Force Photometry for ZTF Transients

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1 Introduction

As far as I understand, the current ZTF (Zwicky Transient Facility) alert pipeline generates a ZTF source once a transient is detected. By definition, a "detection" means that the observed flux is five times larger than the flux uncertainty. Real-time light curve of ZTF sources will be uploaded to the marshal webpage, and human scanners can keep track of targets of interest. Thence, the marshal webpage does not contain information before the first detection, but the median flux can already be larger than zero (e.g., four times the flux uncertainty). With early photometry, we can better constrain the explosion time of different types of transients.

The idea behind force photometry is to perform PSF photometry on exactly the same coordinate on every epoch.

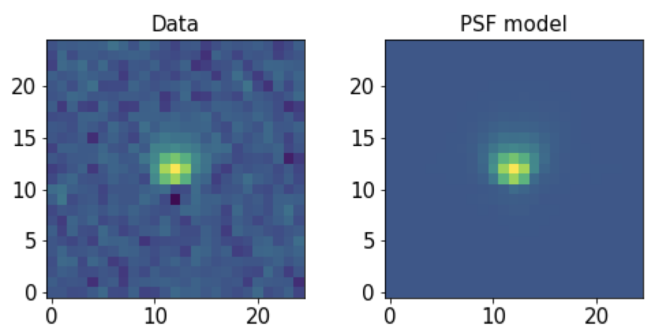

Figure 1: 25×25 pixel cutouts of source image and psf model image.

2 PSF Fitting

In this package, I use the two-parameter model. Photometric uncertainty for each pixel is:

$$\sigma_i^2 = \frac{\mathrm{DN}}{\mathrm{gain}} + \sigma_b^2 \tag{1}$$

2.1 One-parameter Model

Model:

$$\chi^2 = \sum_{i=0}^{N-1} (y_i - bx_i)^2 \tag{2}$$

Maximum likelihood:

$$\frac{\partial \chi^2}{\partial b} = 0 \tag{3}$$

Solution:

$$F_{\mathrm{psf}} = b \ \ = \frac{\sum x_i y_i}{\sum x_i^2} \tag{4a}$$

$$\sigma_{F_{\mathrm{psf}}} = \sigma_b = \sqrt{\sum \left(\frac{\partial b}{\partial y_i}\right)^2 \sigma_i^2} = \frac{\sqrt{\sum x_i^2 \sigma_i^2}}{\sum x_i^2} \tag{4b}$$

2.2 Two-parameter Model

Model:

$$\chi^2 = \sum_{i=0}^{N-1} (y_i - bx_i - a)^2 \tag{5}$$

Maximum likelihood:

$$\frac{\partial \chi^2}{\partial b} = 0 \tag{6a}$$

$$\frac{\partial \chi^2}{\partial a} = 0 \tag{6b}$$

Solution:

$$F_{\mathrm{psf}} = b = \frac{N \sum x_i y_i - \sum x_i \sum y_i}{N \sum x_i^2 - (\sum x_i)^2} \tag{7a}$$

$$a = \frac{\sum x_i^2 \sum y_i - \sum x_i \sum x_i y_i}{N \sum x_i^2 - (\sum x_i)^2} \tag{7b}$$

$$\begin{aligned}\sigma_{F_{\mathrm{psf}}} = \sigma_b &= \sqrt{\sum \left(\frac{\partial b}{\partial y_i}\right)^2 \sigma_i^2} \\ &= \frac{\sqrt{N^2 \sum x_i^2 \sigma_i^2 - 2N \sum x_i \sum x_i \sigma_i^2 + (\sum x_i)^2 \sum \sigma_i^2}}{N \sum x_i^2 - (\sum x_i)^2}\end{aligned} \tag{7c}$$

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