



Photometry of Supernovae with Makali'i

How to perform photometry specifically on supernovae targets using the free image processing software, Makali'i



This worksheet describes how to use photometry to investigate the changing brightness of the 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 Makali'i software previously or carried out photometry, it is recommended that you read through and complete the **Photometry with Makali'i** worksheet.

Identifying your Targets

Step 1: First, open the Makali'i software programme. Go to **Open**, and 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:

<https://makalii.mtk.nao.ac.jp/>

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.

Photometric Analysis of your Supernova Target

From completing the Photometry with Makali'i worksheet, you should have now decided on the most 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.

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

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

<https://gaia.ac.uk/alerts>



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

Step 4: Go to **Photometry** on the toolbar at the top of the screen and select **Aperture**.

Step 5: Under Radius, select the **SemiAuto** option and **Find Centre**, then under Radius Setup input the options given below. For the **Star Radius** option, you should input the appropriate value you identified in the Photometry with Makali'i worksheet.

Sky InRadius: 12 pixels

Sky Radius Width: 5 pixels

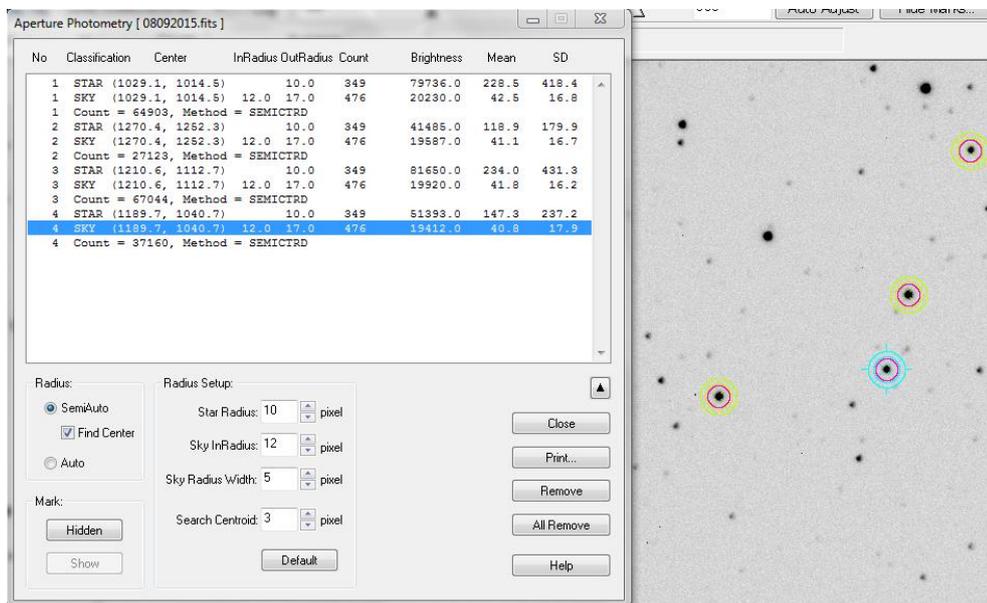
You cannot have a Star Radius that is a larger value than the Sky InRadius, you will therefore need to set the Sky InRadius first. You will need to use the **same** photometry settings across all of your measurements.

Note: If you have not completed the Photometry with Makali'i worksheet, a Star Radius value of 10 would be suitable.

Step 6: Now click on the centre of your supernova target and your individual comparison stars. Your measurements should appear in the Aperture Photometry box similar to Figure 1.

Note: See the Photometry with Makali'i worksheet for how to select comparison stars.

Figure 1 – Aperture photometry measurements for supernova target and comparison stars on Makali'i.



Step 7: Select **Print** and save your results under an appropriate name. This will save the data as a CSV file.

Step 8: Close the aperture photometry box and the image you have just used. You do not need to save the changes you have made.



Step 9: Repeat Steps 3 to 7 for each of your images, making sure you measure the objects in the **same order** for each image.

Unfortunately, there is no way of making Makali'i remember the settings you have selected so these steps have to be carried out for every image and a separate files must be saved. Save these files under a suitable name that will allow you to recognise what the files represent. You may want to use the same name as the image file you have measured or you may want to use the observation date, or number them in order of observation.

Presenting your Data

Step 10: When you have completed Steps 3 to 7 for each of your images, open your data into an **Excel Spreadsheet** (or similar software) and transfer **all the data onto one spreadsheet**.

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

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

Figure 2 – Photometry results obtained from Makali'i presented in an Excel spreadsheet.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Number	Obj X	Obj Y	Obj Radiu	Obj Pix	Obj Count	Obj Mean	Obj SD	Sky X	Sky Y	Sky InRadi	Sky Width	Sky Pix	Sky Count	Sky Mean	Sky SD	Result	CoiRadius
2	1	1016	1001	10	349	36955	105.8883	146.862	1016	1001	12	5	476	10008	21.02521	16.29015	29617.2	SEMI
3	2	1260	1237	10	349	20085	57.55014	65.08598	1260	1237	12	5	476	9850	20.69328	17.0807	12863.05	SEMI
4	3	1198	1099	10	349	37121	106.3639	144.8663	1198	1099	12	5	476	9389	19.72479	15.9232	30237.05	SEMI
5	4	1176	1026	10	349	26252	75.22063	94.97091	1176	1026	12	5	476	9103	19.12395	16.33934	19577.74	SEMI
6	1	989	1003	10	349	78660	225.3868	155.3703	989	1003	12	5	476	74512	156.5378	19.04739	24028.3	SEMI
7	2	1232	1240	10	349	66837	191.51	82.33851	1232	1240	12	5	476	74371	156.2416	20.0241	12308.68	SEMI
8	3	1171	1099	10	349	85084	243.7937	193.4898	1171	1099	12	5	476	74432	156.3697	19.02944	30510.96	SEMI
9	4	1149	1028	10	349	81407	233.2579	207.3941	1149	1028	12	5	476	74668	156.8655	18.84999	26660.92	SEMI
10	1	971	1043	10	349	31681	90.7765	136.0654	971	1043	12	5	476	14761	31.0105	17.07823	20858.33	SEMI
11	2	1212	1283	10	349	20817	59.64756	66.69113	1212	1283	12	5	476	15224	31.98319	17.79764	9654.866	SEMI
12	3	1152	1142	10	349	33789	96.81662	152.6649	1152	1142	12	5	476	15699	32.98109	17.94768	22278.6	SEMI
13	4	1131	1070	10	349	25026	71.70774	95.02249	1131	1070	12	5	476	14801	31.09454	15.87138	14174.01	SEMI
14	1	992	1039	10	349	155842	446.5387	91.7334	992	1039	12	5	476	184672	387.9664	24.4772	20441.73	SEMI
15	2	1231	1278	10	349	145200	416.0458	56.73099	1231	1278	12	5	476	183834	386.2059	24.58717	10414.15	SEMI
16	3	1173	1138	10	349	162966	466.9513	120.8732	1173	1138	12	5	476	185677	390.0777	25.18011	26828.87	SEMI
17	4	1152	1067	10	349	152822	437.8854	75.2314	1152	1067	12	5	476	185056	388.7731	24.77892	17140.18	SEMI
18	1	972	1021	10	349	203247	582.3696	124.4035	972	1021	12	5	476	249827	524.8466	26.60273	20075.52	SEMI
19	2	1211	1259	10	349	194226	556.5215	72.74328	1211	1259	12	5	476	248919	522.9391	26.06461	11720.26	SEMI
20	3	1152	1119	10	349	211215	605.2006	163.7521	1152	1119	12	5	476	250811	526.9139	25.8862	27322.06	SEMI
21	4	1131	1048	10	349	200742	575.192	106.8532	1131	1048	12	5	476	249326	523.7941	27.37461	17937.85	SEMI
22	1	973	1013	10	349	212324	608.3782	90.82932	973	1013	12	5	476	265226	557.1975	25.79401	17862.08	SEMI
23	2	1214	1253	10	349	206192	590.808	64.22235	1214	1253	12	5	476	265815	558.4349	25.74817	11298.23	SEMI
24	3	1155	1111	10	349	223258	639.7077	139.8077	1155	1111	12	5	476	266441	559.75	26.98526	27905.25	SEMI
25	4	1135	1041	10	349	212349	608.4499	91.48571	1135	1041	12	5	476	266689	560.271	27.10546	16814.42	SEMI

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

Step 11: 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.

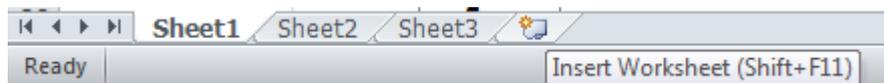


Note: You should also include the top row of column titles in each instance; this is so that you know what the data in each column corresponds to.

Then **Copy and Paste** these values into an additional spreadsheet tab by right-clicking on the highlighted boxes 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 box on the spreadsheet and select 'Paste'. (See Figure 4).

Figure 4 – Highlighting all the data for the supernova target (object 1) in Excel to then copy and paste into a separate spreadsheet.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Number	Obj X	Obj Y	Obj Radiu	Obj Pix	Obj Count	Obj Mean	Obj SD	Sky X	Sky Y	Sky InRadi	Sky Width	Sky Pix	Sky Count	Sky Mean	Sky SD	Result	Cor Radius
2	1	1016	1001	10	349	36955	105.8883	146.862	1016	1001	12	5	476	10008	21.02521	16.29015	29617.2	SEMI
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26	1	1003	1034	10	349	43488	124.6074	236.2915	1003	1034	12	5	476	21782	45.7605	17.72625	27517.58	SEMI
27	2	1243	1273	10	349	39066	111.397	199.4723	1243	1273	12	5	476	21266	44.67647	18.68065	23473.91	SEMI
28	3	1184	1132	10	349	71513	204.9083	471.4353	1184	1132	12	5	476	21322	44.79412	19.39558	55879.85	SEMI
29	4	1163	1061	10	349	51287	146.9542	297.2394	1163	1061	12	5	476	21759	45.71218	19.10044	35333.45	SEMI
30	1	1020	1043	10	349	32315	92.59312	140.1244	1020	1043	12	5	476	9115	19.14916	14.76756	25631.94	SEMI

Step 12: Repeat this for the rows corresponding to 2, 3 and 4 under the Number column corresponding to your three comparison stars.

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

Step 13: 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 **Result Count**.



The **counts** 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 Results Count is the aperture radius that you set.

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 counts

$$\text{magnitude} = -2.5 \times \log_{10} \text{counts}$$

On Microsoft Excel this formula is typed as:

=-2.5*LOG10(Result Count)

Where (Result Count) is the value corresponding to each star in each individual image.

Step 14: 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 box, left-click the bottom right corner of the box and holding the mouse down, drag the corner down the rest of the column. This will automatically fill the remaining boxes with the corresponding equation.

Step 15: 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.

C	D	E	F
SN	Comparison 1	Comparison 2	Comparison 3
-12.0193	-11.08623901	-12.06591259	-11.41529296
-11.9401	-11.03370956	-12.01793273	-11.37107072
-12.2426	-11.35572004	-12.32691559	-11.68416904
-11.9561	-11.09530479	-12.06715029	-11.4101748
-12.0679	-11.33248692	-12.29976681	-11.63363
-11.9854	-11.31585213	-12.31170436	-11.67823574
-12.6143	-12.08036539	-13.04910123	-12.4039104
-12.4955	-12.01986007	-12.98883981	-12.40385086
-12.2178	-11.79753181	-12.76622534	-12.11035405
-12.1643	-11.80832079	-12.7713889	-12.11730875
-12.0578	-11.72178991	-12.69788199	-12.04404833
-12.0862	-11.90207124	-12.86244176	-12.17522661
-12.1906	-11.99788339	-12.96712099	-12.31691697
-12.0274	-11.89201298	-12.87329494	-12.20490913



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 16: 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 17: 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 time 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.

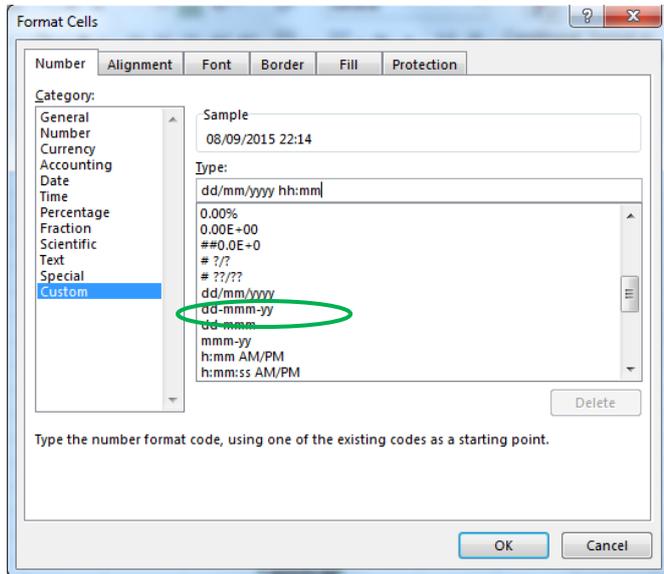
Step 18: You will probably notice that the format has changed. We now need to change the format of the cells within this column. To do this, keep the full column highlighted and right-click your mouse. Select **Format Cells** → **Custom**. Then type in the following in the text box at the top:

dd/mm/yyyy hh:mm



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 3.09×10^{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 19: 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

Step 20: 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).

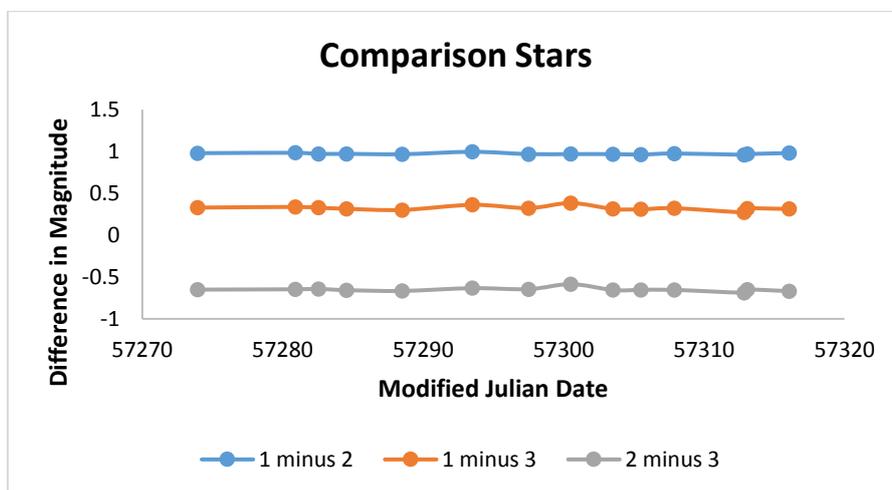
This means they are all non-variable stars (i.e. they display a constant brightness and any variability seen is due to factors discussed in the 'Photometry in Astronomy' worksheet).

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 21: 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:

$$=(\text{comparison star 1 magnitude} + \text{comparison star 2 magnitude} + \text{comparison star 3 magnitude})/3$$



Step 22: 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 23: 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 24: 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**').

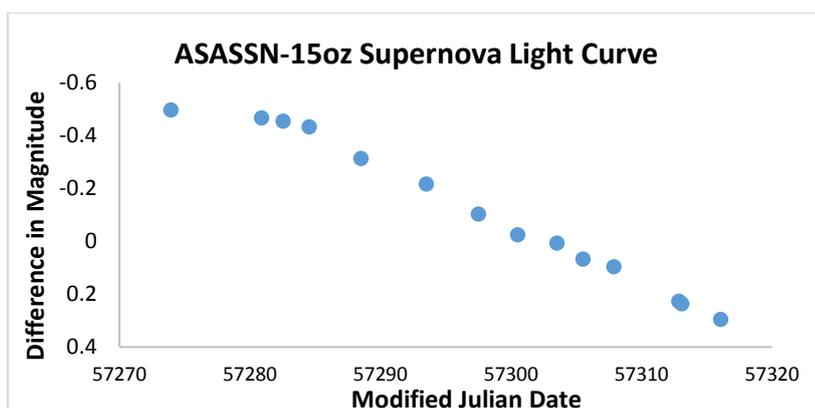
You now have a light curve of your supernova! Its shape should appear similar to Figure 9. Here you can see how the magnitude of the supernova varies in comparison to the average magnitude of the non-variable comparison stars.

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

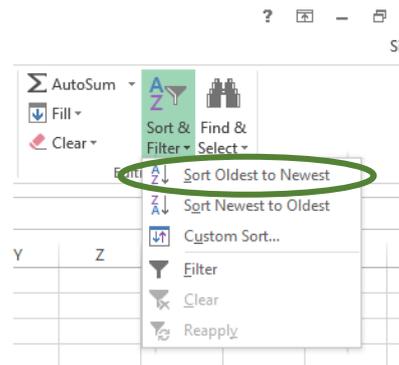




Appendix 1 – Organising your Data into Chronological Order

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





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.

