

Photometry of supernovae (transient point sources)

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Two types of (SN) photometry

Real Time :

- Used for detection and allow for real time follow-up decisions.
- Performed on image subtractions.

After the fact :

- Performed using the whole image sequence (even after the SN has faded away).
- Meant to be optimal in some sense (see later), mostly for distance estimation.

Framework

- Wide field camera, CCD mosaic.
- Large ditherings between visits, possibly with rotations.
- Images are affected by a whole suite of instrumental effects.

Instrumental effects

Optics

- Distortions
- PSF chromaticity
- Vignetting
- Non uniformity of filters
- Differential chromatic refraction

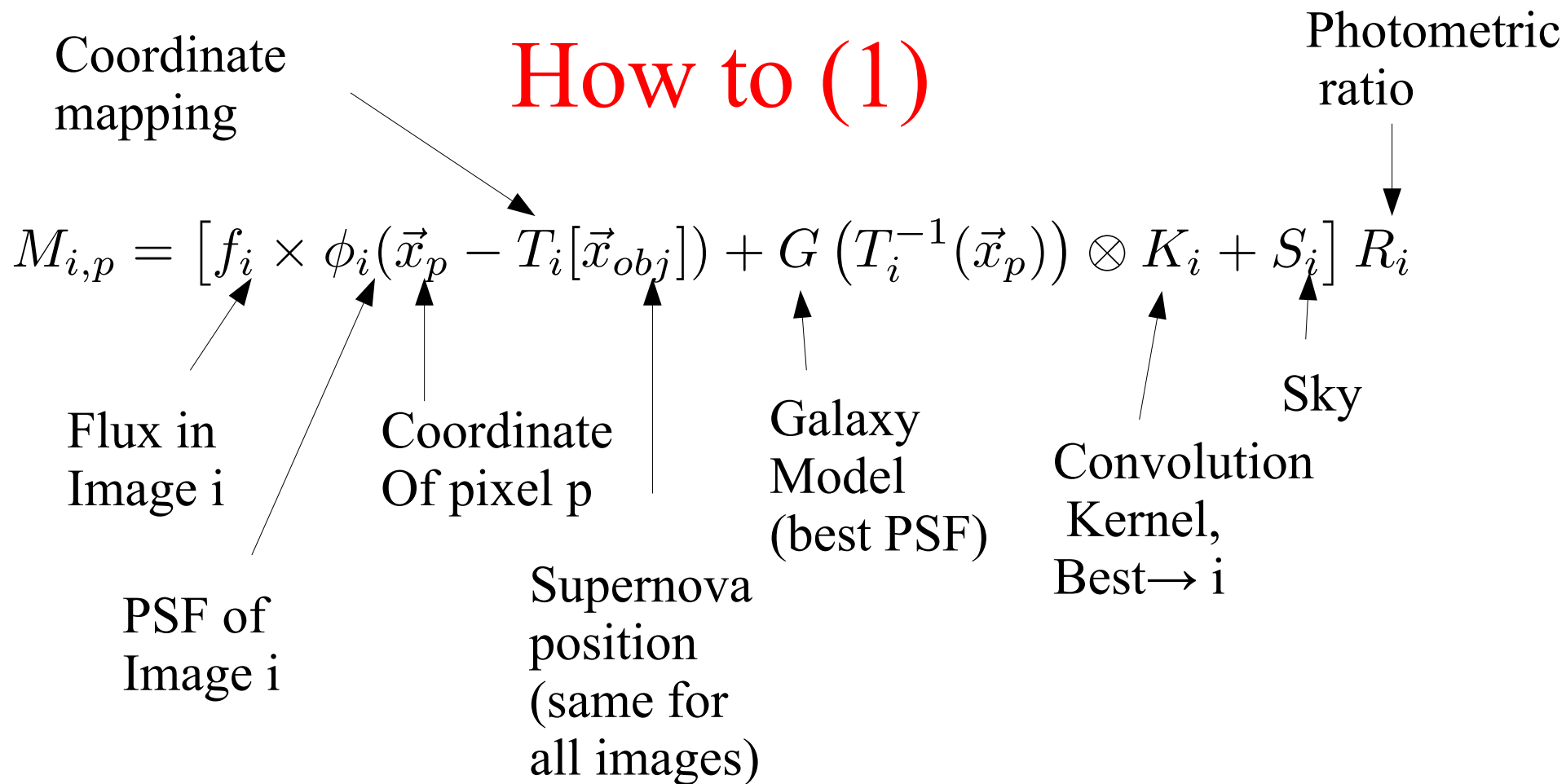
Sensors

- Non-linearity of video chains
- Brighter-fatter

After-the-fact photometry

- “scene modeling”: fit a forward model to an image sequence describing a time-variable point source (SN) sitting on a static background (galaxy).
- It is different from photometry on image subtractions:
 - It does not require a deep “template” from good-seeing SN-free images.
 - No image resampling.
 - It delivers a covariance matrix of measured fluxes.
- With an infinite set of images, the two techniques are identical.
- The scene modeling is optimal (regarding shot noise), not just asymptotically optimal.

How to (1)



G is a pixelized model of the galaxy, at the ref image quality (i.e. the best).
 K_i is determined from PSF's.

For images free of SN light, f_i is forced to 0.

One S_i has to be 0.

How to (2)

$$M_{i,p} = [f_i \times \phi_i(\vec{x}_p - T_i[\vec{x}_{obj}]) + G(T_i^{-1}(\vec{x}_p)) \otimes K_i + S_i] R_i$$

Prerequisites:

- T_i : astrometric mappings between images (both ways)
- R_i : photometric mappings between images
- PSFs for all images
- A rough idea of an SN-free image set.
- A rough SN position (~ 1 pixel or so).

For the least-squares fit, the computing time depends mostly on the number of parameters of the galaxy model, and the number of images.

What are we measuring ?

- Supernova fluxes ?
- Not exactly: we want the ratio of SN fluxes to fluxes of neighboring stars,
- Measured using the same technique, in the same images.
- Then, SN magnitudes are derived from magnitudes of neighboring stars....
- Usually obtained using aperture photometry

What are we measuring?

$$m_{SN} = -2.5 \log_{10} \left[\frac{\phi_{SN}}{\phi_{star}} \frac{\phi_{star}}{\phi_{standard}} \right] + m_{standard}$$



PSF



Aperture

$$m_{SN} = -2.5 \log_{10} \left[\frac{\phi_{SN}}{\phi_{star}} \right] + m_{star}$$

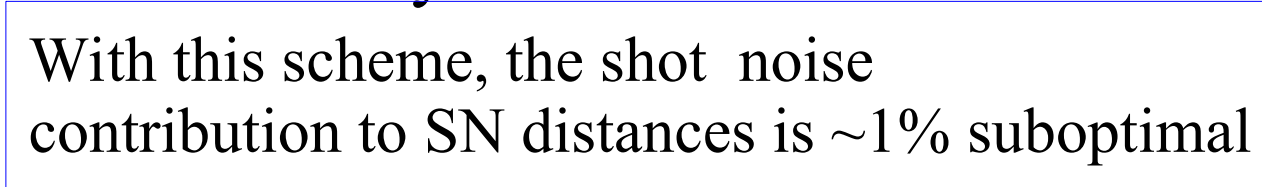


PSF

Averaged over
stars around the SN

Least squares

$$\chi^2 = \sum_i \sum_p w_{i,p} (M_{i,p} - I_{i,p})^2$$

- $w_{i,p} = 1/I_{i,p}$?
 - Bad because the weighted residuals are biased by shot noise because $I_{i,p}$ appears twice.
- $w_{i,p} = 1/(V_i + f_i \phi_{i,p})$? V_i : sky shot noise
 - Arguable because it renders the flux estimator non linear. Unbiased only if the PSF is accurate.
- $w_{i,p} = 1/V_i$: 

With this scheme, the shot noise contribution to SN distances is $\sim 1\%$ suboptimal

 - OK for faint sources, sub-optimal for bright sources. **Unbiased for any PSF shape.**

Technicalities of scene modeling

- It is worth to provide derivatives to the minimizer. The problem is “semi-sparse”, and almost linear.
- For the galaxy model, splines are a good option, 1knot per pixel is OK for well-sampled images
- Kernels can be computed right away from PSF’s evaluated at the SN location.
- If the SN is very faint in some band, the position should be fixed to the position in other bands.
- Lightcurves of neighboring stars can dominate the CPU budget (depending on SN density)

The “prerequisites”: PSF

- The difficult part is to accommodate the BF effect, but the shape fidelity is not an issue for this application, at variance with shear.
- We assume that the video chain non-linearity correction has been determined and applied.

The “prerequisites”: astrometry

- Jointcal was built to fit a relative solution (without any reference to an external catalog). Not clear if it is useful in the Gaia era.
- All available astrometry codes miss the ability to rotate the instrument distortion model w.r.t the focal plane. This is needed if one relies on an (empirical) instrumental solution.
- It is probably useful to account for chromatic differential refraction (jointcal has the code).
- However, the accuracy of the astrometric solution is a mild issue since it affects both SNe and neighboring stars in the same way.

The “prerequisites” : photometry

- One needs a uniform photometric response across the focal plane, preferably for PSF photometry. This is sometimes called a “star flat”, because it can be determined from dithered observations of a semi-dense stellar field.
- This does not come trivially from SNe observations (low star density)
- Even when the photometric response is uniform, one should allow for a scale per exposure or even something more flexible.

Performance assessment

- Almost trivial on an equatorial mount. Using real images:
 - pickup a (bright) star
 - copy a scaled down version not too far, shifting by an integer number of pixels
 - Compare the recovered flux ratio to the scale-down factor
- On an alt-az mount, with varying position angle?
with BF-affected CCDs ?
 - Not easy to avoid relying on the PSF model...

Actual performance on SNLS@CFHT

1306.5153

- Based on star shift-and-scale.
- Equatorial mount, small dithers ($\ll 1$ CCD)
- Thin CCDs : negligible brighter-fatter effect
- $\rightarrow O(0.1\%)$ accuracy (below other systematics)
- For LSST, the context is less favorable (sensors, ditherings, rotator ...), and the requirements are stronger. But there is no show-stopper.