Final Project AST 5201

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Abstract

This project involved photometry for the three band g, r and i of the supernova *SN2017eaw* located in galaxy of *NGC 6946*. After finding the offset in each band, by comparing the instrumental magnitude with the magnitude in the PanSTARRS, the magnitude of *SN2017eaw* was calculated. Compared to the photometry found in Open Supernova Catalog, the observed magnitudes $m_g = 13.499 \pm 0.0226$, $m_r = 12.872 \pm 0.0234$, and $m_i = 12.775 \pm 0.0064$ were close for the g and i band, and slightly less close for the r band. Worth noting are the surprisingly small errors, which are a consequence of small errors in the offset. Next, the magnitudes were corrected for extinction, and from this, the following absolute magnitudes of *SN2017eaw* were found $M_g = -17.08\ (-0.26, +0.28)$, $M_r = -17.35\ (-0.24, +0.26)$, and $M_i = -17.24\ (-0.22, +0.24)$. Finally, the three scientific images were combined in `DS9` to form a false RGB image of the supernova and its host galaxy. As an additional task, the significance of detection was calculated for a laser beam.

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Introduction

For this project, supernova *SN2017eaw* in galaxy *NGC 6946* with the reported distance $d = 7.73 \pm 0.78\,\mathrm{Mpc}$ was studied [1]. Starting with skyflats and a combined bias file used in the previous labs, photometry was performed on scientific images taken June 16$^{\mathrm{th}}$ 2017 in the g, r and i bands. This was done by first subtracting the overscan region and then correcting for the flat-fields. Second, offsets were found by subtracting the magnitude of 10 standard stars found in the `PanSTARRS` catalog with their corresponding instrumental magnitude found using `imexam`. From this, the observed magnitudes of *SN2017eaw* were obtained and compared to values found in the Open Supernova Catalog (OSC). Moreover, the observed magnitudes were also corrected for extinction, and this enabled me to find the extinction-corrected absolute magnitude for *SN2017eaw*. Finally, the three science frames for the different bands were combined in `DS9` to give a false RGB image*, see Figure 1. In addition, the figure contains a compass and a ruler, which both were added directly in `DS9`. As a final task, the significance of detection was calculated for an extraterrestrial civilization, pointing a laser beam towards us.

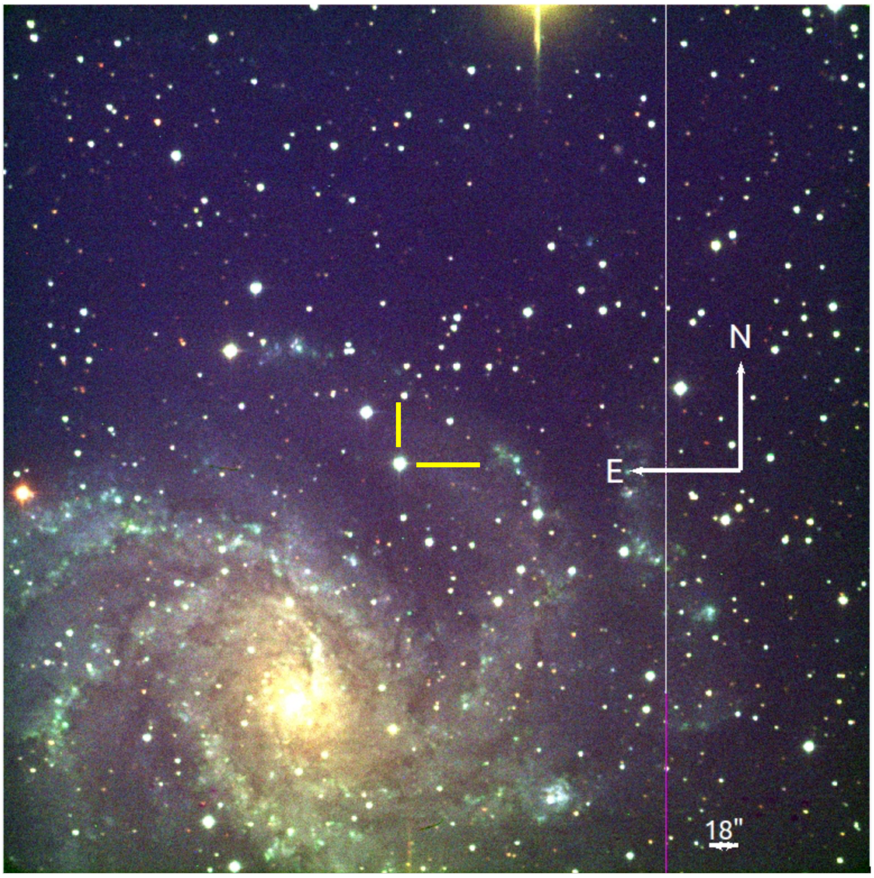


Figure 1: False RGB image constructed in `DS9` of *SN2017eaw* and its host galaxy *NGC 6946* along with a ruler and a compass.

**I felt that I was a bit limited in DS9 to do further artistic improvements to the figure. I would have liked to slightly reduce the greens maybe.*

Extraction of Photometry

To extract the photometry, code from Optical lab IV and the "old" combined bias frame generated in the same lab was used. Then, the final reduced science frames were uploaded to `nova.astrometry.net`, giving the coordinates in WCS for the 10 standard stars chosen for each band. Table 1, 2 and 3 contain coordinates (physical and RA, Dec), PSF magnitude from `PanSTARRS`, instrumental mag, and offset for 10 chosen standard stars in the g, r and i band respectively. The offsets were found by $m_{\text{PSF}} - m_{\text{inst.}}$. Furthermore, in Appendix A, I explored the result from `PanSTARRS` catalog, and what I did to obtain my values.

In addition, the average offsets before and after removing the two most extreme values for all bands along with the standard deviations are given in Table 4. Lastly, the instrumental magnitude and observed magnitude of *SN2017eaw* are given in Table 5.

Table 1: Physical coordinates (`xpix` and `ypix`), WCS coordinates (RA Dec), PSF magnitude from `PanSTARRS`, instrumental mag, and offset for 10 chosen standard stars in the g band.

Star	`xpix` `ypix`	**Ra** **dec**	m_{PSF}	$m_{\text{inst.}}$	**Offset**
1	715.85 213.87	308.73097596 60.23944511	16.6294	14.907	1.7224
2	468.83 77.58	308.66087351 60.25892483	16.2422	14.494	1.7482
3	373.71 284.85	308.63345439 60.22971295	16.3701	14.676	1.6941
4	179.22 283.43	308.57809873 60.23005079	14.9420	13.249	1.6930
5	923.12 361.52	308.78965940 60.21836748	16.2679	14.505	1.7629
6	54.29 486.45	308.54230507 60.20143968	16.6550	14.978	1.6770
7	772.64 39.25	308.74750089 60.26406254	15.6638	13.938	1.7258
8	312.67 308.99	308.61604511 60.22634748	16.5099	14.826	1.6839
9	349.58 666.74	308.62600738 60.17576978	15.5127	13.929	1.5837
10	58.55 249.36	308.54379171 60.23493847	17.2603	15.559	1.7013

Table 2: Physical coordinates (`xpix` and `ypix`), WCS coordinates (RA Dec), PSF magnitude from PanSTARRS, instrumental mag, and offset for 10 chosen standard stars in the r band.

Star	`xpix` `ypix`	**Ra** **dec**	$m_{\mathbf{PSF}}$	$m_{\mathbf{inst.}}$	**Offset**
1	717.27 213.87	308.73141252 60.23936967	15.7466	14.092	1.6546
2	468.83 77.58	308.66093306 60.25886237	15.6510	13.962	1.6890
3	375.13 284.85	308.63393554 60.22966158	15.5331	13.875	1.6581
4	314.09 306.15	308.61653861 60.22670197	15.8938	14.27	1.6238
5	159.34 272.08	308.57255836 60.23163030	15.2600	13.635	1.6250
6	468.83 79.0	308.66093074 60.25866176	15.6510	13.962	1.6890
7	923.12 361.52	308.78967004 60.21828487	15.8103	14.132	1.6783
8	947.26 487.87	308.79625486 60.20040735	16.9850	15.284	1.7010
9	40.09 916.61	308.53791461 60.14065535	17.5611	15.838	1.7231
10	281.43 998.95	308.60627561 60.12885488	15.4401	13.753	1.6871

Table 3: Physical coordinates (`xpix` and `ypix`), WCS coordinates (RA Dec), PSF magnitude from `PanSTARRS`, instrumental mag, and offset for 10 chosen standard stars in the i band.

Star	`xpix` `ypix`	**Ra dec**	$m_{\mathbf{PSF}}$	$m_{\mathbf{inst.}}$	**Offset**
1	816.65 176.96	308.75981903 60.24444026	13.8273	12.41	1.4173
2	771.22 39.25	308.74716429 60.26394467	14.5034	13.112	1.3914
3	372.29 282.01	308.63316292 60.23001792	15.1291	13.735	1.3941
4	115.33 533.3	308.55974253 60.19470215	15.1108	13.728	1.3828
5	717.27 216.71	308.73145135 60.23892855	15.3154	13.92	1.3954
6	183.48 81.84	308.57969688 60.25844060	16.6108	15.193	1.4178
7	402.11 364.35	308.64151956 60.21836023	14.1435	12.754	1.3895
8	928.8 63.39	308.79199516 60.26036072	16.6571	15.267	1.3901
9	931.64 530.46	308.79177192 60.19436898	16.3083	14.903	1.4053
10	281.43 1001.79	308.60629543 60.12839531	15.2117	13.812	1.3997

Table 4: Offsets for the different band before and after being adjusted.

Band	**Offset**	**Adj. Offset**
g	1.70 ± 0.047	1.71 ± 0.023
r	1.67 ± 0.031	1.67 ± 0.023
i	1.40 ± 0.011	1.39 ± 0.006

Table 5: Instrumental magnitude and estimation of observed magnitude of *SN2017eaw*

Band	$m_{\mathbf{inst.}}$	$m_{\mathbf{obs.}}$
g	11.793	13.499 ± 0.0226
r	11.199	12.872 ± 0.0234
i	11.381	12.775 ± 0.0064

Comparing Photometry to References

In Table 6, the observed magnitudes (found by me) in the g, r and i band along with the converted B, R and I magnitudes are compared to magnitudes provided in the project instructions from Open Supernova Catalog (OSC). Put differently, the values in the OSC column are the given values. The OSC magnitudes were converted to g, r and i using the provided formulae, and since $V - R = 13.18 - 12.67 = 0.51 < 0.93$ the first formula was used for the $r - R$ conversion. Similarly, the observed values in g, r and i were also converted to B, R and I using the provided formulae, again with the first formula for $r - R$.

Table 6: Observed magnitudes along with the magnitudes from Open Supernova Catalog (OSC) for the g, r, i, B, R, I and V bands. Note that the the observed magnitudes in g, r and i were converted to B, R, I, and the OSC magnitudes in B, R, I were also converted to g, r, i.

Band	**Obs. mag**	**OSC mag**
g	13.499 ± 0.023	13.686 ± 0.030
r	12.872 ± 0.023	13.686 ± 0.026
i	12.775 ± 0.006	12.675 ± 0.023
B	13.993 ± 0.023	14.18 ± 0.03
R	11.856 ± 0.029	12.67 ± 0.02
I	12.339 ± 0.010	12.24 ± 0.02
V	–	14.18 ± 0.03

Comparing the observed values to the given values, the g/B and i/I band values seem to be quite close while the r/R values deviate more. Interestingly, the errors for the observed magnitudes are in general smaller than the OSC magnitudes, which is most certainly a consequence of the smaller errors in the offset values used to correct the instrumental magnitudes. Again, I discuss this in more detail in Appendix A, but it is obvious that the small difference between the magnitudes obtained from PanSTARRS and the observed magnitudes gives the small errors.

In addition, I could not get the `'w'` command in `imexam` to work (I think someone else also had that issue during the labs), which meant that it was difficult to check whether some of the chosen standard stars were saturated. Maybe that could explain the larger differences in the r band. In effort to avoid this while picking the stars, I tried to choose somewhat medium bright stars. Another obvious approach to get more reasonable values would be to examine more standard stars.

Galactic Extinction for the Bands

To determine the extinction for the different bands, I used the website provided in the pdf (`https://ned.ipac.caltech.edu/forms/calculator.html`) with the Ra and dec values for *SN2017eaw*. For the epoch, I entered the acquisition date 6/16/17 in decimal years as instructed on the website. After entering all values, the extinction values were taken from the left table (E. Schlafly et al.).

Next, the extinction-corrected magnitudes for the bands were found by $m_{\text{intrinsic}} = m_{\text{obs}} - A_\lambda$.

With $d = 7.73 \pm 0.78\,\mathrm{Mpc}$ as found by [1], the distance modulus calculated accordingly

$$m - M = 5\log_{10}(d/10) = 29.4\,(-0.23,\ +0.21),$$

where the error is non-symmetric due to the log function. Rearranging gives the absolute magnitude $M = m - 5\log_{10}(d/10)$ and the extinction-corrected absolute magnitude $M = m_{\mathrm{obs}} - A_\lambda - 5\log_{10}(d/10)$. To summarize, extinction values and the corrected magnitudes are available in Table 7. As a double check the corrected magnitudes are lower than $m_{\mathrm{obs.}}$ in Table 5, good! As a refresher, I consulted [2] and my notes from the lecture on March 24$^{\mathrm{th}}$ for some equations and explanations of the extinction.

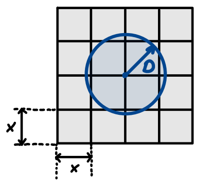
Table 7: Extinction (A_λ), extinction-corrected magnitude and extinction-corrected absolute magnitude for the different bands.

Band	$\boldsymbol{A_\lambda}$	**Corr.** $\boldsymbol{m}$	**Corr.** $\boldsymbol{M}$
g	1.134	12.36 ± 0.05	$-17.08\,(-0.26,\ +0.28)$
r	0.784	12.09 ± 0.03	$-17.35\,(-0.24,\ +0.26)$
i	0.583	12.20 ± 0.01	$-17.24\,(-0.22,\ +0.24)$

Significance Calculation

For the significance calculation, I followed the notes from lecture 4, assuming a Poisson distribution [3]. In the full calculation, available in Figure 2, I calculated both the number of sigmas and the signal-to-noise ratio, however, they both gave a similar result of 16 and 15 respectively. In conclusion, both values would make the detection significant.

Exposure background: $B = 201.2$ ADU/pixel
Pixel size: $x = 0.6''$
CCD gain: $g = 3\ e^-/\mathrm{ADU}$
FWHM: $f = 2''$
Aperture: $D = 1.3''$
Measured ADU: $\Phi = 3468$ ADU



First I note that $D = 1.3'' \simeq 0.67 f = 1.34''$

Area of a pixel: $x^2 = (0.6'')^2 \Rightarrow$ Background per area: $B/x^2 = 558.89 \Rightarrow$ Background e^-/area: $gB/x^2 = 1676.67$

Background in aperture (e^-): $\frac{gB}{x^2}\pi D^2 \simeq 8902$; Measured e^- in aperture: $\Phi g = 10404$

Counts in aperture from potential source (e^-): $10404 - 8902 \simeq 1502 \equiv S$

Assuming a Poisson dist. Finding significance by $S = 1502$ & $\lambda = 8902$

The standard dev. $\sigma = \sqrt{\lambda} = \sqrt{8902} \simeq 94$;

$$\left.\begin{array}{l} \text{Number of } \sigma \text{ for source: } S = n\sigma \Rightarrow n = S/\sigma = \dfrac{1502}{\sqrt{8902}} \simeq 15.9 \simeq 16 \\[2ex] \text{Computing signal-to-noise ratio: } S/N = \dfrac{1502}{\sqrt{\underbrace{1502}_{\text{Source noise}} + \underbrace{8902}_{\text{Background}}}} = 14.7 \simeq 15 \end{array}\right\} \text{Giving a similar result}$$

Figure 2: Full calculation of the significance of detection and the signal-to-noise ratio.

References

[1] S. D. Van Dyk, W. Zheng, J. R. Maund, *et al.*, "The Type II-plateau Supernova 2017eaw in NGC 6946 and Its Red Supergiant Progenitor," *The Astrophysical Journal*, vol. 875, no. 2, p. 136, Apr. 2019, ISSN: 1538-4357. DOI: 10.3847/1538-4357/ab1136. [Online]. Available: http://dx.doi.org/10.3847/1538-4357/ab1136.

[2] A. R. Choudhuri, "Astrophysics for physicists," in Cambridge University Press, 2010, ch. 6, p. 158.

[3] P. Kelly, *Lecture 4*, Lecture in AST 5201, University of Minnesota, Twin Cities, Feb. 3, 2025. [Online]. Available: https://canvas.umn.edu/courses/492027/files/folder/Lectures?preview=50209611.

A PanSTARRS Magnitudes

To obtain the standard star magnitudes using the PanSTARRS catalog, I followed the procedure given in Optical Lab V. To begin, the physical coordinates were converted to WCS coordinates and then used to search in the catalog one star at the time. However, since each search gave roughly $3 - 10$ values of λ`MeanPSFMag` (λ = band), I first tried using the mean of all magnitudes, which gave much more reasonable errors for the offsets but offset values were quite high. Consequently, the observed magnitudes (see Table 8) were also significantly higher than the values from the Open Supernova Catalog. Instead, what I ended up doing was to take the minimum value found in the list from PanSTARRS for each standard star, as that gave magnitudes closer to the ones reported in the Open Supernova Catalog. However, with this approach, the errors were maybe too small.

Table 8: Instrumental magnitude, estimation of observed magnitude of *SN2017eaw* and the mean offset using the **mean** of all PanSTARRS magnitudes found.

Band	$m_{\text{inst.}}$	$m_{\text{obs.}}$	Offset
g	11.793	16.721 ± 0.8387	4.928
r	11.199	16.646 ± 0.5801	5.447
i	11.381	16.429 ± 0.5688	5.048

Additionally, I decided to plot the instrumental magnitudes from `imexam` against the standard star magnitudes from PanSTARRS. First, using the min in Figure 3 and then using the mean in Figure 4. In Figure 3, there clearly a linear relationship between the instrumental magnitudes and PanSTARRS magnitudes. Figure 4, on the other hand, shows no such patterns between the instrumental magnitudes and PanSTARRS magnitudes, which gives larger errors when estimating the offset.

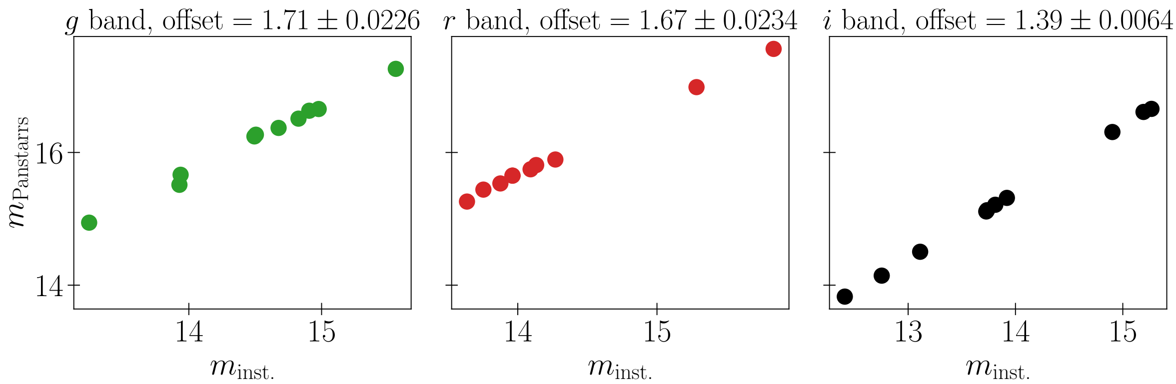


Figure 3: Magnitude from `PanSTARRS` vs instrumental magnitude measured in `imexam` for all 10 standard stars. Here, with the **min** of all values in the catalog.

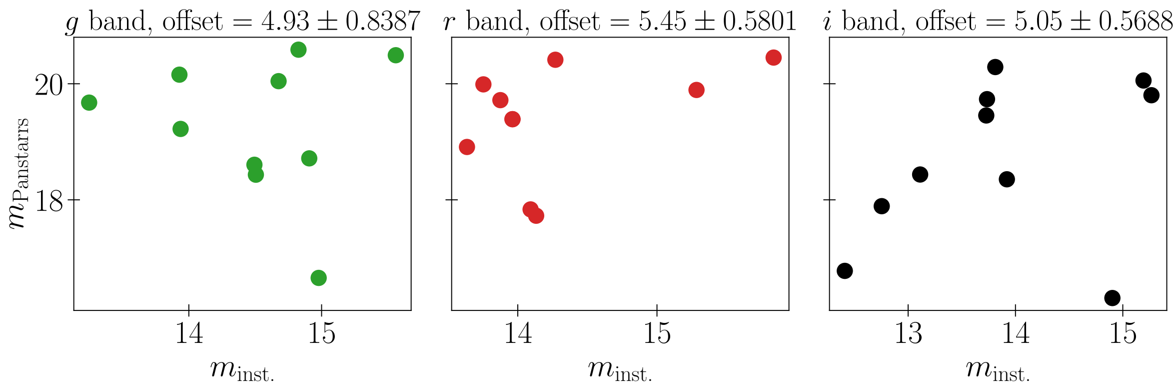


Figure 4: Magnitude from `PanSTARRS` vs instrumental magnitude measured in `imexam` for all 10 standard stars. Here, with the **mean** of all values in the catalog.