Expt.4: Transient Source Observation and Photometry

Author: Mohammed Safeer Zaheer

Student ID: 20014777

Course Name: Practical Astronomy 1: Technique

Course Code: PHAS0043

Date Completed: 15/Dec/2022

Abstract

The main aim of this experiment was to conduct aperture photometry of a transient object (in this case, possibly a cataclysmic variable) via use of multiple images (r- and g-sloan) of the object in different filters and via use of standard stars in ALADIN catalogs. Use of multiple filters allowed for correction of colour, resulting in more accurate magnitude estimates for the main object: Gaia16bnz. The magnitudes were found to be $m_0(g) = 15.568$ and $m_0(r) = 9.504$. The uncertainties for these calculations were found to be:

$\sigma_m(g) = 0.0025$, $\sigma_m(r) = 0.0037$ and $\sigma_{std}(g) = 0.0291$, $\sigma_{std}(r) = 0.0569$.

Although these magnitudes are not accurate to measurements of mags on https://gsaweb.ast.cam.ac.uk/, taking an average of the two does give a value more fit for the current trend in brightness. Also, the uncertainties calculated were good, as the values are much smaller than the main values.

Introduction

The word 'transient' has the definition:

lasting only for a short time; impermanent.

This is a very useful word in our daily lives as most things we encounter in our day are transient. They always change. But for astronomical objects, you would expect that changes HAVE to be happening over massive timescales that are imperceptible to us. So, what do we mean when we call something a transient source in the astronomical context? In astrophysics, a transient object is an object that increases and then subsequently decreases in brightness over a (relatively) short period of time. The kinds of objects that can fall into this definition are quite broad as they can range from catalysmic variable stars, to supernova explosions, to microlensing events. Since they are so varied, keeping a look-out for transient sources is essential, as they can be useful in understanding topics like gravitational lensing, energetic stellar events (which could lead to black-holes) and even stellar evolution. The timescales for transient activity can also vary, with some occurring over a few seconds, while others occurring over years. They can also be periodic.

In this experiment, we observed the transient object Gaia16bnz, which was first alerted to by the Gaia satellite due to a dip in brightness. But when further observations were made, it was noted that the brightness varied over time, increases and decreasing in the timescales of about 2-3 years (https://gsaweb.ast.cam.ac.uk/alerts/alert/Gaia16bnz/). Thus, it is possible that it is a catalysmic variable star, although very little is understood about what causes the variations in brightness.

In this experiment, we will be conducting aperture photometry to get reliable estimate of the magnitude of Gaia16bnz in g and r (sloan) filters.

Data

The imaging for Gaia16bnz was done in ‘r’ and ‘g’ (sloan) filters via the C14-East telescope at University of London Observatory.

Fig 1: Image of Gaia16bnz in g-filter via C14-East.

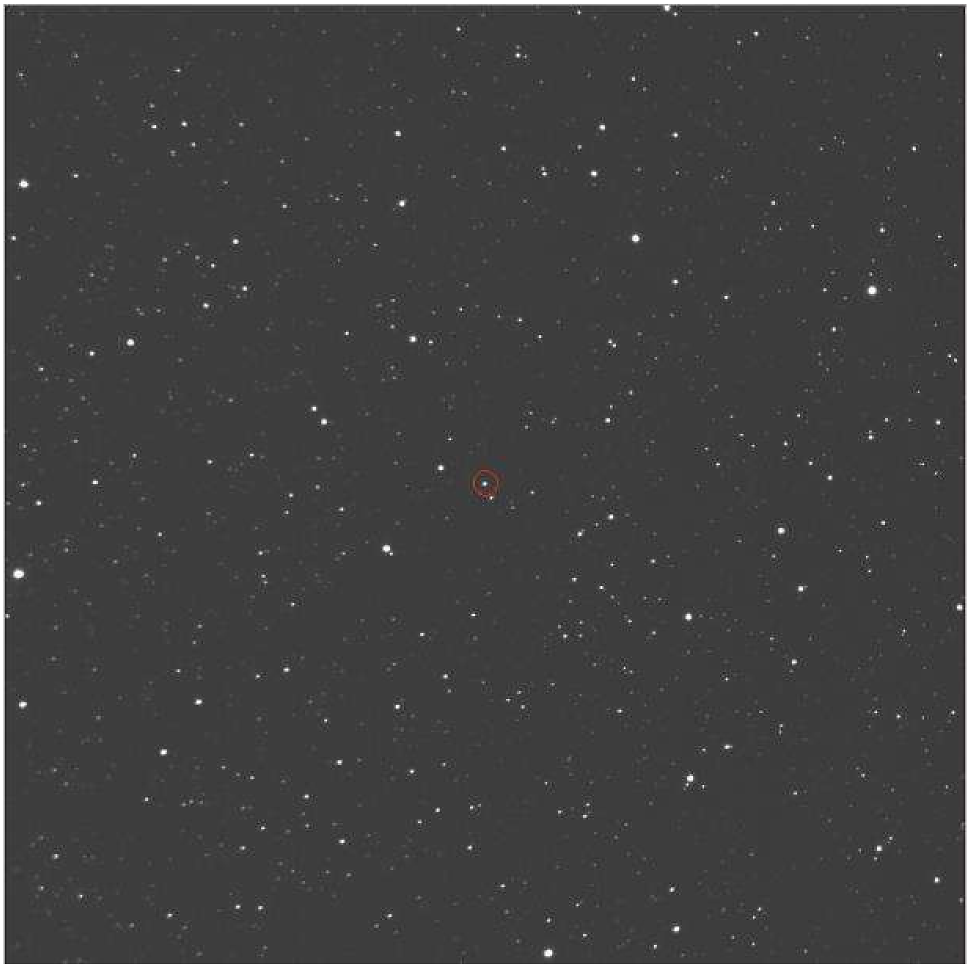

Fig 2: Image of Gaia16bnz in r-filter via C14-East.

Procedure and Results

Preparing the images for photometry

After downloading the fits images of Gaia16bnz from ChRIS (4 images for each filter), I first checked if the images were plate-solved by opening them in SAOImageDS9 and moving the cursor over the image to see if the RA and Dec values corresponded to what would be expected. After I confirmed this, I then stacked the fits-files for each filter. This was done using the pipeline scripts provided to us on our Linux machines along with the stacking method described in Appendix C of Expt 4: Part 1's script. I then checked for any misalignment in the stacked images. The g-filter images had misalignment due to one of the fits images, and so I removed it from the stacking process and ran it again. I also removed a fit-image from the r-filter's stack to keep the number of images used for stacking in each filter the same. Thus, the stacked-images in Fig 1 and Fig 2 were obtained.

Conducting the Photometry

To begin the photometry of the two images, I first needed to identify 5-6 standard stars in the field with known magnitudes in the desired filters (g and r). I found the required data on these stars using Aladin on the Linux terminal. I further used the 'SLOAN SDSS DR12' catalog to find stars in the field that had magnitude measurements in g- and r-sloan filters. Thus, I found the following standard stars:

Index	Object ID	R.A	Dec	g	r	Err_g	Err_r
1	123766646532433	55.04125964	49.35104197	15.86152	11.99742	0.0127673	0.000739476
2	123766713963544	54.99962828	49.39191159	10.76589	10.28559	0.000715484	0.000719192
3	123766713963538	54.94309466	49.32169516	14.26811	11.05604	0.003760715	0.000779891
4	123766646532433	55.17246036	49.37524738	12.73747	11.50933	0.00087498	0.000833294
5	123766713963538	54.95080785	49.32823207	11.74157	13.74842	0.000753179	0.007547498
6	123766713963538	54.8894156	49.26130016	13.15293	12.66817	0.002359279	0.00217737

Table 1: Data collected on the standard stars in Gaia16bnz's field.

Next, I loaded up the stacked g-filter fit image of Gaia16bnz onto GAIA imaging software to conduct aperture photometry of the standard stars. To do this, I first needed a well-justified aperture-size to use for this step. This was done using the FWHM of the standard stars. I measured the FWHM of each star using the slice tool in GAIA. Then I used that to get a mean FWHM of 4.18 ± 0.258844. Then multiplying this by 2, I got the aperture size, which is 8.36 ± 0.517688.

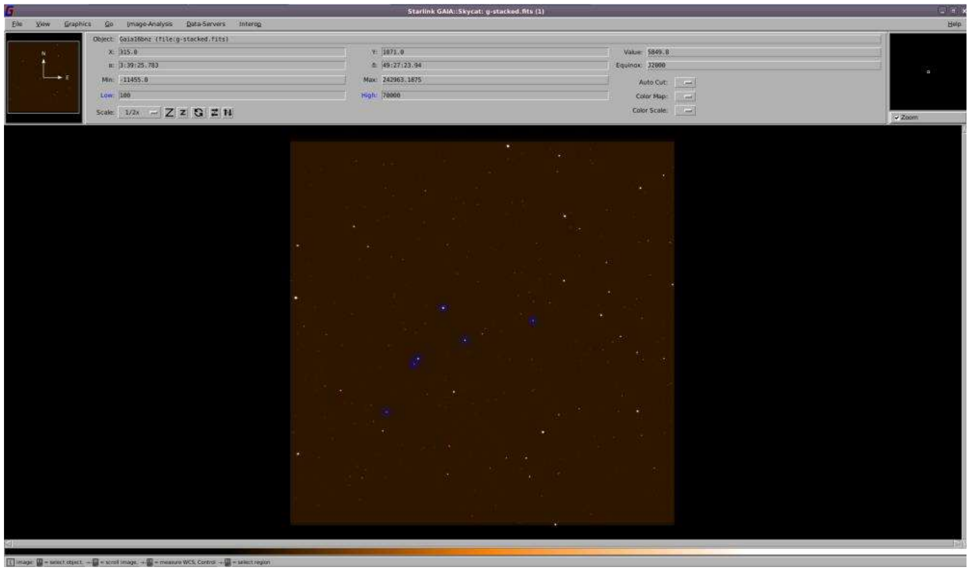

Fig 3: Screencap of the apertures used in GAIA for the g-filter.

Thus, using this aperture size, I conducted aperture photometry (in data counts) to get the following data from both filters:

	index	x	y	count	sky	signal	m1
r-filter	1	694.78	737	3622	3930.9	791220	10.25425686
	2	608.57	865	16520	3988.1	3608500	8.606683226
	3	492.83	642	2770	3961.1	605150	10.54534241
	4	965.63	815	5625	3929.6	1228800	9.776296993
	5	508.64	663	6956	3976.8	1519700	9.545605341
	6	382.17	451	2134	3942.4	466250	10.82845289
g-filter	1	694	737	5221.6	5866.4	1140700	9.857071396
	2	608	866	20693	5883.4	4520200	8.362105873
	3	493	643	2117.5	5883	462570	10.83705634
	4	965	815	4115.3	5845.8	898970	10.115637
	5	508	664	9509	5884.3	2077200	9.206304215
	6	382	451	4957.8	5870	646130	10.47420024

Table 2: Data obtained from GAIA for the standard stars.

Here, m_1 was obtained using the equation (from 'Task 4: Part 2' script),

$$m_1 = -2.5 \cdot \log(N_s) + z \qquad (N_s = Signal)$$

where z = 25 was used as a reasonable trial-point. We also need the (g-r) value for each star, which can be calculated by subtracting m1 of g-filter from m1 of r-filter for each star. This gives us:

Index	C1
1	-0.397185462
2	-0.244577353
3	0.291713936
4	0.339340009
5	-0.339301126
6	-0.354252653

Table 3: (g-r) values for each star.

Next, we use the equation,

$$m_1 = m_0 + z_1 + \varepsilon_1 C_1$$

Here, m_0 is the magnitude of the standard stars for each filter obtained from the SLOAN catalog on ALADIN (labelled "g" and "r" in Table 1). We also set ε_1 to zero, to ignore color-dependent effects. Thus, rearranging the equation above and calculating for z_1 we get:

	index	z1
r-filter	1	-1.743163141
	2	-1.678906774
	3	-0.510697594
	4	-1.733033007
	5	-4.202814659
	6	-1.839717112
g-filter	1	-6.004448604
	2	-2.403784127
	3	-3.431053658
	4	-2.621832997
	5	-2.535265785
	6	-2.678729765

Table 4: z_1 values for each star in each filter using the above equation.

Now, I will plot $m_1 - m_0$ (which is z_1) on the y-axis and C_1 values on the x-axis for each filter and then use the np.polyfit function in python to obtain a line-of-best-fit and its parameters (slope and y-intercept). Here we get,

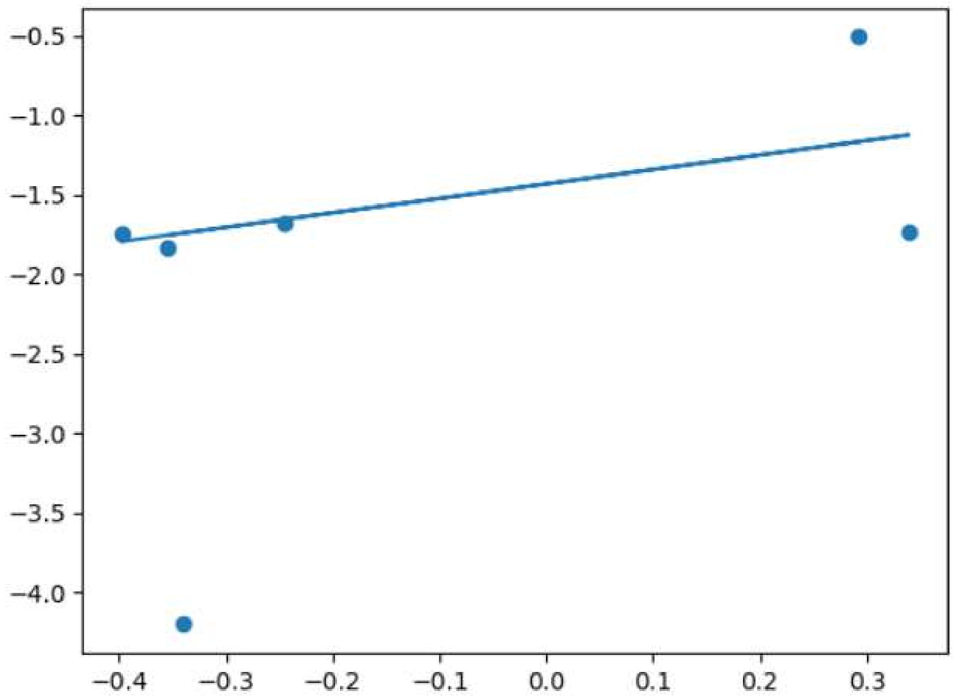

Fig 4: Scatterplot of z1 against C1 for **r-filter**, along with line of best fit.

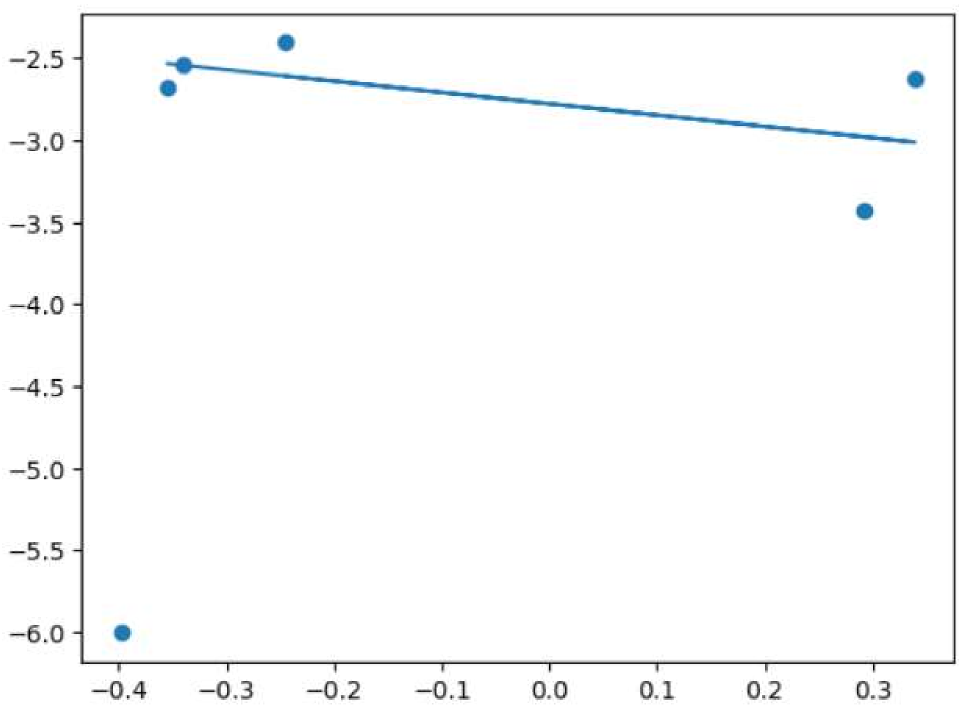

Fig 5: Scatterplot of z1 against C1 for g-filter, along with line of best fit.

The line-of-best-fit's slope is the same as ε_1, and the y-intercept is the same as z_1.

So here, for the **r-filter**,

$$\varepsilon_1 = 0.90926203 \pm 0.72395624 , z_1 = -1.43473439 \pm 0.2386461$$

And for the **g-filter**,

$$\varepsilon_1 = -0.69130969 \pm 0.53890038 \text{ , } z_1 = -2.77659035 \pm 0.17053229$$

The uncertainties were calculated by adding 'cov=True' into the np.polyfit code, which outputs the covariance matrix which can then be used to obtain the uncertainties of each value above.

Now, we finally conduct photometry on the main star, gaia16bnz, using the same procedure as before (using GAIA imaging software). We get:

	x	y	Count	Sky	Signal	m1
g-filter	764.49	762.64	3011.2	5856.2	657750	10.45484786
r-filter	764.32	762.47	1597.3	3923	348910	11.14321646

Table 5: Aperture Photometry data for Gaia16bnz taken via GAIA.

Here, m1 was calculated as previously, using the equation $m_1 = -2.5 \cdot \log(N_s) + z$, where z = 25.

Now that we have the ε and z values, all we need is the instrument colour, C (g-r), for the main star we are observing. This was done via an iterative method where equations 2 & 3 were used from Expt4: Part 1's script. C, which is substituted for the (B-V) term in the script, starts off at zero and is changed until the values of 'g' and 'r' are such that C = g – r. Thus, we get:

$$C = 3.38 \pm 0.949$$

The uncertainty is achieved via following error propagation formulae for arithmetic scenerios, starting with the errors in the epsilon and z values.

Now that we have all the values we need, we can finally estimate the true magnitude of the star using the equation, $m_1 = m_0 + z_1 + \varepsilon_1 C_1$.

Substituting the known values, we get:

$$m_0(g) = 15.568 \text{ , } m_0(r) = 9.504$$

<u>Sky-brightness & Uncertainty calculations</u>

From Table 5, we know that $N_{sky}(g) = 5856.2$ and $N_{sky}(r) = 3923$.

Using the equations for m1 and m0, we get $m_0(g) = 20.694$ and $m_0(r) = 14.377$.

Next, we calculate N_B, the background flux, and N_s, the source flux.

$$N_s(g) = signal_g \cdot gain = 657750 \cdot 1.44 = 947160$$

$$N_s(r) = signal_r \cdot gain = 348910 \cdot 1.44 = 502430$$

For the equation below, 'r' is the aperture size, which is 8.36.

$$N_B(g) \sim gain \cdot \pi r^2 \cdot N_{sky} = 1.44 \cdot 219.56 \cdot 5856.2 = 1851573$$

$$N_B(r) \sim gain \cdot \pi r^2 \cdot N_{sky} = 1.44 \cdot 219.56 \cdot 3923 = 1240321$$

Now, we can calculate the signal-to-noise ratio (SNR) via the equation:

$$SNR(g) = \frac{N_s}{\sqrt{N_s + 2N_B}} = 439.22$$

$$SNR(r) = \frac{N_s}{\sqrt{N_s + 2N_B}} = 290.90$$

These SNR values are very good estimates for the uncertainty in the flux measurements.

The values we have calculated for the SNR suggest is a good quality image as the uncertainties in magnitude these give are:

$$\sigma_m(g) = \frac{1.086}{SNR} = 0.0025$$

$$\sigma_m(r) = \frac{1.086}{SNR} = 0.0037$$

These are small compared to the instrument magnitudes obtained for Gaia16bnz, and thus, the noise in the image is small compared to the actual useful signal.

Let's finally compute the actual uncertainty in the measurement on the standard system,

$$\sigma_{std}(g) = \sigma_m^2 + \sigma_z^2 = 0.0025^2 + 0.1705^2 = 0.0291$$

$\sigma_{std}(r) = \sigma_m^2 + \sigma_z^2 = 0.0037^2 + 0.2386^2 = 0.0569.$

Conclusions

While the uncertainties on the values obtained are pretty good, there are ways to get more precise measurements to reduce the uncertainties. One change that can be made is using more standard stars during the aperture photometry to get a better fit trend line, thus making our best-fit parameters more precise. Also, varying the aperture size based on the star m=being measured might also help as the aperture then fits better around each target, resulting in more precise data. Also being more mindful of observing conditions and controlling them better could result in better SNR values.

The final magnitudes we achieve are not very accurate in comparison to recent data that was taken via https://gsaweb.ast.cam.ac.uk/, where most recent magnitude measurements put the object at 12.82 magnitude. This could be due to our magnitudes being in g and r filters specifically, as I do not know the filter used for the observation mentioned above. However, taking an average of our g and r magnitudes gives a value close to the recently observed values, which may lend some accuracy to my measurements. Assuming that the measurements on the website are averages over filters, if we take an average of our mags, we get a value of 12.536 which falls well into the pattern previously observed for this target. Depending on the accuracy of my measurements, this value may indicate an increase in brightness of Gaia16bnz, as it has maintained ~12.8 mags for the past 2.5 years with little variation.

The colour term was quite significant in this case, as not including would have lead to an average measurement of about 11.5 mags, which would be much higher than highest recorded brightness of about 12.47 mid-2015. Since there is no gradual increase in brightness in recent measurements that would lead up to such a high measurement, we can conclude that the color term was significant in the measurements.