Astronomy 61

Lab 2: Astrometry and Tri-Colour Imaging

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1 Purpose

The purpose of this lab is to familiarize ourselves with capturing CCD images of astronomical objects (such as star fields and nebula) using a professional telescope. This involves: 1) preparing for an observing run by making the appropriate field selection based on factors such as air mass and altitude; 2) operating the telescope on the roof of the UCT astronomy building; 3) obtain the tricolour image of an interesting object using PYRAF and ds9; 4) perform astrometry (both manually and using an automated astrometry server) on a star field to determine the pixel scale of the CCD and the right ascension and declination of any object in the image.

2 Procedure

2.1 Field Selection

It is crucial to select the appropriate field before the observing session. The first field is used to perform astrometry and should therefore contain at least 10 - 15 fairly bright star (with $V < 12mag$). The second field will be an interesting object that can be captured for tri-colour imaging. Both field should be as close to the zenith as possible (about 60° above the horizon as a rule of thumb) so that it will not be obstructed by tall buildings and is less affected by the city light. Both objects should also ideally have air mass below 1.7 to minimize the effect of atmospheric turbulence.

Our group selected one of the standard star field with the field center at RA: $06^h52^m10^s$ and DEC: $-0°25'00"$ for the astrometry part of the observing and NGC 2440 and Horsehead Nebula for the tri-colour imaging part.

The group was informed that the observation date will be on 28 January 2015 and the observing time is between 20:00 and 22:00 local time. Using JSkyCalc, we recorded the airmass and altitude of the object at 20:00, 21:00 and 22:00 local time and ensure that the observing conditions for the object of interest is reasonable. This is presented in the table below:

Object	RA	DEC	Dimensions	Alt (20:00; 21:00; 22:00)	Air mass (20:00; 21:00; 22:00)
NGC 2440	$07^h41^m54.91^s$	$-18°12'29.70"$	74" x 42"	$+37°03'44"$; $+49°41'49"$; $+61°51'46"$	1.656; 1.310; 1.134
Horsehead Nebula	$05^h40^m59.00^s$	$-02°27'30.00"$	8' x 6'	$+50°48'23"$; $+58°02'36"$; $+59°55'09"$	1.289; 1.178; 1.155
Standard star field	$06^h52^m10.00^s$	$-00°25'00.00"$	30' x 30'	$+37°08'49"$; $+47°31'28"$; $+55°11'09"$	1.652; 1.354; 1.217
M46	$07^h41^m46.82^s$	$-14°48'36.00"$	27' x 27'	$+35°28'18"$; $+47°59'26"$; $+59°47'55"$	1.719; 1.344; 1.157

Table 1: Field selection before observing run

The group expect the observing time to be around 21:30. This correspond to an air mass of below 1.5 and an altitude of between 50° and 60° above the horizon for the objects we have selected, which is within a reasonable range.

2.2 Observing

The night was clear and there only a few clouds in the sky during the time of our observation. There is a gibbous moon that is fairly bright but fortunately, the object of interest is far away enough from the moon in the sky to be affected. The group arrived at the site (the observatory on the roof of the UCT Physics and Astronomy building) at approximately 20:45. We were informed that due to mechanical failure, we have to adjust the position of the dome of the observatory manually. There were also some technical issues with the software but the TA managed to resolve the problem and the group commenced observing at around 21:30.

The telescope has an apperture of 14" and software used is TheSkyX Version 10.3.0.The CCD used is STL-6303E and the average CCD temperature is around $-9°$ to $-10°$. For the lab, images are taken using 2 x 2 bin. Four different filters - Hydrogen alpha (Ha), Blue, Tripled ionized oxygen (Oiii) and V - are used in the lab.

The TA took the flat field images through the different filters before sun set. They have also taken the dark image and the bias image through the different filters on our behalf. We were instructed to proceed with observing the star field for the astrometry part of the lab.

It was noted during the observing that the standard star field we have selected for astrometry is too dim. At that point, we could either increase the exposure time or select another star field. We chose the latter option and the TA Mackenzie Jones assigned the group to look at M46, which is an open star cluster.

For the star cluster M46, we noted that an exposure time of 30 sec through the Blue filter would give a count of around 10,000 per pixel in the bright region, which is ideal. We proceed to take a series of 3 images, each of exposure time 30 sec, through the blue filter. The CCD temperature is steady at around $9°C$ to $10°C$, which is acceptable. The observation log entry for M46 (30 sec exposure and blue filter) is presented in Table 2:

Object:	**M46**		
File name:	M46*51.fit	M46*52.fit	M46*53.fit
Local time of observation:	21:28:19	21:28:57	21:29:35
Air mass:	1.28	1.28	1.28
Exposure time (sec):	30.000	30.000	30.000
Filter:	Blue	Blue	Blue
CCD temperature($°C$):	-9.79	-10.20	-10.20

Table 2: CCD series of M46 taken using a Blue filter and 30 sec exposure time

We performed the same procedure for M46 through the V filter. However, because M46 is dimmer in the V wavelength compared to the Blue wavelength, we require a longer exposure time to get a count of roughly 10,000 count per pixel at the brighter region. Since the count rate is linear with exposure time, and we noted that at 30 sec exposure the count rate is roughly 400 counts per pixel, we triple the exposure time so as to triple the count rate. The count rate for an exposure time of 90 sec through the V filter is above 10,000, as we have expected. The observation log entry for M46 (90 sec exposure and V filter) is presented in Table 3:

Object:	**M46**		
File name:	M46*54.fit	M46*55.fit	M46*56.fit
Local time of observation:	21:36:10	21:37:48	21:39:25
Air mass:	1.25	1.28	1.28
Exposure time (sec):	90.000	90.000	90.000
Filter:	V	V	V
CCD temperature($°C$):	-9.79	-10.20	-10.20

Table 3: CCD series of M46 taken using a V filter and 90 sec exposure time

For the object of interest, we chose NGC 2440 and the Horsehead Nebula. The group noted that NGC 2440 is too dim and its apparent dimension is too small. We decided after looking at the CCD image that we wanted to capture an object that will look more interesting. Fortunately, the second object (the Horsehead nebula) that we have selected covers a wider field of view and looks interesting through the telesope.

We capture 3 CCD images of the Horsehead nebula through 3 different filters: Ha (red), Oiii (green) and Blue (blue) so that we can subsequently construct a RGB colour image of Horsehead nebula. We select the exposure time for the different filter based on the same principle outlined above. We take a 30 sec exposure through each of the filter and scale the exposure time accordingly to achieve a count of roughly 10,000 to 20,000 count per pixel, bearing in mind the linear relationship between exposure time and count rate. The observation log entry for Horsehead nebula (Ha(30 sec), Oiii(180 sec) and Blue(30 sec)) is presented in Table 4:

Object:	**Horsehead Nebula**		
File name:	Horsehead*58.fit	Horsehead*59.fit	Horsehead*62.fit
Local time of observation:	21:54:24	22:01:50	22:42:49
Air mass:	1.17	1.17	1.2
Exposure time (sec):	100.000	180.000	30.000
Filter:	Ha	Oiii	Blue
CCD temperature($^{\circ}C$):	-9.79	-10.20	-10.20

Table 4: CCD images of Horsehead nebula taken with different filter and exposure time

During our initial field selection, we did not take into account the moon; it was fortunate that our target is not too close to the moon in the sky. One of the lessons learnt from this lab is that we should consider the angle between the moon and our object during the time of observing in future observation sessions.

3 Analysis

3.1 Adjusting the images to account for flat and bias

It is crucial to account for flat and bias before analysing the science frame (or the image of the object). The image can be adjusted for bias by performing image subtraction and divison as shown below:

$$outputimage = \frac{Scienceframe - Biasframe}{Flatfield - Biasframe} \tag{1}$$

It was determined from the first lab that the dark current of the CCD used (STL-6303E) is 0.0090 ± 0.0005 electron/pixel/sec, which translates to about 1.8 electron/pixel over the longest exposure time of 180 sec. Since the gain as determined from the first lab to be 1.4 electron/adu, the noise introduced by dark current is roughly 1 count per pixel. Given that the bright pixels in the CCD has a count of around 10000 count per pixel, the error introduced by dark current is about 0.0001%, which is low enough to be ignored.

To create the master bias frame, we first combine the 25 bias images taken with the CCD using the *imcombine* command on PyRAF. We then subtract the master bias from all the images (the object and the flat field) using the *imarith* command. Next, we create master flat field for each filter (Ha, Blue, Oiii and V) by doing the following:

1. Combine the flat fields (with the bias subtracted) of the same filter with *imcombine*, with the *combine* paramenter set to "median" and the *scale* parameter set to "mean". The IRAF tutorial provides the detailed instruction. The count of each pixel is combined by taking the median count so as to eliminate outliers introduced by cosmic ray. Each of the flat fields are also scaled such that they have the same mean. The PyRAF

command for combining all the flat field image for the blue filter and creating the master flat field for the blue filter, for instance, is outlined below:

c1¿ imcombine $flat\_bias_blue * .fit$ $masterflat_blue.fit$ *combine=median scale=mean*

2. Use *imstat* tp find the mean of the master flat.

3. Use *imarith* to divide the master flat by its mean so that the mean is 1.0 i.e. the master flat is normalized. This is necessary because the flat image has a large number of counts per pixel, whereas the object images have relatively few counts per pixel (astronomical objects are faint). T aherefore scaling factor need to be introduced.

Perform the same steps for the V, Oiii and Ha filter so that a master flat field is obtained for each filter. Divide the object image by its corresponding master flat field using *imarith.* For example, if the object is taken through the blue filter, it should be divided by the normalized Blue flat field.

3.2 Astrometry

Astrometry is crucial in order to calculate the pixel scale in arcsec/pixel and to convert from pixel co-ordinates (X,Y) to celestial equatorial co-ordinates (RA, DEC). In this lab, we performed astrometry using 2 independent methods:

1) Manually by comparing our image with the Digitized Sky Survey (DSS) image

2) Automatically by using an online astrometry calibration software (nova astrometry)

We selected one of the 30 sec exposure through the blue filter image of M46 to perform astrometry (M46*51.fit). The same procedure can be applied for all 6 other images of M46 (3 images with blue filter and 30 sec exposure and 3 images with V filter and 90 sec exposure) if necessary.

Astrometry using DSS

First, we download a Digitized Sky Survey (DSS) image from `http://archive.stsci.edu/cgi-bin/dss_form` of the star field M46. The image is retrived from the "POSS1 Blue" filter of DSS since we will be comparing it with our image which is taken with the blue filter. The center of the field for M46 in RA and DEC is presented in Table 1 and we chose a height and width of 30 arcmin by 30 arcmin to correspond roughly with the filed of view of the CCD (STL-6303E) used.

Figure 1 is the CCD image of M46 adjuster for flat and bias, taken through the blue filter and with an exposure time of 30 sec. Figure 2 is the DDS image of M46 (30 arcmin by 30 arcmin). It is difficult to match the stars from the CCD image with those in the DDS image because there are too many stars in the field to discern any pattern. Therefore, we zoom in onto each image and attempt to adjust for the orientation by inverting (the image is inverted due to the way the optics work within the telescope) and rotating it.

Figure 3 is the same CCD image zoomed in. It was determined by looking at the pattern of the star that the image has to be inverted left-right and rotated roughly 120° clockwise. Figure 3 shows the image zoomed in, inverted and rotated. Figure 4 shows the same field of view of the image with DSS. Seven stars are circled and labelled to show the comparison between the two images. Compass arrows are also included in Fig 1 - Fig 4 to denote North and East.

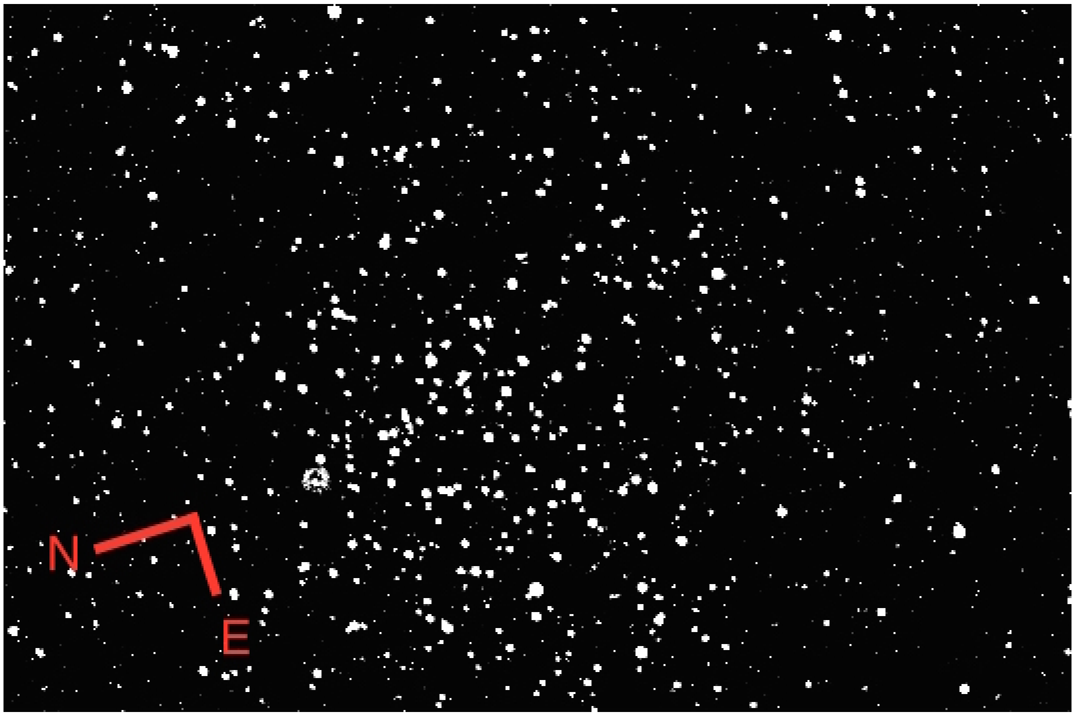


Fig. 1: CCD image of M46 adjusted for flat and bias (30 sec exposure and Blue filter)

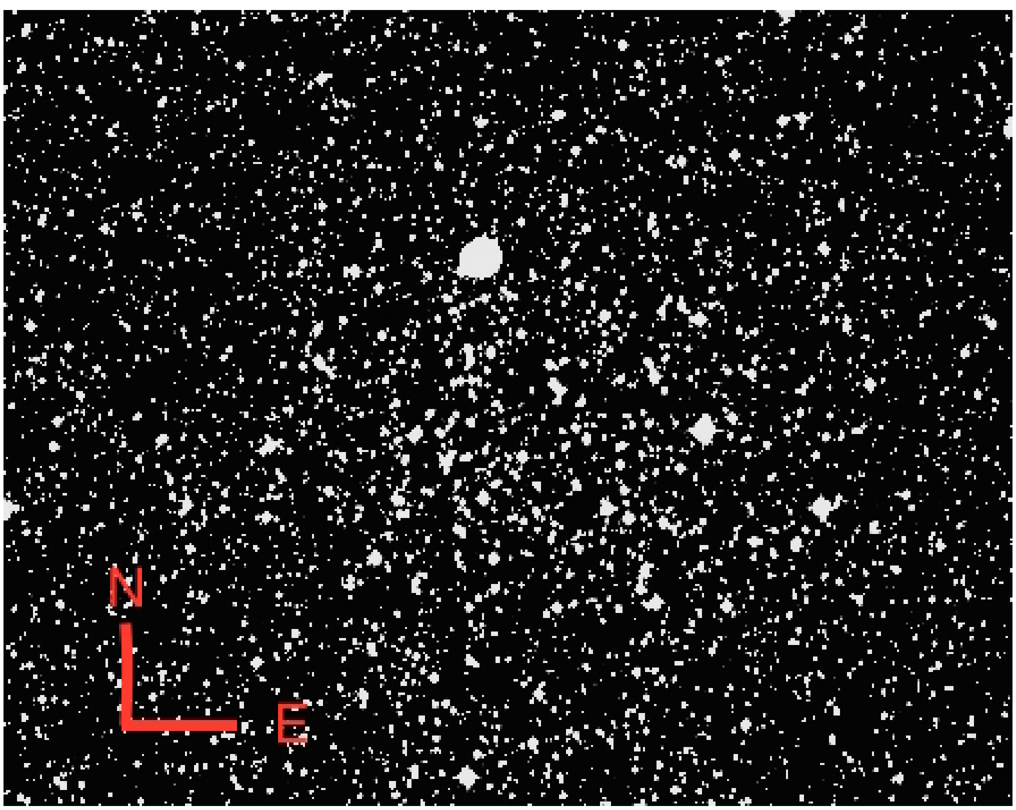


Fig. 2: Digitized Sky Survey (DSS) of M46 (30' x 30')

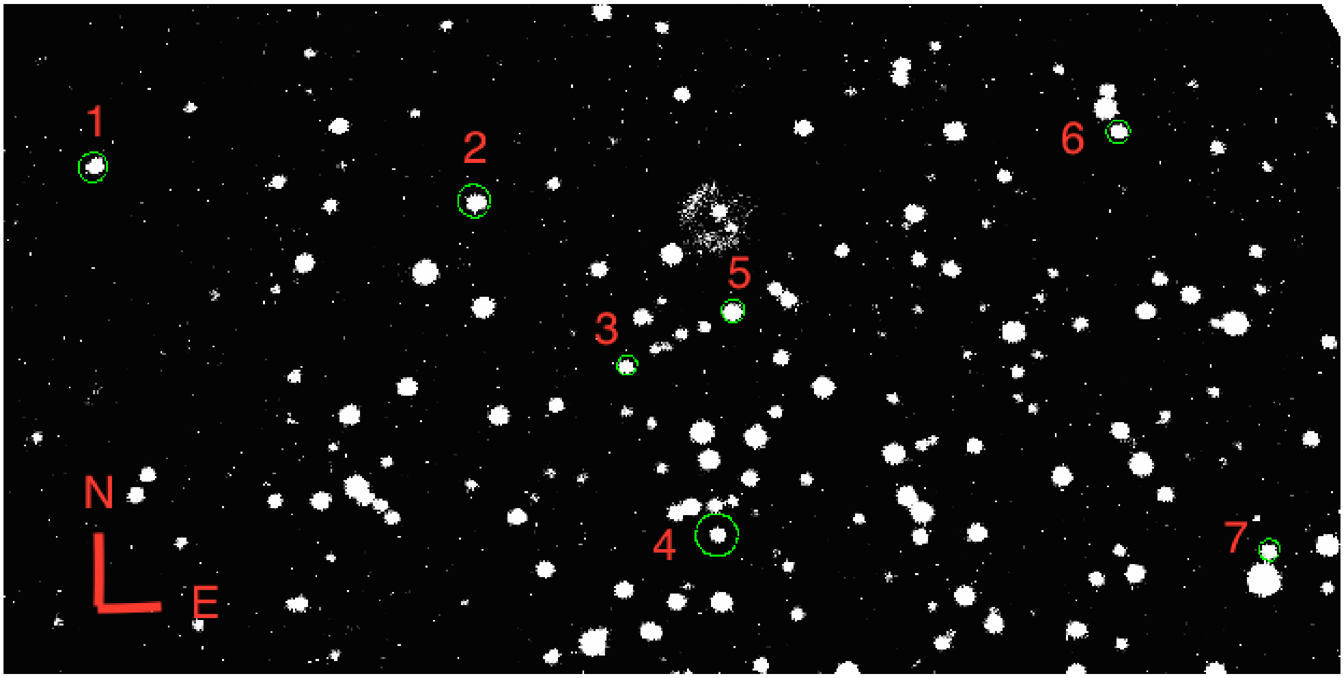


Fig. 3: CCD image of M46 zoomed in, rotated (120°) and inverted left-right to align with DSS image

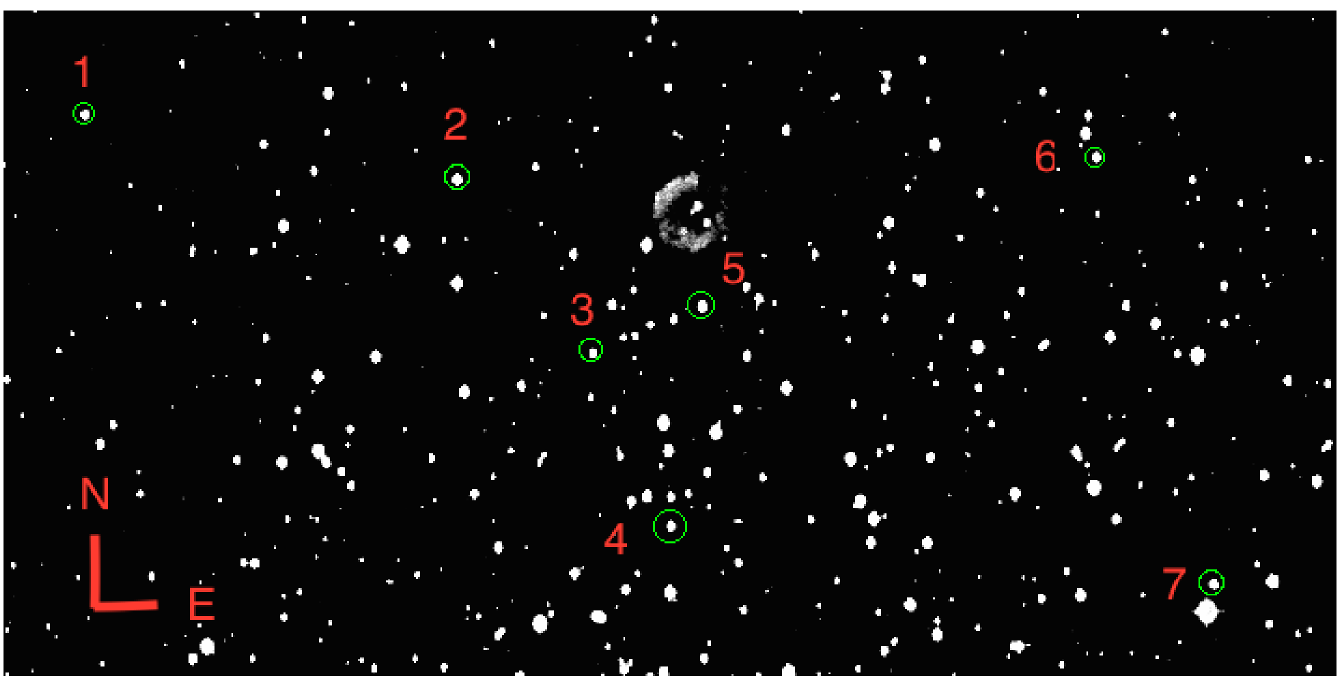


Fig. 4: DSS image with stars circled for comparison with CCD image

The celestial equatorial co-ordinates for the 7 stars are measured using the DSS image (Fig 4). The corresponding pixel co-ordinates are measured using the CCD image (Fig 3). The data are presented in Table 5. The RA and DEC of each of the star are also converted to arcsec. This is based on the fact that there is 360° in 24 hour. In addition, there is 60 arcmin in 1° and 60 arcsec in 1 arcmin. The calculations are presented below:

$$1hour = \frac{360^\circ}{24hour} = 15^\circ = 15^\circ \times \frac{3600"}{1^\circ} = 54000" \quad (2)$$

There is 900" in a minute and 15" in a second. The conversion for RA and DEC to arcsec is also presented in Table 5.

Star	RA(h,min,sec)	DEC(deg,arcmin,arsec)	X(pix)	Y(pix)	RA(arcsec)	DEC(arcsec)
1	$07^h42^m22.895^s$	$-14^\circ42'55.95"$	260.777	612.419	416143.43	52975.95
2	$07^h42^m02.992^s$	$-14^\circ43'44.12"$	379.231	445.250	415844.88	53024.12
3	$07^h41^m55.763^s$	$-14^\circ45'55.76"$	495.441	419.968	415736.45	53155.76
4	$07^h41^m51.514^s$	$-14^\circ48'09.17"$	599.250	422.166	415672.71	53289.17
5	$07^h41^m49.917^s$	$-14^\circ45'20.51"$	498.827	356.104	415648.76	53120.51
6	$07^h41^m29.012^s$	$-14^\circ43'22.80"$	519.188	128.837	415335.18	53002.80
7	$07^h41^m22.556^s$	$-14^\circ48'50.29"$	754.044	172.055	415238.34	53330.29

Table 5: Comparison of stars in CCD image (X,Y pixel) with DSS coordinates (RA, DEC)

Since the field of view is relatively small, we can find the distance between two stars in arcsec using Pythagorean theorem without accounting for spherical trigonometry. The distance between two stars in pixels can also be calculated using Pythagorean theorem.

For instance, to find the distance between star 1 and 2 (denoted by d_{1-2}) in arcsec and pixel, we performed the following calculation:

$$d_{1-2pix} = \sqrt{(RA_1 - RA_2)^2 + (DEC_1 - DEC_2)^2} \quad (3)$$

$$d_{1-2arcsec} = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \quad (4)$$

Since there are 7 stars, there wil be in total 6+5+4+3+2+1 = 21 possible distances between any 2 of the 7 stars. The 21 distances in pixel and arcsec are presented in Table 6. S1-S2 denotes the distance between star S1 and S2 (eg 2-6 denotes the distance between star 2 and star 6). The pixel scale in arcsec/pixel is calculated for each of the 21 distances.

S1-S2	Distance (pixel)	Distance (arcsec)	arcsec/pixel
1-2	204.88	302.41	1.48
1-3	303.49	444.93	1.47
1-4	388.28	565.40	1.46
1-5	349.81	515.36	1.47
1-6	548.30	808.69	1.47
1-7	661.24	971.98	1.47
2-3	118.93	170.55	1.43
2-4	221.23	316.06	1.43
2-5	149.17	218.53	1.47
2-6	345.98	510.15	1.47
2-7	463.81	679.43	1.46
3-4	103.83	147.85	1.42
3-5	63.95	94.51	1.48
3-6	292.10	429.43	1.47
3-7	358.24	527.80	1.47
4-5	120.20	170.35	1.42
4-5	304.06	442.64	1.46
4-7	294.14	436.31	1.48
5-6	228.18	334.94	1.47
5-7	314.66	341.51	1.09
6-7	238.80	341.51	1.43

Table 6: Calculation of the distance between 2 stars in pixel and arcsec. S1-S2 denotes the distance between star S1 and star S2

$$pixelscaleerrorbar = \frac{pixelscale_{max} - pixelscale_{min}}{2} = \frac{1.48arcsec/pixel - 1.09arcsec/pixel}{2} = \pm 0.195arcsec/pixel \quad (5)$$

The average pixel scale is 1.44 arcsec/pixel and the error bar is calculated to be 0.195 arcsec/pixel. This gives us a pixel scale of:

$$pixelscale = 1.44 \pm 0.20arcsec/pixel \quad (6)$$

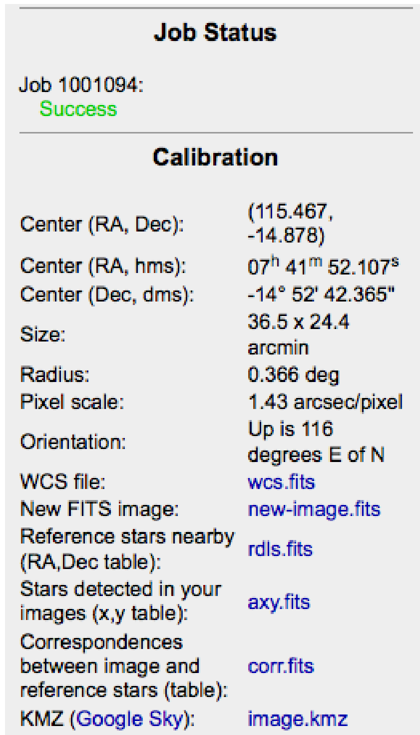
Astrometry using Astrometry Nova

We used an automated astrometry server to check the results that we obtained using the manual method. Using two independent methods to perform astrometry and checking that the results obtained are approximately the same would boost our confidence level in the accuracy of our approach.

The CCD image of M46 (blue filter with exposure time 30 sec, accounted for flat and bias) is uploaded onto `http://nova.astrometry.net` to be calibrated. Fig 5 and Fig 6 show the results of the automated astrometry calibration.

The pixel scale obtained using the automated calibration is 1.43 arcsec/pixel. We compare this with the pixel scale obtained using the manual method (1.44 ± 0.20 arcsec/pixel) and note that they are sufficiently close, with a percentage deviation of less than 0.7%.

The automated astrometry calibration gives an orientation of up being 116 degrees E of N. We compare this with the orientation that we obtained in the previous section using DSS (up being 120 degrees E of N) and note that the results once again agree well with each other.



Job Status

Job 1001094:
Success

Calibration

Center (RA, Dec):	(115.467, -14.878)
Center (RA, hms):	07^h 41^m 52.107^s
Center (Dec, dms):	-14° 52' 42.365"
Size:	36.5 x 24.4 arcmin
Radius:	0.366 deg
Pixel scale:	1.43 arcsec/pixel
Orientation:	Up is 116 degrees E of N
WCS file:	wcs.fits
New FITS image:	new-image.fits
Reference stars nearby (RA,Dec table):	rdls.fits
Stars detected in your images (x,y table):	axy.fits
Correspondences between image and reference stars (table):	corr.fits
KMZ (Google Sky):	image.kmz

Fig. 5: Calibration using Astrometry nova

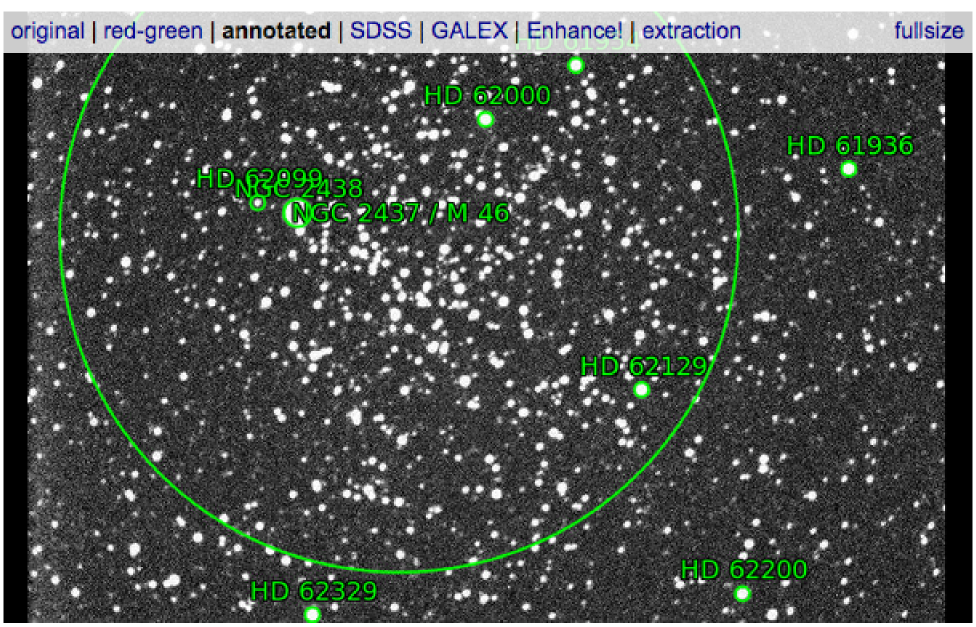


Fig. 6: Annotated image by Astrometry nova

In addition, we comare the RA and DEC of the 7 stars obtained using the manual method (presented in Table 5) and the automated method (presented in Table 7 below) and calculate how much they differ. The differences are recorded in Table 7.

Star	RA using nova (h,min,sec)	DEC using nova(deg,arcmin,arsec)	$RA_{DSS-nova}$ (sec)	$DEC_{DSS-nova}$ (arcsec)
1	$07^h42^m22.822^s$	$-14°42'56.58"$	0.073	-0.63
2	$07^h42^m02.972^s$	$-14°43'44.52"$	0.02	-0.4
3	$07^h41^m55.752^s$	$-14°45'56.70"$	0.011	-0.94
4	$07^h41^m51.497^s$	$-14°48'09.24"$	0.017	-0.07
5	$07^h41^m49.888^s$	$-14°45'20.26"$	0.029	0.25
6	$07^h41^m28.895^s$	$-14°43'22.64"$	0.117	0.16
7	$07^h41^m22.550^s$	$-14°48'50.67"$	0.006	-0.38

Table 7: Comparison of RA and DEC obtained from DSS with astrometry nova for labelled stars

It is noted that the differences in RA obtained with DSS and nova are all less 0.1 sec with the average difference being 0.039 sec. The RA obtained with nova is consistently less than that obtained with DSS, which suggest that there is a systematic error in calculating the RA. This is probably due to the difference in calibration technique.

It is also noted that the difference in DEC obtained with DSS and nova are all less than 1 arcsec. However, unlike the RA data, the DEC obtained with nova is neither consistently less or consistently more than the one obtained with DSS i.e. there seem to be a random error. The average difference (the modulus, or absolute difference) between the DEC obtained with DSS and nova is calculated to be 0.40 arcsec.

The above comparison reveals that the WCS coordinates found by Astrometry Nova agree closely with the DSS coordinates. This boost our confidence level in the accuracy of the astrometry performed using both the manual and automated method.

3.3 Tri-colour imaging

To make a colour image of the Horsehead Nebula, it is necessary to:

1. Align the images taken with the Ha (red), Oiii (green) and Blue (blue) filter

2. Combine the images taken with the 3 filters

Aligning the 3 images

To align the 3 images, we selected 6 registration stars that appear in all 3 images. The 6 registration stars are annotated in Fig 7 (Ha filter), Fig 8 (Blue filter) and Fig 9 (Oiii filter). We let the CCD image of the Horsehead Nebula taken through the blue filter to be the reference image and will align the images taken with the Ha and Oiii filter to the reference. Using the *imexamine* command, we are able to obtain the X and Y pixel coordinates of the 6 registration stars in the reference image. The positions are recorded in a .txt file named coord.txt.

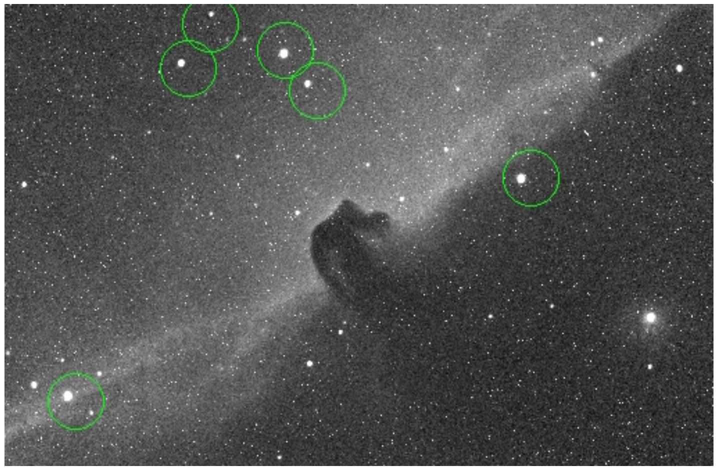


Fig. 7: Horsehead Nebula Aligned (Ha and exposure time 100 sec)

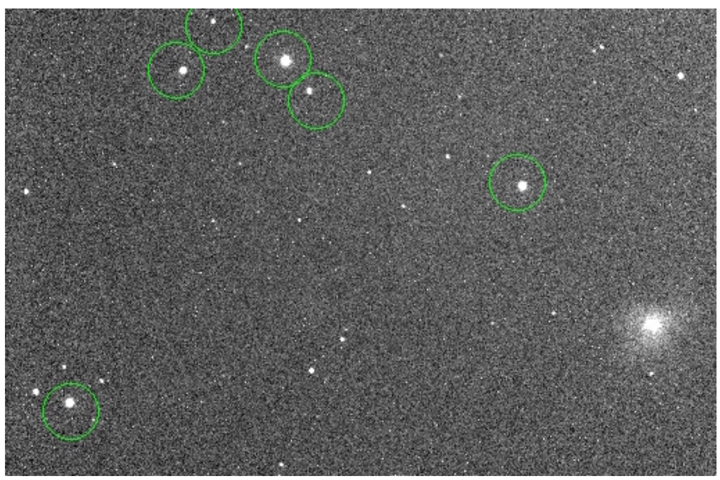


Fig. 8: Horsehead Nebula Aligned (Blue and exposure time 30 sec) - this is also the reference image

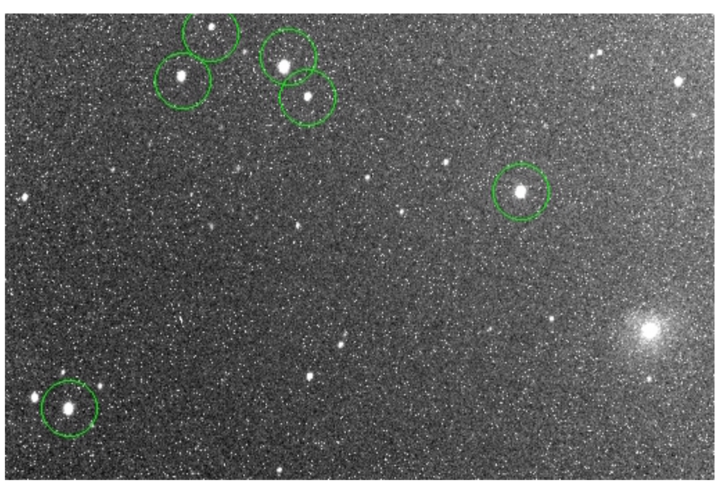


Fig. 9: Horsehead Nebula Aligned (Oiii and exposure time 180 sec)

Next, we estimated the X and Y shift of a star in the Ha image and the Oiii from the same star in the Blue image. The shifts are defined as follow:

$$X_{shift} = X_{ref} - X_{input} \tag{7}$$

$$Y_{shift} = Y_{ref} - Y_{input} \tag{8}$$

The shift in coordinates are saved in a .txt file named shift.txt. It should be noted that the shift of the reference image is by definition (0,0). The shift thatis recorded is approximately 40 pixels in both X and Y direction. This is because during our observing, we encountered a problem with the software and have to restart the software. The last image (taken with the blue filter) was taken for us by the TA. The time lapse between taking the first image of Horsehead (Ha filter; taken at 21:54:24) and the last image (Blue filter; 22:42:49) is about 48 mins apart, during which the telescope probably has been realigned. This explain the large shift.

The images can then be aligned using the *imalign* command. The parameters are set as follow:

input: HorseheadBlue.fit,HorseheadHa.fit,HorseheadV.fit

referenc: HorseheadBlue.fit

coords: coord.txt

output: HorseheadBlueAlign.fit,HorseheadHaAlign.fit,HorseheadVAlign.fit

shifts: shift.txt

Combining the 3 images

We can use ds9 to combine the shifted images to create a colour image. The online ds9 tutuorial provides the instruction to create the color images. The Ha filter correspond to red in the RGB frame of ds9; Oiii filter corresponds to green; and Blue filter corresponds to blue.

Figure 10 shows the Tri-colour image that formed when the 3 different images (Ha, Blue, Oii) are not aligned and it demonstrates the importance of alignment.

Figure 11 shows the Tri-colour image formed after the 3 images are aligned. All 3 filtered images are set at zscale and linear and are thus given equal weightage.

Figure 12 shows the same Tri-colour image as Figure 11, but with Ha set as zscale and histogram while Oiii and blue set as zscale and linear. Histogram is used for Ha because it has the shortest exposure time and we want to increase the weight assigned to it when combining the image to make up for the short exposure time.

Figure 13 uses zscale and power for Oiii and Blue but zscale and histogram for Ha. Again, this is to assign more weight to the Ha filter to make up for the shorter exposure time.

Figure 14 uses zscale and histogram for Ha, zscale and linear for Blue and zscale and power for Oiii. The scaling used for Figure 12 tries to take into account the difference in exposure time for all 3 filter, with Ha (exposure time 30 sec) given the most weightage, followed by Blue (exposure time 100 sec) and Oiii (exposure time 180 sec). Of course, the scaling is just a rough estimate in accounting for the differences in exposure time.

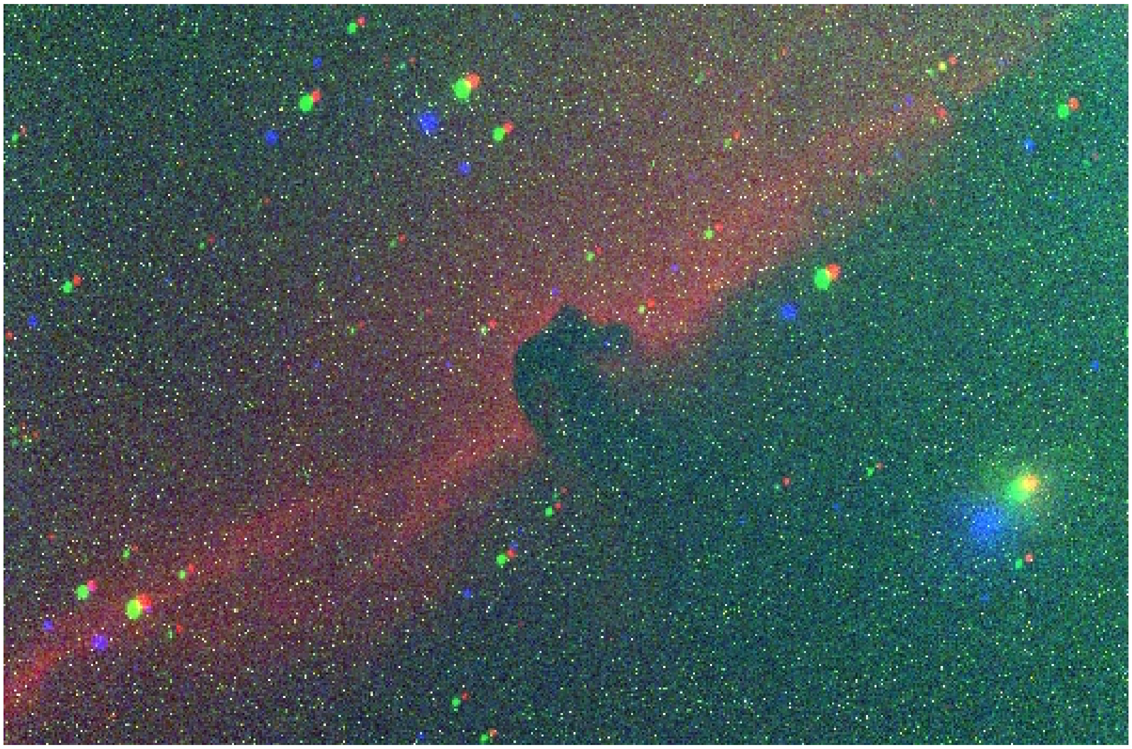


Fig. 10: Horsehead Nebula with Ha (zscale and linear), Oiii (zcale and linear) and Blue (zscale and linear)

Fig. 11: Horsehead Nebula with Ha (zscale and linear), Oiii (zcale and linear) and Blue (zscale and linear)

Fig. 12: Horsehead Nebula with Ha (zscale and histogram), Oiii (zcale and linear) and Blue (zscale and linear)

Fig. 13: Horsehead Nebula with Ha (zscale and histogram), Oiii (zcale and power) and Blue (zscale and power)

Fig. 14: Horsehead Nebula with Ha (zscale and histogram), Oiii (zcale and power) and Blue (zscale and linear)

3.4 Signal to noise ratio

The signal to noise ratio for a single pixel, according to Jansen (2006), is given as:

$$\frac{S}{N} = \frac{S_{*} \cdot G}{\sqrt{S_{*} \cdot G + S_s \cdot G + t \cdot dc + R^2}} \tag{9}$$

where S_* is the signal due to the astronomical object, such as bright stars in the image, in counts per pixel, S_s is the background signal or signal in the sky, in counts per pixel, t is the exposure time in sec, dc is the dark current in electron/pixel/sec and R is the readout noise in electron/pixel and G is the gain in electron/adu.

It was determined from the previous CCD lab that:

$G = 1.416 electron/adu$

$R = 13.56 electron/pixel$

$dc = 0.009 electron/pixel/sec$

To find the signal of the star s_* in counts, we create a circle on ds9 centred on a bright star and record the number of counts and the area of the circle in pixels A_*. Dividing s_* by A_* would yield the signal of the star per pixel i.e. $S_* = \frac{s_*}{A_*}$. Similarly, to find the signal of the sky s_s in counts, we create a circle on ds9 centred on a relatively dark area of the field and record the number of counts and the area of the circle in pixels A_s. Dividing s_s by A_s would yield the signal of the sky per pixel i.e. $S_s = \frac{s_s}{A_s}$.

We perform the same calculation for 3 separate stars in each image and 3 separate dark regions. We then repeat it for the other filters (Ha, Blue and Oiii). The data are recorded in Table 8.

	Ha	Blue	Oiii
s_*1/ counts	374159	492011	384430
s_*2/ counts	951367	1154760	1302500
s_*3/ counts	630899	755732	470895
s_s1/ counts	15007	16221	14848
s_s/ counts	33350	31729	31663
s_s/ counts	21505	22954	22447
A_*1/ pixels	133	134	133
A_*2/ pixels	208	209	209
A_*3/ pixels	163	162	162
A_s1/ pixels	162	161	162
A_s2/ pixels	213	208	211
A_s3/ pixels	162	162	163

Table 8: Signal of star s_*, signal of sky S_s, area of star slected A_* and area of sky selected A_s for 3 different regions

Using equation (9), we calculate the S/N ratio for the 3 different regions with the Ha, Blue and Oiii filter. The mean S/N ratio and the corresponding error bar is recorded in Table 9.

	1	2	3	mean	error bar
S/N_{Ha}	60.7519	69.9406	61.6454	64.1126	4.59435
S/N_{Blue}	78.0649	86.2726	91.8901	85.4092	6.9126
S/N_{Oiii}	71.6358	79.0067	61.3814	70.6746	8.81265

Table 9: Signal of star S_*, signal of sky S_s, area of star slected A_* and area of sky selected A_s for 3 different regions

Therefore, the S/N ratio for Horsehead Nebula as observed through the Ha, Blue and Oiii filter are as followed:

$$S/N_{Ha} = 64 \pm 5 \tag{10}$$

$$S/N_{Blue} = 85 \pm 7 \tag{11}$$

$$S/N_{Oiii} = 71 \pm 9 \tag{12}$$

4 Summary

We learnt about pre-lab preparation (field selection) and observation techniques in this lab. In particular, we noted that the air mass of the object, the altitude, its angle with the moon, its apparent dimensions and apparent magnitude are important factors to consider during field selection. We also learnt to operate a telescope (the telescope located on the roof of the UCT Physics and Astronomy building) and to use the software commonly used by professional astronomers (TheSkyX). During observing, we learnt to scale the exposure time when taking images through the different filter according to the counts in the bright region (counts increases linearly with exposure time).

We also learnt to analyze the images. In particular, we learnt to align the images so that we can combine the red (Ha filter), blue (Blue filter) and green (Oiii filter) images to form a tri-colour image. We performed this with images of the Horsehead Nebula. We also learnt to perform astrometry on our image. We performed astrometry manually and using an automated server. The pixel scale obtained using manual calibration is 1.44 ± 0.20 arcsec/pixel and this is close the pixel scale obtained with automated calibration (1.43 arcsec/pixel). The celestial equatorial co-ordinates of 7 selected stars obtained using DSS is also found to be close to the values obtained with the automated astrometry server.

Finally, we calculate the signal to noise S/N ratio for the Horsehead nebula for Ha, Blue and Oiii filter. We obtained $S/N_{Ha} = 64 \pm 5$, $S/N_{Blue} = 85 \pm 7$ and $S/N_{Oiii} = 71 \pm 9$.

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6 References

Astrometry Nova. Retrieved from: `http://nova.astrometry.net`. Accessed on: 2 February 2015.

Digitized Sky Survey. Retrieved from: `http://archive.stsci.edu/cgi-bin/dss_form`. Accessed on: 30 January 2015.

DS9 Tutorial. Retrieved from: `http://ds9.si.edu/doc/user/rgb/index.html`. Accessed on: 30 January 2015.

IRAF Tutorial. Retrieved from: `http://www.twilightlandscapes.com/IRAFtutorial/`. Accessed on: 30 January 2015.

Jansen, R.A. 2006. Astronomy with Charged Coupled Device. 49 - 50.

7 Appendix

Frame #	Type	Local Time	Airmass	ExpTime(s)	Filter
4027	Bias	7:42:39	1.35	0.00	V
4028	Bias	7:42:50	1.35	0.00	V
4031	Bias	7:43:16	1.35	0.00	V
4035	Bias	7:43:48	1.35	0.00	V
4036	Bias	7:43:57	1.35	0.00	V
4073	Bias	7:46:35	1.39	0.00	Ha
4075	Bias	7:46:53	1.39	0.00	Ha
4078	Bias	7:47:19	1.39	0.00	Ha
4081	Bias	7:47:54	1.39	0.00	Ha
4082	Bias	7:48:02	1.39	0.00	Ha
4106	Bias	8:39:19	1.00	0.00	Blue
4108	Bias	8:39:38	1.00	0.00	Blue
4029	Bias	7:42:59	1.35	0.00	V
4030	Bias	7:43:07	1.35	0.00	V
4032	Bias	7:43:24	1.35	0.00	V
4033	Bias	7:43:22	1.35	0.00	V
4034	Bias	7:43:40	1.35	0.00	V
4074	Bias	7:46:45	1.39	0.00	Ha
4076	Bias	7:47:02	1.39	0.00	Ha
4077	Bias	7:47:10	1.39	0.00	Ha
4079	Bias	7:47:27	1.39	0.00	Ha
4080	Bias	7:47:45	1.39	0.00	Ha
4107	Bias	8:39:29	1.00	0.00	Blue
4109	Bias	8:39:46	1.00	0.00	Blue
4110	Bias	8:39:54	1.00	0.00	Blue
4040	Flat Field	8:12:39	1.17	3.00	Blue
4041	Flat Field	8:12:51	1.17	3.00	Blue
4042	Flat Field	8:13:01	1.17	3.00	Blue
4043	Flat Field	8:13:13	1.17	3.00	Blue
4044	Flat Field	8:13:25	1.17	3.00	Blue
4045	Flat Field	3:17:27	1.17	3.00	V
4046	Flat Field	8:17:42	1.17	3.00	V
4047	Flat Field	8:17:58	1.17	3.00	V
4048	Flat Field	8:18:13	1.17	3.00	V
4049	Flat Field	8:18:28	1.17	3.00	V
4083	Flat Field	8:01:19	1.17	3.00	Oiii
4084	Flat Field	8:01:31	1.17	3.00	Oiii
4085	Flat Field	8:01:42	1.17	3.00	Oiii
4086	Flat Field	8:01:53	1.17	3.00	Oiii
4087	Flat Field	8:02:04	1.17	3.00	Oiii
4088	Flat Field	8:02:21	1.16	3.00	Ha
4089	Flat Field	8:02:32	1.16	3.00	Ha
4090	Flat Field	8:02:43	1.16	3.00	Ha

Table 10: Observation Log (to be continued)

Frame #	Type	Local Time	Airmass	ExpTime(s)	Filter
4091	Flat Field	8:02:56	1.16	3.00	Ha
4092	Flat Field	8:03:07	1.16	3.00	Ha
4093	Flat Field	8:04:23	1.16	3.00	Ha
4094	Flat Field	8:04:34	1.16	3.00	Ha
4095	Flat Field	8:04:45	1.16	3.00	Ha
4096	Flat Field	8:04:56	1.16	3.00	Ha
4097	Flat Field	8:05:08	1.16	3.00	Ha
4051	M46	9:28:19	1.28	30.0	Blue
4052	M46	9:28:57	1.28	30.0	Blue
4053	M46	9:29:35	1.28	30.0	Blue
4054	M46	9:36:10	1.25	90.0	V
4055	M46	9:37:48	1.25	90.0	V
4056	M46	9:39:25	1.24	90.0	V
4058	Horsehead	9:54:24	1.17	100	Ha
4059	Horsehead	10:10:50	1.17	180	Oiii
4062	Horsehead	10:42:49	1.19	30.0	Blue
4037	Dark	7:44:56	1.34	180	V
4038	Dark	7:48:06	1.34	180	V
4039	Dark	7:51:42	1.34	180	V
4111	Dark	8:40:18	1.00	180	Blue

Table 11: Observation Log (continued)