Light Curve Analysis of AT2023hpb

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Abstract

In this research project, we conducted a photometric analysis of the cataclysmic variable (CV) star AT2023hpb using data obtained from the Las Cumbres Observatory Global Telescope Network (LCOGTN). Our observations were carried out in three different filters, namely i, g, and r, over a span of 10 days. Our focus was to ascertain the variability in the luminosity of AT2023hpb by constructing light curves from our photometric data. Following extensive preprocessing steps, we utilized the photometric software Astroart to extract raw data from the images. The uncertainty in photometric measurements was calculated using Castro's equation, further ensuring the robustness of our analysis. Our results revealed a sudden increase in the star's brightness towards the end of the observation period. The limited observation window served as a major constraint in identifying any definite pattern in the variability.

1 Introduction

Supernovae are fascinating and incredibly powerful astronomical events that occur at the end of a star's lifespan. They signify the explosive death of a massive star and release an immense amount of energy in the process. These events are among the most energetic phenomena in the universe and have a significant impact on the surrounding space. The visual manifestation of a supernova is relatively short-lived, typically lasting a few months, when considering the entire lifespan of a star. Only a small fraction of stars in a typical galaxy possess the potential to undergo a supernova event. This capability is limited to stars of high mass and certain uncommon types of binary star systems involving white dwarfs.[1].

Astronomers classify supernovae into two primary types: Type I and Type II. They determine the type based on the supernova's light patterns and the presence of specific chemical elements in its spectra. If the spectrum of a supernova shows hydrogen lines, it is classified as Type II. If there are no hydrogen lines, it is classified as Type I.

Type I supernovae occur in binary star systems, where two stars orbit around a common center of mass. One of the stars is a white dwarf, a compact stellar remnant composed mostly of carbon and oxygen. The white dwarf accretes matter from its companion star until it reaches a critical mass known as the Chandrasekhar limit. At this point, the white dwarf undergoes a rapid and violent thermonuclear explosion, releasing an enormous amount of energy[2]. The formation process of Type Ia supernova is shown in figure 1. Type II supernovae, on the other hand, involve the collapse of a massive star with a minimum mass of about eight times that of our Sun. These stars burn their nuclear fuel through a process of fusion, fusing lighter elements into heavier ones. Eventually, the core of the star becomes predominantly composed of iron, which cannot sustain nuclear fusion. Without the energy generated by fusion to counteract gravity, the core collapses inward rapidly. The infalling matter rebounds and releases a colossal burst of energy, resulting in a supernova explosion.

We can typically study supernovae when their brightness, indicated by their apparent magnitude, is below 16. However, none of the recently observed supernovae meet this cri-

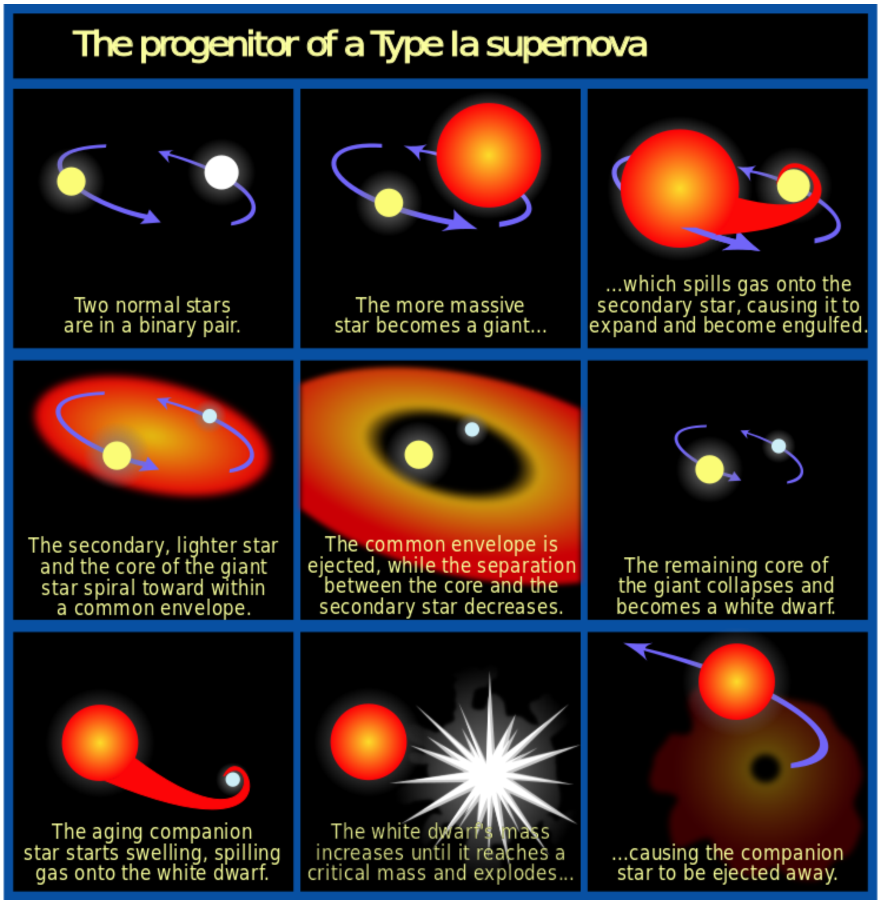


Figure 1: Formation process of type Ia supernova[3]

terion. As a result, we have selected a variable cataclysmic star as the focal point for our observation instead. Cataclysmic variable stars, also known as CV stars, are a type of binary star system characterized by irregular and dramatic changes in luminosity. These systems consist of a white dwarf star and a companion star, often a main-sequence star or a red dwarf. This is similar to the conditions for type Ia supernova formation, therefore, a CV star has a probability of developing into a supernova[4]. The target of our observation, AT2023hpb, was first discovered on May 1st, 2023 and located at R.A. 00:51:11.790, Decl. -73:11:30.30, with discovery magnitude 14.2[5].

In the context of variable stars, light curve analysis has been an essential tool [6]. A light curve is a graphical representation of the brightness or the flux of a celestial object as a function of time. Such analyses are pivotal to studying the variability in the luminosity of stars, thereby providing insights into their inherent properties and the underlying physical processes [7].

Historically, the first recorded observations of a variable star date back to the year 1596 when David Fabricius noted the variability in the brightness of the star Mira [8]. Since then, our understanding of variable stars and the techniques used to study them have significantly evolved. The advent of CCD photometry in the 20th century ushered in an era of accurate and precise photometric observations [9].

This project revolves around the cataclysmic variable star AT2023hpb, which is part of a binary star system where a white dwarf accretes matter from a companion star. We conducted a photometric analysis of AT2023hpb using the Las Cumbres Observatory Global Telescope Network.

2 Methods

This project is based on the images collected by the Las Cumbres Observatory located at Cerro Tololo and Siding Spring, site code LSC and COJ, respectively. 0.4m LCO telescopes were used to make observations with filters SDSS g', SDSS r', and SDSS i'. The observation request is shown below.

Table 1: Observation Request

Target Name	RA (J2000)	Dec (J2000)	Filter	Exposures	Integration Times (s)	Observational Windows
AT2023hpb	00:51:11.790	-73:11:30.30	SDSS g'	2	100	Every 2 days (repeat for 2 weeks)
AT2023hpb	00:51:11.790	-73:11:30.30	SDSS i'	2	100	Every 2 days (repeat for 2 weeks)
AT2023hpb	00:51:11.790	-73:11:30.30	SDSS r'	2	100	Every 2 days (repeat for 2 weeks)

We received images taken from May 10th to May 20th, with the absence of May 12th, which is different from our arrangement. In this case, we have 4 images for every filter on each day, then 120 images in total.

Astroart 8 was mainly used to process the images and obtain AT2023hpb's magnitude during our observational window. For the photometry, four reference stars were selected manually, and we used the same set of reference stars for each image that we processed. GAIA DR2 was chosen as our ATLAS catalog, shown in figure 2. From this catalog, the information of the four selected reference stars is shown in figure 2, and ATLAS provides the location for these four reference stars nearby NGC 290, shown in figure 3. After performing the astrometry and photometry process in Astroart, we select AT2023hpb on each image and obtain its magnitude calculated by Astroart. The Astroart information for AT2023hpb on May 11th and May 15th are shown in figure 4 and figure 5. Additionally, the images taken on May 20th are not applicable, as the CV is invisible under all three filters, shown in figure 6.

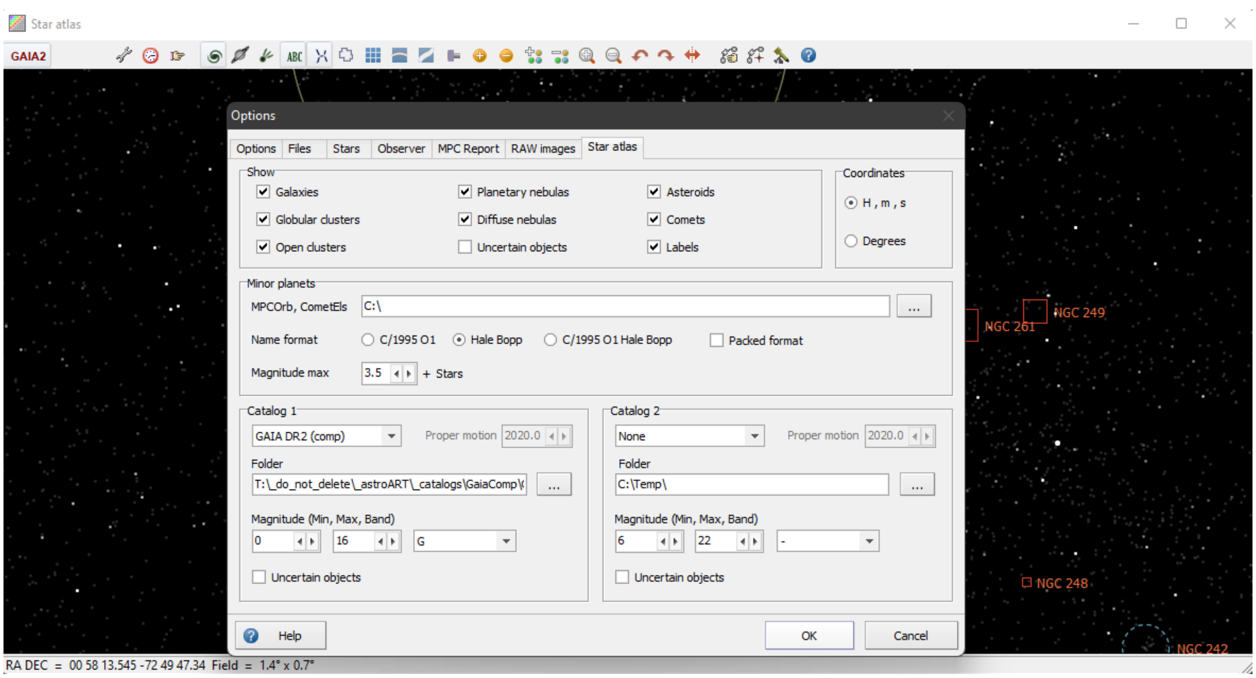


Figure 2: Formation process of type Ia supernova[3]

Table 2: Reference stars data

Reference Stars	RA (J2000)	Dec (J2000)	Mag.	O-C pos	O-C mag	FWHM	Round	S/N	PSNR
1	00:52:51.242	-73:06:53.67	10.916	0.17	0.11	5.44	0.41	856.0	81
2	00:51:30.906	-73:01:23.17	10.534	0.08	0.04	5.36	0.43	978.3	82
3	00:53:09.925	-73:13:24.62	10.866	0.20	0.07	5.52	0.41	791.1	80
4	00:52:27.383	-73:15:06.75	11.747	0.11	0.00	5.54	0.44	485.6	73

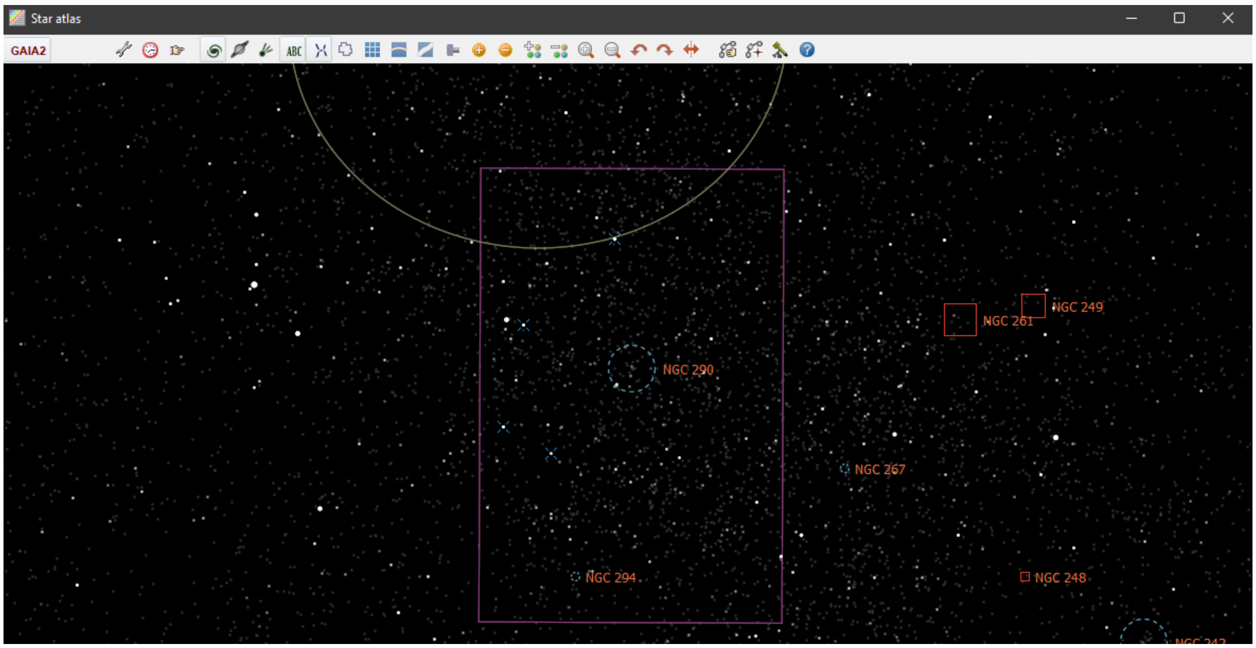
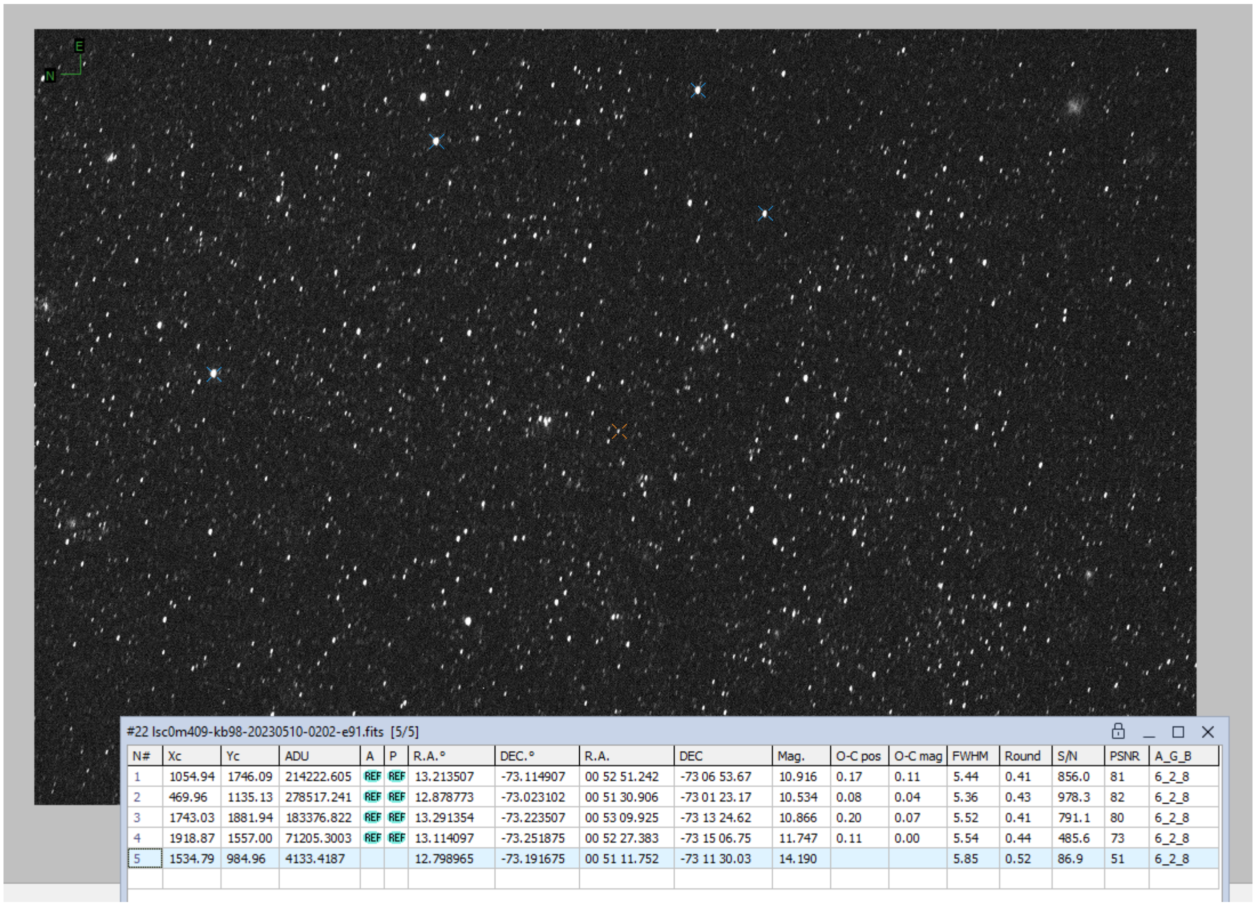
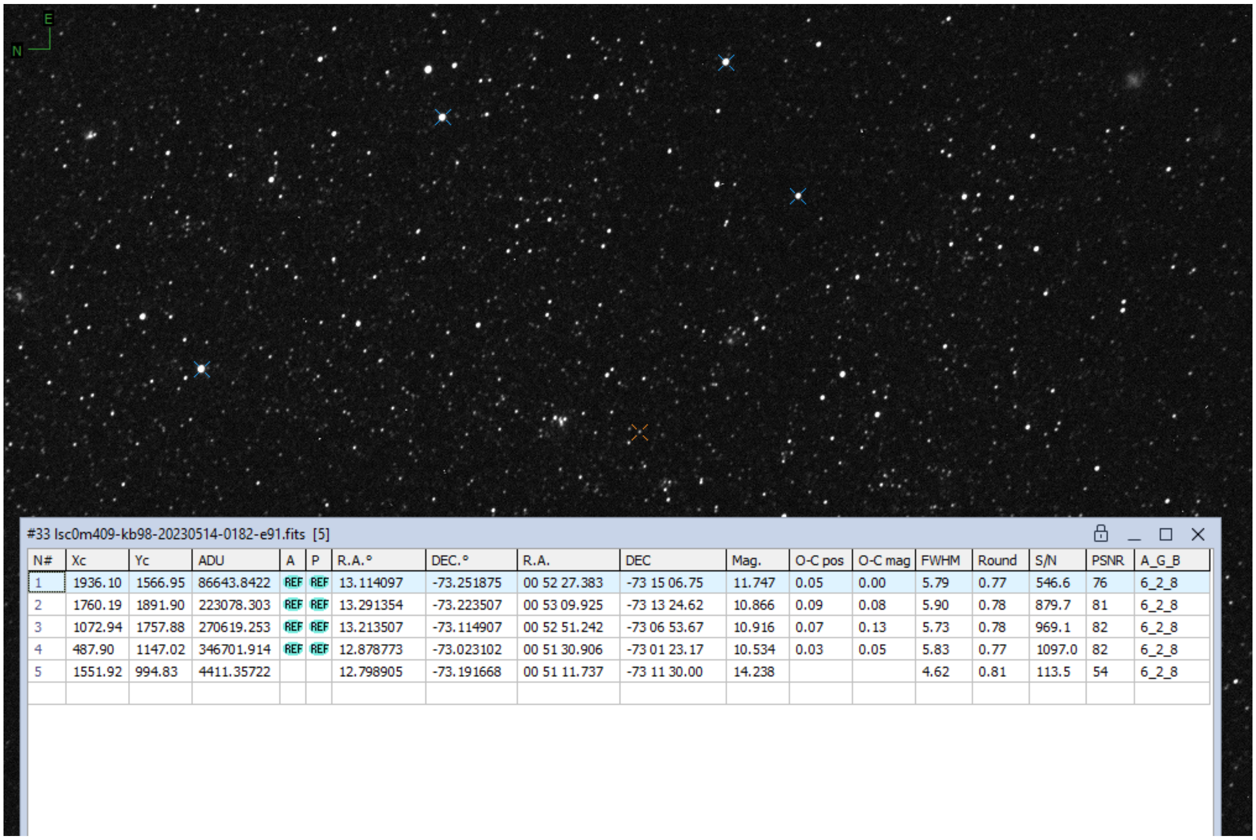


Figure 3: Reference stars shown in ATLAS, labeled by blue cross



N#	Xc	Yc	ADU	A	P	R.A.°	DEC.°	R.A.	DEC	Mag.	O-C pos	O-C mag	FWHM	Round	S/N	PSNR	A_G_B
1	1054.94	1746.09	214222.605	REF	REF	13.213507	-73.114907	00 52 51.242	-73 06 53.67	10.916	0.17	0.11	5.44	0.41	856.0	81	6_2_8
2	469.96	1135.13	278517.241	REF	REF	12.878773	-73.023102	00 51 30.906	-73 01 23.17	10.534	0.08	0.04	5.36	0.43	978.3	82	6_2_8
3	1743.03	1881.94	183376.822	REF	REF	13.291354	-73.223507	00 53 09.925	-73 13 24.62	10.866	0.20	0.07	5.52	0.41	791.1	80	6_2_8
4	1918.87	1557.00	71205.3003	REF	REF	13.114097	-73.251875	00 52 27.383	-73 15 06.75	11.747	0.11	0.00	5.54	0.44	485.6	73	6_2_8
5	1534.79	984.96	4133.4187			12.798965	-73.191675	00 51 11.752	-73 11 30.03	14.190			5.85	0.52	86.9	51	6_2_8

Figure 4: May 11th filter g, with AT2023hpb labeled by an orange cross and reference stars labeled by blue



N#	Xc	Yc	ADU	A	P	R.A.°	DEC.°	R.A.	DEC	Mag.	O-C pos	O-C mag	FWHM	Round	S/N	PSNR	A_G_B
1	1936.10	1566.95	86643.8422	REF	REF	13.114097	-73.251875	00 52 27.383	-73 15 06.75	11.747	0.05	0.00	5.79	0.77	546.6	76	6_2_8
2	1760.19	1891.90	223078.303	REF	REF	13.291354	-73.223507	00 53 09.925	-73 13 24.62	10.866	0.09	0.08	5.90	0.78	879.7	81	6_2_8
3	1072.94	1757.88	270619.253	REF	REF	13.213507	-73.114907	00 52 51.242	-73 06 53.67	10.916	0.07	0.13	5.73	0.78	969.1	82	6_2_8
4	487.90	1147.02	346701.914	REF	REF	12.878773	-73.023102	00 51 30.906	-73 01 23.17	10.534	0.03	0.05	5.83	0.77	1097.0	82	6_2_8
5	1551.92	994.83	4411.35722			12.798905	-73.191668	00 51 11.737	-73 11 30.00	14.238			4.62	0.81	113.5	54	6_2_8

Figure 5: May 15th filter g, with AT2023hpb labeled by an orange cross and reference stars labeled by blue

Figure 6: May 20th filter g, AT2023hpb is invisible

3 Raw Data and Error Analysis

3.1 Raw Data

Following the above procedure, we obtained the raw data for all three filters, shown in the tables below.

Table 3: Raw data of AT2023hpb for filter SDSS i'

Date (Site)	Magnitude	FWHM	Round	S/N	PNSR
May 10 (LSC)	14.257	3.81	0.89	200.4	67
May 11 (LSC)	14.377	3.66	0.91	188.5	65
May 13 (LSC)	14.389	4.06	0.99	206.3	67
May 14 (LSC)	14.380	4.30	0.81	193.3	64
May 15 (LSC)	14.493	4.94	0.90	185.1	65
May 16 (LSC)	14.584	4.39	0.93	192.8	66
May 17 (COJ)	14.901	3.40	0.94	270.1	71
May 18 (LSC)	14.585	4.25	0.91	197.0	66
May 19 (COJ)	14.395	6.12	0.86	170.8	65
May 20 (LSC)	N/A				

Table 4: Raw data of AT2023hpb for filter SDSS g'

Date (Site)	Magnitude	FWHM	Round	S/N	PNSR
May 10 (LSC)	14.026	4.77	0.52	99.1	53
May 11 (LSC)	14.190	5.85	0.52	86.9	51
May 13 (LSC)	14.284	4.90	0.82	113.8	53
May 14 (LSC)	14.151	4.23	0.83	134.1	57
May 15 (LSC)	14.238	4.62	0.81	113.5	54
May 16 (LSC)	14.214	4.31	0.85	141.4	57
May 17 (COJ)	14.229	3.55	0.82	201.5	62
May 18 (LSC)	14.238	3.90	0.81	146.9	57
May 19 (COJ)	13.609	6.79	0.92	139.1	57
May 20 (LSC)	N/A				

Table 5: Raw data of AT2023hpb for filter SDSS r'

Date (Site)	Magnitude	FWHM	Round	S/N	PNSR
May 10 (LSC)	14.430	4.07	0.95	242.6	64
May 11 (LSC)	14.507	3.61	0.88	223.5	63
May 13 (LSC)	14.549	4.26	0.91	246.5	65
May 14 (LSC)	14.449	4.38	0.90	249.0	65
May 15 (LSC)	14.547	5.10	0.88	223.2	64
May 16 (LSC)	14.666	4.55	0.87	243.7	65
May 17 (LSC)	15.083	3.36	0.97	351.0	71
May 18 (COJ)	14.735	4.13	0.84	244.9	65
May 19 (COJ)	14.267	5.94	0.71	218.8	63
May 20 (LSC)	N/A				

3.2 Error Analysis

From Professor Lubin's course note, we have the equation for the signal-to-noise ratio:

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

In the above table 3, 4, and 5, we have a signal-to-noise ratio (SNR) given by Astroart. The photometric uncertainties for each image can be calculated by Castro's equation[10]:

$$\sigma_{m_{\text{inst}}} = \frac{2.5}{\ln(10)}\frac{\sigma_I}{I} = \frac{2.5}{\ln(10)}\frac{N}{S} \tag{2}$$

Then we obtain the following photometric data with uncertainty shown in the following tables:

Table 6: Photometric Data with Uncertainty for filter i

Date (Site)	Magnitude	Uncertainty
May 10 (LSC)	14.257	0.0054
May 11 (LSC)	14.377	0.0058
May 13 (LSC)	14.389	0.0053
May 14 (LSC)	14.380	0.0056
May 15 (LSC)	14.493	0.0059
May 16 (LSC)	14.584	0.0056
May 17 (COJ)	14.901	0.0040
May 18 (LSC)	14.585	0.0055
May 19 (COJ)	14.395	0.0064

Table 7: Photometric Data with Uncertainty for filter g

Date (Site)	Magnitude	Uncertainty
May 10 (LSC)	14.026	0.0110
May 11 (LSC)	14.190	0.0125
May 13 (LSC)	14.284	0.0095
May 14 (LSC)	14.151	0.0081
May 15 (LSC)	14.238	0.0096
May 16 (LSC)	14.214	0.0077
May 17 (COJ)	14.229	0.0054
May 18 (LSC)	14.238	0.0074
May 19 (COJ)	13.609	0.0078

Table 8: Photometric Data with Uncertainty for filter r

Date (Site)	Magnitude	Uncertainty
May 10 (LSC)	14.430	0.0045
May 11 (LSC)	14.507	0.0049
May 13 (LSC)	14.549	0.0044
May 14 (LSC)	14.449	0.0044
May 15 (LSC)	14.547	0.0049
May 16 (LSC)	14.666	0.0045
May 17 (LSC)	15.083	0.0031
May 18 (COJ)	14.735	0.0044
May 19 (COJ)	14.267	0.0050

4 Results

From the above data of AT2023hpb's magnitude under filters i, g, and r, we can plot its light curve in this period.

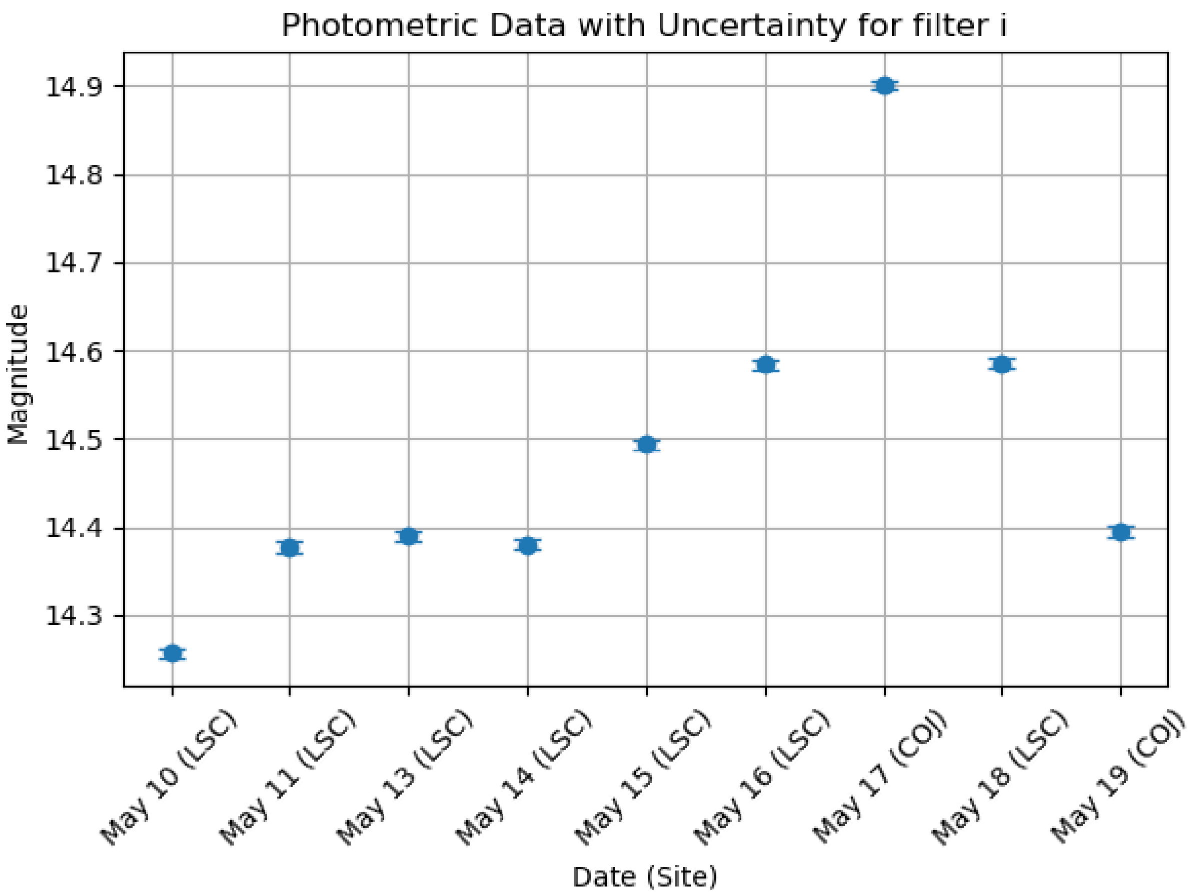


Figure 7: Photometric Data with Uncertainty for filter i

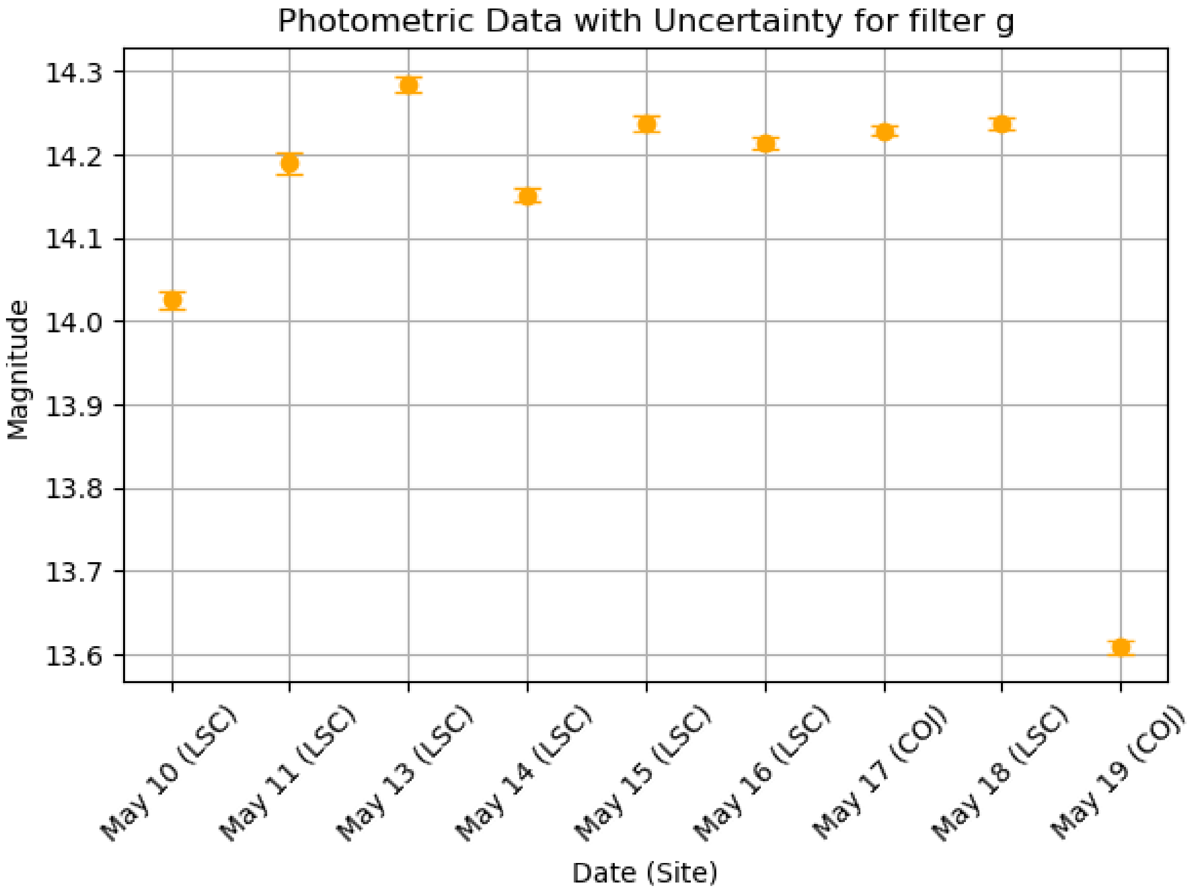


Figure 8: Photometric Data with Uncertainty for filter g

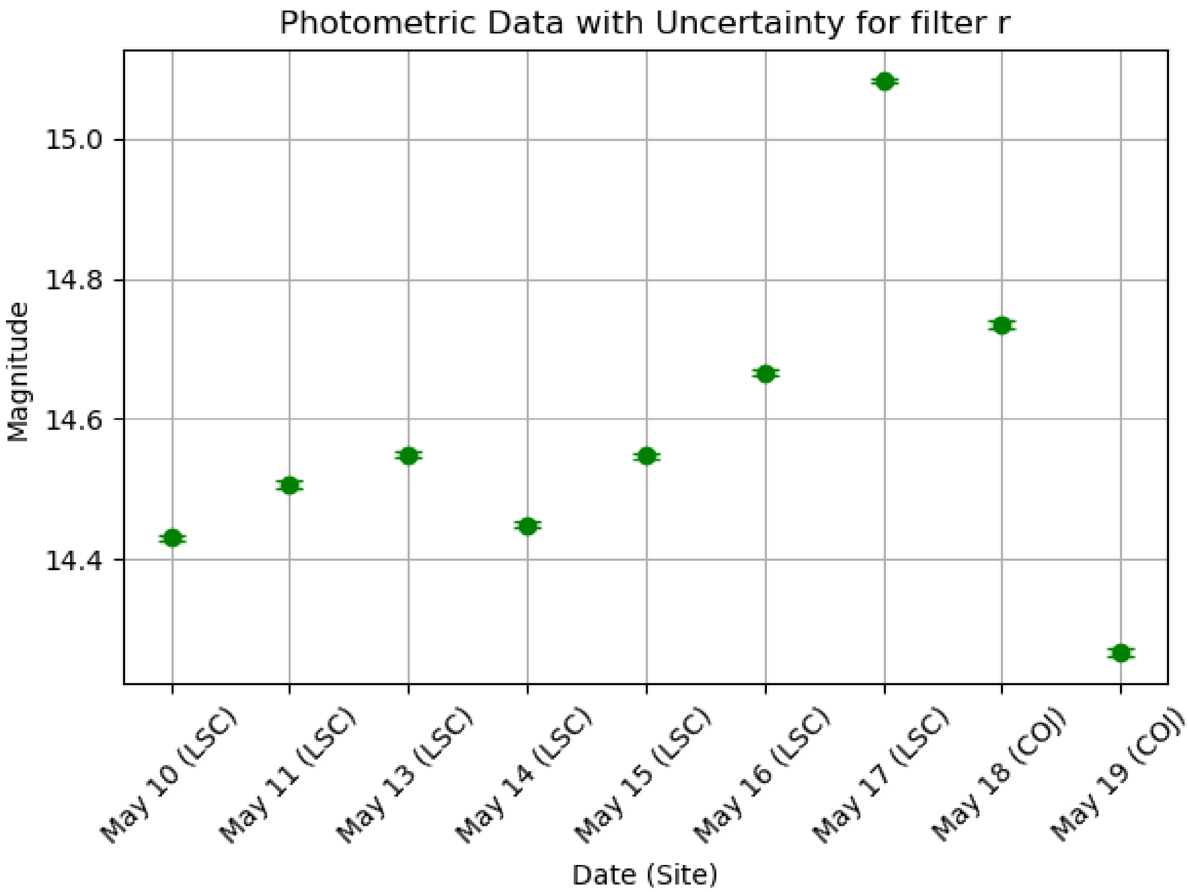


Figure 9: Photometric Data with Uncertainty for filter r

To have a positive correlation between the horizontal axis and the luminosity of AT2023hpb, the sign of the apparent magnitude has been reversed. Additionally, using Python, a quadratic model was fitted to the refined data to obtain the best possible fit. The complete light curve of AT2023hpb is shown in figure 10.

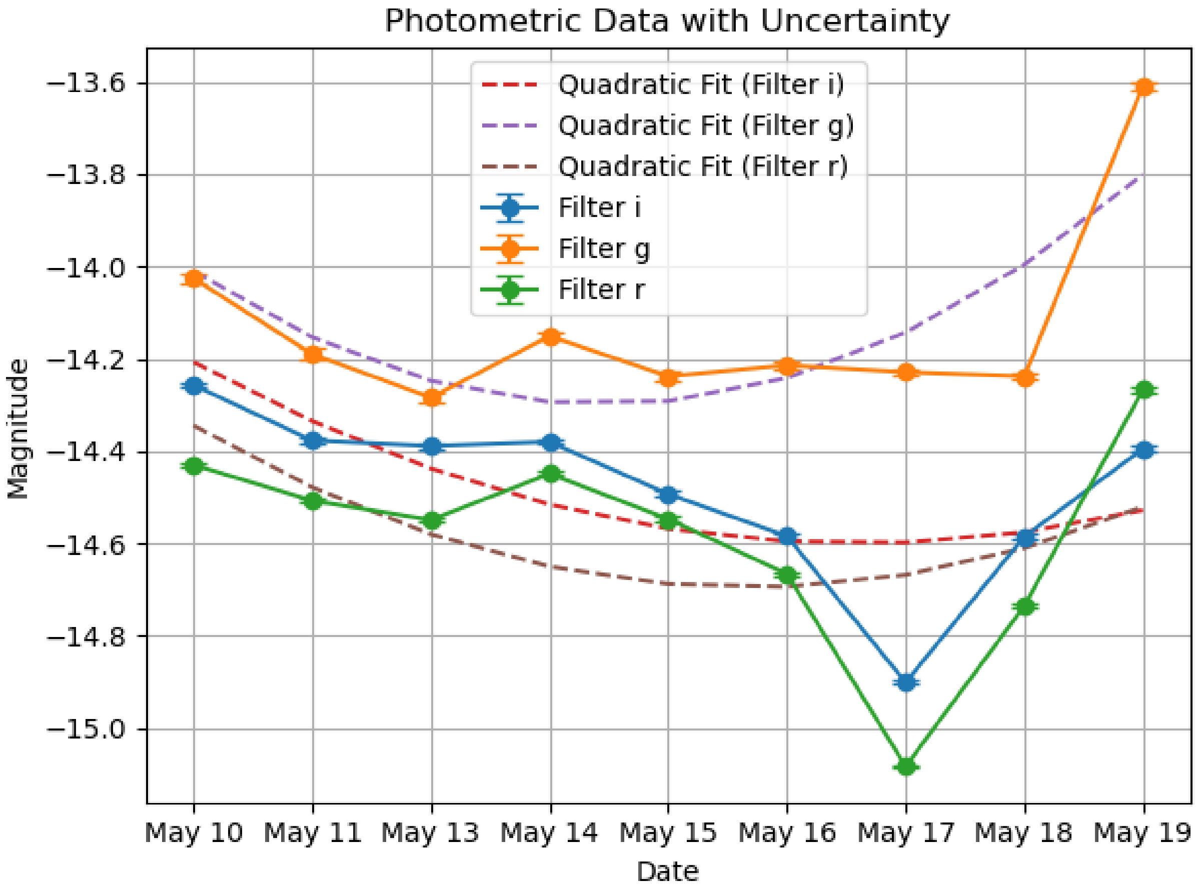


Figure 10: Photometric Data with Uncertainty

5 Discussion

In this project, since the time interval for observing AT2023hpb is too short, a complete and clearly regular pattern cannot be obtained. We can see a sudden increase in the brightness of this CV at the end of the observation period. If we had more time to monitor the star, we would have the opportunity to investigate this interesting phenomenon further. From the above data, our measurement is relatively accurate because the uncertainty is very small compared to the magnitude. But still, we can further improve the signal-to-noise ratio with more exposure as well as superimposed image preprocessing In addition, ultimately, it would be ideal for us to find a recently active supernova and continuously observe its brightness changes, and compare it with spectrograms provided by other institutions to further verify our results.

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