SN 2022wsp: A Type II-P Supernova Through Light Curve Analysis

Introduction

On October 2nd at 23:59:19 UTC the supernova 2022wsp was detected by DLT40. It was detected at RA 23:00:03.559, DEC +15:58:43.86 in the host galaxy NGC 7448.[1] Its spectrum was taken a few days later. This spectrum showed strong He II and H alpha lines, which classified the supernova as a young type II supernova.

The aim of this project will be twofold: First, to place the supernova SN 2022wsp into a subcategory based on its light curves (a measurement of the magnitude of the supernova through multiple filters over time). Second, to use various models of supernovae light curves for type II supernovae to determine estimates of other parameters, such as ejected mass, progenitor radius, etc.

Historically, supernovae (SNe) have been classified into two broad categories, type I and type II, based on the presence of hydrogen absorption lines. The obvious presence of H I optical absorption lines (Balmer series absorption lines) indicated a Type II classified supernova, while those that do not show the presence of hydrogen are classed under Type I.[5] These two subclasses are then further divided based on other criteria, such as Type Ia indicating the

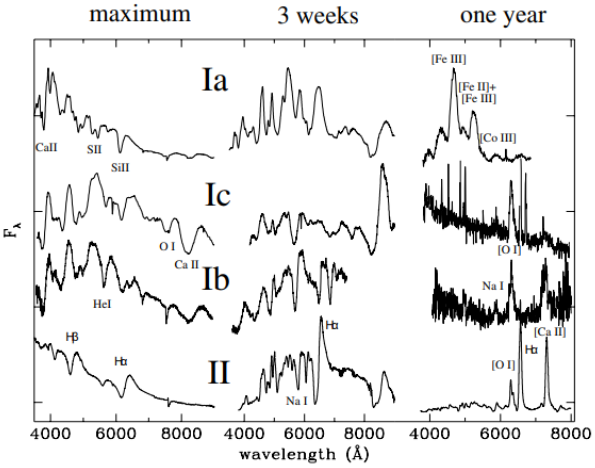


Figure 1: The rest frame spectra of the main SN types at maximum, three weeks, and one year after maximum with SN 1996X for type Ia, SN 1994I and SN 1997B for type Ic, SN 1999dn and SN 1990I for type Ib, and SN 1987A for type II. Source: Turatto (2003).

presence of Silicon absorption lines. As such, this broad classification is most often done by spectroscopy.

With the exception of SNe Ia, which are thought to arise from white dwarf binary systems, supernovae are generally accepted to arise from the core collapse of massive stars, in which case the strong hydrogen absorption lines indicate that the collapsing star would have kept a hydrogen envelope prior to explosion responsible for the absorption.[3]

These core-collapse SNe happen when the nuclear fusion in the core slows enough that the pressure it creates can no longer support the weight of the star. The core itself becomes very dense under its own gravity, becoming a neutron star or a black hole. This collapse subsequently releases a wave of neutrinos that interact with the outer stellar envelope, causing it to explode.

Very few SNe, especially SNe II, have had their progenitors directly identified with their properties known,[8] such as the peculiar type II SN 1987A and the type II-P SN 2008bk. However, to help us determine where core-collapse SNe lie in the evolutionary patterns of stars, especially massive stars, learning the identity of their progenitor will help us to learn about the end stage of the life cycle of different types of stars. Future identification of the stellar predecessors to supernovae and their properties will help us to challenge the currently accepted models of stellar evolution.

Methods

Our data was collected with 0.4 meter telescopes through the Las Cumbres Observatory at their site in Tenerife. Images were taken every two days from October 19th, 2022 through November 18th, 2022. Each time a 50 second exposure through a Bessel-B filter and a second 50 second exposure through a Bessel-V filter were captured.

A 50 second exposure time was originally chosen in order to attempt to achieve a signal to noise ratio (SNR) of about 100. However, our data resulted in a much lower SNR of about 14 in the V band and of about 6 in the B band, which makes photometry more difficult, especially in the B band. The supernova is much dimmer in the B band, and as such it has proven far more difficult to pick out the luminosity of the supernova from the sky background noise.

Additionally, one night of exposures ended up unusable, as just noise with no features distinguishable, so there is a hole in our data at October 25th.

The LCO images were first put into composite image in false color, with the B filter imaged in blue and the V filter imaged in yellow to make areas of the image where the two exposures are equal display in grayscale.

The exposures were then processed in AstroArt to take photometric magnitudes from each. Reference stars for the photometry were done by searching the location of the supernovae on the Aladin Lite sky atlas and matching stars to those visible in the LCO images. Six reference stars were used: TYC 1711-1670-1, GPM 345.096669+16.007644, BD+15 4742, 2MASS J22595656+1600142, Pul -3 1500095, and TYC 1711-525-1. Their magnitudes in both the Bessel B filter and the Bessel V filter were taken from the SIMBAD database. They ranged in magnitude from around 14.8 to around 10.3, and none were obviously saturated in the data images.

The first analysis we will take on is to confirm that 2022wsp is in fact a type II supernova using its light curve instead of spectroscopy and to subclassify it into a type II-P or II-L. Type II supernovae decline in brightness much more slowly than type I supernovae, and type II-L curves decline faster than type II-P, especially in the early regime that we are looking at, so we can do this by comparing decline rates in blue filter magnitude using averages from a compilation study of SNe light curves.[4]

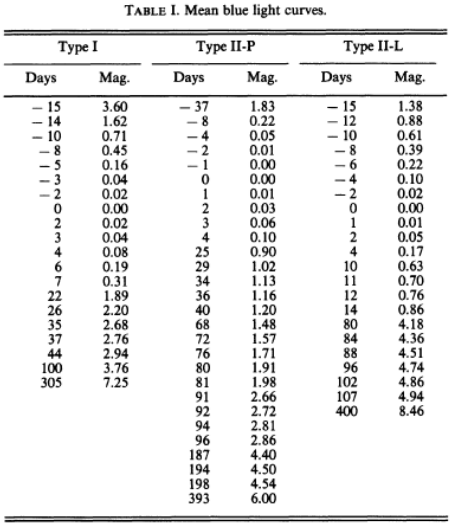


TABLE I. Mean blue light curves.

Type I		Type II-P		Type II-L	
Days	Mag.	Days	Mag.	Days	Mag.
− 15	3.60	− 37	1.83	− 15	1.38
− 14	1.62	− 8	0.22	− 12	0.88
− 10	0.71	− 4	0.05	− 10	0.61
− 8	0.45	− 2	0.01	− 8	0.39
− 5	0.16	− 1	0.00	− 6	0.22
− 3	0.04	0	0.00	− 4	0.10
− 2	0.02	1	0.01	− 2	0.02
0	0.00	2	0.03	0	0.00
2	0.02	3	0.06	1	0.01
3	0.04	4	0.10	2	0.05
4	0.08	25	0.90	4	0.17
6	0.19	29	1.02	10	0.63
7	0.31	34	1.13	11	0.70
22	1.89	36	1.16	12	0.76
26	2.20	40	1.20	14	0.86
35	2.68	68	1.48	80	4.18
37	2.76	72	1.57	84	4.36
44	2.94	76	1.71	88	4.51
100	3.76	80	1.91	96	4.74
305	7.25	81	1.98	102	4.86
		91	2.66	107	4.94
		92	2.72	400	8.46
		94	2.81		
		96	2.86		
		187	4.40		
		194	4.50		
		198	4.54		
		393	6.00		

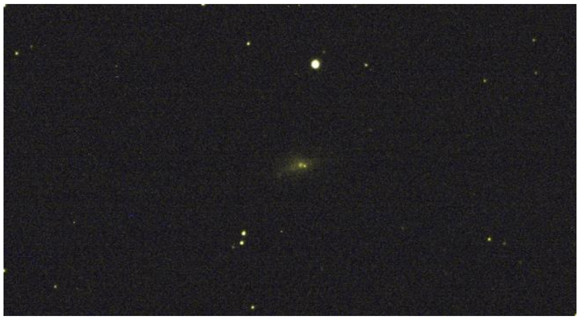
Figure 2: Light curves in magnitudes below maximum for type I, II-P, and II-L supernovae. Source: Doggett and Branch (1985).

After this, we can hopefully use the light curves to determine estimates for other parameters, such as ejected mass and progenitor radius. A 2004 study[9] will be especially helpful for this, as it modeled type II supernova with a wide variety of parameter sets. These estimates will likely be more difficult to do quantitatively and will likely be very rough estimates.

Results

Images in false color:

10/19/2022



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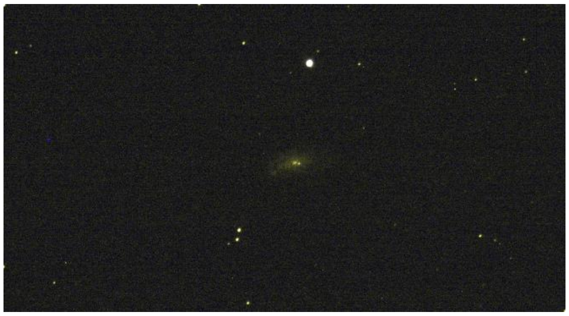

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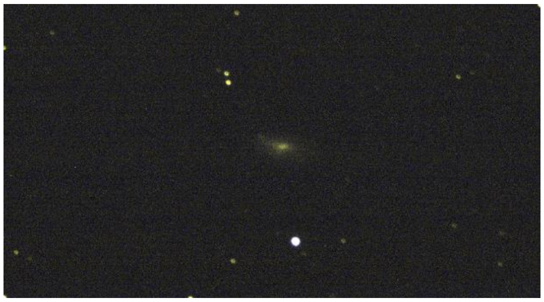

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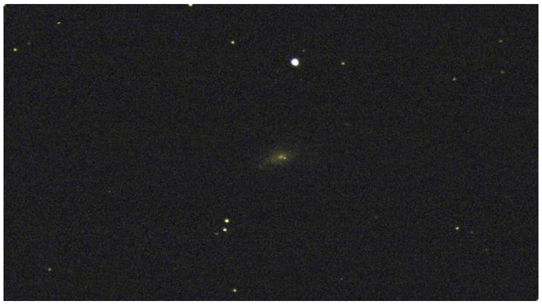

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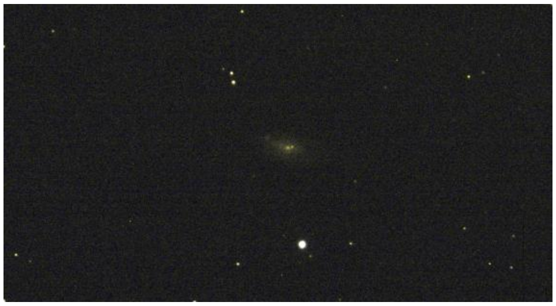

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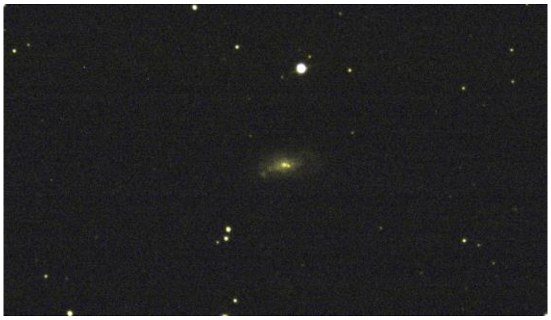

11/14/2022

11/16/2022

11/18/2022

It is clear from just a cursory glance over the data in Table 1 below that there is excessive error in the data that will affect the accuracy of the light curves that we produce. We can calculate this error quantitatively using the SNR. A simplified SNR can be calculated[7] from our image data as follows:

$$SNR = \frac{S}{\sqrt{S + B + DC + RN^2}}$$

Where S is the signal flux, B is the background flux, DC is the dark current of the camera, and RN is the readout noise of the camera. This gives:

$$SNR_V = 14.1, SNR_B = 6.2$$

Table 1: V and B filter magnitudes by day (in days after October 18th 2022)

	V band magnitude		B band magnitude
1	15.80	**1**	15.96
3	16.17	**3**	15.64
5	16.14	**5**	15.55
9	16.00	**9**	15.64
11	15.97	**11**	16.34
13	16.12	**13**	15.80
15	16.12	**15**	15.82
19	16.12	**19**	15.70
21	16.23	**21**	16.85
23	16.18	**23**	15.97
25	15.88	**25**	17.97
27	16.12	**27**	15.92
29	16.24	**29**	15.78
31	15.99	**31**	16.84

From those SNR values, an error in the photometric magnitude can be calculated[2] to provide a confidence range for our data:

$$\sigma_m = \frac{2.5}{\ln 10 \times SNR}$$

This equation gives errors:

$$\sigma_{m_V} = 0.077, \sigma_{m_B} = 0.175$$

With this error a scatter plot with error bars of the data over time can be created to spot any outliers and immediate trends in the data. Next, to create an accurate, smoother model for the light curve to compare against, the egregious outliers were removed from the data and a best fit quadratic model was fitted with python.

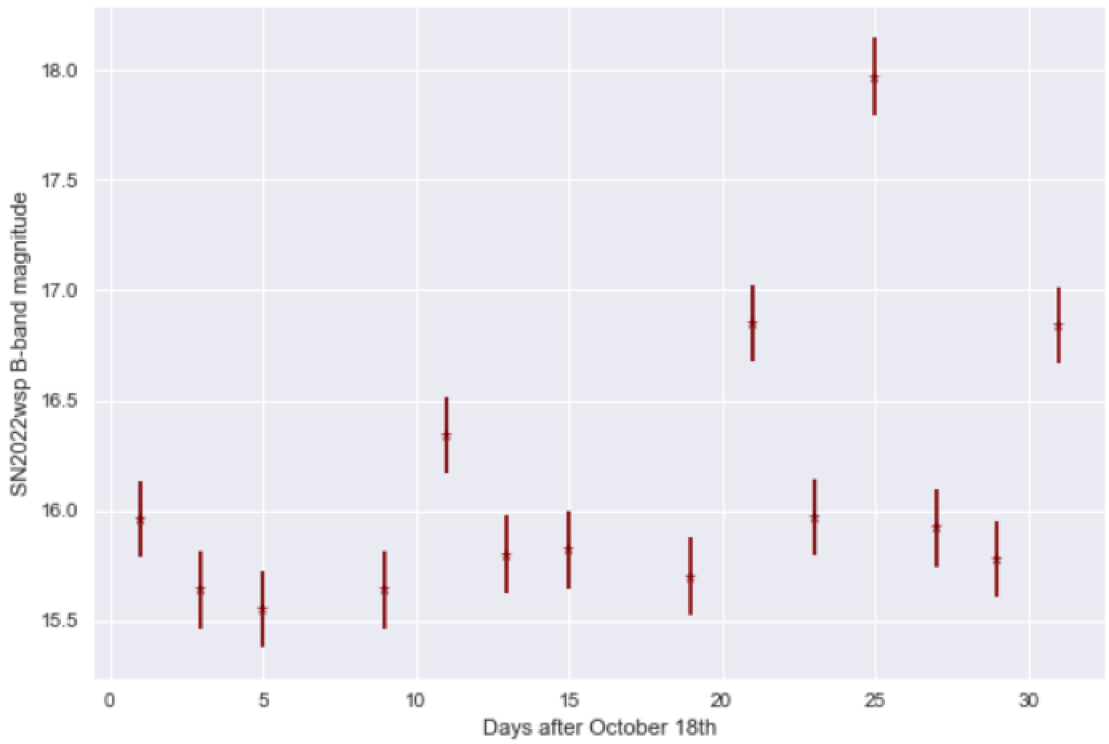

Figure 3: Bessel B filter magnitudes October 19th 2022 through November 18th 2022, without outliers removed

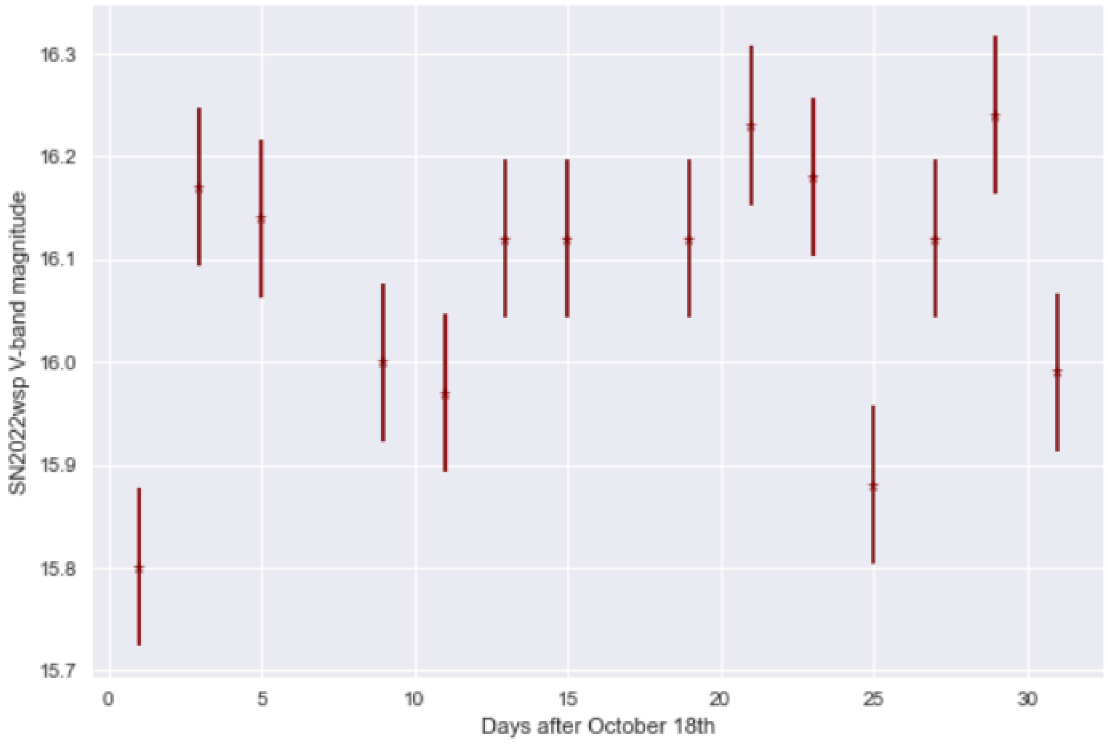

Figure 4: Bessel V filter magnitudes October 19th 2022 through November 18th 2022, without outliers removed

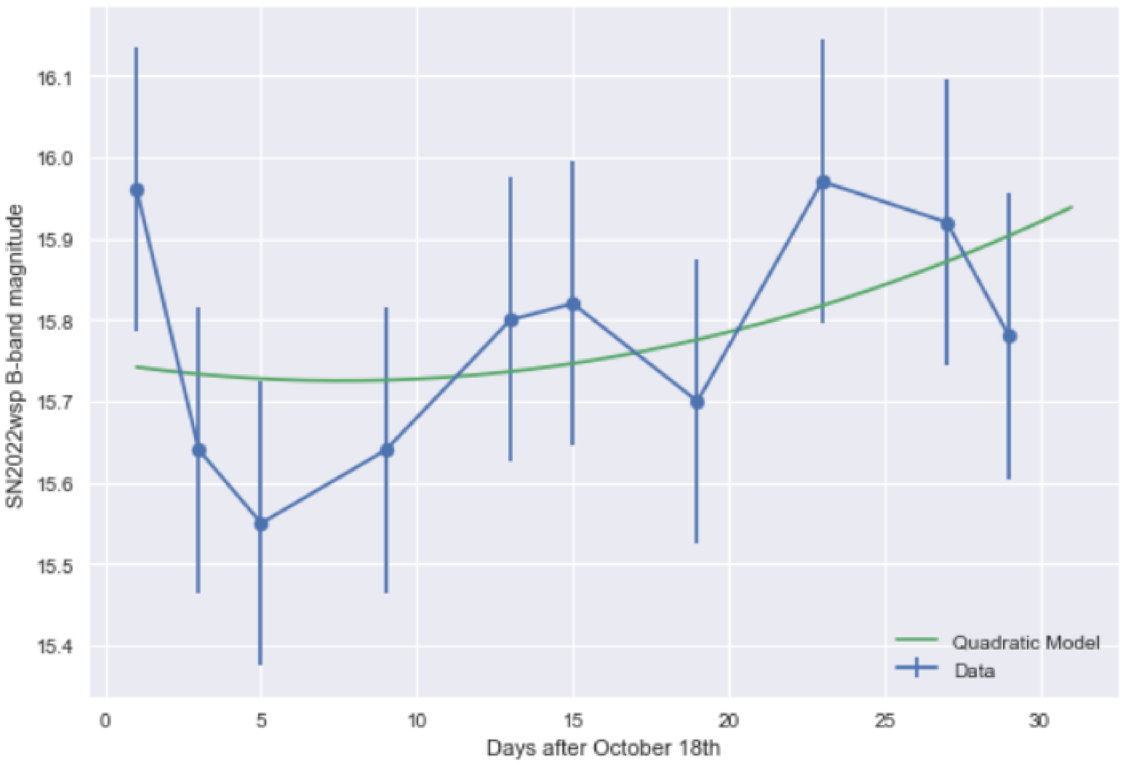

Figure 5: Quadratic model best fitted to the Bessel B filter magnitudes over time, with outliers removed.

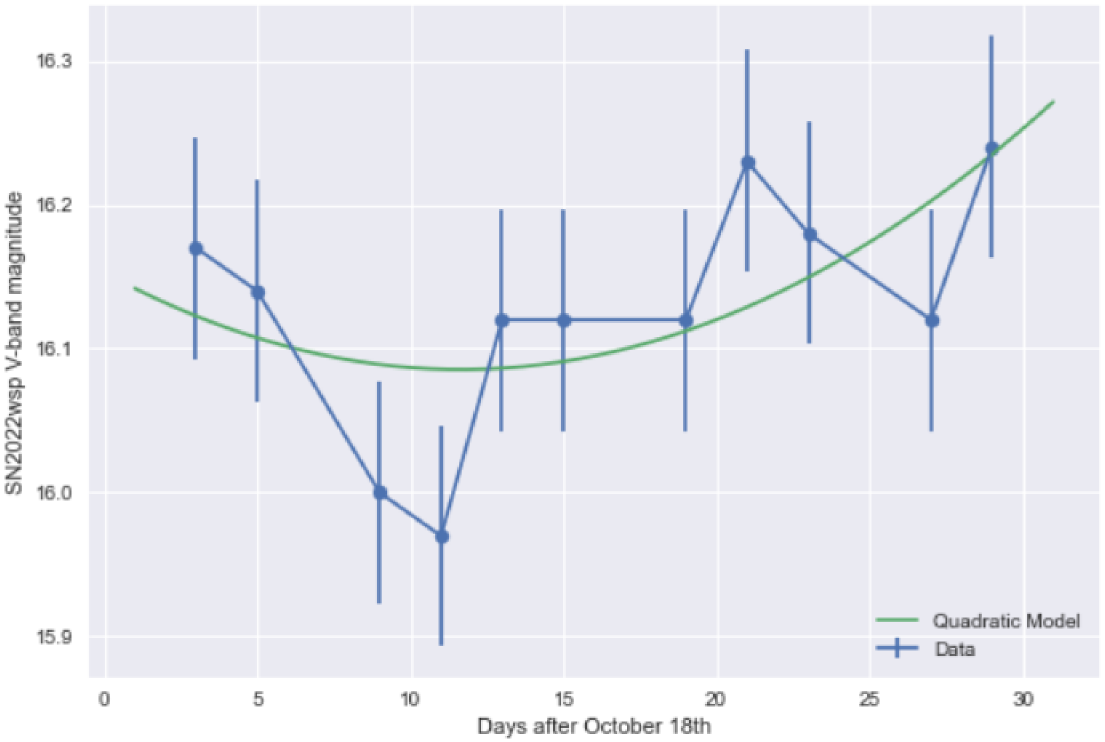

Figure 6: Quadratic model best fitted to the Bessel V filter magnitudes over time, with outliers removed.

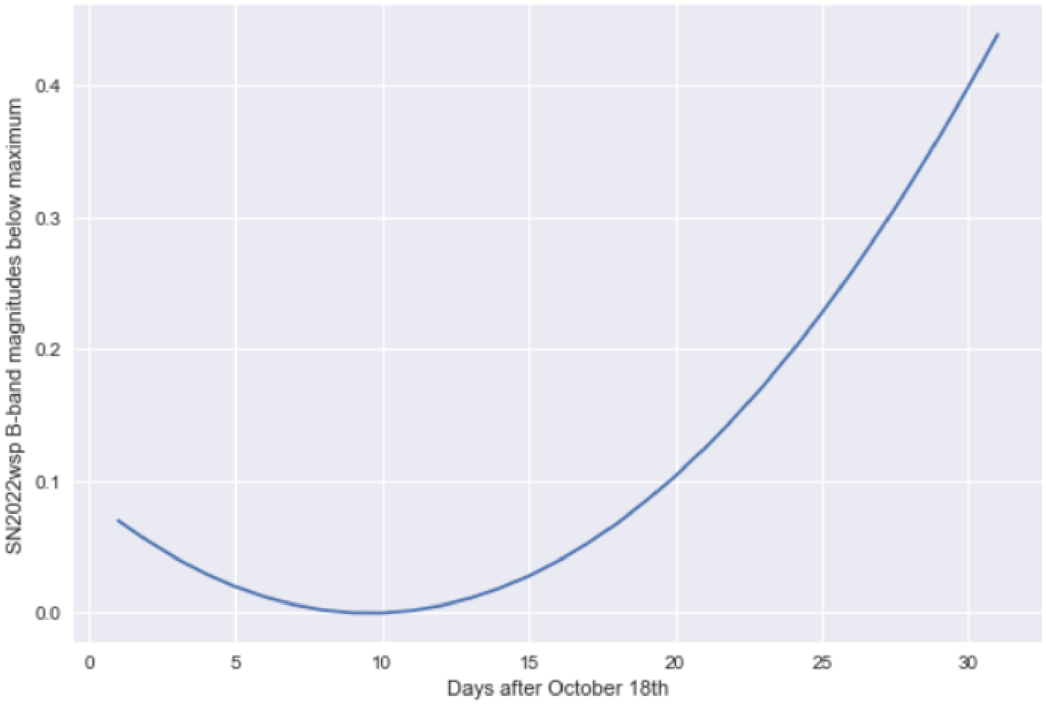

Figure 7: Same model for B filter magnitudes, in difference from maximum magnitude.

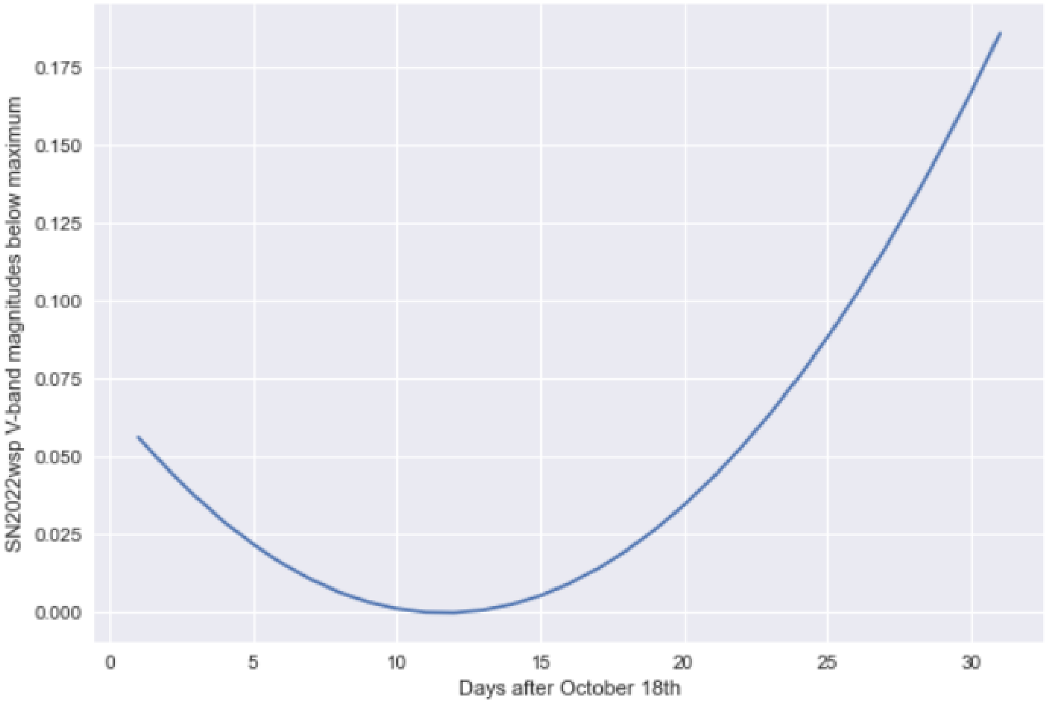

Figure 8: Same model for V filter magnitudes, in difference from maximum magnitude.

Another thing that this model allowed for was to determine a day of maximum brightness. This is important for subtyping the supernovae, as this is one of the main metrics against which we will be comparing 2022wsp.

The next step was to truncate our data to only include the datapoints after the maximum brightness and map a linear best fit model. This gives us a value of the rate of decrease from the maximum brightness in magnitudes per day to later compare the Bessel B filter with the composite results from Doggett and Branch (1985). The Bessel B linear model using this method had a rate of decrease of 0.0089 magnitudes per day.

The first step in analyzing this data was to determine the subtype. Comparing Figure 7 against the aforementioned average light curves for Type II-L and II-P SNe, as shown below, suggests that SN2022wsp is a Type II-P supernova, as the slow decrease in magnitude in the approximately twenty days after maximum brightness is shown in both Figure 7 and the Type II-P average from Doggett and Branch (1985).

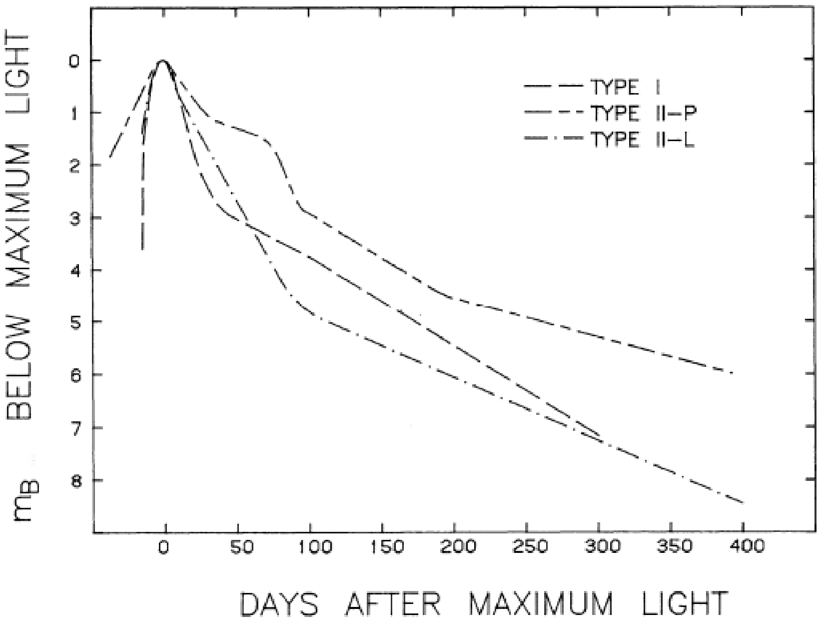

Figure 9: SNe Light Curve averages. Source: Doggett and Branch (1985)

This conclusion is corroborated by the projected slope of decrease in the post-maximum time. The study cites Type II-P to average about 0.0075 magnitudes per day, which, though slightly slower than our data’s model of 0.0089 magnitudes per day, matches this more closely than the average for Type II-L of 0.012 magnitudes per day. This is especially true if the last data point—a point which was ultimately not considered an egregious outlier enough to be thrown out but does seem to have more significant error than most—is ignored, in which case the modeled slope from the data actually falls below the Type II-P average, putting 2022wsp firmly into the II-P category.

Unfortunately, the data had too much error and was thus too imprecise to qualitatively model features like progenitor radius and ejected mass. All that can be effectively estimated by comparison with Young (2004) is that 2022wsp is likely to be on the lower end of explosion energy, as higher explosion energies fall faster from their peak brightness (as shown in Figure 10 below).

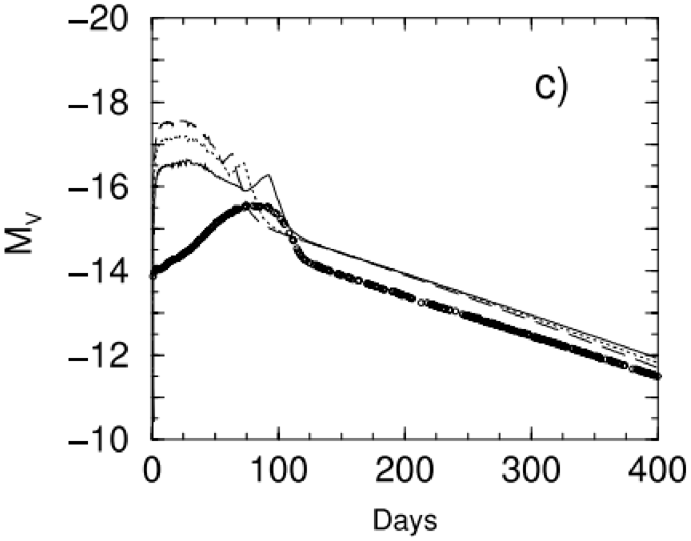

*Figure 10: 3*10^51 ergs (dashed line), 2*10^51 ergs (dotted line), 1*10^51 ergs (solid line) Source: Young (2004)*

Conclusions

It can be concluded with fair certainty that sn2022wsp is likely to be a Type II-P supernova as opposed to a Type II-L. However, there is still some room to find evidence to the contrary with clearer imaging of the SN. It can also, with far, far less certainty be estimated that 2022wsp is a supernova with lower explosion energy, though this is not particularly clear at all and would likely not be solidified by clearer imaging of the light curve and would likely require direct detection of the progenitor to confirm.

The real takeaway from this project is that measurements of the magnitude needs a far higher signal to noise ratio than we were able to achieve.

The first thing that would change in a repeat experiment would be to change the data collection procedure to eliminate the noise that made photometry difficult. Instead of a single 50 second exposure, several somewhat shorter exposures through each filter added together would help to alleviate the harsh noise plaguing our data. Additional aid from a spectroscope would also be massively helpful and open up more opportunities.

Additionally, a set of exposures without a filter would help with modeling, as many models use bolometric magnitude light curves, though plenty use the B and V magnitudes that we used as well. This would help to retrieve more accurate bolometric magnitudes than we would have been able to through comparatively rudimentary bolometric corrections that we would have done but were unable to due to the high error in both B and V magnitudes.

References

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