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PHYS 134L

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Photometry of Recent Type Ia Supernova - SN 2022wpy

Abstract

This paper presents the muti-bands photometry of a recent type Ia supernova: SN2022wpy in NGC 1659. We did 15 nights of observations from 2022/10/27 to 2022/11/26 using Las Cumbres Observatory global telescope network's 0.4-meter telescope with SBIG STL6303 camera in every other night. We successfully measured the apparent magnitude of V B g' r' bands and plotted the light curve. While our observations did not cover the peak date 2022/10/20, we still found that the B bands magnitude dropped faster than other bands. Our light curve can reaffirm this is a type Ia supernova. Such detailed V and B bands measurements are not found in any other open database for SN2022wpy. This work is the only detailed observations for these two bands in this timeframe.

Introduction

Supernovae are the violet explosions of stars in universe. The oldest supernova documented observation can be traced back to 393 AD(Clark and Stephenson). Supernovae are one of the few astronomical events that happen in the human time scale. The explosion usually last about few months, and the peak brightness is about the entire galaxy. The time-domain astronomy is a subfiled in astrophysics that focus on such “short” event compared to the billion-years cosmological time scale.

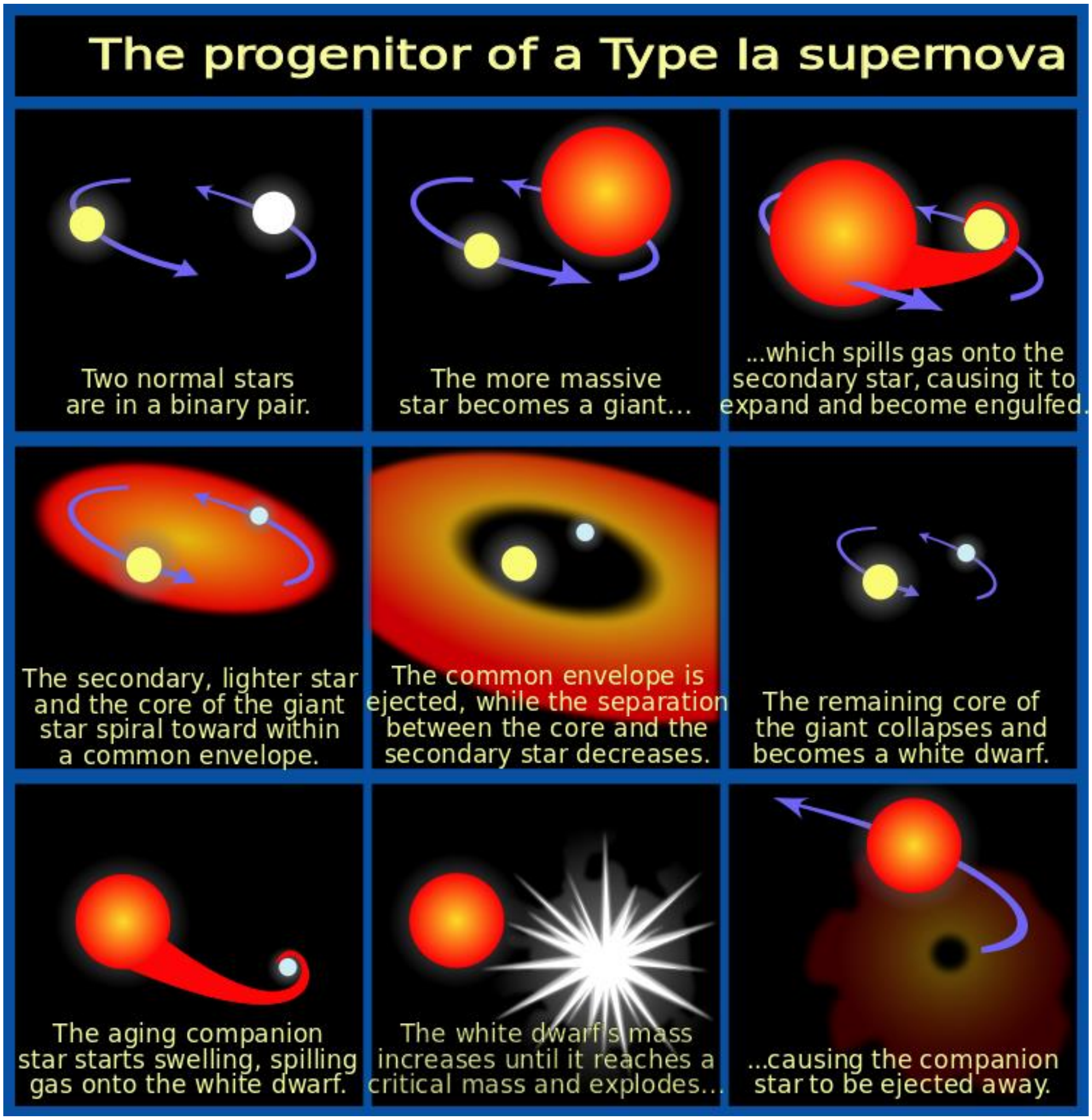
No one can predict supernova yet. No one knows when and where the next supernova will happen. In fact, everyday there are some new supernovae happening, but most of them were not detected by us due to the limitation of our observation resources. However, this has been improved a lot, thanks to the advancement in our technology. We already captured most of type Ia supernovae within z=0.02 and I calculated a birth rate based on large survey data(Zhang) in 2017 based on the large surveys data.

Supernova is not only very beautiful to see but also important to our life. Initially, our universe only has H and He from the big bang. Heavier were formed from the nuclear fusion inside of stars. However, stars can only produce up to iron due to the binding energy barrier. Without supernova, all element heavier than Fe would not be formed. Those included many elements that are essential to human body and life. In that sense, we are all star dusts.

To understand the physics the physics of supernova can help us understand the environment of the host galaxy and reveal the history of the universe. The use of type Ia supernova as a standard candle discovered the accelerating universe (Riess et al.), which received the Nobel Prize in Physics in 2011.

There are different types of supernovae. The most common classification is by its spectrum signature. There are two main types: Type I has no hydrogen lines and Type II has hydrogen lines. There are also sub-types of type I: Type Ia has a silicon line; Type Ib has a non-ionized helium line; Type Ic has week or no helium line. Also, many sub-types of type II. The progenitors of supernovae are still a frontier of astrophysics research. The widely accepted theory is that the Type Ia supernovae are from white dwarf accretion and other types are from core collapse. In this study, our target is a Type Ia supernova.

Type Ia supernovae are very special since they are commonly believed that they are not from core collapse. Type Ia supernova are from white dwarf accretion. The following carton is from the Space Telescope Science Institute (Ann) shows the progenitor of a type Ia Supernova:



Type Ia supernovae have same peak luminosity because the white dwarf's Chandrasekhar mass is a constant determinate by the electron degeneracy pressure. Thus, when the white dwarf's mass reached the 1.44 solar mass, it will become a Type Ia supernova with an absolute magnitude of M_V=-19.3. Therefore, it can be used as a standard candle to measure the distance in universe.

Project Background

The PHYS 134L course provided observation time from Las Cumbres Observatory global telescope network's 0.4-meter telescope with SBIG STL6303 camera(Brown et al.). When we researched our potential projects, we realized that the 0.4-meter telescope has many limitations. Therefore, we decided to observe a recent nearby Type Ia supernova: SN 2022wpy. We are measuring its light curve in four different bands. The magnitude is about 15-18, so it is with the power of this small telescope.

SN 2022wpy

Here is some basic information of this supernova from the IAU Transient Name Server (TNS) (Gal-Yam):

Discovery date: 2022-10-03

Discovery magnitude: 18.968

Discovered by ATLAS

Type Ia

Redshift z=0.0152

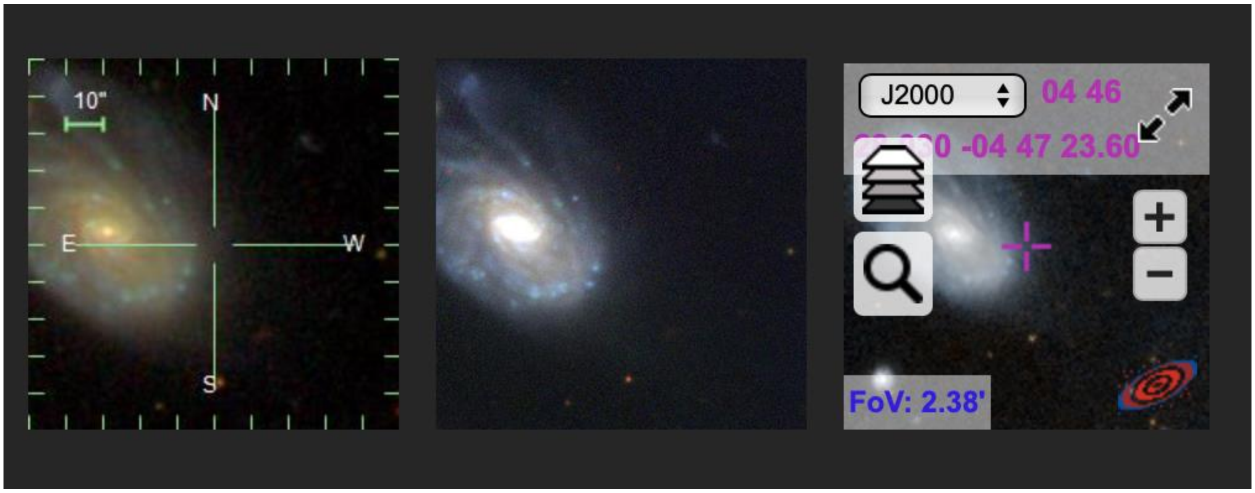
Host NGC 1659

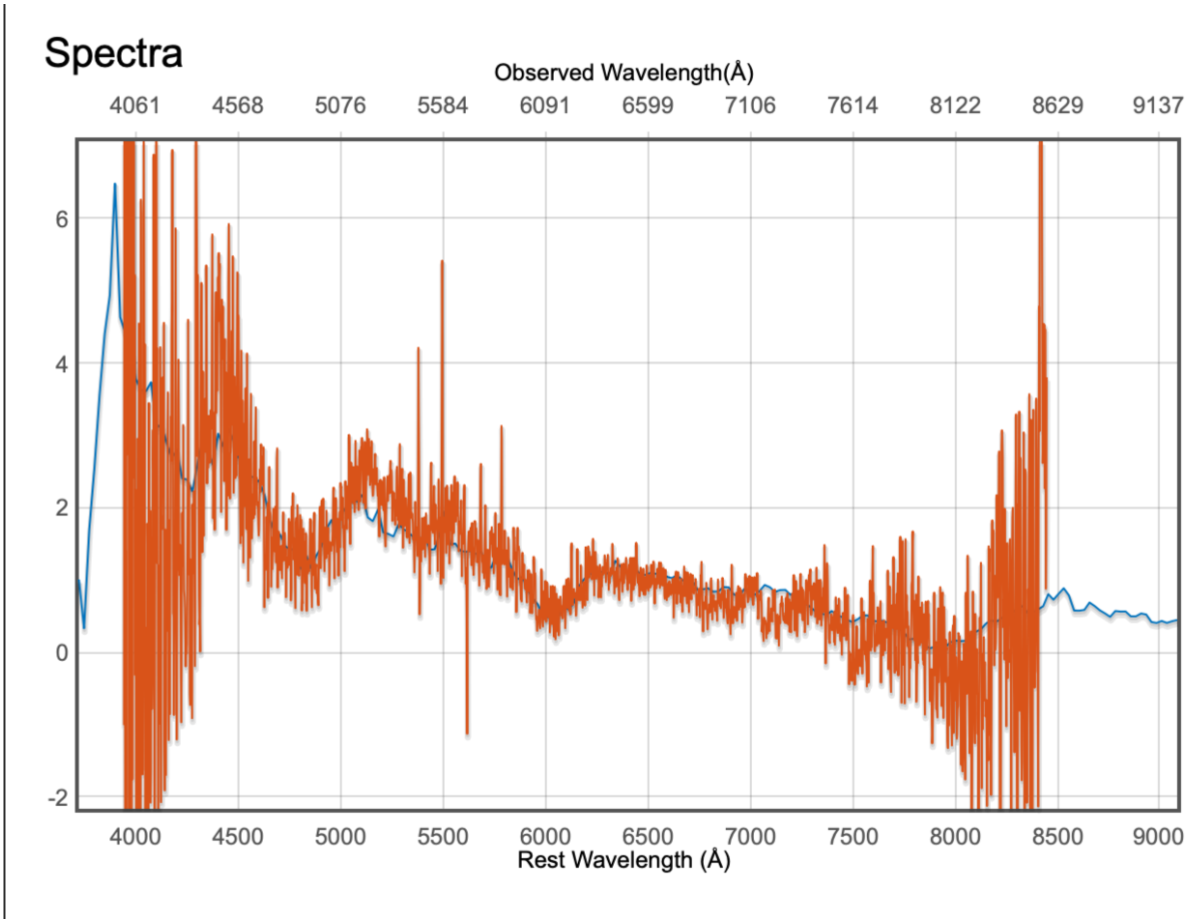
Peaked around 2022-10-20, at mag ~15

Position:

(RA, Dec) = (71.616757, -4.789910)

(RA, Dec) = (04:46:28.022, -04:47:23.677)





Spectrum by Zwicky Transient Facility(Bellm)

Method

Our observation

We requested LCO observation time using the 0.4 telescope to observe this recent supernova on 2022-10-28. We initially proposed 6 different band with 100s*3 every other night. However, it required too much observation time than the time available to us. Therefore, our approved proposal is this:

Target Name	RA (J2000)	Dec (J2000)	Filter	# Exposures	Integration Time (s)	ObservationaWindows
SN 2022wpy	71.616751074	-4.78986403275	Bessell B	2	80s*2	ASAP Every two days (repeat observation for a month)
SN 2022wpy	71.616751074	-4.78986403275	Bessell V	2	80s*2	ASAP Every two days (repeat observation for a month)
SN 2022wpy	71.616751074	-4.78986403275	SDSS g’	2	80s*2	ASAP Every two days (repeat observation for a month)
SN 2022wpy	71.616751074	-4.78986403275	SDSS i’	2	80s*2	ASAP Every two days (repeat observation for a month)

Those bands are commonly used for supernova photometry. We choose the bands that covered most of the optical spectra. We requested SDSS i’ filter in our proposal, but for some reason it was executed as SDSS r’ filter. The LSST is taking r’ g’ photometry of this supernova every two days since 2022-10-04. I initially planned to compare my LCO g’ band with LSST as a check. Now we can compare both g’ band and r’ band.

Instrument

Here are the details of the instruments we used(Brown et al.):

Telescope Structure:

Mounting: Meade 16-inch (40cm) RCS tube and 3-element optics, mounted in LCO equatorial C-ring mounting

Basic Optics: Primary, secondary and Corrector plate (Meade) with LCO focus mechanism driving corrector plate/secondary

Maximum slewing speed: 10 degrees per s

Tracking accuracy without guiding: ~1"

Blind pointing accuracy: ~30"

Camara SBIG STL-6303:

Format 3Kx2K 9-micron

FOV (arcmin): 29.2 x 19.5

Pixel size (1x1 binning, arcsec): 0.571

Default binning: 1 x 1

Cycle time (readout+overhead; 1x1 binning, s): 14 s

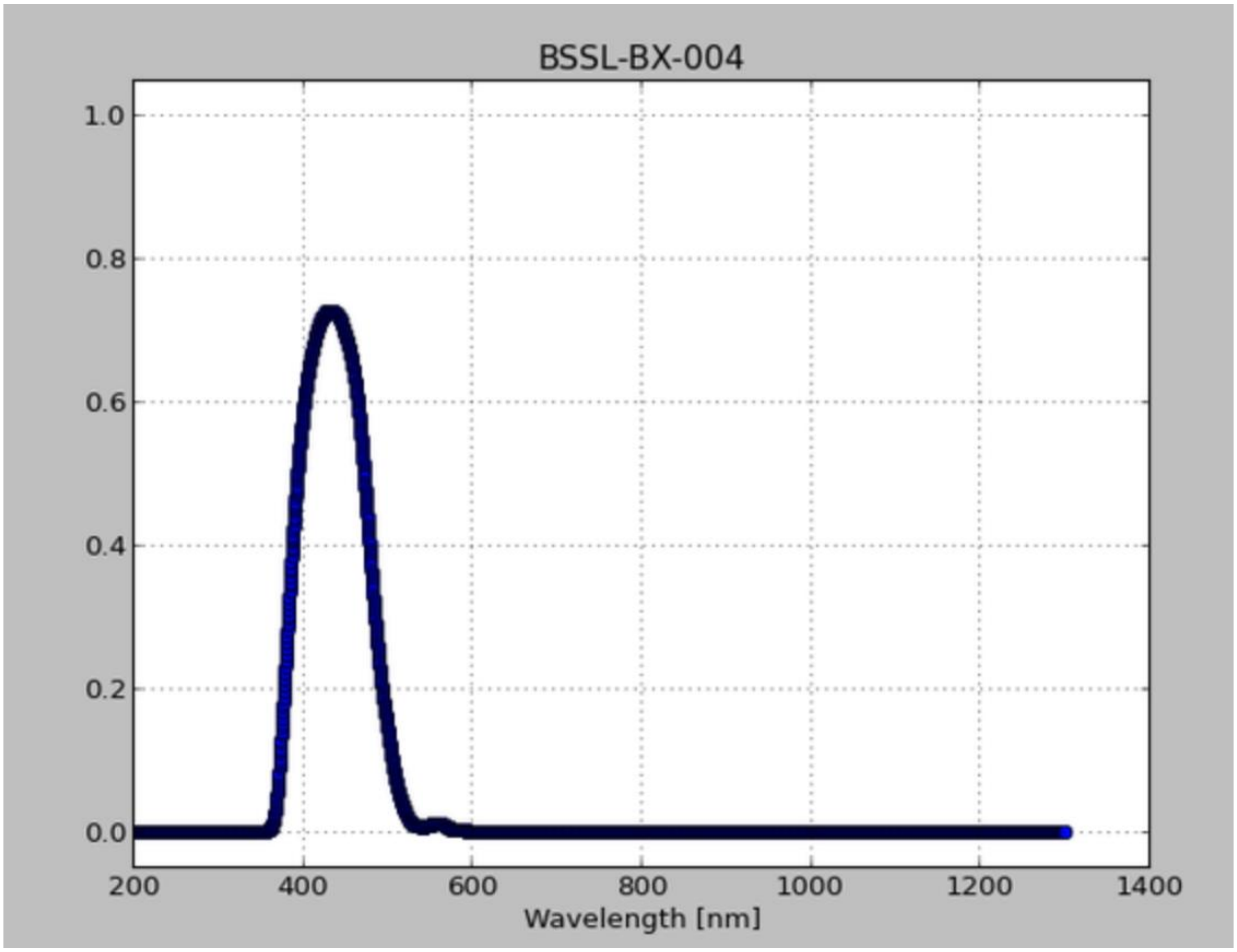
Read noise (e-): 14.5

Gain (e-/ADU): 1.6

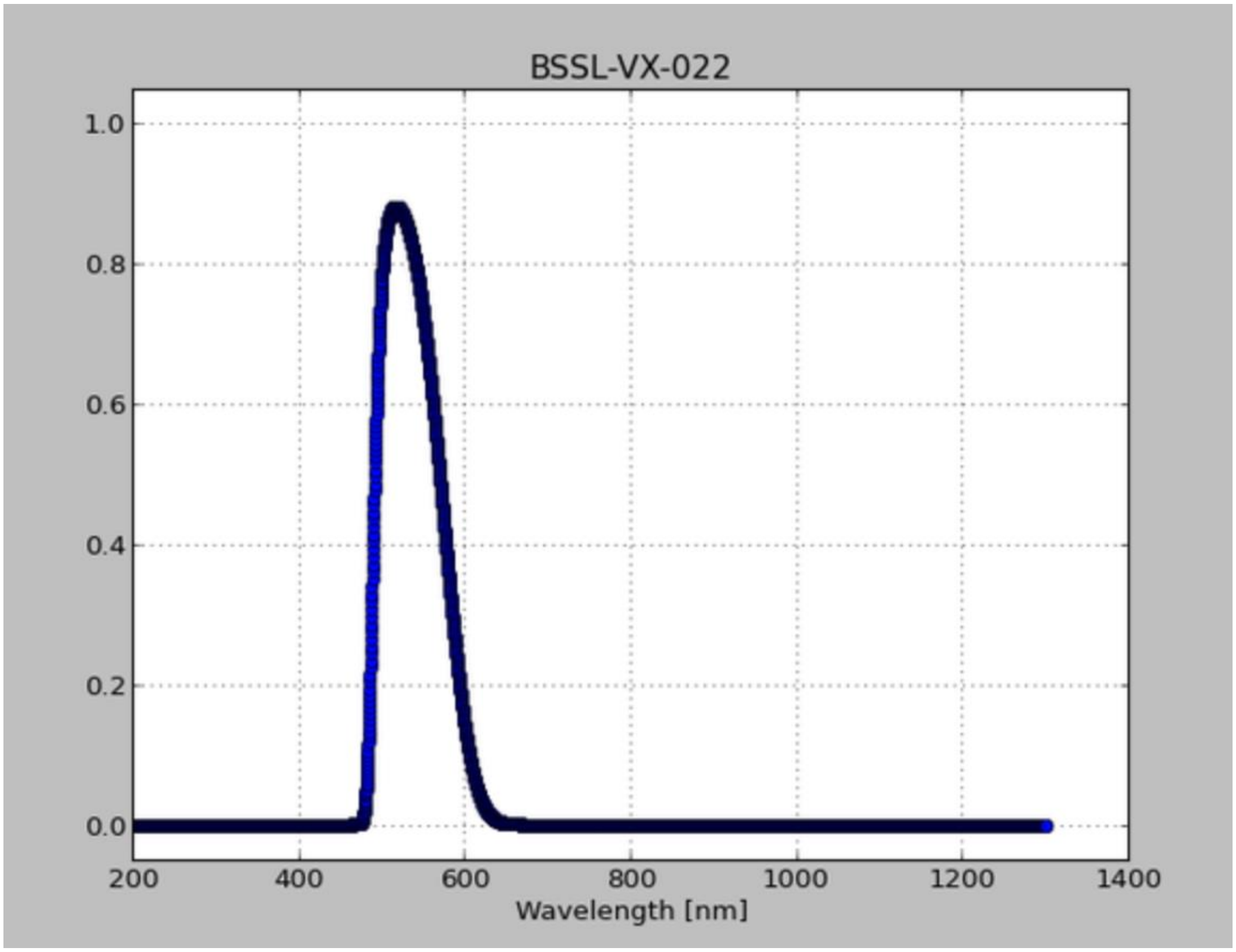
Dark current (e-/pix-s): 0.03 @ -100 C (estimated)

Filters Sloan u', g', r', i', Johnson-Cousins B, V, Pan-STARRS w, z_s

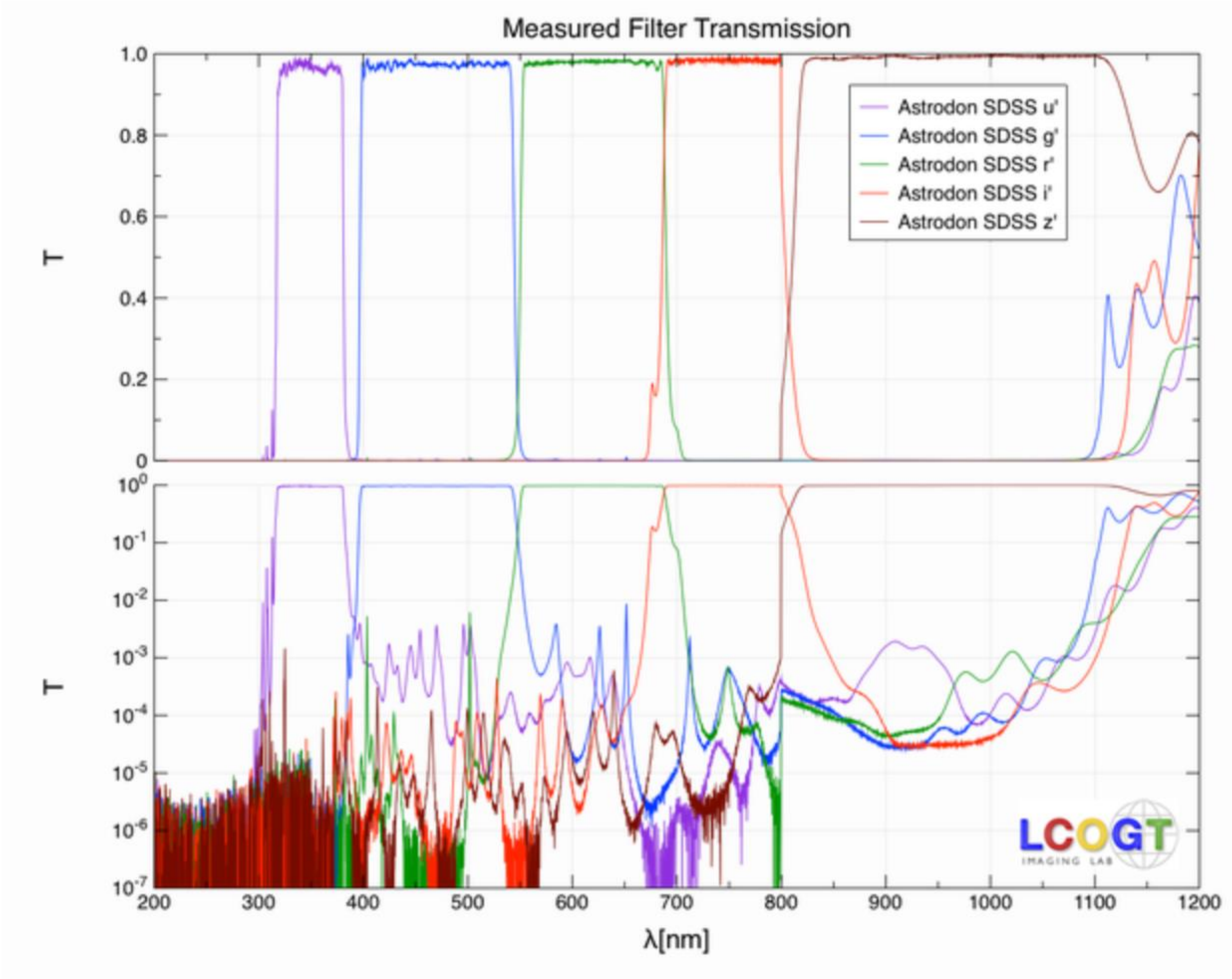
The filters we used:



Bessell B


BSSL-VX-022
1.0
0.8
0.6
0.4
0.2
0.0
200
400
600
800
1000
1200
1400
Wavelength [nm]

Bessell V



The SDSS g' and r'

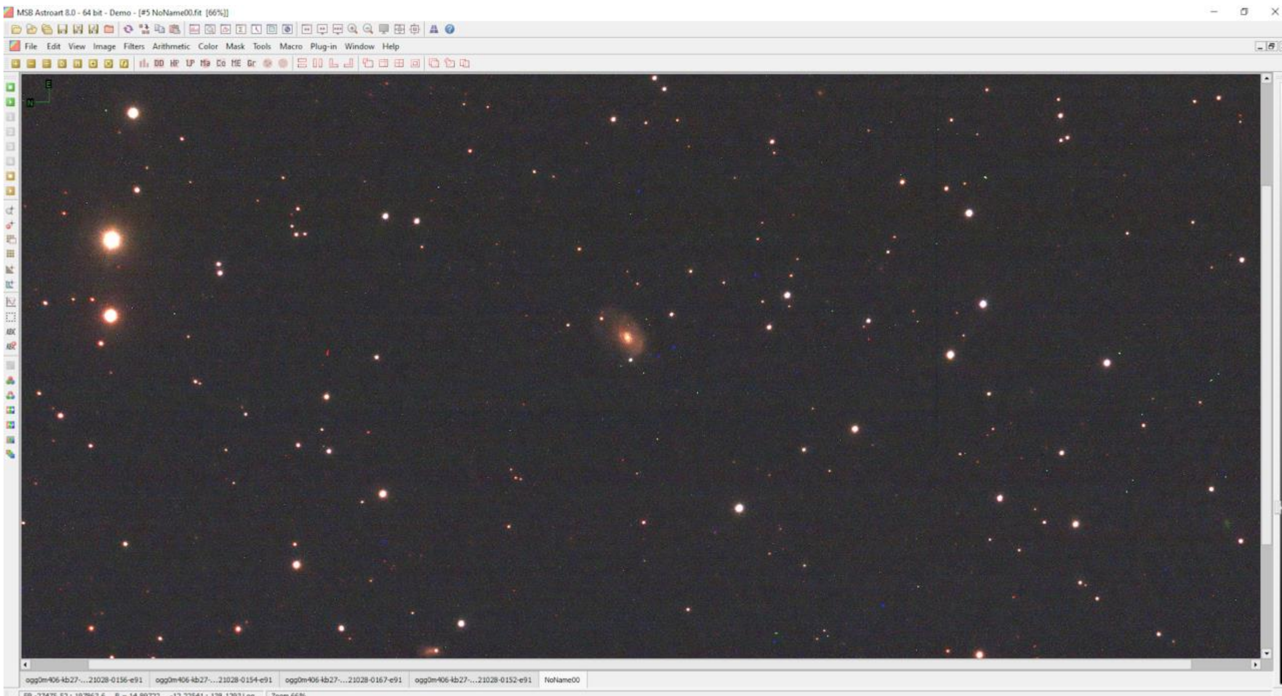
Those band are not overlaping each other, so they can provide us many information.

Our collected data

Our LCO observation started from 2022-10-27 to 2022-11-26. There are 15 nights of observation in a month. Each observation nights includes 8 images: 2 images from 4 bands. Therefore, in total we have 120 images.

Image processing/Photometry Process

We use the LCO's uncompressed FITS file. I pre-examined the FITS images by SAO DS9. I confirmed that the supernova was visible and did not overexpose. I also used AstroArt to make a RGB color image from r' g' B bands.



The demo version of AstroArt could not save file, so I could only take a screenshot of my work from it. The supernova is located at the lower (West) part of the galaxy. This color image is just for illustration purpose. It is not necessary "real color". However, the concept of color itself is subjective anyway. To learn more about "color", join my student-led seminar in Spring 2023!

There are many tools to do photometry on astronomical image. Some paid software, but more often astronomer use open-source python packages such as Astropy. Our group decided to try different technique then compare our results. I personally used AstroArt, while my groupmate

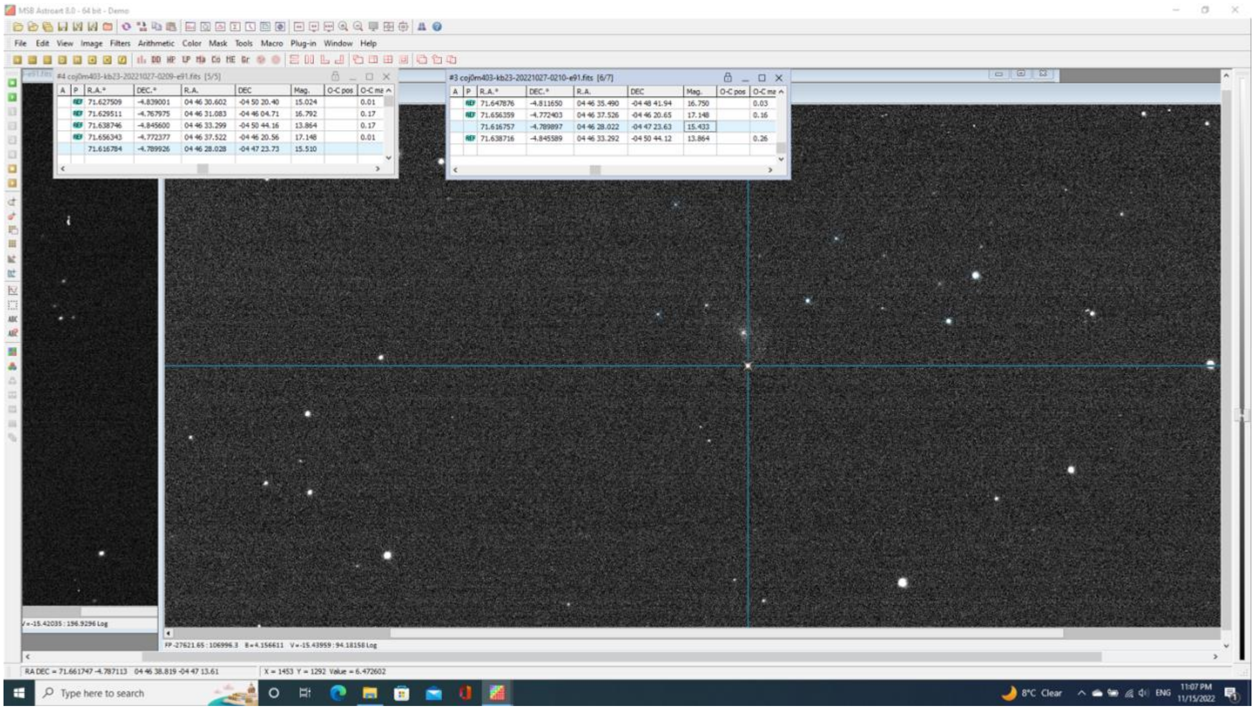
(Jack) is using some python packages to do the photometry for the same set of data, so we can compare the difference of those tools.

Reference stars

Every successful astronomical photometry requires reference stars. Reference stars are the set of stars in the field of view that with known magnitudes. I used APASS catalog (Henden et al.)to get the magnitudes. APASS catalog has magnitudes of V B u’ g’ r’ i’ z’ PansSTARRS Y bands. We are only interested in VB g’r’ bands. Within the field of view. I chose 6 reference stars manually.

RA (deg)	Dec (deg)	Johnson V (V)	Johnson B (B)	Sloan g' (SG)	Sloan r' (SR)
71.627527	-4.839044	14.348	15.024	14.667	14.194
71.629461	-4.767949	16.092	16.792	16.368	15.913
71.63268	-4.804566	14.845	15.693	15.258	14.575
71.638703	-4.845641	13.257	13.864	13.514	13.142
71.647825	-4.811632	15.754	16.75	16.248	15.431
71.656313	-4.772341	15.852	17.148	16.496	15.327

I choose those stars as reference because they are not too far from our target. They are relatively close to the supernova’s brightness, about 14-16 mag.



I needed to use mouse to click each reference star and the supernova in the image. And then use keyboard to input its magnitude manually for different bands. I had to repeat this process for each individual image. So total of 800 manual matches have been done. I would say this is definitely not the fastest way even with AstroArt, but I choose to do so because I want to actively examine each image by my own eyes.

Photometry by AstroArt

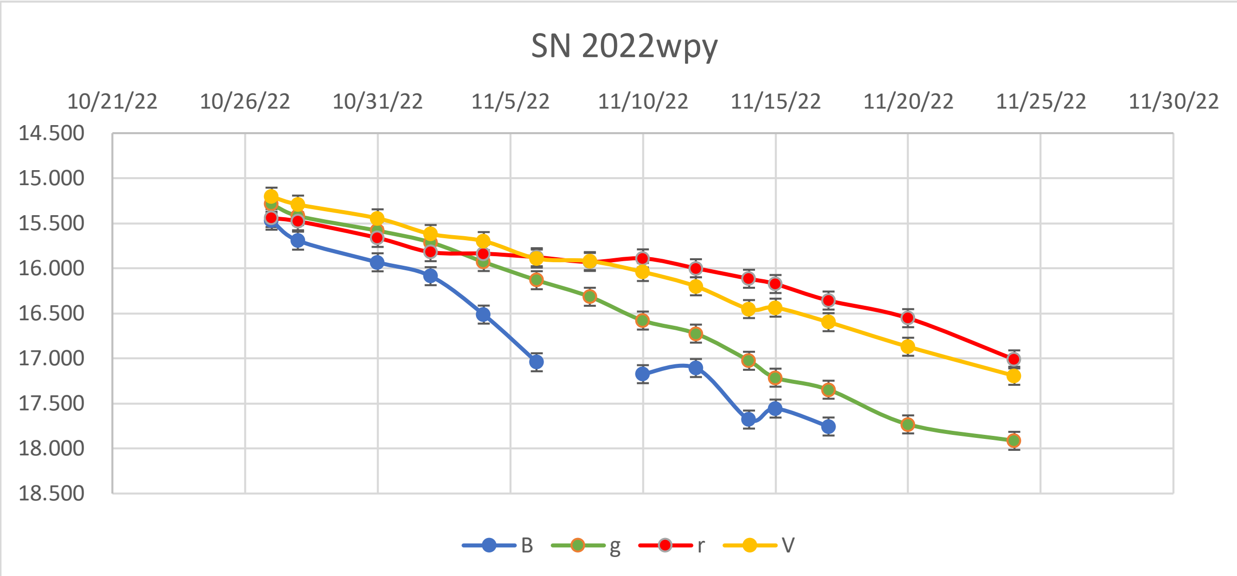
After I matched the reference stars, I used photometry function in AstroArt to calculate the magnitude of the supernova. I assumed the CCD reading is linear. This assumption is generally valid for CCD with good cooling, especially in this small interval as a good first order approximation. AstroArt does have option to do non-linear fitting. However, I considered that it might cause overfitting issue due to the few reference points and might also cause more systematic error. I did attempt few nonlinear fittings, the result does not show significant difference. My measured magnitude is recorded in this table.

	B	B	B(ave)	g	g	g(ave)	r	r	r(ave)	V	V	V(ave)
2022/10/27	15.51	15.433	15.472	15.287	15.285	15.286	15.54	15.345	15.443	15.199	15.211	15.205
2022/10/28	15.646	15.74	15.693	15.424	15.416	15.420	15.482	15.474	15.478	15.292	15.294	15.293
2022/10/31	15.971	15.896	15.934	15.57	15.597	15.584	15.657	15.668	15.663	15.417	15.474	15.446
2022/11/2	16.104	16.071	16.088	15.681	15.744	15.713	15.795	15.847	15.821	15.58	15.659	15.620
2022/11/4	16.574	16.454	16.514	15.922	15.939	15.931	15.834	15.84	15.837	15.71	15.686	15.698
2022/11/6	17.043	17.043	17.043	16.193	16.072	16.133	15.851	15.903	15.877	15.873	15.911	15.892
2022/11/8	Full Moon NG			16.202	16.43	16.316	15.926	15.933	15.930	15.92		15.920
2022/11/10	17.175		17.175	16.566	16.594	16.580	15.902	15.878	15.890	16.094	15.988	16.041

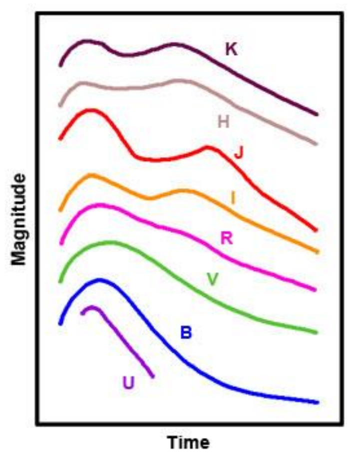
2022/11/12	17.107	17.107	16.656	16.794	16.725	16.018	15.981	16.000	16.188	16.212	16.200
2022/11/14	17.679	17.679	17.023	17.03	17.027	NG (lost tracking)	16.116	16.116	16.405	16.5	16.453
2022/11/15	17.557	17.557	17.246	17.182	17.214	16.181	16.168	16.175	16.442	16.432	16.437
2022/11/17	17.756	17.756	17.372	17.323	17.348	16.377	16.339	16.358	16.577	16.619	16.598
2022/11/20	NG		17.652	17.813	17.733	16.558	16.549	16.554	16.866	16.875	16.871
2022/11/24	NG		17.915		17.915	17.025	16.997	17.011	17.193	NG	17.193
2022/11/26	NG Weather?										

There were two images for each band for each night. In some images, due to the comic ray or any other unexpected noise, not all reference stars are good to use. Note that since the 2022/11/6, B band images have low signal to noise ratio to be analyzed individually. However, I managed to stack the two images which increased S/N ratio. Therefore, there is only one magnitude reported. Some NG night was due to the low signal noise ratio, it might caused by bad weather and full moon.

Here is the light curve from our observation in 4 bands, the error bar is in size of 0.1.

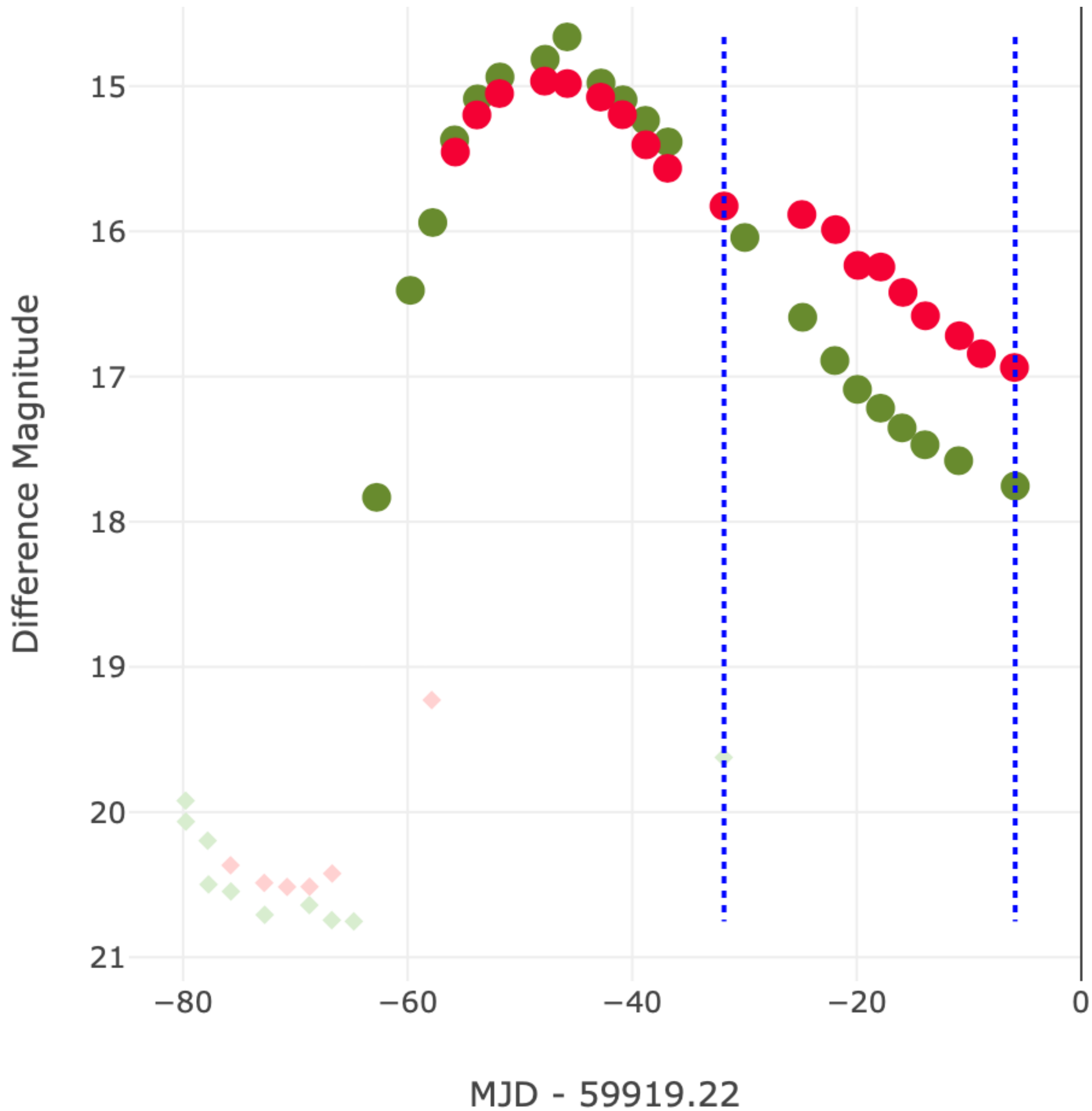


We can see that different bands have different rate of dropping. The faster dropping in B band is expected:



(Cosmos)

I also check my g' r' magnitude with Zwicky Transient Facility (ZTF)'s data points(Bellm et al.). The ZTF uses a 1.22-meter telescope with fully automated pipeline. My data and ZTF data agreed mostly in the error bar. This indicated my method was valid.



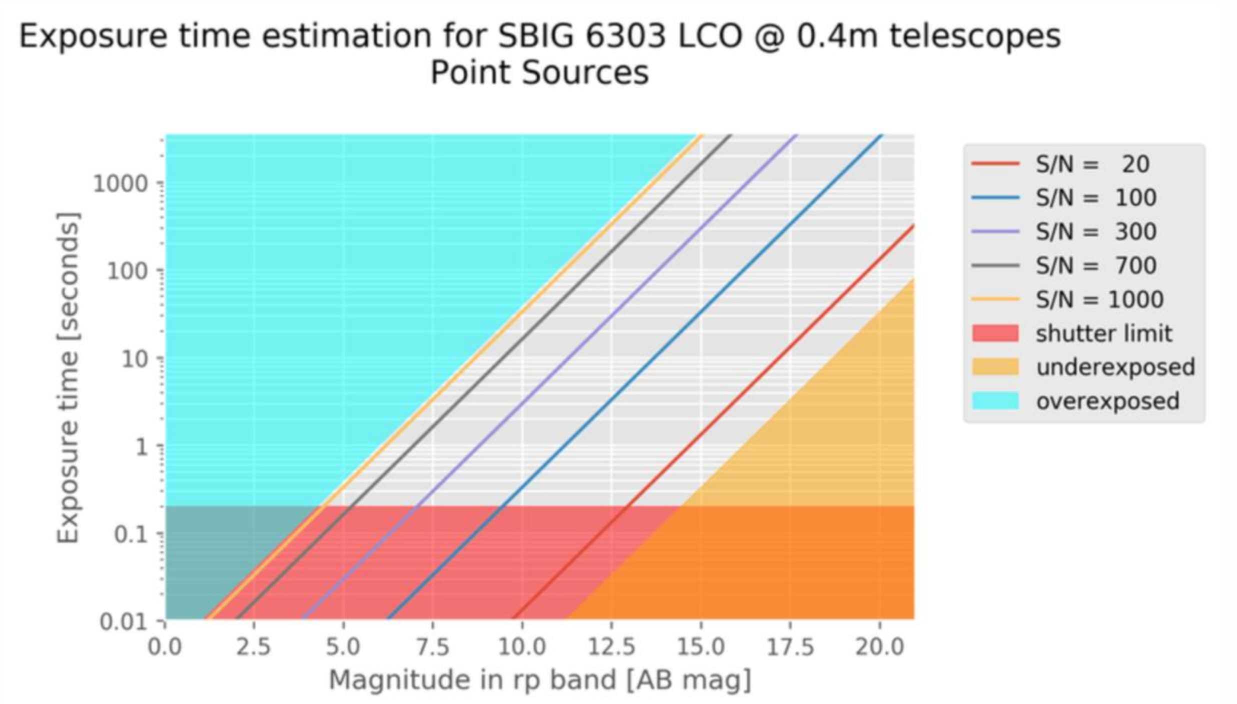
Error Analyzes

Signal Noise Ratio

The theoretical signal noise ratio can be calculated from the equation from Prof. Lubin's PHYS 134L note:

$$\frac{S}{N}=\frac{FA_{\varepsilon}\sqrt{\tau}}{\left[\frac{N_R^2}{\tau}+FA_{\varepsilon}+i_{DC}+F_{\beta}A_{\varepsilon}\Omega\right]^{1/2}}=\frac{FA_{\varepsilon}\sqrt{\tau}}{\left[\frac{N_R^2}{\tau}+N_T\right]^{1/2}}=\frac{FA_{\varepsilon}\tau}{\left[N_R^2+\tau N_T\right]^{1/2}}. \qquad (2.11)$$

The LCO's 0.4 telescope's S/N already been calculated and can be found on LCO website:



In practice, the signal noise ratio of each star can also be read from the photometry process in AstroArt. The signal noise ratios of the reference stars are all greater than 100. Thus, the error of the reference stars is less than 1%. The signal noise ratio of the supernova decreased over this one-month period, but I managed to only use the data or stacked data with S/N greater than 50 to make measurements. Therefore, the overall error bar is smaller than 5%. Therefore, 0.1 mag (~10%) is very safe choice.

Systematic Error

There is a systematic error that I realized in my photometry process. The supernova is in the host galaxy. The background contamination cannot be ignored. This caused a shift to underestimate the visual magnitude. This error is still within the 0.1 mag error bar.

Conclusion

I successfully measured the light curve of the Type Ia supernova SN 2022wpy with our firsthand data set. The result is promising and agreed with other's data and theory. The AstroArt manual photometry is labor consuming, but I learnt from it a lot. This is also a good example to show a doable but also scientific meaningful project in the scope of PHYS 134L course. I really enjoy the project and hoping my work can be submitted to online database so people can use it. I appreciate the support from Prof. Philip Lubin and our TA Jeonghwa Kim. I couldn't finish this project without their help and guidance.

Things that can be done differently:

Compare the groupmate's measurement.

Plot the light curve with JD or MJD instead of MDY

Try use different methods/tools if time permit. Maybe the MaxIm DL

Report our magnitude to online data base. LSST only has frequent g' r' magnitude. Our V B magnitudes could be the only firsthand information for this supernova. (we can do it now)

Observe different bands like SDSSi'.

Maybe use python pipline

More reference stars

Do data redaction by myself, now LCO did it for us.

Work Cited

Ann, Feild. *The Progenitor of a Type Ia Supernova*. 27 Oct. 2004, http://hubblesite.org/newscenter/archive/releases/star/supernova/2004/34/image/d/.

Bellm, Eric C. *The Zwicky Transient Facility*. arXiv:1410.8185, arXiv, 29 Oct. 2014. *arXiv.org*, http://arxiv.org/abs/1410.8185.

---. “The Zwicky Transient Facility: System Overview, Performance, and First Results.” *Publications of the Astronomical Society of the Pacific*, vol. 131, no. 995, Jan. 2019, p. 018002. *arXiv.org*, https://doi.org/10.1088/1538-3873/aaecbe.

Brown, T. M., et al. “Las Cumbres Observatory Global Telescope Network.” *Publications of the Astronomical Society of the Pacific*, vol. 125, no. 931, Sept. 2013, pp. 1031–55. *DOI.org (Crossref)*, https://doi.org/10.1086/673168.

Clark, D. H., and F. R. Stephenson. *The Historical Supernovae*. Nov. 1982, pp. 355–70. *NASA ADS*, https://ui.adsabs.harvard.edu/abs/1982ASIC...90..355C.

Cosmos. *Type Ia Light Curve*. https://astronomy.swin.edu.au/cosmos/T/Type+Ia+supernova+light+curves.

Gal-Yam, A. *The TNS Alert System*. Jan. 2021, p. 423.05. *NASA ADS*, https://ui.adsabs.harvard.edu/abs/2021AAS...23742305G.

Henden, A. A., et al. “VizieR Online Data Catalog: AAVSO Photometric All Sky Survey (APASS) DR9 (Henden+, 2016).” *VizieR Online Data Catalog*, Jan. 2016, p. II/336. *NASA ADS*, https://ui.adsabs.harvard.edu/abs/2016yCat.2336....0H.

Riess, Adam G., et al. “Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant.” *The Astronomical Journal*, vol. 116, no. 3, Sept. 1998, pp. 1009–38. *DOI.org (Crossref)*, https://doi.org/10.1086/300499.

Zhang, Jichen. *The Study of Birth Rate of SNe Ia in Nearby Universe*. Chinese Astronomical Society.