distance moduli were usually derived, using the 'Virgo Infall' velocities[6], through the Ned Wright's Cosmological Calculator[7] adopting a standard cosmology ($H_0 = 73$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_\Lambda = 0.7$ and $\Omega_M = 0.3$).

## 2.4 SN photometry using SNOoPY

The final magnitudes of the objects presented in this thesis were obtained using the PSF-fitting technique and calibrated using the equations reported above, using a dedicated pipeline: SuperNOva PhotometrY ( SNOoPY; Cappellaro 2014). SNOoPY is a reduction pipeline specifically designed to perform PSF-fitting or template subtraction on multi-band photometric data obtained with different instruments and telescopes. The pipeline consists in a collection of PYTHON scripts calling standard IRAF tasks through PYRAF. Other specific analysis tools are also used, namely SEXTRACTOR[8] (Bertin & Arnouts 1996) for source extraction and star/galaxy separation, DAOPHOT[9] (Stetson 1987) to compute the magnitudes of the sources through the PSF-fitting technique and HOTPANTS[10] to perform template subtraction. Information on specific instruments (CCD features such as *gain, read-out-noise: RON, pixel-scales* and *datamin/datamax*, filters, UTs, sites and exposures) are available for a number of telescopes, but other specific instruments can be included in a configuration file (called 'snoopy.default'), so that photometry can be computed also from images obtained with different instrumental set-up configurations. An example of configuration file (for the instrument AFOSC mounted at the 1.82 m Copernico telescope located at Mount Ekar, Asiago, Italy) is reported below:

```
[AFOSC]
site:        ASIAGO
datamin:     -100
datamax:     60000.
epadu:       0.9
readnoise:   7.8
object:      OBJECT
exposure:    EXPTIME
mjd:         MJD
dateobs:     DATE-OBS
airmass:     AIRMASS
filter:      FILTER
scale:       0.52
seeing:      PSF_FWHM
UBVRI:       U,B-Bessel,V-Bessel,R-Bessel,i
ugriz:       u-Sloan,g-Sloan,r-Sloan,i-Sloan,z-Sloan
```

Different instruments can be included in the configuration file, so the photometric analysis can be performed simultaneously on different images. CCD gain and RON are used for cosmic-rays rejections. The pixel-scale is another fundamental feature, which is mostly used in the PSF determination. The keyword relative to the 'Modified Julian Date' (defined as JD − 2400000.5) is also used by the pipeline in the calibration of the instrumental magnitudes (as will be described in Section 2.4.5).

[6]based on the model of Mould et al. (2000) considering the influence of the Virgo Cluster only

[7]`http://www.astro.ucla.edu/~wright/CosmoCalc.html`

[8]`http://www.astromatic.net/software/sextractor`

[9]`http://www.star.bris.ac.uk/~mbt/daophot/`

[10]`http://www.astro.washington.edu/users/becker/v2.0/hotpants.html`

### 2.4.1 Preliminary steps

Pre-reduced images (see Section 2.1) can be organised in lists and different pre-requisites can be tested using the command ECLIST, which performs different checks on the image headers, giving error messages when any crucial keywords or information on the instrumental set-up are missing. An example of an ECLIST output is reported below:

```
 filename    object    instrument    dateobs       mjd        filter   b expos airm  seei
science_r PSNJ09p76 ALFOSC_FASU 2015-06-22  57195.906    r-Sloan  r  120   1.98 0.99
science_i PSNJ09p76 ALFOSC_FASU 2015-06-22    ERROR      i-Sloan  i  120   1.90 0.98
science_z PSNJ09p76 ALFOSC_FASU 2015-06-22  57196.012    z_Sloan  z  120   1.90 ERROR

********** Completed in  0 sec
```

where the 'MJD' is missing in the *i*-band image, while the *z*-band image does not include the keyword relative to the seeing. In the first case, the task ECMJD can be used, which reads basic information in the image header (such as the UT date of the observation) and computes the MJD of the frame's exposure:

```
usage: ecmjd.py [-h] [-d DATEOBS] [-t TIMESTART] [-e EXPTIME] [-m MJDKWR] [-r]
                [-v]
                list

Compute MJD and update keyword

positional arguments:
  list                  file list

optional arguments:
  -h, --help            show this help message and exit
  -d DATEOBS, --dateobs DATEOBS
                        DATE OBS keywork or 1900/01/31 (default: DATE-OBS)
  -t TIMESTART, --timestart TIMESTART
                        UT start OBS keyword or 00:00:00 (default: 00:00:00)
  -e EXPTIME, --exptime EXPTIME
                        EXPTIME keyword or seconds (default: 0)
  -m MJDKWR, --mjdkwr MJDKWR
                        MJD keyword (default: MJD-OBS)
  -r, --redo            Re-do (default: False)
  -v, --verbose         Print diagnostic informations (default: False)
```

The seeing can be computed using the ECSEEING task:

```
usage: ecseeing.py [-h] [-r] [-t THRESHOLD] [-i] imglist

Measure seeing

positional arguments:
  imglist               iraf format

optional arguments:
  -h, --help            show this help message and exit
  -r, --rseeing         re-measure seeing (default: False)
  -t THRESHOLD, --threshold THRESHOLD
                        Source detection threshold (default: 10.0)
  -i, --interactive     interactively select stars (default: False)
```

which measures the mean FWHM from non-saturated stars. Note that in the given image, or list of images, a valid astrometric calibration must already be performed. New keywords are hence added to the image headers, corresponding to the name given in the SNOoPY default file.

Astrometric calibration has to be performed before starting. Astrometry can be checked using the CHECK option in the ECLIST task. The task ECASTROAUTO automatically performs astrometric calibration on an image (or a list of images) comparing the positions of the stars in the field with either the USNO-A2.0 catalog of astrometric standards[11] or the 2MASS catalogs:

```
usage: ecastroauto.py [-h] [-r REFERENCE | -s SNCOO] [-t THRESHOLD]
                      [-c {ua2,2mass}] [-f {rscale,rxyscale,general}]
                      [-x XFRAME] [-w WSEEING] [-i] [-v]
                      imglist

Astrometric calibration

positional arguments:
  imglist               iraf format list (if * use quote)

optional arguments:
  -h, --help            show this help message and exit
  -r REFERENCE, --reference REFERENCE
                        reference image (input files must be all of the same
                        field (default: None)
  -s SNCOO, --sncoo SNCOO
                        field center: RA,DEC or file with RA DEC(input files
                        must be all of the same field) (default: None)
  -t THRESHOLD, --threshold THRESHOLD
                        Source detection threshold (default: 10.0)
  -c {ua2,2mass}, --catalog {ua2,2mass}
                        astrometric catalog (ua2|2mass) (default: 2mass)
  -f {rscale,rxyscale,general}, --fitgeometry {rscale,rxyscale,general}
                        plate solution geometry to be used (default: rscale)
  -x XFRAME, --xframe XFRAME
                        Trim border (default: 10)
  -w WSEEING, --wseeing WSEEING
                        seeing [fwhm in arcsec] (default: 1.0)
  -i, --interactive     Interactive mode (default: False)
  -v, --verify          verify mode (default: False)
```

This task is based on the IRAF task CCMAP, which uses the (RA, Dec) coordinates to generate an astrometric solution for the single frame. If a list of images is given, the first astrometric solution is used as a reference to calibrate the astrometry for all the other images.

When the source is particularly faint, and in order to avoid saturation, it is common to take a number of exposures instead of a very long one. Multiple exposures, in fact, can be median-combined in order to increase the SNR of the single images. SNOoPY combines consecutive images using the task ECDITHER:

```
usage: ecdither.py [-h] [-i] [--seeing SEEING] [-t THRESHOLD] [-x XFRAME]
                   [-l TOLERANCE] [-s] [-w] [-b BPM] [-v]
                   imglist outfile

Combine dithered images. WARNING: it herits the setting of the saved imcombine
parfile

positional arguments:
  imglist               img1,img2,... or @list
  outfile               output file name
```

[11] http://tdc-www.harvard.edu/catalogs/ua2.html

```
optional arguments:
  -h, --help            show this help message and exit
  -i, --interactive     Interactive mode (default: False)
  --seeing SEEING       seeing FWHM [arcsec] (default: 1.0)
  -t THRESHOLD, --threshold THRESHOLD
                        Source detection threshold (default: 5.0)
  -x XFRAME, --xframe XFRAME
                        Trim border (default: 5)
  -l TOLERANCE, --tolerance TOLERANCE
                        Tolerance in pixel (default: 1.0)
  -s, --sky             Subtract sky (default: False)
  -w, --wcs             use wcs (default: False)
  -b BPM, --bpm BPM     use bad pixel mask (give name)? (default: )
  -v, --verbose         Enable progress report (default: False)
```

which is based on the IRAF task IMCOMBINE. The alignment is made on the basis of the position of common sources in two different exposures, which can be selected manually (using the -i option), or automatically (e.g. selecting the -w option, if the images have already been astrometrically calibrated).

### 2.4.2 PSF

Several factors contribute to the variation of the PSF from one image to another, like different seeing and hence atmospheric conditions, telescope tracking, or geometric distortion over the field of view. For all these reasons, the PSF should be determined separately on each available frame.

The PSF is usually generated by averaging the profiles of a few stars in the field. Given the importance of a correct PSF determination, these sources must be selected among the best exposed, unsaturated (see Figure 2.3 for a visual example of saturated and unsaturated stars) and isolated stars in the field.

SNOoPY includes a task which automatically selects the best stars in the field using SEXTRACTOR algorithms. The automatic rejection of saturated stars is made on the basis of the *datamin* and *datamax* values included in the 'snoopy.default' file for each instrument. The task ECPSF uses the SN RA and Dec [J 2000] coordinates in an input file and returns the local average PSF. The source to be fitted is not used to compute the local PSF. Positional and optional arguments (although in general the automatic selection gives the best results) are reported below:

```
usage: ecpsf.py [-h] [-w WSEEING] [-f FITRAD] [-t THRESHOLD] [-p PSFSTARS]
                [-d DISTANCE] [-r] [-g] [-i] [-s] [-v]
                img sncoo

Automated psf creation

positional arguments:
  img                   file name
  sncoo

optional arguments:
  -h, --help            show this help message and exit
  -w WSEEING, --wseeing WSEEING
                        seeing [FWHM in pixel] (default: None)
  -f FITRAD, --fitrad FITRAD
                        fit radius (FWHM units) (default: 1.0)
  -t THRESHOLD, --threshold THRESHOLD
                        Source detection threshold (default: 10.0)
  -p PSFSTARS, --psfstars PSFSTARS
```

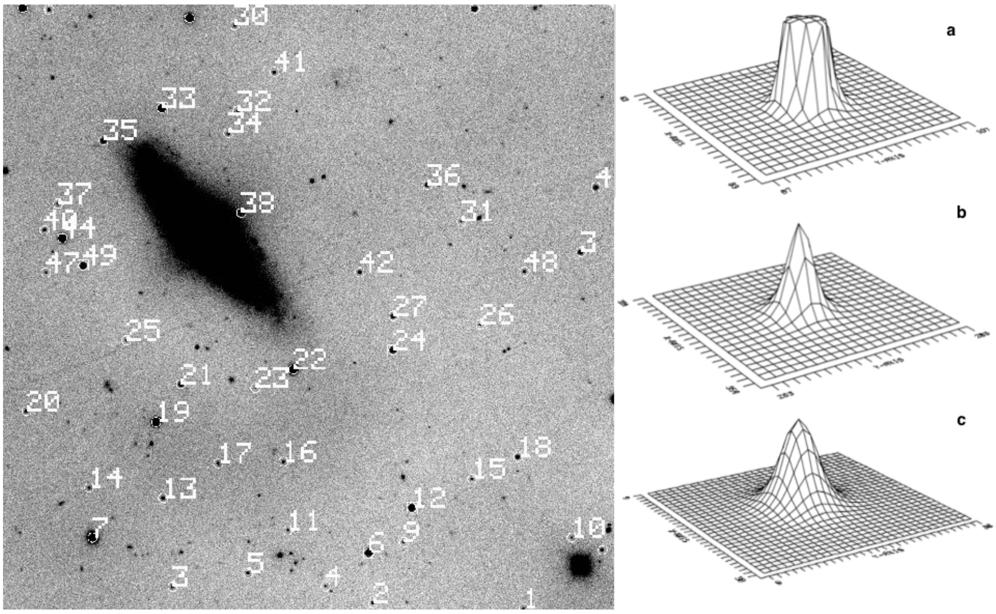

Figure 2.3: Output image of the task ECPSF. All the stars measured are labelled with a number and are marked with circles. The stars used to compute the local PSF are marked by squared circles. The procedure automatically exclude saturated or the non-isolated stars of the frame. Aperture magnitudes of all the measured stars in the field are written on a specific output file. Example of saturated **(a)** and unsaturated **(b)** star. PSF stars must be selected among the best exposed, unsaturated and isolated stars in the field. An example of a resulting PSF is also shown **(c)**.

```
                         Maximum number of psf stars (default: 5)
  -d DISTANCE, --distance DISTANCE
                         Minimum star separation (in unit of FWHM) (default:
                         10)
  -r, --redo             Re-do (default: False)
  -g, --generic          Generic instrument (default: False)
  -i, --interactive      Interactive mode (default: False)
  -s, --show             Show PSF output (default: False)
  -v, --verbose          Print diagnostic informations (default: False)
```

Selected stars are also displayed (see Figure 2.3 and the resulting PSF can be also checked (panel c of the same Figure) using the *-s* option. PSF stars can also be selected manually and single star profiles checked using the *-i* option.

The output consists in a file named '*.psf.fits' which contains the PSF analytical model and the residuals. A file named '*.sn' is also created, including a number of information needed for the following steps, such as the aperture photometry for all the measured stars in the field along with the magnitudes of the stars used to compute the PSF (stars labelled with circles and squared circles respectively in Figure 2.3), but also information on the instrument, filters, airmass, exposure times and MJD of the observation. An example of this output file is reported below:

```
PSNJ09p76r_sloan-image 1of2    ALFOSC_FASU    2015-06-22T21:44:17.991     57195.91 r
Exptime 120.0    Airmass 1.98006959315    FWHM[pix]    5.4    Ap.Corr. -0.029 +/- 0.033
           RA             DEC   magp(2)  magph(3)  err     mph(4)    magfit    err   diff
  9:13:13.828   76:24:45.92   -6.468   -6.522   0.028   -6.576    -6.459   0.024
  9:13:48.613   76:24:55.99   -7.220   -7.256   0.015   -7.273    -7.131   0.017
  9:13:22.041   76:24:56.16   -5.711   -5.777   0.057   -5.830    -5.751   0.038
  9:13:35.497   76:25:04.31   -6.415   -6.533   0.027   -6.614    -5.889   0.040
```

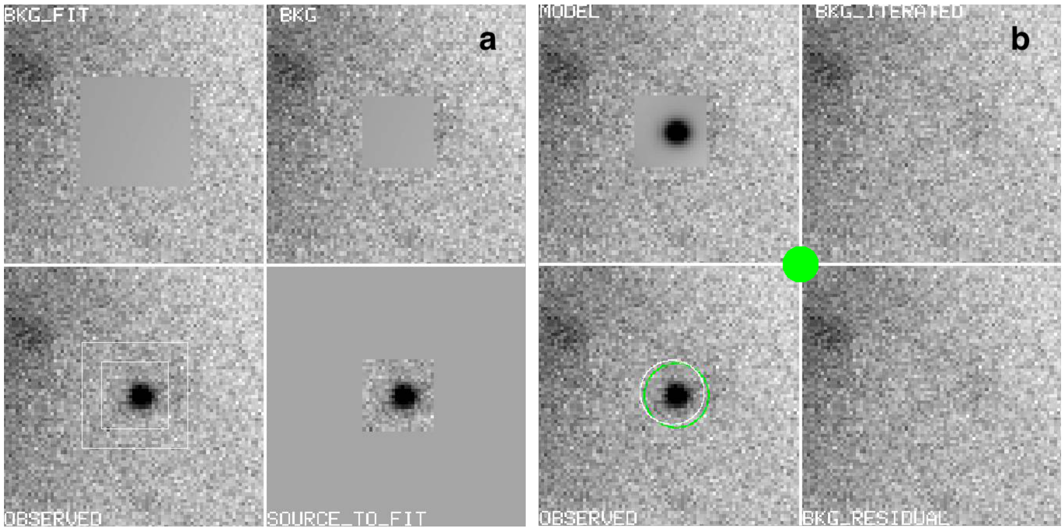


Figure 2.4: Example of image output in the interacting mode of ECSNFIT. **a)** First, background is estimated and subtracted to the region of the source, the source is then fitted and subtracted, in ordere to compute a new estimate of the background. **)** Finally, the source is fitted again using the iterated background estimate, and the residuals are shown to check the quality of the final fit. An accurate estimate of the source's centroid is also performed and the result is displayed by the green open circle in the **b** panel, while the central filled green circle indicates that the SNR estimate at the position of the sources is $\gtrsim 10$ (see Section 2.4.3).

```
9:13:14.527   76:25:16.57  −10.224  −10.264   0.002  −10.279   −10.225    0.007  −0.039
9:12:33.974   76:25:17.98   −6.417   −6.433   0.036   −6.488    −6.549    0.025
9:13:08.437   76:25:23.21   −5.490   −5.507   0.069   −5.406    −5.431    0.062
9:12:39.271   76:25:25.68   −5.339   −5.310   0.093   −5.175    −5.423    0.055
9:13:28.584   76:25:30.50   −5.679   −5.745   0.057   −5.751    −5.680    0.040
9:13:07.033   76:25:44.16  −10.449  −10.487   0.002  −10.501   −10.483    0.008  −0.004
```

This file contains comprehensive information about the frame, including the final instrumental magnitude of the source and the errors.

### 2.4.3 PSF fitting

SNOoPY performs automatic PSF-fitting with the specific task ECSNFIT:

```
usage: ecsnfit.py [-h] [-b BKG_PAR] [-f FITRAD] [-w WSIZE] [--recenter] [-r]
                  [-i] [-m] [-g] [-v]
                  img

SN fit

positional arguments:
  img                   file name

optional arguments:
  -h, --help            show this help message and exit
  -b BKG_PAR, --bkg_par BKG_PAR
                        Bgk fit annulus (in,out) and order (x,y) (default:
                        2.,3.,2,2)
  -f FITRAD, --fitrad FITRAD
                        fit radius (FWHM units) (default: 1.0)
  -w WSIZE, --wsize WSIZE
                        display window size (FWHM units) (default: 15)
  --recenter            recentering (default: True)
  -r, --redo            Re-do (default: False)
  -i, --interactive     Interactive (default: False)
```

```
  -m, --manual          Manual adjustment (default: False)
  -g, --generic         Generic instrument (default: False)
  -v, --verbose         Print diagnostic informations (default: False)
```

A file named '*.res.fits' is also generated, containing the residual of the PSF-fit (see Figure 2.4). The fitting procedure is performed as follows: the local analytic PSF is fitted to the source, whose position is obtained in pixel coordinates in the '.sn' pre-generated file (see Section 2.4.2). The procedure interactively asks the user if the input coordinates actually refer to the desired source, and a specific algorithm re-centers the target's coordinates when necessary (Figure 2.4). The local background is then estimated, and the analytic local PSF is fitted to the selected source. Using the inferred instrumental magnitude, the source is then subtracted and the background is better estimated on the 'clean' frame. This new 'iterated' background is then used to fit the analytic PSF to the source.

As SNe are transient objects, their luminosity typically fades at late phases and eventually their apparent magnitudes become fainter than the limiting magnitudes of astronomical instruments. A crucial role in determining the limiting magnitude of an astronomical image is played by the SNR for a given source in the field:

$$(SNR)_{x,y} = \frac{(I + BKG) \times adu}{\sqrt{(I + BKG) \times adu + ron^2}}, \qquad (2.4)$$

which affects the precision of the photometry. The limiting magnitude is typically affected by the contribution of different sources of noise, but strongly depends on the atmospheric conditions. Sky transparency, moon light contamination and seeing are the most important sources of noise in ground-based images. The SNR of the fitted source is reported in the fit summary (Figure 2.4): a green circle is printed when the SNR is $\gtrsim 10$, a blue square appears if the SNR is between 3 and 10 and a red triangle indicated that the SNR is $< 3$. When no sources are detected at the SN position, SNOoPY automatically compute the limiting magnitude of the image adopting a limiting SNR of 2.5 (Figure 2.5, although this value can be changed by the user) using the task ECLIMIT:

```
usage: eclimit.py [-h] [-s SNR] [-w WSIZE] [-r] [-i] [-g] img

Estimate upper limit with artificial star

positional arguments:
  img                   file name

optional arguments:
  -h, --help            show this help message and exit
  -s SNR, --snr SNR     S/N threshold for limit (default: 2.5)
  -w WSIZE, --wsize WSIZE
                        display window size (FWHM units) (default: 15)
  -r, --redo            Re-do (default: False)
  -i, --interactive     Interactive (default: False)
  -g, --generic         Generic instrument (default: False)
```

Photometric errors are obtained through the 'artificial star' technique, in which a fake star with the same magnitude and profile of the fitted source is placed, in the background iterated PSF-fit residual image, in a position close, although not coincident, with the SN position. The artificial image is then processed through the same steps, and the magnitude of the fake star recovered using the procedures described above. The dispersion of different measurements obtained from a number of these experiments (with the artificial star placed in slightly different positions) is then taken as an estimate of the instrumental magnitude error, and combined in

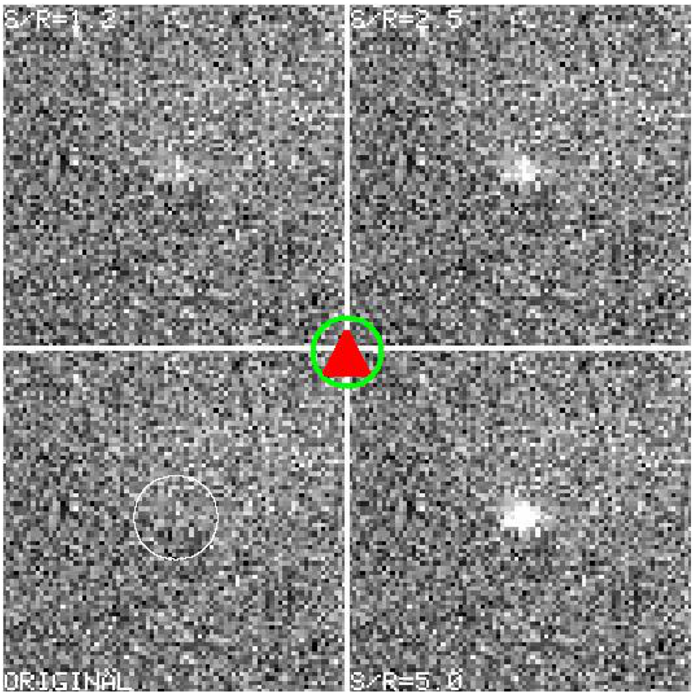


Figure 2.5: Example of limiting magnitude computation. The limiting SNR in this example was left to default value of 2.5. The circled triangle symbol indicate that the source was not detected in the image.

quadrature with the PSF-fit error returned by DAOPHOT. SNOoPY automatically performs artificial stars experiments using the task ECARTERR:

```
usage: ecarterr.py [-h] [-a ARTSHIFT] [-v] [-g] img

Artificial star experiments for latest sn fit

positional arguments:
  img                   file name

optional arguments:
  -h, --help            show this help message and exit
  -a ARTSHIFT, --artshift ARTSHIFT
                        shift [pix] for artstar experiments (default: 2.0)
  -v, --verbose         Print diagnostic informations (default: False)
  -g, --generic         Generic instrument (default: False)
```

### 2.4.4 Template subtraction

When a template image is available, this can be subtracted to images in which the SN is clearly visible. As stated above, this technique is particularly useful in the case of strong host galaxy contamination, or when the magnitude of the source is comparable to the background. This is performed in SNOoPY through a number of steps:

- First, a geometric transformation is computed, in order to scale the template image to the selected frame. This step is performed using several common stars in the fields, taking advantage of the astrometric calibration, which must already be performed.
- The template image is subtracted using the PSF match, degrading the image with the best seeing.

Finally, either aperture or PSF-fitting photometry can be used to the subtracted images, although SNOoPY adopts by default PSF-fitting photometry on the subtracted images also, as it proved to be less sensitive to residual background variations. SNOoPY performs the subtraction of template images using HOTPANTS, through the task ECSNDIFF :

```
usage: ecsndiff.py [-h] [-t THRESHOLD] [-s SNR] [-x XTASKS] [-i] [-v]
                   [-f FITGEOMETRY] [--nrxy NRXY] [--nsxy NSXY] [--ko KO]
                   [--bgo BGO] [--afssc] [--psfstars PSFSTARS]
                   [--distance DISTANCE] [--bkg_par BKG_PAR] [--wsize WSIZE]
                   [--recenter] [--fitrad FITRAD]
                   img ref sncoo

Image difference with hotpants and SN mag with psf fit

positional arguments:
  img                    new image
  ref                    reference
  sncoo                  sn coo

optional arguments:
  -h, --help             show this help message and exit
  -t THRESHOLD, --threshold THRESHOLD
                         Source detection threshold (default: 5.0)
  -s SNR, --snr SNR      S/N threshold for limit (default: 2.5)
  -x XTASKS, --xtasks XTASKS
                         task to be performed r-register, d-ifference, f-it
                         (default: rdf)
  -i, --interactive      interactive mode (default: False)
  -v, --verbose          Enable task progress report (default: False)

image registration:
  -f FITGEOMETRY, --fitgeometry FITGEOMETRY
                         ccmap fit geometry (rscale,rxyscale,general ...)
                         (default: rscale)

hotpants difference:
  --nrxy NRXY            number of image region in x y directions (default:
                         1,1)
  --nsxy NSXY            number of region stamps in x y directions (default:
                         8,8)
  --ko KO                spatial order of kernel variation within region
                         (default: 1)
  --bgo BGO              spatial order of background variation within region
                         (default: 1)
  --afssc                use selected stamps (default: False)

psf fit:
  --psfstars PSFSTARS    maximum number of psf stars (default: 5)
  --distance DISTANCE    minimum star separation (in unit of FWHM) (default: 5)
  --bkg_par BKG_PAR      bgk fit annulus (in,out) and order (x,y) (default:
                         2.,3.,1,1)
  --wsize WSIZE          display window size (FWHM units) (default: 15)
  --recenter             recenterig (default: True)
  --fitrad FITRAD        fit radius (FWHM units) (default: 1.0)
```

### 2.4.5 Calibration

The calibration of instrumental magnitudes to the final apparent magnitudes is based on the set of equations (2.3), in which the $a_\lambda$ and $b_\lambda$ terms play a crucial role. These terms are the ZP and CT respectively, and are fundamental parameters that should be inferred for each instrument and observational night. In SNOoPY, photometric calibration is performed using a set of selected stars in the SN field, calibrated using ZPs and CTs obtained during photometric nights with the task ECPH:

```
usage: ecph.py [-h] [-m MAG] [-p {johnson,sloan}] [-w] [-s] [-i] [-d] imglist

Measure standard field and derive zero points

positional arguments:
  imglist               list of images

optional arguments:
  -h, --help            show this help message and exit
  -m MAG, --mag MAG     Magnitude limit for standards (V band) (default: 20.0)
  -p {johnson,sloan}, --photosys {johnson,sloan}
                        photometric system (johnson|sloan) (default: johnson)
  -w, -web              Retrive Sloan table from DRS10 (default: False)
  -s, --stetson         Include stetson table (default: False)
  -i, --interactive     Interactive (default: False)
  -d, --display         Display matched star (default: False)
```

which writes ZPs and CTs for each specific instrument and photometric night in an output file. An example of this file (called 'phot.ph') is reported below:

```
### AFOSC 2012-02-28    57073
U UB 19.929 0.011 0.196 0.018
B BV 22.881 0.010 0.026 0.017
V BV 23.706 0.011 0.021 0.019
V VR 23.705 0.012 0.037 0.035
R VR 23.492 0.007 -0.019 0.020
R RI 23.492 0.007 -0.018 0.019
I RI 22.622 0.007 -0.107 0.021
u ug 21.277 0.014  0.109 0.008
g gr 24.322 0.011  0.044 0.013
r gr 24.102 0.020 -0.057 0.029
r ri 24.065 0.025  0.007 0.101
i ri 23.452 0.014  0.007 0.035
z iz 23.338 0.030 -0.358 0.219
```

The observations of 'standard' fields, namely fields of stars with well known magnitudes and range of colours is helpful to calibrate photometric data. The comparison of measured magnitudes with calibrated magnitudes directly provides ZPs and CTs for specific nights and instrumental set-ups, which can be used to calibrate the local standard sequence. Nonetheless, the observation of standard stars fields (e.g. from the lists of Landolt 1973, 1983, 1992) must be performed during photometric nights only.

Photometric conditions are ensured when the uncertainties in the final magnitudes are not affected by variations in the atmospheric throughput as well as instrumental sensitivity, and instrumental conditions are therefore constant over the sky and the observation time (Stetson 2013).

The local sequence of calibrated stars can be generated using the task ECREFSTAR:

```
usage: ecrefstar.py [-h] [-p PHOTLOG] [-i] [-c CTOLERANCE] [-v] [-a] list

Calibrate local reference stars

positional arguments:
  list                  file list

optional arguments:
  -h, --help            show this help message and exit
  -p PHOTLOG, --photlog PHOTLOG
                        Photo calibration file (default: )
  -i, --interactive     Interactive (default: False)
```

```
  -c CTOLERANCE, --ctolerance CTOLERANCE
                        coordinate matching tolerance [arcsec] (default: 1.0)
  -v, --verbose         Print diagnostic informations (default: False)
  -a, --astro           Check astrometry (default: False)
```

Alternatively, the local sequence can be obtained using the ECZEROPOINT task:

```
usage: eczeropoint.py [-h] [-p PHOTLOG] [-m MAGLIM] [-i] [-w]
                      [-c {sloan,apass}]
                      imglist

measure photometric zero point against sloan or apass

positional arguments:
  imglist               image list

optional arguments:
  -h, --help            show this help message and exit
  -p PHOTLOG, --photlog PHOTLOG
                        Photo calibration file (default: )
  -m MAGLIM, --maglim MAGLIM
                        Magnitude limit for selection (default: 19.0)
  -i, --interactive     Interactive (default: False)
  -w, --write           write catalog (default: False)
  -c {sloan,apass}, --catalog {sloan,apass}
                        photometric catalog) (default: sloan)
```

The *-w* option, in particular, checks for archival SDSS magnitudes for the given frame, and automatically writes a file containing the local standard Sloan magnitudes, but also derives (and writes in an output file) the $UBVRI$ Johnson-Cousins magnitudes using the relations obtained by Chonis & Gaskell (2008, see Equations 2.5).

$$\begin{aligned} B &= g + (0.327 \pm 0.047)(g-r) + (0.216 \pm 0.027) \\ V &= g - (0.587 \pm 0.022)(g-r) - (0.011 \pm 0.013) \\ R &= r - (0.272 \pm 0.092)(r-i) - (0.159 \pm 0.022) \\ I &= i - (0.337 \pm 0.191)(r-i) - (0.370 \pm 0.041) \end{aligned} \tag{2.5}$$

Archival photometric ZPs and CTs obtained during photometric nights are needed to calibrate non photometric nights, and must be provided in a separate file. These parameters are used by SNOoPY to determine the magnitude of the local standards in the frames obtained during non-photometric nights. Finally, these values are compared to those obtained during photometric nights using the task ECNIGHTCAL:

```
usage: ecnightcal.py [-h] [-p PHOTLOG] [-i] [-c CTOLERANCE] [-d] list localref

Check zero point fro each night/filter

positional arguments:
  list                  file list
  localref              local reference

optional arguments:
  -h, --help            show this help message and exit
  -p PHOTLOG, --photlog PHOTLOG
                        Photo calibration file (default: None)
  -i, --interactive     Interactive (default: False)
  -c CTOLERANCE, --ctolerance CTOLERANCE
                        coordinate matching tolerance [arcsec] (default: 1.0)
  -d, --display         Display position of local reference (default: False)
```

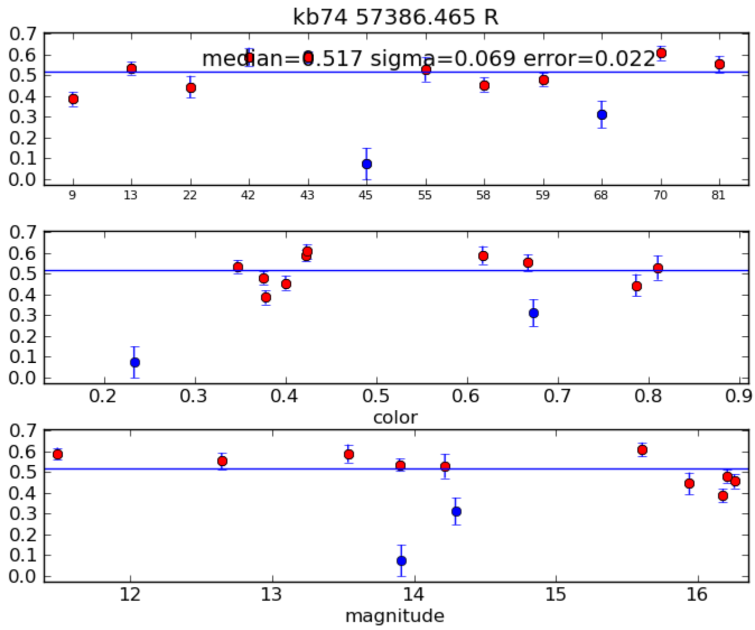


Figure 2.6: Comparison of the measured magnitudes of the stars of the local sequence in a non-photometric night with the calibrated ones. Blue stars are rejected and are not used to compute the ZP correction. Calibration errors are also reported, along with basic information on the specific frame.

producing a list of corrections to the ZPs to be applied to the images obtained during non-photometric nights which is then written in a file named 'zerocor.dat':

```
kb74 57057.320 B  0.395 0.084 V  0.499 0.029 R  0.459 0.034 I  0.417 0.046
kb74 57067.490 B  1.665 0.066 V  1.857 0.065 R  1.820 0.080 I  1.820 0.079
kb74 57073.475 B  0.439 0.063 V  0.559 0.040 R  0.520 0.027 I  0.485 0.046
```

### 2.4.6 Final apparent magnidutes

The final apparent magnitudes are obtained using the command ECSNCAL, which is summarised below:

```
usage: ecsncal.py [-h] [-p PHOTLOG] [-z ZEROCORFILE] [-i] list

Derive SN apparent magnitude and checks reference stars

positional arguments:
  list                  file list

optional arguments:
  -h, --help            show this help message and exit
  -p PHOTLOG, --photlog PHOTLOG
                        Photo calibration file (default: None)
  -z ZEROCORFILE, --zerocorfile ZEROCORFILE
                        File with zeropoint for each night (default: None)
  -i, --interactive     Interactive (default: False)
```

where photometric ZPs and CTs along with the information on their corrections must be provided. Corrected ZPs and CTs are applied to the instrumental magnitudes obtained in the previous steps and final apparent magnitudes are written on a file named ‘snlc.dat’. The results can be also displayed using the -*i* option.