ZTF simulations of Goldstein et al 2018: template 1 and rescaled crossing coefficients

1 ZTF simulations

The main purpose of this article is to test different of methods based on Crossing statistics on 'good' 2-image light curves of ZTF gLSNe simulations compiled in [1]. By 'good' we mean the system obeys the following criteria

- The shape of the data resembles that of a light curve. This sorting is done by visual inspection.
- The system has total 200 data points combining r,g and i bands.
- $0.5 \leq \mu \equiv \mu_2/\mu_1 \leq 2.0$
- time delay $dt \geq 10$.

We have total 33 such systems.

2 The model: Template 1 + Crossing Statistics + stretch (optional)

We consider the intrinsic light curve as a template multiplied by crossing statistics (now the coefficients are readjusted):

$$f(t) = g(t) \times C_0 \left[1.0 + C_1 t_s + C_2(2t_s^2 - 1) + C_3(4t_s^3 - 3t_s) + C_4(8t_s^4 - 8t_s^2 + 1) + ...\right] \ , \qquad (1)$$

where the coefficients $C_0, C_1, C_2, C_3...$, describe the crossing statistics. In this report we test different setups (sections 4,5,6,7) with the above scaling. Note that the variable in the crossing functions can be defined as

- $t_s \equiv t/t_{max} \in (0, 1)$
- or, $t_s \equiv 2.0 \times (t/t_{max}) - 1 \in (-1, 1)$

depending on the setup. t_{max} is the largest time of observation after the explosion.

In this report we use the template

$$g(t) = \frac{1}{2\sigma\sqrt{\pi}t} \exp\left[-\frac{(\ln t - m)^2}{2\sigma^2}\right] \qquad (\log - \mathrm{normal}) \ , \qquad (2)$$

which we call 'Template 1'.

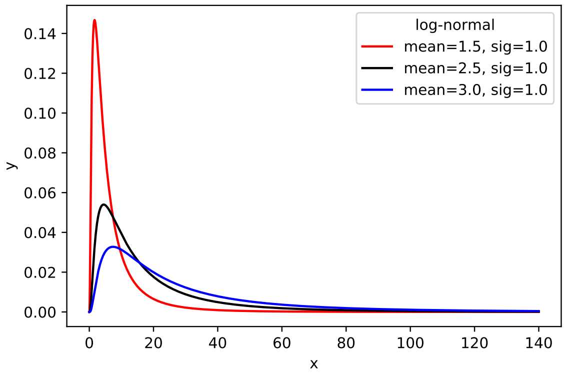
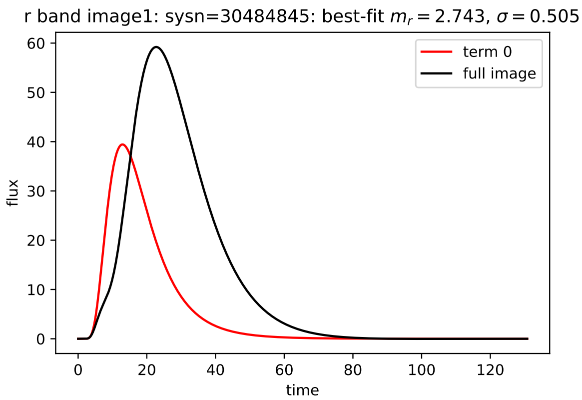
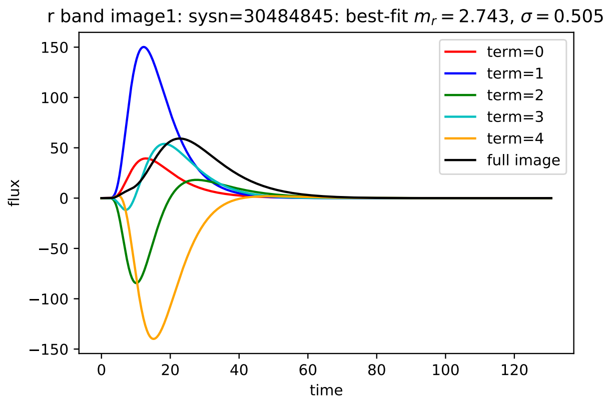


Figure 1: log-normal template, see equation (2) with fixed $\sigma = 1$ and various m. As we increase m, the peak shifts towards right and the width also increases even if we had fixed σ.



(a) template and the final image



(b) various terms

Figure 2: System number=30484845, best-fit image 1 in a particular fitting model. **(a):** Left panel shows the best-fit template (red) is quite different in width and maxima from the final image flux (black). Thus the crossing terms can substantially change the shape of the template. **(b)** The final image involves cancellation of large higher order terms; still we get a smooth image! term= is the template $= g(t) \times C_0$; term$= i$ corresponds to the ith order crossing term $= g(t) \times C_0 \times C_i$. Note the that is no stretch involved in this fitting.

3 Different models and priors

Priors on m and σ in (2): I tried fitting with the priors: $\sigma \in \{2,4\}$ and $m - \sigma^2 \in \{2,4\}$ (or $m \in \{6,20\}$). But the fits were pretty bad. After some investigations I conclude the following points:

- The variance of log-normal is dependent on both σ and m, so is its width. This fact can be explicitly seen in figure 1. I saw in earlier analyses that σ mostly varies between $\{0.5, 2.8\}$ preferring values close to ~ 0.8. Similarly m prefers values close to 2.5 to 5.
- The shape (mode, width) of the template (after choosing m and σ) can be quite different from the final image (after applying the crossing terms). This can be seen in figure 2. The conclusion is that it would very difficult to guess what exact shape (width, mode) of the template will be preferred by this method to fit the data even though we know the shape of the data.

Therefore, I set quite relaxed priors: $0.1 \leq \sigma \leq 3.5$ and $1 \leq m \leq 16$. The fits became good again.

We used the following priors on the parameters.

- $0.25 \leq \mu \leq 4.0$ (I may tighten this prior a little bit)
- $0 \leq dt \leq 75$.
- For all the bands: $0.1 \leq \sigma \leq 3.5$ and $1 \leq m \leq 16$ in (1).

Now we use the 5 following setups for analysing each system.

1. **npC1**=No priors on C's. $t_s \in (0,1)$. Note this is different from the earlier fittings (summarized in the previous 66 figure report) in terms of crossing coefficients rescaling.
2. **npC2**=No priors on C's. $t_s \in (-1,1)$
3. **pC1**=Priors on C's: $C_1,\ C_2,\ C_3, ... \in \{-10,10\}$, no prior on C_0. $t_s \in (-1,1)$
4. **pC2**=Priors on C's: $C_1,\ C_2,\ C_3, ... \in \{-10,10\}$, no prior on C_0. $t_s \in (0,1)$
5. **pC3**=Priors on C's: $C_1,\ C_2,\ C_3, ... \in \{-10,10\}$, no prior on C_0. $t_s \in (0,1)$, also the free parameter t_0 [1] is discarded.

While testing each of the above 5 setups we also use two 2 different orders of crossing terms:

- C4 = 4th order Crossing statistics (up to C_4) + no stretch.
- C2 = 2nd order Crossing statistics (up to C_2) + no stretch.

Note that in this exercise, we do not consider any 'stretch' in any of the models.

Therefore, each gLSNe system here is tested/fitted $5 \times 2 = 10$ times. Also we plot 3 (*mu-dt* confidence levels, individual image reconstructions, confidence levels of the crossing coefficients) figures per fit, so each system has 30 figures in total.

Out of the 33 'good' systems we analyse 8 systems here. The plots for each system is given in a separate pdf file uploaded in the github link https://github.com/deltasata/Unresolved-Sne/tree/master/Rescaled_Cs_revised. The filenames start with the system number: 'sysn_system_no.....pdf'. You can compare the results obtained here with the old results (file names start with OLD) where I did not rescaled the crossing coefficients. In this exercise , we would have clearer idea about which method works better in what circumstances and serves our purpose more efficiently.

References

[1] D. A. Goldstein, P. E. Nugent and A. Goobar, Astrophys. J. Suppl. **243** (2019) no.1, 6 doi:10.3847/1538-4365/ab1fe0 [arXiv:1809.10147 [astro-ph.GA]].

[1] t_0 accounts for any offset to the explosion time, i.e. explosion happens at $t = t_0$. Therefore, removing the free parameter t_0 means we assume at $t = 0$ the SN exploded.