Photometry

Data Analysis Techniques in Astronomy and Planetary Science

BSc(Hons) Astronomy, Space Science and Astrophysics

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1 Photometry Analysis

Photometry is a measurement system used by astronomers in image processing, in particular the measurement of a celestial objects brightness over time utilizing the star magnitude index where the higher the number, the fainter the star looks to a naked eye and the lower the number, the brighter it looks to the naked eye ([?]). Such measurements can help determine the temperature of the star that can assist in finding out the stars distance, size and density ([?]).

Photometry works by capturing the light flux of the individual pixels of a star and then measuring and subtracting the sky background light flux that is emitted from the star, from the light flux to give the total flux light the star emits, this flux can then be converted into a magnitude. As atmospheric extinction i.e gas, clouds, exists between the camera and the target object, its sometimes necessary to select comparison stars and thus calculate the differential magnitude that can tell the exact magnitude of the star if extinctions does exist between.

2 Single Photometry Method

2.1 Single-Star Photometry

Single-Star photometry is used to determine a stars brightness by measuring the total light emitted from the star and then subtracting the light of the background sky. By selecting the "M82-x20.fts" from the AIP4WIN tutorial packet, which is a stack of 20 infrared images of the Messier 82 galaxy with a 60 second exposure ([?]). Utilizing the 'single star' photometry tool, 4 stars were selected as shown in ??, upon each star is an aperture radius which is changed in size to encapsulate all the light in the star. Following the aperture radius is two annuli, where the inner annulus measures the light emitted from the star into the sky background and the outer annulus measures the sky background surrounding the selected star. The inner and outer annuli will then be subtracted as sky background against the light inside the aperture radius.

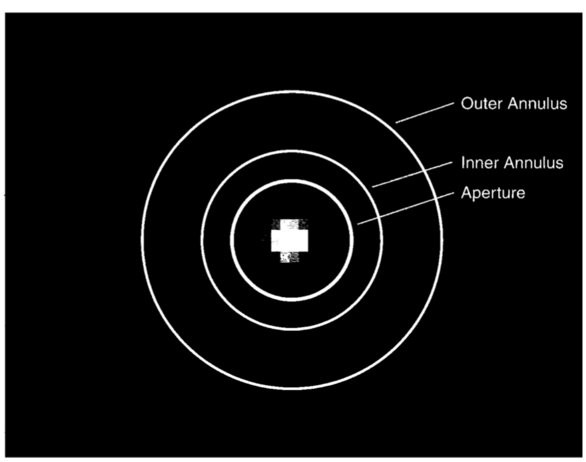

Figure 1: Illustration of the aperture radius, inner and outer annulus and their suitable distance from the star

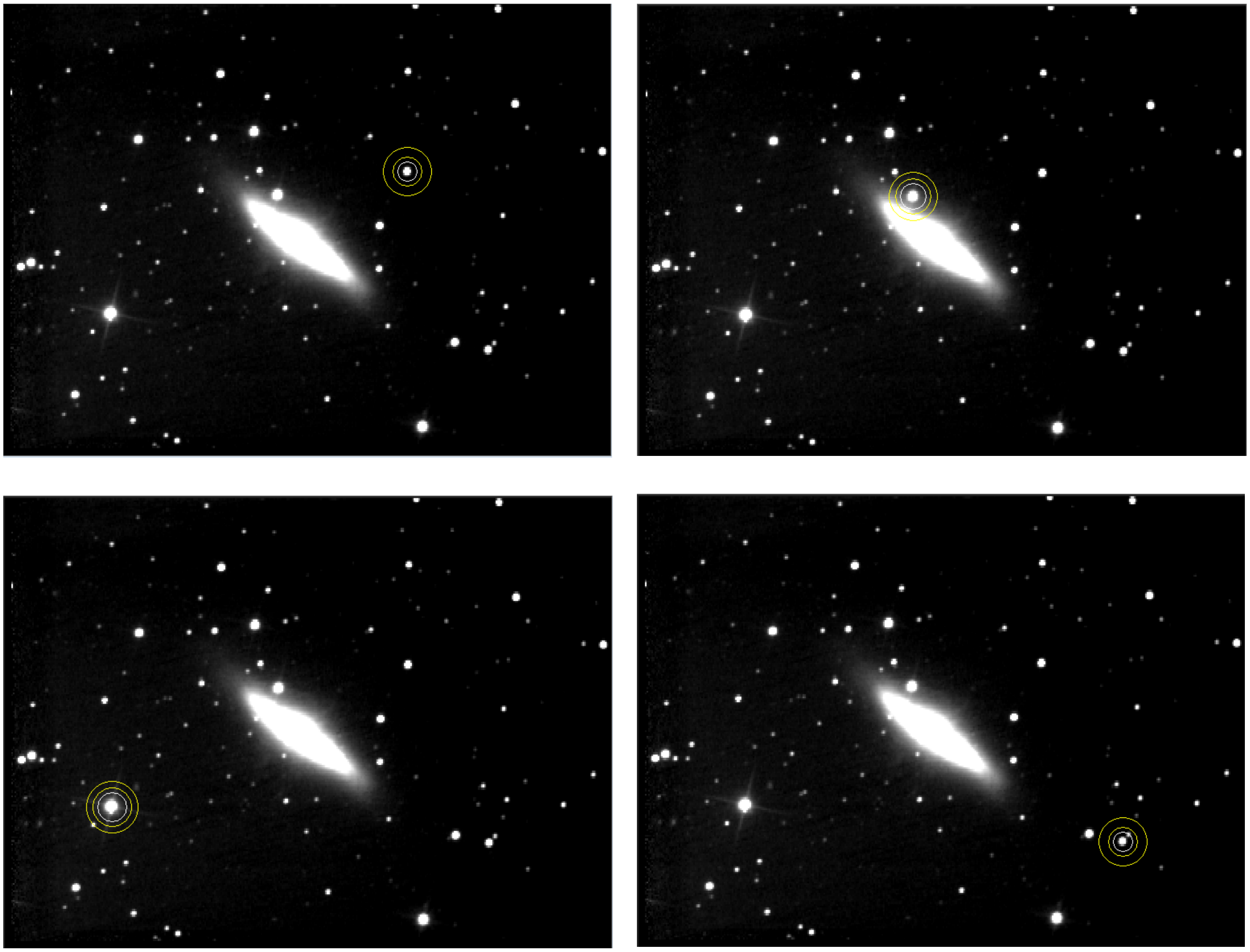

Figure 2: AIP4WIN image of the Messier 82 galaxy with the photometry tool 'Single-Star' depicting the aperture, inner and outer anuli around each target star for photometric measurements of four stars surrounding the galaxy. Star 1 = top right, Star 2 = top right, Star 3 = bottom left and Star 4 = bottom right.

AIP4WIN Photometry settings for all four target single-star images						
Target Star	Aperture Radius	Inner Annulus Radius	Outer Annulus Radius	Sky Annulus Pixels	Integration Time (s)	Zero Point
S1	6.0	9.0	15.0	236	60	25
S2	6.0	11.0	15.0	171	60	25
S3	9.0	11.0	16.0	179	60	25
S4	6.0	9.0	15.0	100	60	25

Photometric data collected of the four target single-star images							
Target Star	$Star_X$	$Star_Y$	ADU_{Max}	ADU_{Sky}	ADU_{Star}	Magnitude	Sigma
S1	249.999	88.579	2028.0	180.8136	15,567.9	18.965	±0.016
S2	169.516	101.010	3904.0	327.854	36,924.9	18.027	±0.010
S3	65.778	164.720	4086.0	223.56	17,624.0	17.308	±0.007
S4	300.405	183.969	2009.0	175.8789	16,458.02	18.904	±0.016

Table 1: AIP4WIN settings and photometry data of the 4 target 'single-star' stars.

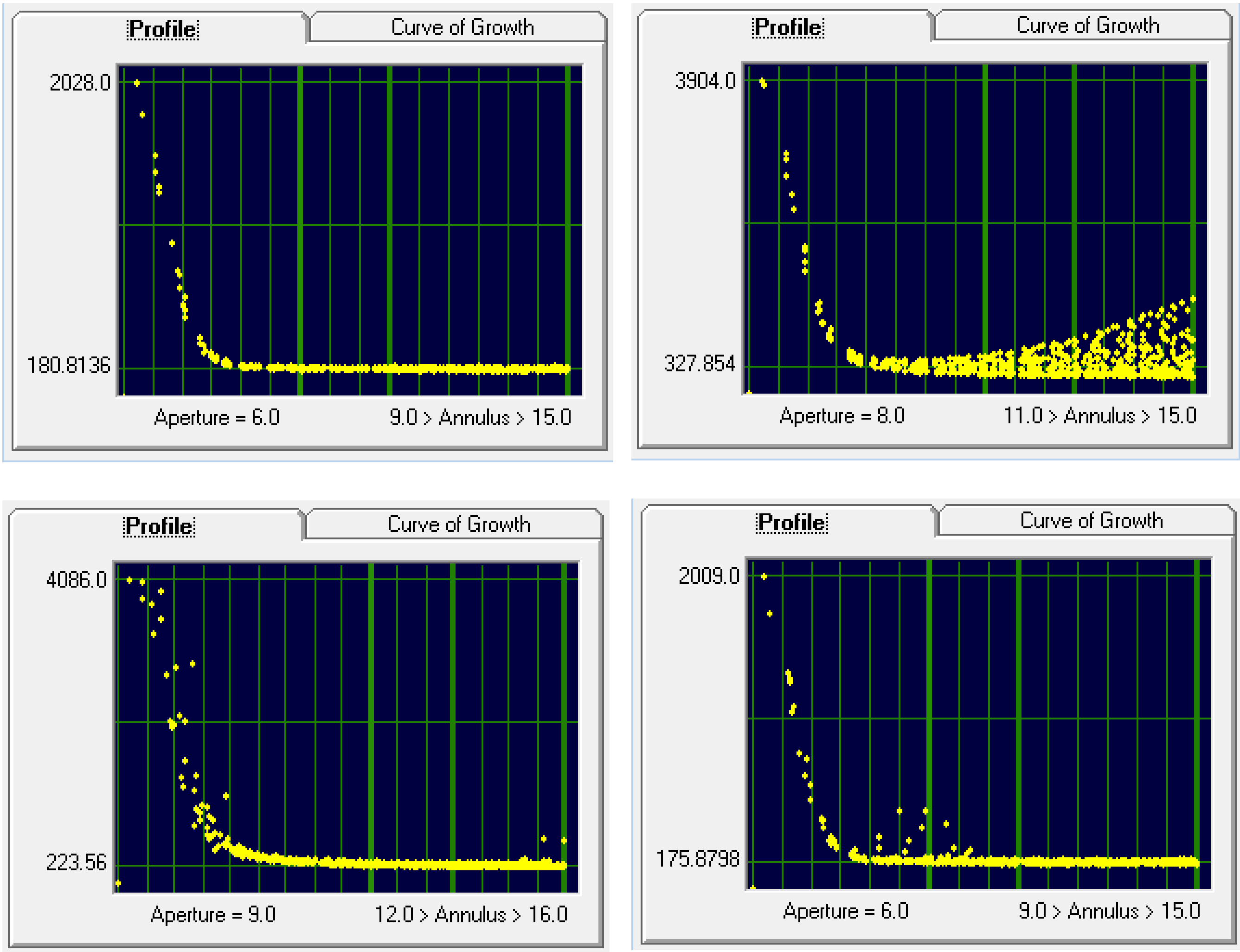

Figure 3: AIP4WIN image of the Messier 82 galaxy with the photometry tool 'Single-Star' depicting the photometric profile of four stars surrounding the galaxy. Star 1 = top right, Star 2 = top right, Star 3 = bottom left and Star 4 = bottom right.

The profile of a star is its brightness over a cross-section, where the individual pixel values of light are plotted against the distance from the centre of the star in reference to the annulus, as they decline gradually it shows a perfect light profile, where the inner annulus of star 2 encases a separate star, the light profile has a spray effect nearer to the annulus.

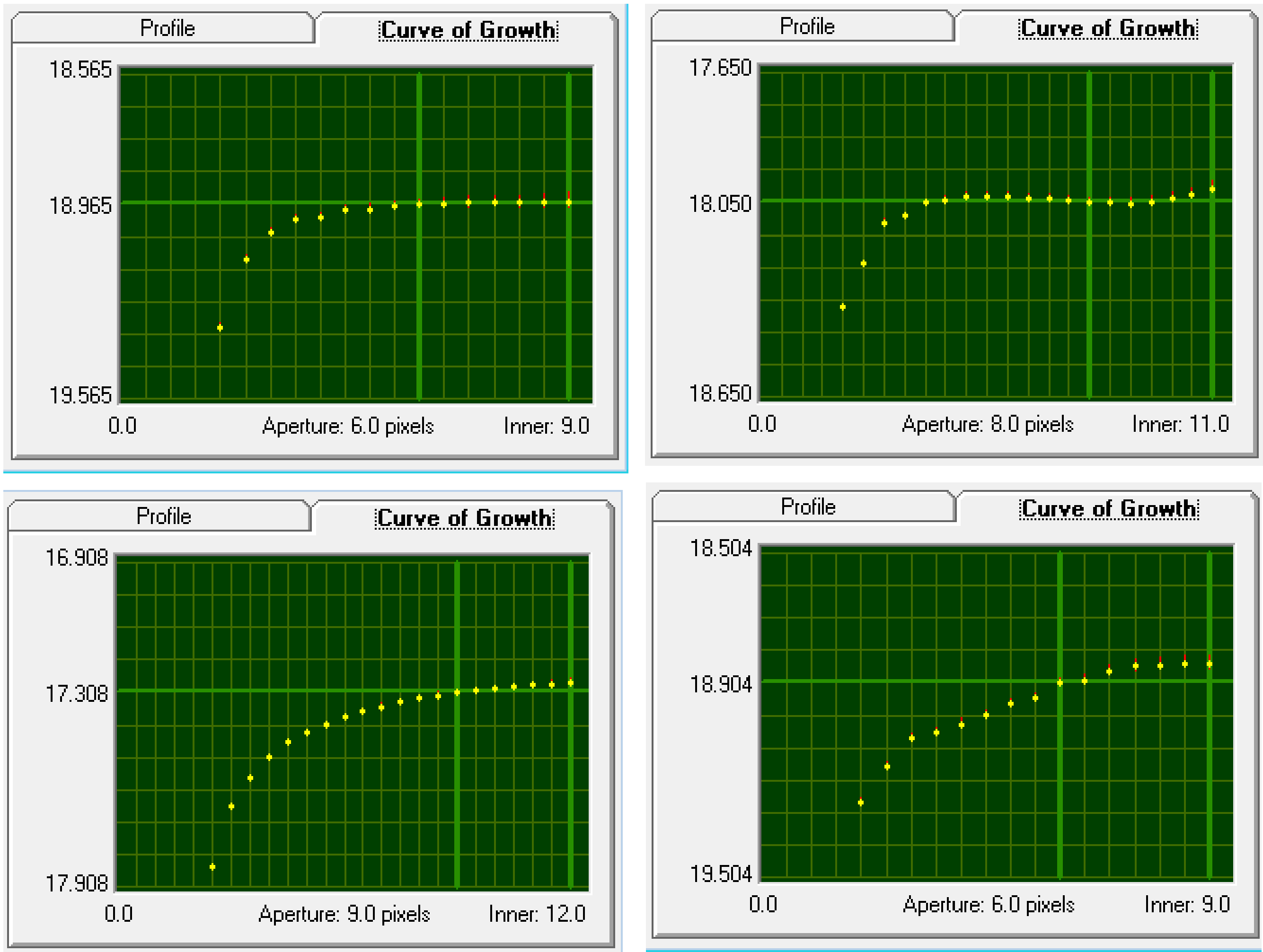

Figure 4: AIP4WIN image of the Messier 82 galaxy with the photometry tool 'Single-Star' depicting the photometric curves of growth of four stars surrounding the galaxy. Star 1 = top right, Star 2 = top right, Star 3 = bottom left and Star 4 = bottom right.

The curve of growth of a star is used to determine a good aperture radius of the star so that it captures all the emitted light, where the graph plots the stars magnitude against the aperture radius. The level regions in stars 1,2 and 3 in **??** shows that the aperture radius is slightly small as the plot doesn't fall near the inner annulus so the it would need to be increased whereas for star 4, the aperture radius is too big that its borders the edge of the M82 galaxy and thus the light emitted from the galaxy itself has disrupted the data.

2.2 Single-Image Photometry

Single-Image photometry is used to calculate the magnitudes of two or more stars and thus also the difference in magnitude of all measured stars. It also measures the light and automatically subtracts the background sky light from it, by selecting comparison stars allows for more accurate measurements to be recorded as atmospheric extinction may cause a incorrect measurement of a stars light flux ([?]).

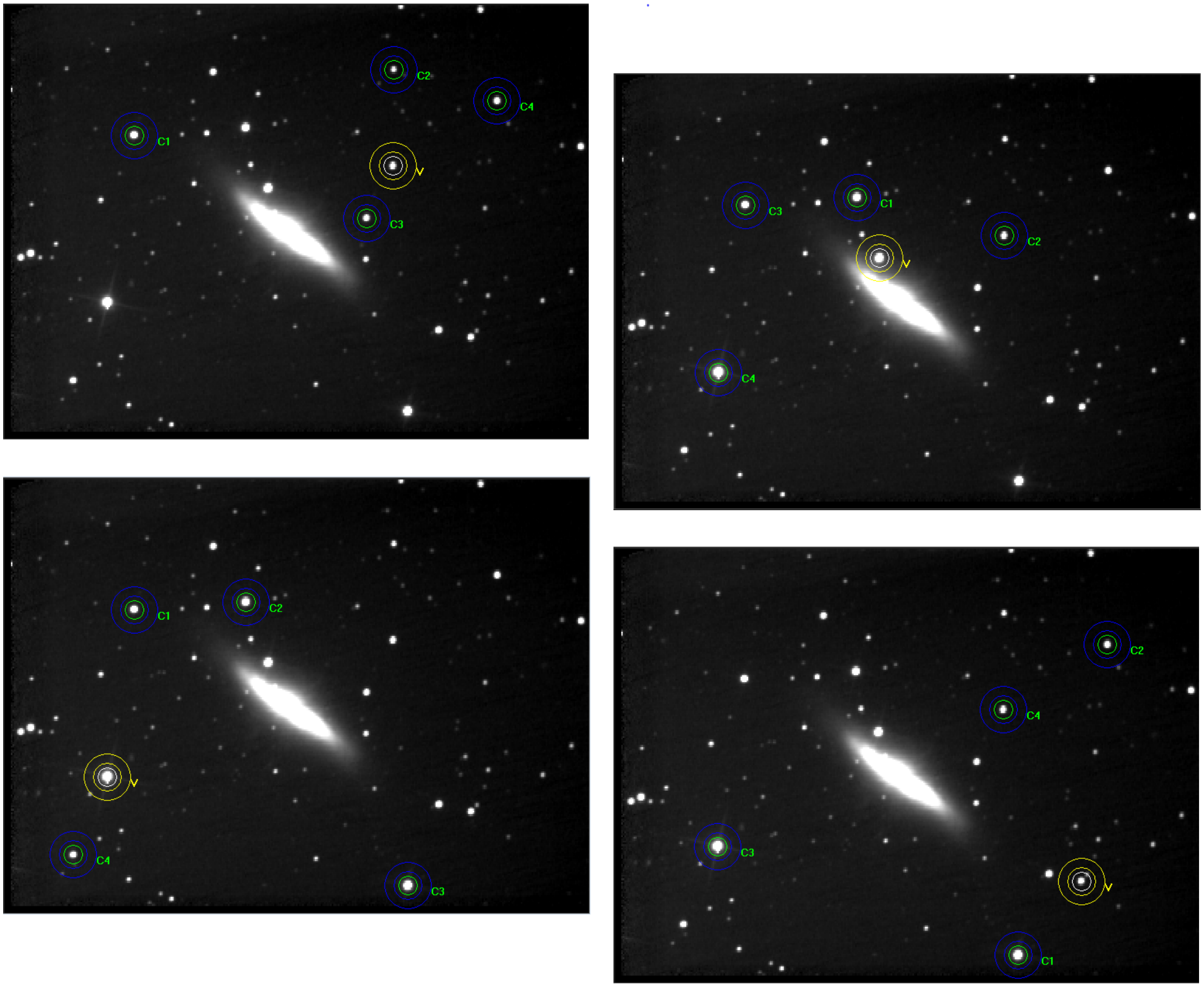

Figure 5: AIP4WIN image of the Messier 82 galaxy with the photometry tool 'Single-Image' depicting the aperture, inner and outer anuli around each target star with 4 comparison stars for each target star for photometric measurements of four stars surrounding the galaxy. Star 1 = top right, Star 2 = top right, Star 3 = bottom left and Star 4 = bottom right.

Utilizing the single image tool, the target star is chosen and a number of comparison stars are selected to which the magnitude will be display as the comparison star/s are brighter or dimmer than the target star as displayed in **??** which the resulting magnitudes are displayed in **??**. **??** also displays the differential magnitude of the target star minus a comparison star so that they can be compared to decipher is the target star is undergoing any atmospheric extinction.

AIP4WIN Photometry settings for all four target single-image images						
Target Star	Aperture Radius	Inner Annulus Radius	Outer Annulus Radius	Sky Annulus Pixels	Integration Time (s)	Zero Point
S1	6.0	9.0	15.0	236	60	25
S2	6.0	9.0	15.0	232	60	25
S3	6.0	9.0	15.0	235	60	25
S4	6.0	9.0	15.0	100	60	25

Photometric data collected of the four target single-image images								
Star	Target	$Star_X$	$Star_Y$	ADU_{Max}	ADU_{Sky}	ADU_{Star}	Magnitude	Sigma
1	Var	249.999	88.579	2028.0	180.8136	15567.9	18.965	±0.0162
1	C1	83.037	71.512	3072.0	203.88	26140.66	18.402	±0.0108
1	C2	250.566	35.092	1247.0	164.0773	8381.197	19.637	±0.0280
1	C3	232.987	117.565	2065.0	195.9958	15285.41	18.985	±0.0167
1	C4	317.147	52.471	1817.0	154.9872	15789.23	18.949	± 0.0154
1	Ens				179.7343	65542.64	17.404	± 0.0078
2	Var	169.516	101.010	3904.0	322.263	37495.18	18.010	0.0091
2	C1	155.045	67.267	3569.0	199.406	33323.62	18.139	0.0089
2	C2	249.999	88.579	2028.0	180.8136	15567.9	18.965	0.0162
2	C3	83.037	71.512	3072.0	203.88	26140.66	18.402	0.0108
2	C4	65.746	164.741	4086.0	228.596	66354.21	17.391	0.0055
2	Ens				203.153	141417	116.569	± 0.0043
3	Var	65.746	164.741	4086.0	228.596	66354.21	17.391	0.0055
3	C1	83.037	71.512	3072.0	203.88	26140.66	18.402	0.0108
3	C2	155.045	67.267	3569.0	199.406	33323.62	18.139	0.0089
3	C3	259.623	225.015	3953.0	186.1348	48049.52	17.741	0.0068
3	C4	43.718	207.962	2561.0	215.597	16862.34	18.878	0.0161
3	Ens				201.301	124355.4	16.709	± 0.0047
4	Var	300.405	183.969	2009.0	175.8798	16458.02	18.904	0.0156
4	C1	259.623	225.015	3953.0	186.1348	48049.52	17.741	0.0068
4	C2	317.147	52.471	1817.0	154.9872	15789.23	18.949	0.0154
4	C3	65.746	164.741	4086.0	228.596	66354.21	17.391	0.0055
4	C4	249.999	88.579	2028.0	180.8136	15567.9	18.965	0.0162
4	Ens				187.6335	145795.5	16.536	± 0.0041

Magnitudes for all four target single-image images			
Star	(V-C1) & Sigma	(C2-C1) & Sigma	(V-Ens) & Sigma
1	0.563 ± 0.0195	1.235 ± 0.0300	1.561 ± 0.0179
2	-0.128 ± 0.0128	0.826 ± 0.0184	1.441 ± 0.0101
3	-1.011 ± 0.0121	-0.264 ± 0.0140	0.682 ± 0.0072
4	1.163 ± 0.0170	1.208 ± 0.0169	2.368 ± 0.0162

Table 2: AIP4WIN settings and photometry data of the 4 target 'single-image' stars.

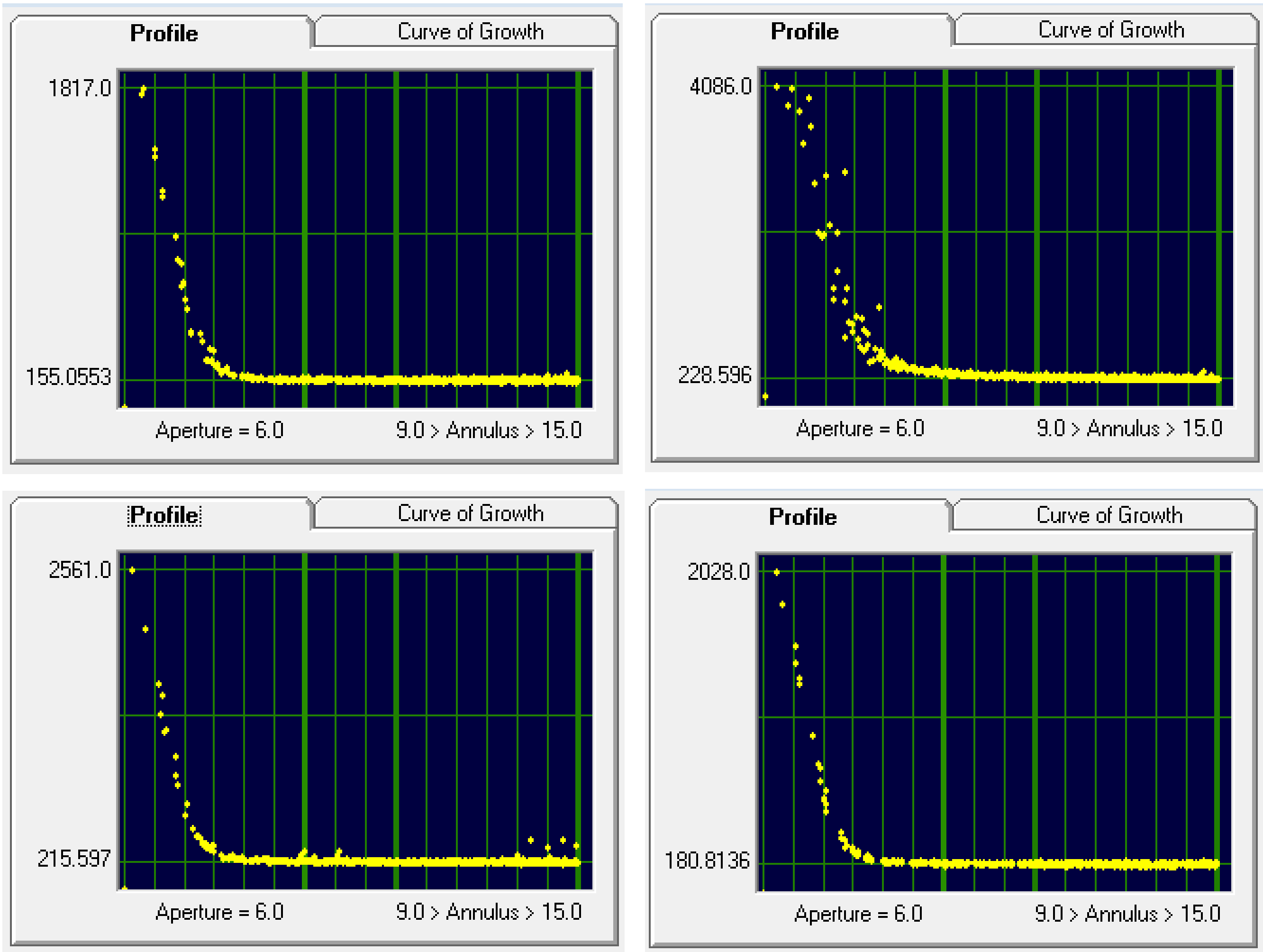

Figure 6: AIP4WIN image of the Messier 82 galaxy with the photometry tool 'Single-Image' depicting the photometric profile of four stars surrounding the galaxy. Star 1 = top right, Star 2 = top right, Star 3 = bottom left and Star 4 = bottom right.

The profiles in **??** show all the target star light flux profile over a cross section, it also shows no interference from any other stars. Below in **??** it confirms this apart from star 2 where the inner annulus sits over a nearby star causing the curve of growth to deviate upwards instead of leveling out, to fix this error would be to make the inner annulus smaller.

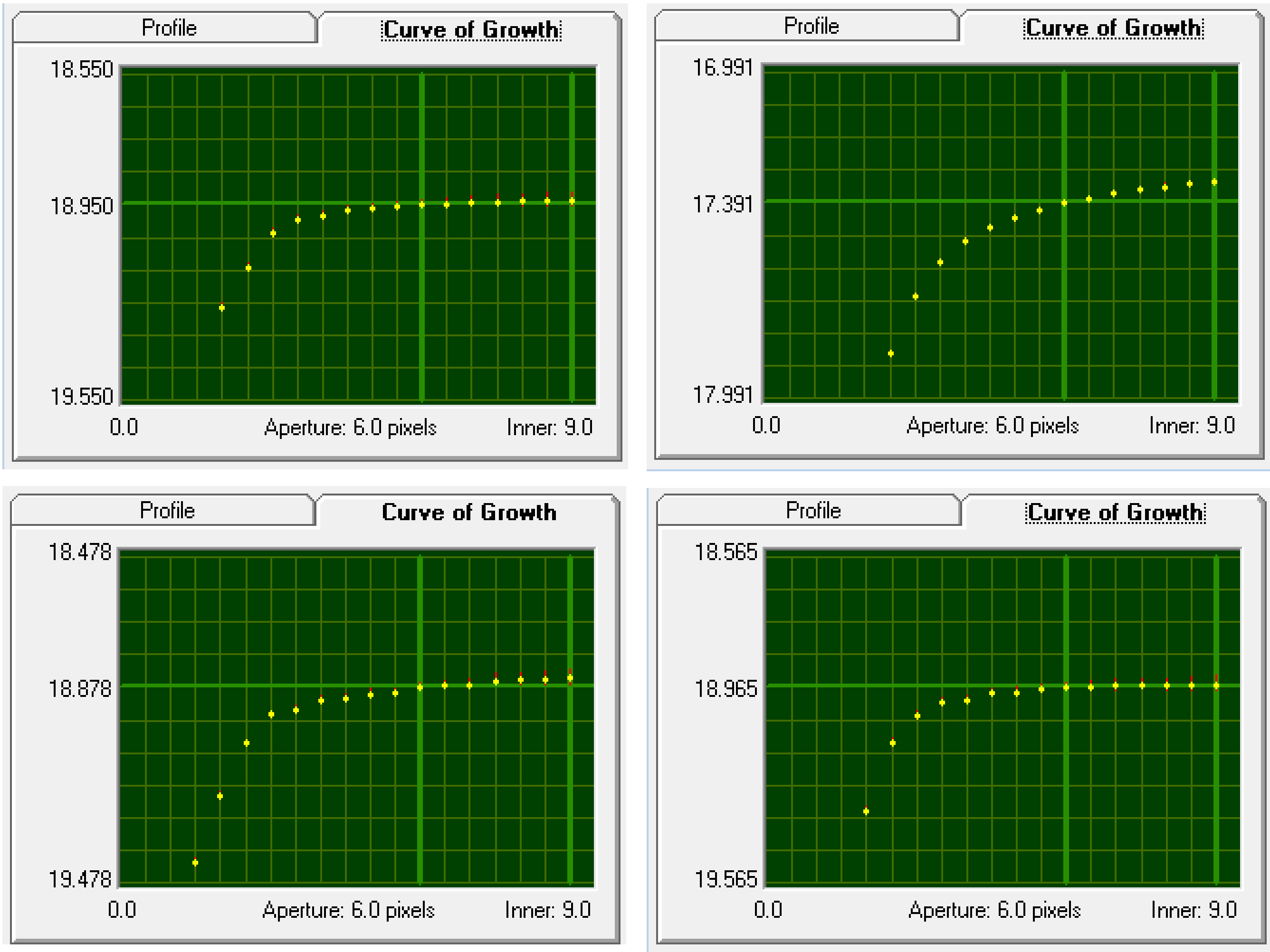

Figure 7: AIP4WIN image of the Messier 82 galaxy with the photometry tool 'Single-Image' depicting the photometric curves of growth of four stars surrounding the galaxy. Star 1 = top right, Star 2 = top right, Star 3 = bottom left and Star 4 = bottom right.

AIP4Win determines the errorbars in **??** and **??** though small, they are a result of the a miscalculation of magnitude, as the star emits light flux that varies over the 60 second exposure time which thus the magnitude can change in values as the light flux fluctuates.

3 Multiple-Image Photometry

Multiple-Image photometry is used to measure raw instrumental or differential magnitudes from multiples images through an automated process ([**?**]). By selecting a series of multiple images that have be taken over time, but first the images need to be calibrated first using two other files that set the zero the multiple image tool. Following this the target stars are selected as shown in **??** and multiple comparison stars to calculate around any atmospheric extinction present in front of the target star. By tracking mainly the target and first comparison star so when the software flicks through the series of images, it will track the two stars accurately due to the calibration earlier. The exported data collected is shown in **??** where the software extracted the magnitudes of each target star and comparison star.

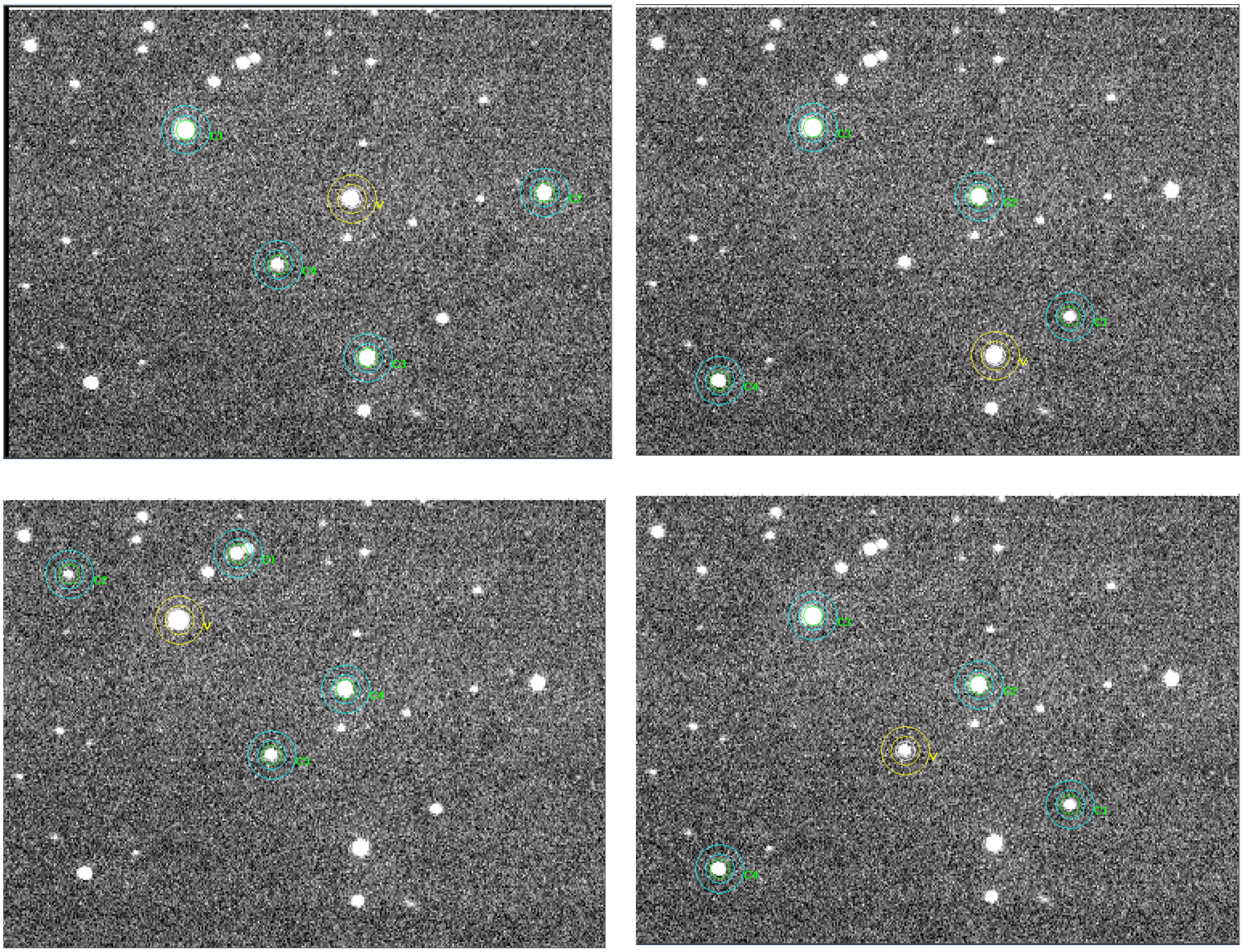

Figure 8: AIP4WIN image of the Messier 82 galaxy with the photometry tool 'Multiple-Images' depicting the aperture, inner and outer anuli around each target star with 4 comparison stars for each target star for photometric measurements of four stars surrounding the galaxy. Star 1 = top right, Star 2 = top right, Star 3 = bottom left and Star 4 = bottom right.

AIP4WIN Photometry settings for all four target single-image images						
Target Star	Aperture Radius	Inner Annulus Radius	Outer Annulus Radius	Sky Annulus Pixels	Integration Time (s)	Zero Point
S1	6.0	9.0	15.0	234	60	25
S2	6.0	11.0	15.0	231	60	25
S3	6.0	11.0	15.0	131	60	25
S4	6.0	9.0	15.0	231	60	25

Photometric data collected of the four target single-image images							
Star	Target	$Star_X$	$Star_Y$	ADU_{Sky}	ADU_{Star}	Magnitude	Sigma
1	Var	215.002	101.791	45.1197	5871.51	19.073	0.0296
1	C1	111.480	64.837	45.2025	17950.15	17.860	0.0118
1	C2	335.038	98.486	44.8369	3365.82	19.677	0.0494
1	C3	224.891	186.961	44.8918	7764.39	18.770	0.0232
1	C4	169.044	137.099	44.6638	1138.267	20.854	0.1354
1	Ens				30218.6	17.294	0.0119
2	Var	224.891	186.961	44.8918	7764.39	18.770	0.0232
2	C1	271.700	166.176	44.5127	949.267	21.051	0.1654
2	C2	215.002	101.791	45.1197	5871.51	19.073	0.0296
2	C3	111.480	64.837	45.2025	17950.15	17.860	0.0118
2	C4	53.397	200.481	44.2076	2787.86	19.882	0.0587
2	Ens				27558.8	17.394	0.0129
3	Var	224.891	186.961	44.8918	7764.39	18.770	0.0232
3	C1	271.700	166.176	44.5127	949.267	21.051	0.1654
3	C2	215.002	101.791	45.1197	5871.51	19.073	0.0296
3	C3	111.480	64.837	45.2025	17950.15	17.860	0.0118
3	C4	53.397	200.481	44.2076	2787.86	19.882	0.0587
3	Ens				27558.8	17.394	0.0129
4	Var	224.891	186.961	44.8918	7764.39	18.770	0.0232
4	C1	271.700	166.176	44.5127	949.267	21.051	0.1654
4	C2	215.002	101.791	45.1197	5871.51	19.073	0.0296
4	C3	111.480	64.837	45.2025	17950.15	17.860	0.0118
4	C4	53.397	200.481	44.2076	2787.86	19.882	0.0587
4	Ens				27558.8	17.394	0.0129

Magnitudes for all four target single-image images			
Star	(V-C1) & Sigma	(C2-C1) & Sigma	(V-Ens) & Sigma
1	1.213 ± 0.032	1.817 ± 0.051	1.779 ± 0.0132
2	-2.282 ± 0.0167	-1.978 ± 0.168	1.375 ± 0.027
3	-2.282 ± 0.167	-1.978 ± 0.168	1.375 ± 0.027
4	-2.282 ± 0.167	-1.978 ± 0.0168	1.375 ± 0.072

Table 3: AIP4WIN settings and photometry data of the 4 target 'multiple-image' stars.

As in **??**, the software subtracts the first comparison star from the target star to give a differential magnitude. Below in **??**, the profile of the difference in magnitude allows us to see how the differential magnitude differs in each images, the errorbars are extreme of three of them at the star has moved significantly over the time duration of the series of images.

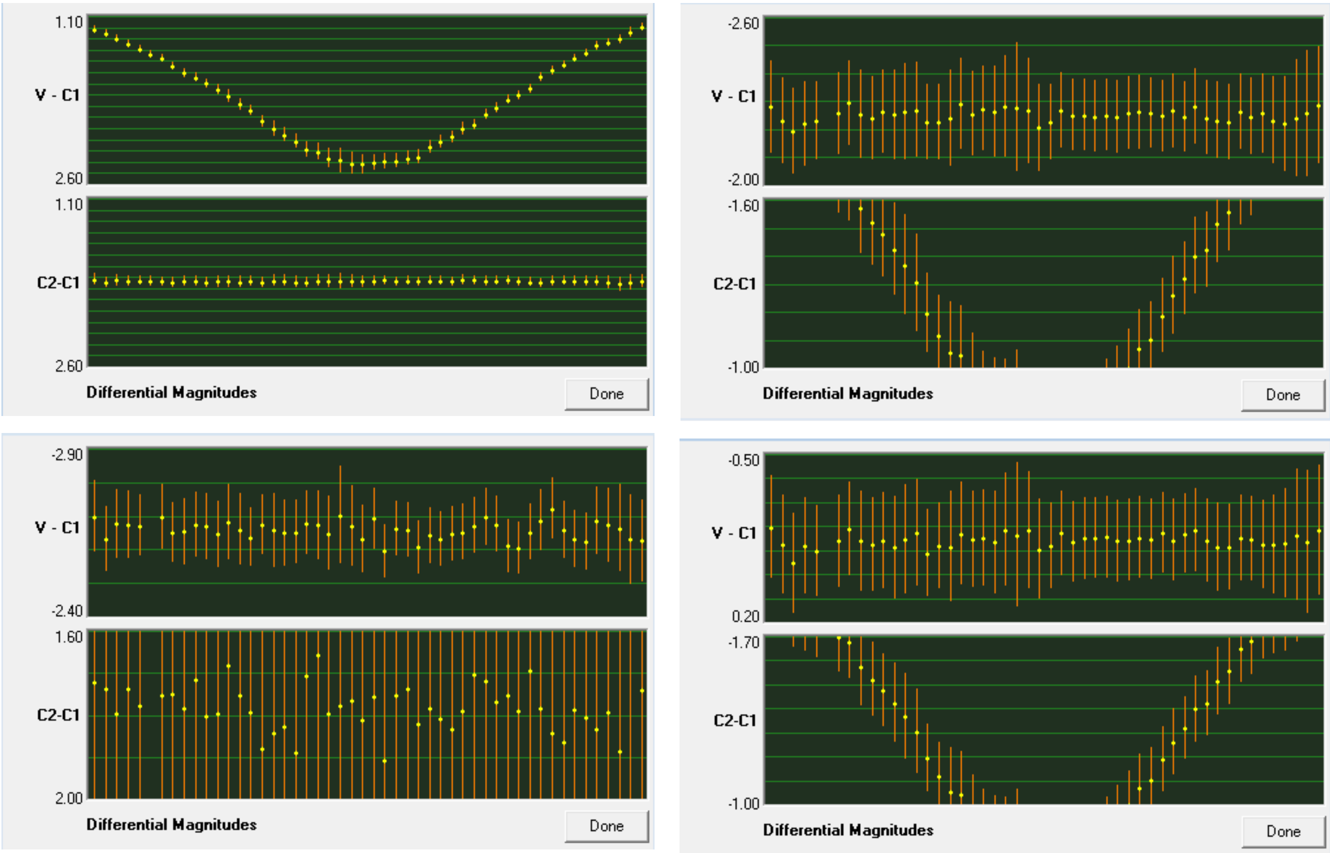

Figure 9: AIP4WIN image of the target star system with the photometry tool 'Multiple-Images' depicting the photometric curves of growth of four stars surrounding the galaxy. Star 1 = top right, Star 2 = top right, Star 3 = bottom left and Star 4 = bottom right.

4 The Carina Nebula

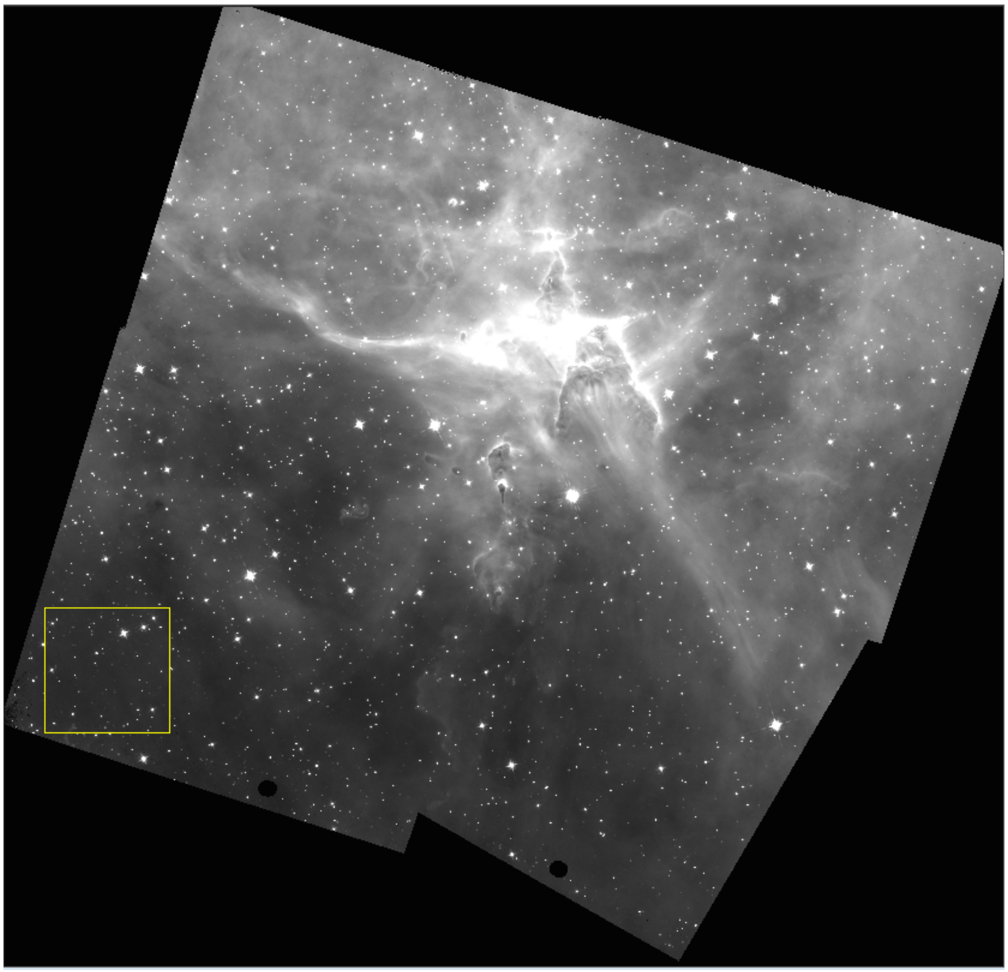

Figure 10: An infrared image of the Carina Nebula source from ([?]).

Sourcing a infrared image (??) of the Carina Nebula ([?]) and cropping a square section of the image at 40 arcseconds across each side allows for a small photometric measurement to take place, though the software only allows for pixels measurements, not arcseconds to be entered so converting 40 arcseconds into pixels:

$$\frac{0.128''}{Pixel} \rightarrow \frac{0.128''}{40''} = 312.5Pixels \tag{1}$$

Figure 11: Two cropped images of the nebula + sky and the sky background.

Selecting an area of the **??** where there is plenty of light from the nebula with a selection of star is necessary to extract as much clear data so to estimate the instrumental magnitude of the nebula in the cropped area. Using the cropped image of the nebula + sky shown in **??**, using the pixel tool on multiple areas of the nebula gives the mean total of pixel counts over a area containing a number of pixels and their individual standard errors shown in **??**. The same is done to a 40 arcseconds cropped section of dark sky background which copies the amount of stars in the original cropped image but has a majority of dark sky illustrated in **??** where the data collected is display in **??**.

Values of light flux for the nebula & sky of the Carina Nebula					
Mean	**Pixels**	**Std Dev**	**Mean**	**Pixels**	**Std Dev**
2.49382	349	0.049855	0.893753	641	0.02178
1.95734	725	0.151801	0.736952	457	0.02077
2.57294	1403	0.036983	0.9239792	1033	0.157065
2.74983	277	0.033442	0.978278	545	0.027846
2.48937	657	0.045167	0.867642	1281	0.022931
2.43827	1425	0.068683	0.907267	401	0.017125
2.34643	1389	0.110985	0.826468	741	0.020146
2.04743	805	0.037392	0.862156	697	0.023058
2.04722	1041	0.083214	0.926473	1033	0.031044
2.00573	697	0.057807	0.975374	1289	0.037345
1.84873	473	0.058754	0.974485	1209	0.022581
2.46837	965	0.039759	0.8529552	275	0.019286
2.85937	811	0.036607	0.826752	517	0.021443
2.35838	965	0.129077	0.9782558	1473	0.021104
2.48284	933	0.109176	0.974245	1245	0.030159
2.58492	497	0.052405	0.878278	697	0.030214
1.88623	505	0.029356	0.8264654	741	0.028294
2.46245	593	0.050433	0.865254	609	0.019732
2.89628	1549	0.118608	0.988724	1177	0.029515
3.17362	1900	0.101	0.998762	1137	0.024223
2.97266	1669	0.07851	0.799624	593	0.021649
2.435344286	**934.6666667**	**0.070429238**	**0.898197267**	**847.1904762**	**0.030824286**

Results of the flux and magnitude of the Nebula only						
	Neb - Sky	Pixels in Area	Total Nebula	Exp.Time (s)	Flux	Magnitude
Values	1.537	98656.25	151649.161	699.232	216.8795	19.159454
Error	0.03960495	98 656.25	3907.27605	699.232	±5.58795	±2.8

Table 4: Tabular results of the Nebula - Sky background calculations.

To obtain a instrumental magnitude of the Carina Nebula its necessary to obtain a magnitude of the nebula without the sky background interference, so in **??** by taking an average mean and standard deviation error, the sky background data will be subtracted from the nebula + sky data. The nebula only value will then multiplied by the amount of pixels in the cropped image which is 98656.25 pixels (312.5 multiplied by itself), this gives a total nebula value of 151649.161. To calculate the amount of flux in the nebula, the total nebula count is divided by the exposure time, then using the flux to calculate the instrumental magnitude.

$$Flux_N = \frac{151649.161}{699.232483} = 216.879456 \pm 5.588 \tag{2}$$

$$M_I = -2.5 \times log(216.879456) + 25 = 19.159454 Mag \pm 2.8 Mag \tag{3}$$

To calculate the nebula + stars instrumental magnitude, the same cropped image of the nebula is used but using the single star tool to measure their individual magnitudes. But this only gives the magnitude of the star not with the nebula, so by measuring the magnitudes of the most prominent stars in nebula image of **??** to which the data is displayed in **??**.

Values of light flux for the stars of the Carina Nebula						
Star	**X Pos**	**Y Pos**	**Magnitude**	**Error**	**Flux**	**Corrected Flux**
1	191.559	74.97	24.551	0.136	1.512167849	149184.8093
2	62.621	58.314	25.459	0.312	0.655239394	64643.46147
3	59.165	120.128	26.131	0.569	0.352858026	34811.64961
4	67.01	172.512	26.219	0.599	0.325386852	32101.4466
5	107.671	191.974	25.736	0.39	0.507691626	50086.95197
6	181.413	199.205	27.344	1.738	0.115451612	11390.02307
7	185.367	144.403	27.403	1.848	0.10934527	10787.59426
8	163.921	37.429	25.463	0.308	0.652829844	64405.74431
9	275.028	86.255	26.987	1.232	0.160398388	15824.30349
10	275.91	143.523	28.358	4.361	0.045373262	4476.355849
		263.651	**11.493**	**4.436742122**	**437712.34**	

Results of the flux and magnitude of the Nebula only						
	Neb - Sky	Pixels in Area	Avg. Neb	Exp.Time (s)	Flux	Magnitude
Values	1.537	98656.25	151649.161	699.232	216.8795	19.159454
Error	0.03960495	98 656.25	3907.27605	699.232	±5.58795	± 0.5 Mag

Table 5: Tabular results of the Star + Nebula calculations.

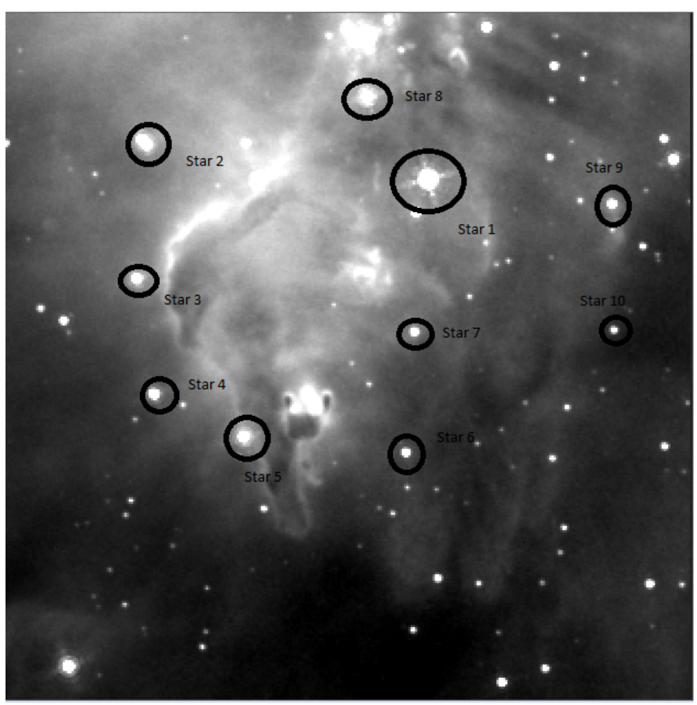

Figure 12: The Stars as in relation to **??**.

The magnitudes are calculated into flux and total using:

$$Flux_S = 10^{(Magnitude-25)/-2.5} = 4.4367 \tag{4}$$

The flux needs to be transformed into counts where it can be related to the pixel area of the image and the exposure time and recalculated into flux:

$$Flux_S = \frac{(4.4367 \times 699.232482) \times 98656.25}{699.232483} = 437712.34 \tag{5}$$

Adding the flux that was calculated for the nebula only to this flux value and finding the instrumental magnitude again but this time for the nebula + stars:

$$M_I = -2.5 \times log(216.879456 + 437712.34) + 25 = 10.8965Mag \pm 0.52Mag \tag{6}$$

This final value for the instrumental magnitude makes sense as the more negative the magnitude, the brighter it is and comparing it to the nebula only magnitude of 19 Mag and as the nebula + stars equals to be 10 which is logical as it contains measurements of stars which are brighter than the nebula itself.