 2 The Presto-Color phase-space diagram of selected objects. The colorful shapes are for "fast transients", while the gray dots gather around Δg = 0 are slow-evolving transients (Bianco *et al*, 2019).

Probability Classifier

A probability classifier was created based on the Presto-Color strategy, with the signals of 880,000 transients generated by simulations from 22 slow-evolving models. The classifier returns a probability of the transient to be a fast one when provided the filter 1, filter 2, ΔT_1, ΔT_2, and the observed magnitude change and color.

Fig. 2 shows a 2-D slice of the classifier with only one class of slow transients plotted (supernovae type Ia). The dots show status of single points in the evolution of the transients. The data points for the slower transients were reduced to 2-D histograms (shown on the back-ground) according to the observation uncertainties, also for a better efficiency in data storage and process.

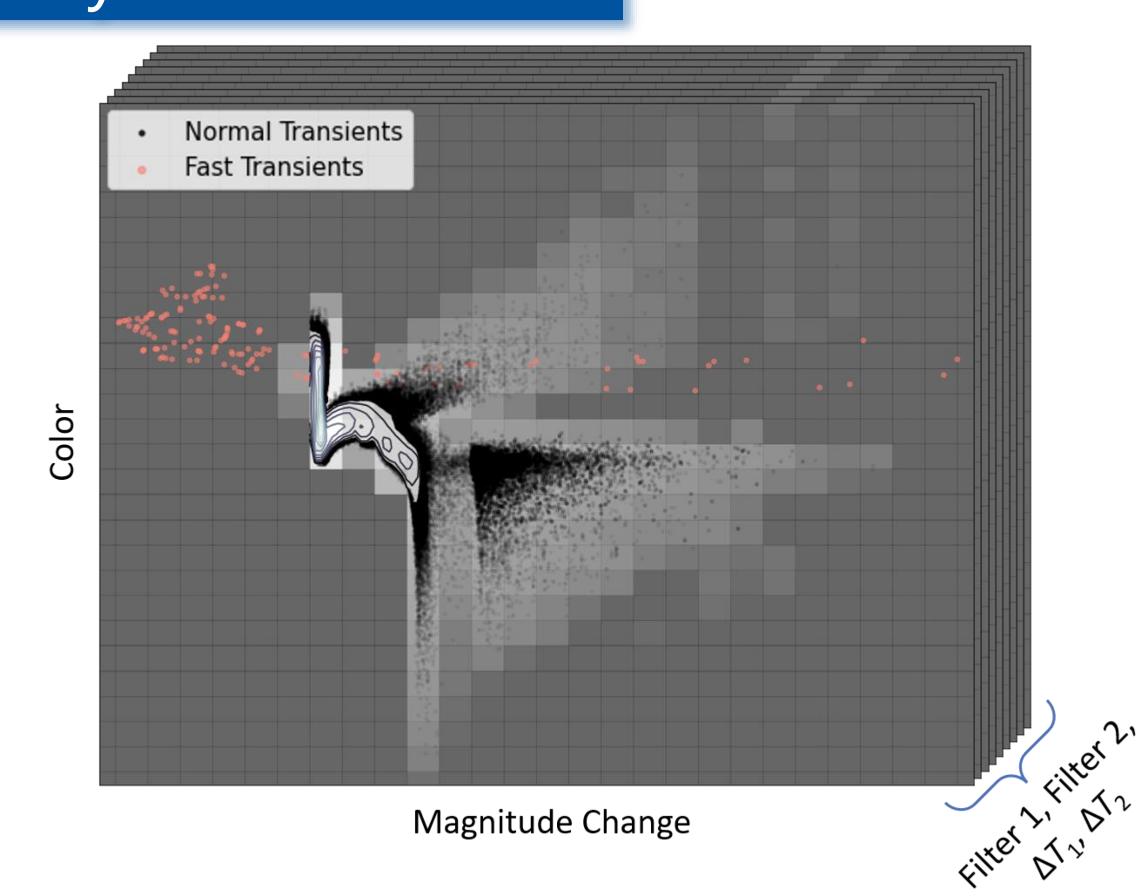

Fig. 3 A 2-D slice example of the classifier. The black dots and contours show the distribution of one slower transient class, supernovae type Ia. The pink dots are exemplary observations of a fast transient class, "kilonova". The 2-D histogram on the background is the result of the binning of the "normal" transient evolutionary tracks (black dots).

Observing Strategy Evaluation

The Presto-Color strategy has different efficacies in identifying "fast transients" when different filters and time gaps are used. This probability classifier can also be used to evaluate and improve the observing strategy. Two ways of scores were designed:

$$S_i = \begin{cases} 1, if\ n_i < thr \\ 0, if\ n_i > thr \end{cases}, \quad S = \sum_i S_i/N,$$

$$P = \sum_i (1 - n_i)/N.$$

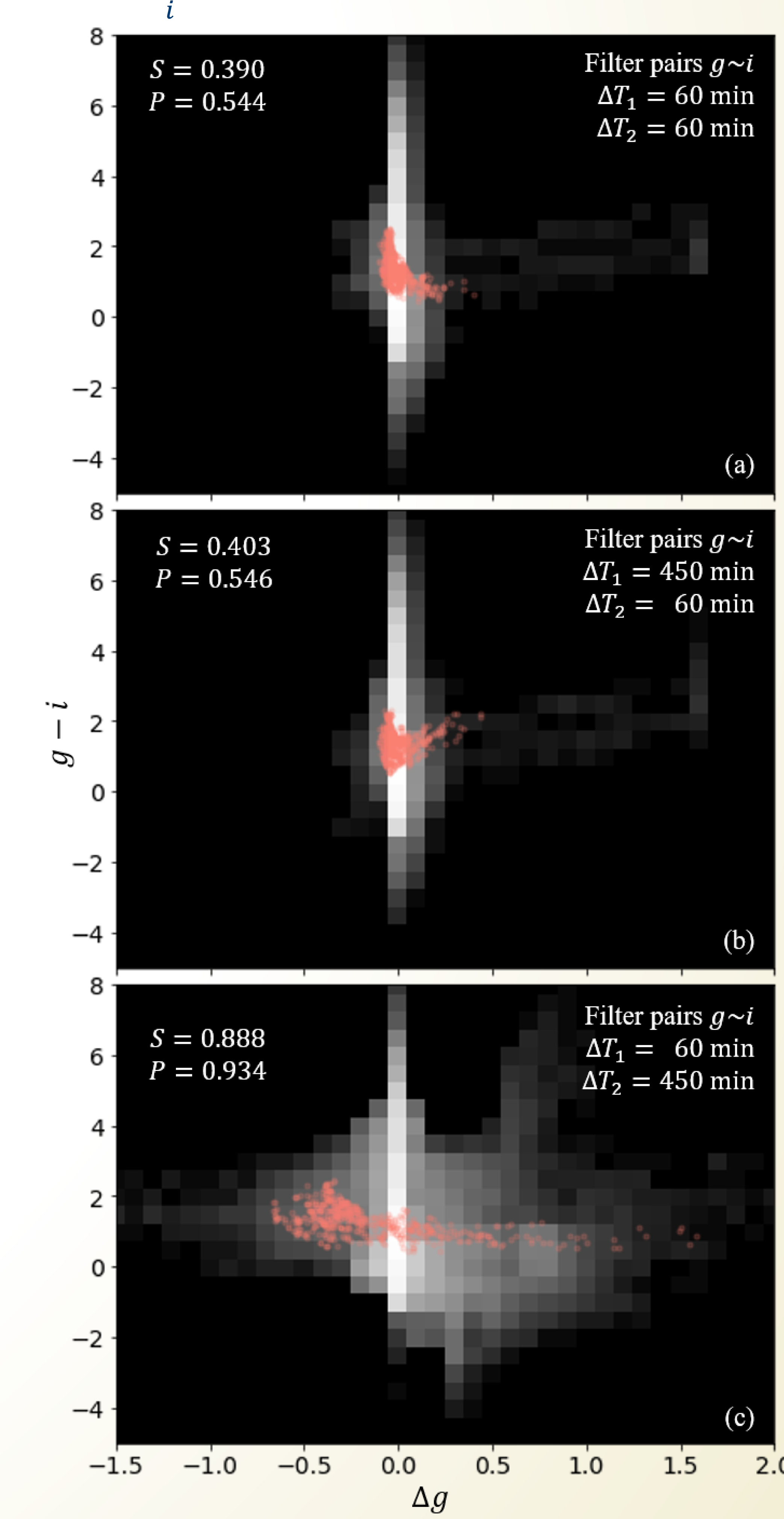

Fig. 4 The results for observations in *g~i* filter pair and 3 combinations of time gaps. The scores suggest smaller ΔT_1 and larger ΔT_2 will have advantages in fast transient identification.