Photometry of Supernovae with SalsaJ

How to perform photometry specifically on supernova targets using the free image processing software, SalsaJ

This worksheet describes how to use photometry to investigate the changing brightness of a supernova target.

When you have carried out your measurements and obtained your data, you will present your results on a graph to display the **light curve** of the target.

Prior to carrying out this activity, if you have not used the SalsaJ software previously or carried out photometry, it is recommended that you read through and complete the '**Photometry with SalsaJ**' worksheet.

Identifying your Targets

Step 1: First, open the SalsaJ software programme. Go to **File → Open** select all your FITS files of the observations from the Faulkes Telescopes you wish to analyse.

If you do not already have it on your computer, you can download it from the link below:

http://www.euhou.net/index.php/salsaj-software-mainmenu-9

Before we can begin the photometry, we must identify the targets we want to measure in the images.

Step 2: Refer to the **Finder Chart**, it shows a field of view containing the supernova target. You will also need to select **three or four comparison stars** within the field to measure as well as the target. You should choose stars that are **similar in brightness** to your target and not too close to the edge of the field.

We use comparison stars in order to account for variations in the measured brightness of the supernovae that are due to other influences that are not related to the star itself.

Note: For more information on comparison stars, see the 'Photometry in Astronomy' worksheet.

Step 3: Your files should have opened in date order, but make a note of the order you will performing your measurements. This will be either the most recent observation to the oldest observation or vice versa.

Note: Remember that the first image you measure will be the last one to have opened.

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Photometric Analysis of your Supernova Target

From completing the Photometry with SalsaJ worksheet, you should have now decided on an appropriate aperture for your analysis. In doing so we can begin to investigate the supernova target to see how it changes in brightness over time.

Step 4: Go to **Analyse → Photometry Settings.**

Note: For instructions on how to adjust the appearance of your images to make them clearer, see 'Photometry with SalsaJ' worksheet.

Step 5: Next to the Star Radius and Sky option, change the settings from Auto to **Forced Star Radius** and **Forced Sky Radius.** Then input the suitable **Star Radius** you identified in the Photometry with SalsaJ worksheet and apply a **Sky Radius of 12**.

Note: If you have not completed the Photometry with SalsaJ worksheet, apply a Star Radius value of 10.

Step 6: Now click on the centre of your supernova target and your individual comparison stars. Your measurements should appear in the Photometry Results box similar to the one seen in Figure 1.
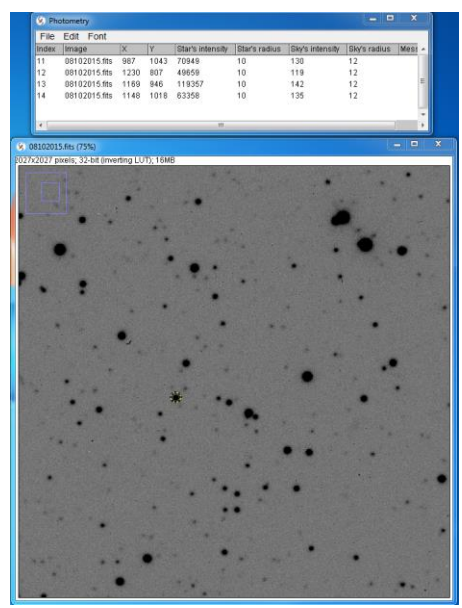
This is to give you the intensity of the star as measured by the CCD in order to determine its brightness. This value is shown in Figure 1 under the fifth column.

Note: See the Photometry with SalsaJ worksheet for how to select comparison stars.

It is likely you will need to **zoom in two or three times** to get a better view of your target. To zoom in select the **magnifying glass** button and then click on the region of your image you wish to magnify.

Figure 1 – Photometry measurements for supernova target and comparison stars on SalsaJ.

Step 7: Repeat Step 6 for each of your images, making sure you measure the objects in the **same order** for each image. You may find it easier to close each image once you have taken your measurements, when prompted you will not need to save the changes you have made.

Step 8: When you have performed your photometry measurements on each of your images, go to your Photometry results box and select **File → Save As**, and save your data under a suitable filename.

Presenting your Data

Step 9: Now you have your data saved, open it into an **Excel Spreadsheet** (or similar software).

Note: As the data will save as a .CSV file, Excel might not recognise it straight away. You will have to search for 'All Files' rather than 'All Excel Files'.

Your results should look similar to those seen in Figure 2. Here the supernova target and three comparison stars have been recorded, where the numbers under the **Index** column represents the following objects:

      1 – Supernova Target
      2 – Comparison star 1
      3 – Comparison star 2
      4 – Comparison star 3

This **order is then repeated** afterwards for each of the images. Therefore, the measurements for each particular star will be found in **every fourth row** after the first measurement for that star.

So your supernova target across the 14 images should correspond to numbers 1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 59 and 63.

Figure 2 – Photometry results obtained from SalsaJ presented in an Excel spreadsheet.

	A	B	C	D	E	F	G	H	I
1	Index	Image	X	Y	Star's intensity	Star's radius	Sky's intensity	Sky's radius	Message
2	1	01102015.fits	999	1003	93681	10	312	14	
3	2	01102015.fits	1239	764	60969	10	306	14	
4	3	01102015.fits	1180	904	151207	10	313	14	
5	4	01102015.fits	1159	976	83219	10	307	14	
6	5	28092015.fits	984	1016	61189	10	881	14	
7	6	28092015.fits	1226	779	33246	10	879	14	
8	7	28092015.fits	1166	919	81451	10	884	14	
9	8	28092015.fits	1144	990	45891	10	879	14	
10	9	21102015.fits	996	1038	63420	10	899	14	
11	10	21102015.fits	1236	799	57630	10	898	14	
12	11	21102015.fits	1176	939	136987	10	913	14	
13	12	21102015.fits	1156	1011	74351	10	910	14	
14	13	23092015.fits	972	1017	66679	10	1135	14	
15	14	23092015.fits	1212	778	33299	10	1124	14	

Now we need to **separate each of the objects** by selecting the data that corresponds to the four separate objects and inserting it into their own spreadsheet.

Step 10: Do this by highlighting all the rows that correspond to your supernova target. You can do this by left-clicking on the first row under the number column on the far left of the page (circled in green in Figure 2), then holding the **Ctrl** key and left-clicking on all other corresponding rows.
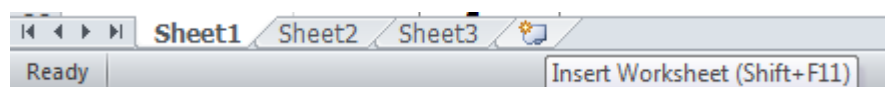
Note: You should also include the top row of column titles in each instance; this is so that you know what the data in each column corresponds to.

Then **Copy and Paste** these values into an additional spreadsheet tab by right-clicking on the highlighted cells and selecting 'Copy'.

To open a new tab, select one of the unused tabs at the bottom of the page or open a new one as shown in Figure 3.

Figure 3 – Opening a new spreadsheet tab in Microsoft Excel.

Then in the new spreadsheet tab, right-click on the top, left-hand cell on the spreadsheet and select 'Paste'. (See Figure 4).

Figure 4 – Highlighting all the data for the supernova target in Excel to then copy and paste into a separate spreadsheet.

	A	B	C	D	E	F	G	H	I
1	Index	Image	X	Y	Star's intensity	Star's radius	Sky's intensity	Sky's radius	Message
2	1	01102015.fits	999	1003	93681	10	312	14	
3	2	01102015.fits	1239	764	60969	10	306	14	
4	3	01102015.fits	1180	904	151207	10	313	14	
5	4	01102015.fits	1159	976	83219	10	307	14	
6	5	28092015.fits	984	1016	61189	10	881	14	
7	6	28092015.fits	1226	779	33246	10	879	14	
8	7	28092015.fits	1166	919	81451	10	884	14	
9	8	28092015.fits	1144	990	45891	10	879	14	
10	9	21102015.fits	996	1038	63420	10	899	14	
11	10	21102015.fits	1236	799	57630	10	898	14	
12	11	21102015.fits	1176	939	136987	10	913	14	
13	12	21102015.fits	1156	1011	74351	10	910	14	
14	13	23092015.fits	972	1017	66679	10	1135	14	
15	14	23092015.fits	1212	778	33299	10	1124	14	
16	15	23092015.fits	1153	918	81454	10	1132	14	
17	16	23092015.fits	1132	990	45611	10	1131	14	
18	17	19092015.fits	971	994	60228	10	81	14	
19	18	19092015.fits	1211	755	27722	10	78	14	

Step 11: Repeat this for your comparison stars data.

You should now have **four separate spreadsheets**, one for your supernova target and one for each comparison star.

Step 12: Save your work so far to prevent losing any of your data. Make sure you save your work as an **Excel Workbook (.xlsx)** and not a CSV file.

Calculating Magnitude

We now need to calculate the **Magnitude**. This is calculated from the **Star's intensity**.

The **star's intensity** value refers to the number of **photons that fell onto the CCD in a given area and is a** measure of how **bright** the star is. The area for the star's intensity is the aperture radius that you set.

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We convert this value into magnitude (the system astronomers use to describe a star's brightness) using the Equation 1:

Equation 1 – Calculating magnitude from intensity

$$magnitude = -2.5 \ x \ \log_{10} star's \ intensity$$

On Microsoft Excel this formula is typed as:

= -2.5*LOG10(Star's intensity)

Where you obtain (Star's intensity) by left-clicking the relevant cell under the 'Star's intensity' column.

Note: For more information on magnitudes, see the 'Calculating Magnitudes' worksheet.

Step 13: For each of your four data sets add a new column titled **Magnitude** and input this equation to calculate the instrumental magnitude for the supernova target and three comparison stars in each image.

Hint: When you've inputted the equation into the first cell, left-click the bottom right corner of the cell and holding the mouse down, drag the corner down the rest of the column. This will automatically fill the remaining cells with the corresponding equation.

Step 14: When you have done this, open a new spreadsheet and **Copy and Paste** the Magnitude values for your four objects.

Note: As you have used a formula to calculate these values, when you paste them into a new spreadsheet you will need to select 'Paste Values'.

Your new spreadsheet should appear similar to Figure 5.

Figure 5 – The magnitude values for the four objects, copied and pasted into a separate spreadsheet, where SN is the supernova target.

	B	C	D	E
1	SN	Comparison 1	Comparison 2	Comparison 3
2	-12.0033	-11.08065898	-12.05309581	-11.40093243
3	-11.9095	-11.0119988	-11.99206004	-11.32303031
4	-12.2258	-11.34975933	-12.27051531	-11.65410585
5	-11.9495	-11.1070614	-12.08165542	-11.38667709
6	-12.06	-11.30607798	-12.27728104	-11.64767399
7	-11.9619	-11.29414417	-12.2694149	-11.64543408
8	-12.5975	-12.04889274	-13.02554206	-12.36869459
9	-12.4818	-11.99893717	-12.97528975	-12.37626506
10	-12.1594	-11.75102368	-12.71577498	-12.05035581
11	-12.1416	-11.77499707	-12.74764697	-12.08546343
12	-11.9365	-11.62499127	-12.61892697	-11.94658985
13	-12.0676	-11.88344051	-12.8408024	-12.15398536
14	-12.1796	-11.99103685	-12.95834547	-12.30848571
15	-12.0056	-11.90162155	-12.84169839	-12.17821704

Ordering the Timescale of your Observations

As our intention is to produce a light curve to see how the brightness of the object changes with time, we need to input the **observation dates**.

Step 15: Open up the **Observation Information** file into Excel (or a similar software). Your screen should appear similar to Figure 6 (it may have more or less columns).

Note: Column 'Time' may not appear in the correct format. If it does not, highlight the column, right-click and select Format Cells. Then under 'Categories', select Date.

Figure 6 – The information for the observations dataset

	A	B	C	D	E	F	G
1			Time	Object	Filter	Exp. Time	R.level
2			08/09/2015 22:14	ASASSN-15oz	V	60	Reduced (ORAC)
3			15/09/2015 21:29	ASASSN-15oz	V	60	Reduced (ORAC)
4			16/09/2015 13:45	ASASSN-15oz	V	60	Reduced (ORAC)
5			17/09/2015 13:02	ASASSN-15oz	V	60	Reduced (ORAC)
6			19/09/2015 12:45	ASASSN-15oz	V	60	Reduced (ORAC)
7			20/09/2015 09:31	ASASSN-15oz	V	60	Reduced (ORAC)
8			21/09/2015 10:11	ASASSN-15oz	V	60	Reduced (ORAC)
9			23/09/2015 05:50	ASASSN-15oz	V	60	Reduced (ORAC)
10			25/09/2015 09:06	ASASSN-15oz	V	60	Reduced (ORAC)
11			26/09/2015 09:04	ASASSN-15oz	V	60	Reduced (ORAC)
12			28/09/2015 10:32	ASASSN-15oz	V	60	Reduced (ORAC)
13			01/10/2015 09:56	ASASSN-15oz	V	60	Reduced (ORAC)
14			02/10/2015 12:32	ASASSN-15oz	V	60	Reduced (ORAC)
15			05/10/2015 12:01	ASASSN-15oz	V	60	Reduced (ORAC)
16			06/10/2015 12:39	ASASSN-15oz	V	60	Reduced (ORAC)

The information we are interested in is under columns, **Time** (column C) as shown in the blue box in Figure 6, this is where we can find the date and time of the observations.

Step 16: Create a new column in on your spreadsheet to the **left** of your magnitude column and copy and paste the Time information in order to match the dates with their corresponding data. Do this by left clicking on the first box in the column and dragging your mouse down the entire column. Then right-click your mouse and select copy. In your own spreadsheet, right-click on the first box under your new date column and select **Paste Values**.

Hint: Your measurements may not be in chronological order so you should refer to your notes about the order you measured your images in to check.

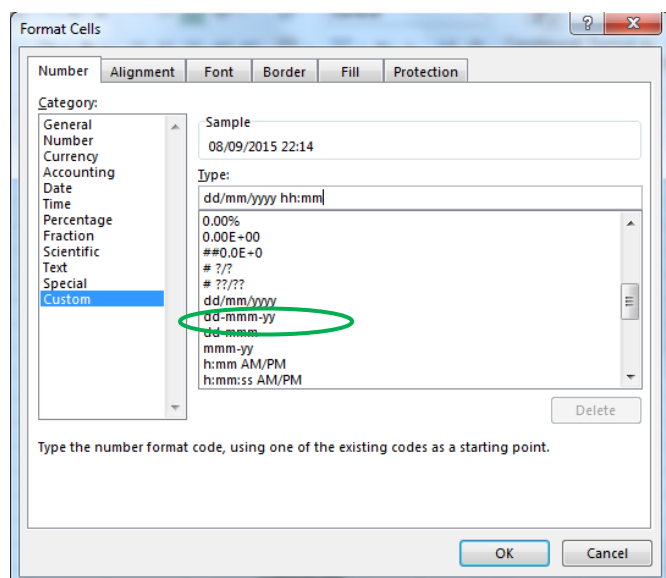If your data is not in chronological order, refer to Appendix 1 for instructions on how to do this.

Step 17: You will probably notice that the format has changed. We now need to change the format of the cells within this column. To do this, keep the full column highlighted and right-click your mouse. Select **Format Cells → Custom.** Then type in the following in the text box at the top:

dd/mm/yyyy hh:mm

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Then select Ok. This is illustrated in Figure 7. Your dates should now look the same as they did in the Observation Information spreadsheet.

Figure 7 – Formatting the cells under the Date column.

Accounting for Instrumental Variability

The magnitude values you have calculated are **Instrumental Magnitudes**.

Instrumental magnitude is different from **apparent magnitude** and **absolute magnitude**. Apparent magnitude is how bright a star appears to us on Earth. Absolute magnitude describes how bright a star would appear if it were located at a distance of 10 parsecs away from Earth (where 1 parsec is equal to 3.09 x 10^{16} metres).

Note: For a more detailed explanation on apparent and absolute magnitude see worksheet "Calculating Magnitudes".

Instrumental magnitude however, as the name indicates, is dependent on the **instruments** that are used to measure the object. In this case, the instruments refer to the telescope and camera.

This is where we apply our measurements of the comparison stars in order to see if the supernova target varies in brightness respectively.

First we need to make sure none of our comparison stars are variable stars.

Note: See Variable Stars and Light Curves worksheet for further information on variable stars.

Step 18: To do this, create **three** more columns and calculate the following for each image:

> **Comparison 1 Magnitude minus Comparison 2 Magnitude**
> **Comparison 1 Magnitude minus Comparison 3 Magnitude**
> **Comparison 2 Magnitude minus Comparison 3 Magnitude**

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Step 19: Now plot each of these the columns against their corresponding dates of the observation in an **XY Scatter Chart**. You should have the date on the X axis and change in magnitude on the Y axis.

As seen in Figure 8, all three lines should appear relatively **flat** (or no more than a variation of 0.1 magnitudes).
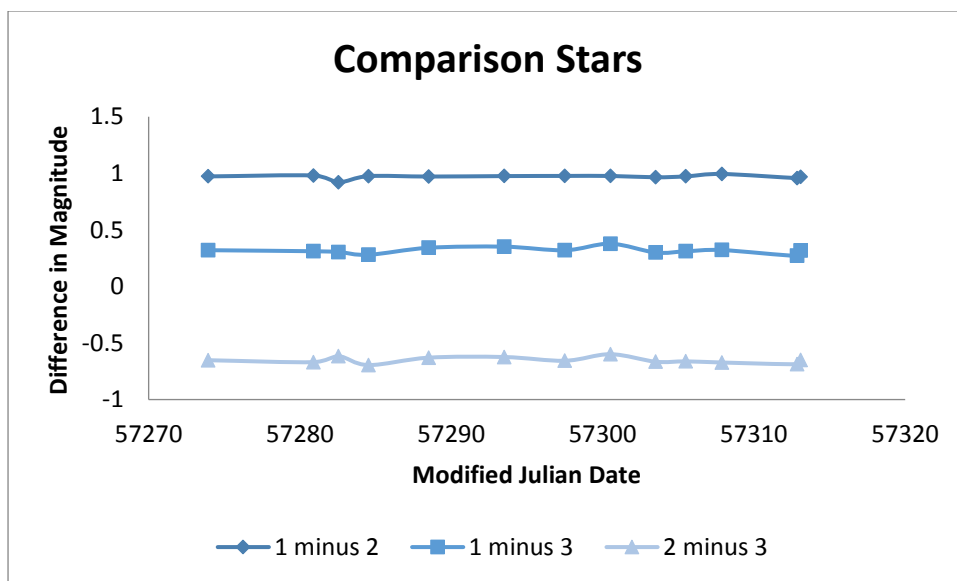
This means they are all non-variable stars (i.e. they display a constant brightness and any variability seen is due to factors discussed in the 'Photometry in Astronomy' worksheet).

If they appear much more variable then they are unsuitable as comparison stars. For example if you find plots displaying comparison star 1 minus comparison star 2 and comparison star 2 minus comparison star 3 both vary (i.e. are not flat and vary by more than 0.1 magnitudes in amplitude), the common factor here is comparison star 2 so we can assume this is a variable star and is not suitable to use in your supernova target measurements.

If this is the case, we can use the average of comparison stars 1 and 3 or try a few more comparison star candidates.

Note: For more on unsuitable comparison stars, see Appendix 2.

Figure 8 – Ensuring that the comparison stars are not variable stars.

Now you know your comparison stars are not variable, we can compare the variability of the supernova target with the average instrumental magnitude of the three comparison stars.

Step 20: Create a new column and calculate the **average magnitude** of the three comparison stars in each image.

To do this in Excel input the following formula:

=(comparison star 1 magnitude + comparison star 2 magnitude + comparison star 3 magnitude)/3

Step 21: You now need to **subtract the average magnitude values of the comparison stars from the instrumental magnitude of the supernova target** for each image. Add another column and input this calculation.

For each observation date, you now have the difference in magnitude between the supernova and the average of the three, non-variable comparison stars.

Plotting your Light Curve

Step 22: Plot the **magnitude values** you have just calculated for the supernova against the **time** of their observation in each image, again in an XY Scatter Chart. You should have date again on the X axis and change in magnitude on the Y axis.

You will need to **reverse the values of your Y axis**. This is because lower magnitude values represent brighter objects than higher magnitude values.

Note: See Calculating Magnitudes worksheet for further explanation.

Step 23: To do this, double click on your values on the Y axis of the graph. A pop up window should appear (or a toolbar on the right-hand side of the document. Tick the box that says '**Display values in reverse order**'.
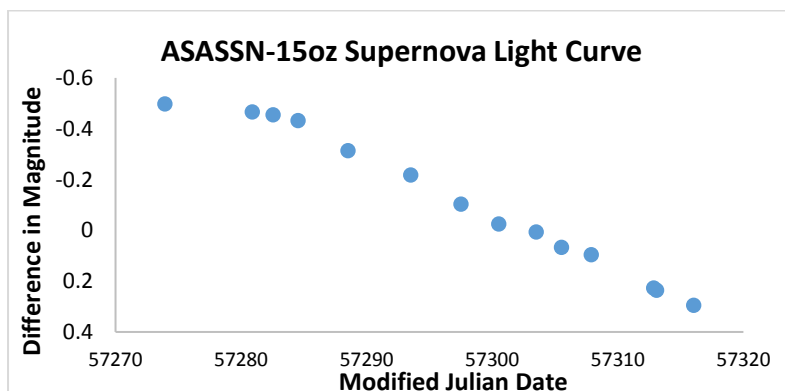
You now have a light curve of your supernova! Its shape should appear similar to Figure 9. Here you can see how the magnitude of the supernova varies in comparison to the average magnitude of the non-variable comparison stars.

Supernova light curves show a **steady fade in magnitude over timescales of more than a month**. If we were to continue observing this object, it would continue to fade until it became too faint for the telescope to detect.

Further corrections are needed to transform the differential magnitude values into apparent or absolute magnitudes but even without converting them, we can still see the correct shape in the light curve by plotting it this way.

Note: For more information on magnitudes and supernovae, see the 'Calculating Magnitudes' and 'An Introduction to Supernovae' worksheets.

Figure 9 – A light curve of an example supernova, ASASSN-15oz
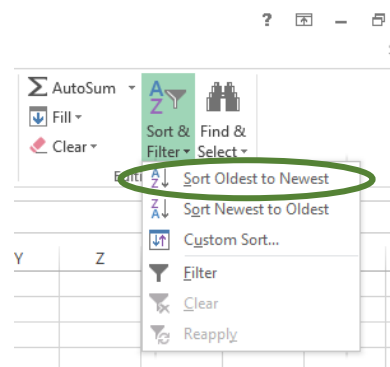

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Appendix 1 – Organising your Data into Chronological Order

To list the data from the earliest observation to most recent observation, highlight all of your data, starting with the date column and including all of the magnitude columns. Then go to the **Home toolbar → Editing → Sort & Filter**, and select **Sort Oldest to Newest,** as seen in the figure below.

	A	B	C	D	E
1	mjd_obs	SN	Comparison 1	Comparison 2	Comparison 3
2	57273.92706	-12.0033	-11.08065898	-12.05309581	-11.40093243
3	57280.89559	-11.9095	-11.0119988	-11.99206004	-11.32303031
4	57282.54368	-12.2258	-11.34975933	-12.27051531	-11.65410585
5	57284.53148	-11.9495	-11.1070614	-12.08165542	-11.38667709
6	57288.50023	-12.06	-11.30607798	-12.27728104	-11.64767399
7	57293.50643	-11.9619	-11.29414417	-12.2694149	-11.64543408
8	57297.50189	-12.5975	-12.04889274	-13.02554206	-12.36869459
9	57300.5185	-12.4818	-11.99893717	-12.97528975	-12.37626506
10	57303.51131	-12.1594	-11.75102368	-12.71577498	-12.05035581
11	57305.50214	-12.1416	-11.77499707	-12.74764697	-12.08546343
12	57307.87413	-11.9365	-11.62499127	-12.61892697	-11.94658985
13	57312.85345	-12.0676	-11.88344051	-12.8408024	-12.15398536
14	57313.08206	-12.1796	-11.99103685	-12.95834547	-12.30848571
15	57316.05212	-12.0056	-11.90162155	-12.84169839	-12.17821704

Σ AutoSum
Fill
Clear
Sort & Find &
Filter Select

Sort Oldest to Newest
Sort Newest to Oldest
Custom Sort…
Filter
Clear
Reapply

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Appendix 2 – Unsuitable Comparison Stars

The Figure below shows an example of a comparison star that would be unsuitable to use when carrying out your photometry. Two of the datasets show a great deal of variation in magnitude (i.e. more than 0.1 magnitude in amplitude). You will notice the common factor is comparison star 2 and so we can assume this is likely to be a variable star. We therefore cannot use this to resolve any variation due to the instruments from this data.