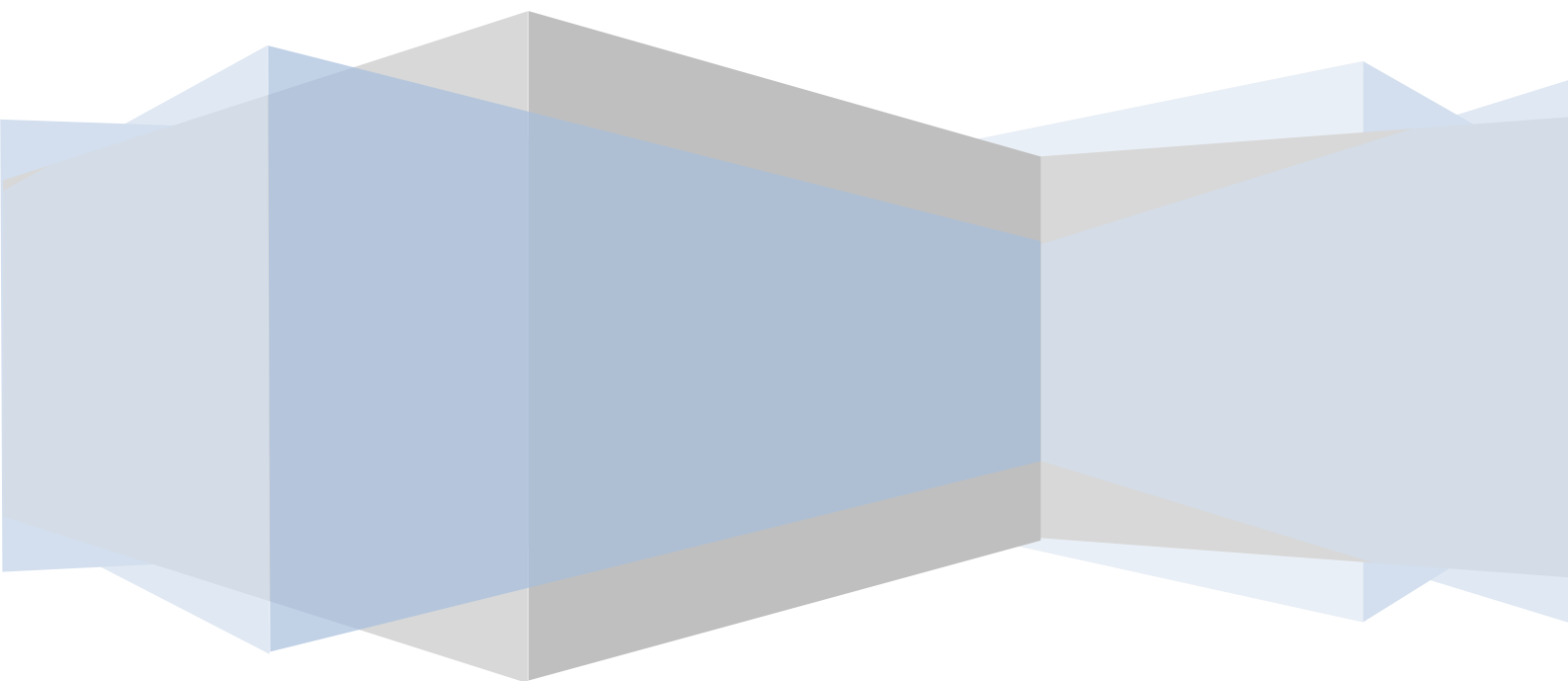


Stephen Maxwell

**Variable Star and Light  
pollution Monitor for the  
Armagh Observatory  
Nuffield Science Bursary Scheme**

Summer 2008



# Abstract

I spent my four week placement in Armagh Observatory. My project is component of an experiment to observe and analyse variable stars and by so doing this aid to the overall creation of a light pollution monitor for the Armagh Observatory. This project is a joint project for another student and I. However I proceeded further into the field of photometry and he to Astrometry. During the course of four weeks there were numerous goals. These include processing a series of images of the night's sky over hours and nights viewed by the polar bear telescope. Before the main project however I had to learn the basics of a Unix based operating system for which I would be working with and processing these images on. These images are processed using a few different pieces of software, these being Astrometry, XEphem and SExtractor. Using the output which I shall gain from these I will have to work out various things, including instrumental magnitude and the error in different results etc. I will have to also study how accurate the tools were in correctly measuring the position of the stars and their "counts". In addition I was to use a software tool which would enable the processing of these images to be undertaken with much more efficiency and ease. I should then proceed into the learning of the basics of the programming language C++ and use this to develop a software tool that will help in the processing of the output and that will be further developed to be able to utilise the Sinbad Astronomical Database in processing this acquired information and also further functions.

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# Introduction

## *What is a variable star?*

Most stars are believed to be constant with their light output over long periods of time. Nevertheless a few show large variations in brightness over time-scales that can vary from a few minutes to a few years, these are known as variable stars.

A variable star can be simply defined as a star that undergoes a great deal of variation in its luminosity. This variation in the stars brightness is caused by two rather different types of factors, these being intrinsic variables and extrinsic variables.

Intrinsic variability in a star basically means that it is the actual luminosity of that particular star that alters and it is not caused by an outside factor. These can be caused by pulsations, as the star may swell and shrink, eruptive variability or cataclysmic and explosive variable stars. Extrinsic variability can be divided into two main groups, which are eclipsing stars and rotating stars. Rotating star variables are when the star has substantial sunspots and when this star rotates the star becomes brighter as the brighter areas are brought round to the field of view and vice versa. Stars can also vary in shape, such as being ellipsoidal, and as the observer views them they can seem to change in brightness depending on how great a size of the stars surface is viewable to the observer. Another type of extrinsic variability is eclipsing stars. This can be seen most apparently in a binary star, a system that consists of two stars orbiting around their centre of mass. When seen at different angles one of these binary stars can be

eclipsing the other causing a reduction in brightness compared to the high level of brightness that can be seen when they are alongside.

Additionally stars that have planets that orbit it or pass in front of it in some way can cause variations. However these variations are very weak and can be problematical to detect and may only be done with extremely accurate observations.

### *What is light pollution?*

Armagh observatory is affected, as in the same way a lot of places throughout the globe are, to light pollution. Light pollution or photo pollution is excess or obstructive light created by humans. It has a number effects such as disrupting ecosystems and several others which include astronomical observatories. Light pollution comes from objects similar to large exterior lighting, advertising, offices, factories, street lights and illuminated sporting venues. The sky glow which is caused by light pollution causes it to be somewhat difficult to detect fainter objects as it diminishes contrast between stars, astronomical objects and the sky itself. Since Armagh Observatory is situated in the middle of a small city it will be affected greatly by this annoyance. There is currently a small number of ways through which to reduce its affect such as a “nebula filter” which will only allow specific wavelengths of light frequently seen in nebulae or specific light pollution filters that reduce to some extent the problem by filtering spectral lines emitted by sodium lamps. This light pollution can have a direct affect on the telescope as well for example causing a glow across the field of view .

My project will involve being an element of an overall experiment in creating a light pollution monitor for Armagh Observatory through which they will be able to measure the affect and level of light pollution as it inevitably is becoming worse as the city becomes increasingly populated and expands.

### *What is magnitude?*

Magnitude is a measure of brightness, particularly used with stars. There are two kinds of magnitudes for stars. One kind is apparent magnitude. The other is absolute magnitude. Apparent magnitude is how bright the star appears to us on earth. Absolute magnitude is the stars actual magnitude. There is a difference in the two as a dim star which is nearby looks bright and a bright star that is far away looks dim. In the 2<sup>nd</sup> century B.C the Greek astronomer Hipparchus described the brightest being first magnitude, next brightness being second magnitude and so on. In the mid 1800s, astronomers determined mathematically what Hipparchus did visually. This was by giving his scale a definable basis. They worked out that first magnitude was on average 100 times brighter than the 6<sup>th</sup> magnitude star. Once further measurements were done they showed that for every increase in one order magnitude there was an increase of 2.51 fold in brightness. This formed an equation of apparent magnitude  $M_v$  which is:

$$M_v = -2.5 \log (f) + \text{constant}$$

Where  $f$  is the flux of that star

$$f = (\text{counts} / \text{exposure})$$

## Materials and Method

The series of images which I received were taken with the polar bear telescope in the Armagh Observatory. This telescope comprises of a set of three wide angled telescopes which are located on fixed mounts on the observatory roof. It consists of a Nikkor f1.4 85mm lens, starlight Express CCD camera, and climate-controlled housing. The lens is built for electronic operation together with a Nikon camera, it is also operated entirely manually in our telescope. In front of the lens there is a UV filter to obstruct UV light and protect the lens.

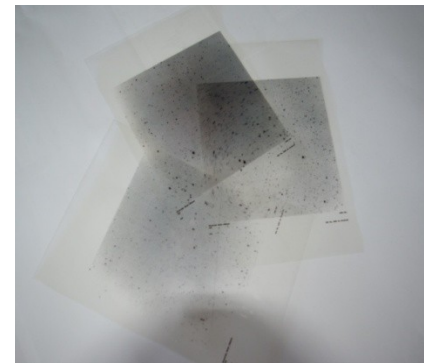


The camera itself is a Starlight Express SXV H-16 camera consisting of a CCD (Charged Coupled Device). The camera has a thermally-controlled jacket which keeps the CCD at a steady low



temperature, and electronics to readout the CCD and sends it to a computer.

The CCD itself, the image to the right, is a Kodak CCD: KAI4021M and is a mega-pixel (2048-2048) 16-bit light collector with a quantum efficiency (QE) of about 42%. The SXV H-16 is a monochrome detector, to accomplish maximum QE, it does not attain colour images. The light falls upon the photo active region of the CCD, which in most cases is an epitaxial layer of silicon. It has an analogue shift register, which enables analogue signals to be transported through consecutive stages. The photons fall onto the CCD and are converted to electrons and stored in pixels on the chip until they are read out. The electrons in each pixel are then converted to a number, ADU (analogue device unit).



The housing of the cameras is standard video-surveillance Camera housing. It has a heated front window and waterproofing, to prevent weather effecting results. The front visor provides some degree of protection from rain and dust nonetheless it does need a wipe from time to time. They are aimed towards a radius of ten degrees centred on the North Celestial Pole, and they overlap so that Polaris will appear in every frame.

The images are stored as FITS files or jpegs. FITS files have both a data section and a header section incorporated within them, which can contain critical information regarding the format of the image. The individual who was observing the image at that time can add additional notes to this header, it develops into a extremely useful tool to possess. Alternatively jpegs are tolerable for displaying images for study but they are not good for data analysis. This type of data compression actually destroys information within the image. So for these reasons the images we dealt with were FIT files.

The initial program which we availed ourselves of to process the images was Astrometry.net. This software distinguishes the stars inside the image and then constructs an equation, in order to fix bearings, which describes the transformation between image coordinates (x,y) and sky coordinates (Right Ascension and Declination).

Following this I proceeded to source extraction using the software SExtractor, which is primarily used to measure the flux (the total number of photons in a given energy interval) recorded by the detector. In our particular case the detector collects the photons and converts them to electrons and following this to "counts". The analysis of the selected image is done in two passes through the data by SExtractor. During the first pass a model of the sky background is assembled, and some global statistics are estimated. During the second pass the image background is subtracted and filtered. Detections are then put through several processes such as deblending and photometry.

What's more we used a shell script that would permit these two programs to work seamlessly together, this is shown on the next page, and provides us with an output file by the extension name of .phot. Found within this .phot file there is located the information which the software has processed arranged in a series of columns, these include Right Ascension and Declination, "counts" and flux etc.

```
#!/bin/bash
# usage: pbt_phot camera xlims ylims
## get frame boundaries from the command line
echo "======"
xlims="1-2048"
ylims="1-2048"
if [ $# -gt 1 ]; then xlims=$2; fi
if [ $# -gt 2 ]; then ylims=$3; fi
echo "frame limits" $xlims $ylims

## tidy up calibrated frames
rm -f $1*-wcs.fit
rm -f $1*-cut.* $1-fix.*
## loop over frames defined by "camera"
for file in $1*.fit
```

```
do

frame=${file%.fit} # edit to remove ".fit"
echo " "
echo "======"
echo "image -- " ${frame}
echo " "
## tidy up files so as not to repeat processing
## rm
${frame}-fix.fit ${frame}-cut.fit ${frame}-wcs.fit
## fix the SX fits format
echo "fits2fits"
fits2fits.py ${frame}.fit ${frame}-fix.fit

## cut the image down to reduce flat-field effects and improve astrometry
echo "fimgextract"
fimgextract ${frame}-fix.fit ${frame}-cut.fit ${xlims} ${ylims}

## do the astrometry – this needs tweaking to optimize reference star selection
echo " "
echo "astrometry"
solve-field ${frame}-cut.fit --no-fits2fits --resort --no-verify --overwrite --new-fits ${frame}-
wcs.fit --scale-units degwidth --scale-low .5 ## --scale-high 5
## extract the photometry
echo " "
echo "photometry"
sex ${frame}-wcs.fit -c ./default.sex -catalog_name ${frame}.phot
## check the exposure time
echo " "
fkeyprint ${frame}-wcs.fit exptime

## tidy up temporary frames
rm ${frame}*-cut.fit ${frame}-fix.fit

done
echo "======"
```

To confirm that the two applications I had used were correct in analysis I made use of two resources I had access to, one being an application by the name of XEphem and another being the Palomar Photographic Sky Atlas. I used these resources to make comparison of the results of Astrometry and SExtractor. I used the Sinbad Astrological Database to input the Right Ascension and declination that I had received as output in order to obtain the identifiers of the stars, which the software had located and I then proceeded to match them with the same stars on the two resources I

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outlined. After that I analysed this achieved data and used it in further research, through the use of spreadsheets and graphs.

I also used two other pieces of software, one called Xcode and another being g++. I made use of these when developing a software tool in C++ to assist in the processing and use of the data I have gathered. I used the Xcode like I would an ordinary text editor to write the C++ code, I use it as it had syntax colouring. To compile the created code for usage I used g++-4.0.1.

## Results

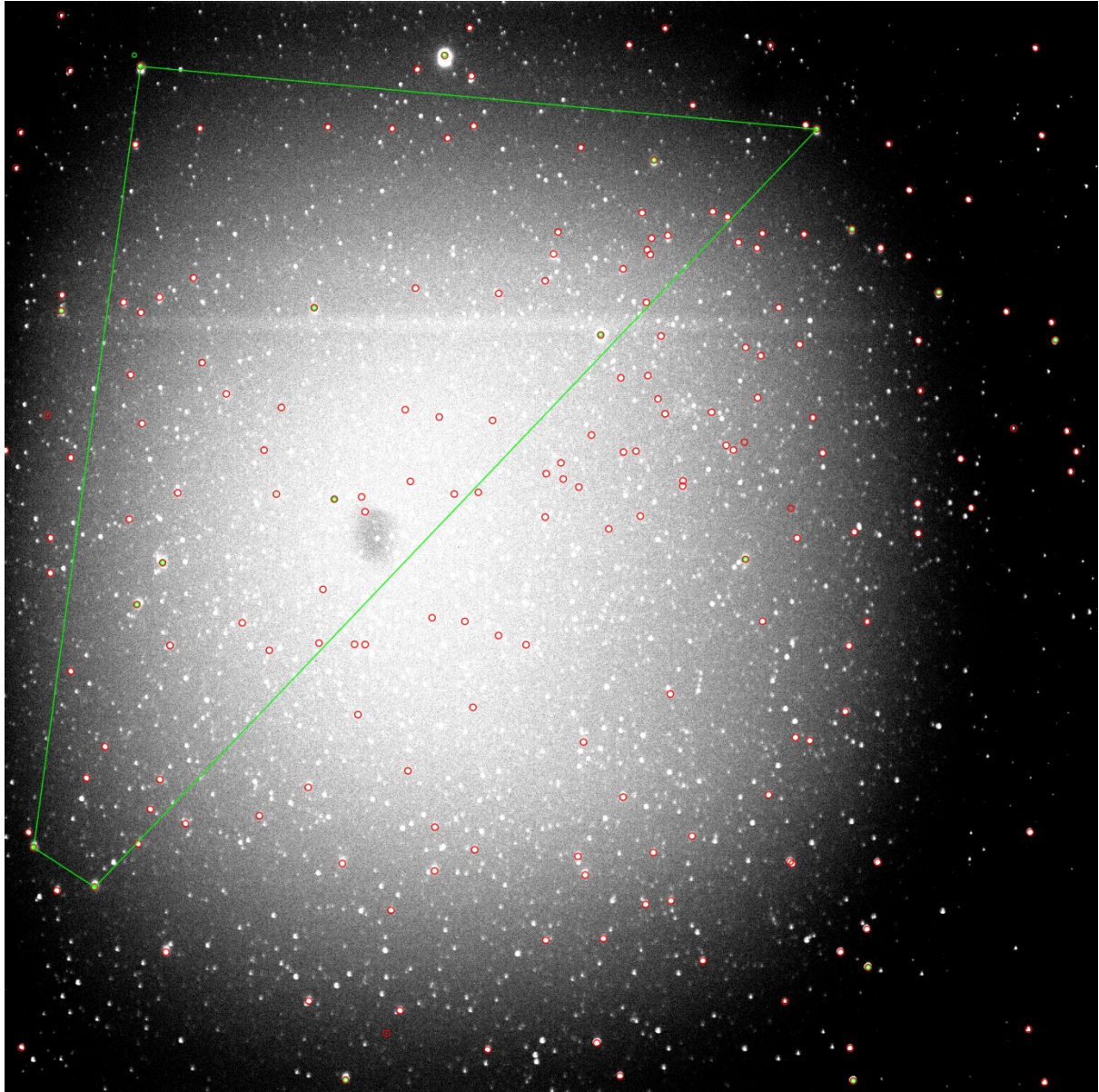
Results from Astrometry.net. The command to get this to process an image is "`$ solve-field <image name>`". The output for the image 128\_20071219.fit is as follows:

---

*Reading input file 1 of 1: "128\_20071219\_12.fit"...*  
*Extracting sources...*  
*simplexy: found 994 sources.*  
*Solving...*  
*Field 1 did not solve (index index-219.fits, field objects 1-10).*  
*Field 1 did not solve (index index-218.fits, field objects 1-10).*  
*Field 1 did not solve (index index-217.fits, field objects 1-10).*  
*Tweaking!*  
*Field 1: solved with index index-216.fits.*  
*Field 1 solved: writing to file ./128\_20071219\_12.solved to indicate this.*  
*Field 1: solvedfile ./128\_20071219\_12.solved: field has been solved.*  
*Creating new FITS file "./128\_20071219\_12.new"...*  
*Field center: (RA,Dec) = (30.48, 84.44) deg.*  
*Field center: (RA H:M:S, Dec D:M:S) = (02:01:54, +84:26:14.6).*  
*Field size: 10.4837 x 10.4773 degrees*  
*Creating plots...*  
*Your field contains:*  
*NGC 188*

As you can see from the output of the Astrometry.net the software managed to solve the image successfully. It was able to recognise 994 stars as shown by (simplexy: found 994 sources), it also acknowledged that the image has located within it Open cluster NGC 188 so it was able to identify the stars and successfully work out the right ascension and declination of the image contents. Its results also gave us the Right Ascension and Declination of the field centre and also the size of the field, which could be useful for measurement of things that fly across the image to work out how fast it is and in so doing discover what that object

is, however we did not use it at this stage. This software also produces the following image:



In the image there is a correlation, marked in green, these are stars which the software has recognised greater than the other stars on the field. From the shape it has marked out it is able to identify the other stars plotting their Right Ascension and Declination from basing its transformation formula upon the shape that was marked out. The red stars that are shown in the image are the 994 objects which it initially recognised.

The command for the use of SExtractor and the output from the image 128\_20071219.fit is below:

```
----- SExtractor 2.5.0 started on 2008-08-22 at 12:23:28 with 1 thread
```

```
    Measuring from: "128" / 2048 x 2048 / 16 bits INTEGER data
```

```
    (M+D) Background: 18355.1 RMS: 219.828 / Threshold: 439.657
```

```
    Objects: detected 2305 / sextracted 2153
```

```
    > All done (in 1 s)
```

As you can see above it shows a measurement of the background level of the sky, value 18355.1 and it shows us that the error in this is +/- 219.828. This means there is an error of approximately 1.2%. It shows that Astrometry.net detected 2305 objects within our image but SExtractor only identified 2153 as being stars. Also when using SExtractor you can choose if you want more data analysed so there would be more or less columns of data depending on what information you were looking to acquire and your purpose.

On the next page is the output received when the two applications are made to work together at consecutive stages using a shell script. This also includes the exposure time on the very bottom line of the output and this will be very useful to us.

```
=====
=  
frame limits 1-2048 1-2048  
rm: invalid option -- x  
Try `rm --help' for more information.  
=====
=  
image -- 128_20071219_12  
fits2fits  
Warning: File size is smaller than specified data size. File may have been  
truncated.  
fimgextract  
astrometry  
Reading input file 1 of 1: "128_20071219_12-cut.fits"...  
Extracting sources...  
simplexy: found 994 sources.  
Solving...  
Field 1 did not solve (index index-219.fits, field objects 1-10).  
Field 1 did not solve (index index-218.fits, field objects 1-10).  
Field 1 did not solve (index index-217.fits, field objects 1-10).  
Tweaking!  
Field 1: solved with index index-216.fits.  
Field 1 solved: writing to file ./128_20071219_12-cut.solved to indicate this.  
Field 1: solvedfile ./128_20071219_12-cut.solved: field has been solved.  
Creating new FITS file "128_20071219_12-wcs.fits"...  
Field center: (RA,Dec) = (30.48,84.44) deg.  
Field center: (RA H:M:S, Dec D:M:S) = (02:01:54, +84:26:14.6).  
Field size: 10.4837 x 10.4773 degrees  
Creating plots...  
Your field contains:  
NGC 188  
  
photometry  
----- SExtractor 2.5.0 started on 2008-08-22 at 09:03:21 with 1 thread  
  
Measuring from: "128" / 2048 x 2048 / 32 bits FLOATING POINT data  
(M+D) Background: 18355.1 RMS: 219.828 / Threshold: 439.657  
Objects: detected 2305 / sextracted 2153  
> All done (in 1 s)  
# FILE: 128_20071219_12-wcs.fits  
# KEYNAME: EXPTIME  
# EXTENSION: 0
```

*EXPTIME = 1.8000000000E+01*

Below is the output of the processed image which is contained in the .phot file. This is the results from the image being put through Astrometry and SExtractor simultaneously by the shell script which was shown in materials and method. This is two percent of the contents of the .phot file below, this illustrates the huge amount of information we actually acquire from the processes.

```
# 1 NUMBER Running object number
# 2 X_WORLD Barycenter position along world x axis [deg]
# 3 Y_WORLD Barycenter position along world y axis [deg]
# 4 X_IMAGE Object position along x [pixel]
# 5 Y_IMAGE Object position along y [pixel]
# 6 FLUX_ISO Isophotal flux [count]
# 7 FLUXERR_ISO RMS error for isophotal flux [count]
# 8 ISOAREA_IMAGE Isophotal area above Analysis threshold [pixel**2]
# 9 THETA_IMAGE Position angle (CCW/x) [deg]# 10 FWHM_IMAGE FWHM assuming a gaussian
Core [pixel]
# 11 ELONGATION A_IMAGE/B_IMAGE# 12 ELLIPTICITY 1 - B_IMAGE/A_IMAGE
1 1 1506116155e+02 8.7020352881e+01 255.612 124.666 2607732 4821.027 398 84.6 14.54
1.511 0.338
2 3 7828415823e+01 8.9240951552e+01 825.029 105.534 9884146 8509.763 1218 89.4 18.02
1.347 0.258
3 1 2600360760e+02 8.6372719833e+01 107.293 28.017 159786.6 2006.427 72 76.1 8.08 1.216
0.177
4 7 0677149145e+01 8.9625133233e+01 779.412 21.242 63202.73 1559.2 46 79.2 6.44 1.319
0.242
5 1 2362513631e+02 8.7691072214e+01 366.823 20.805 57279.64 1572.738 45 85.9 5.63 1.159
0.137
6 3 2045283780e+02 8.7941628454e+01 1214.727 18.124 23175.09 1131.2 23 -89.9 6.01 1.699
0.411
7 1 2568686238e+02 8.7247570101e+01 278.321 13.803 18877.23 1085.664 22 -19.5 4.57 1.195
0.163
8 8 5823022325e+00 8.9665204756e+01 850.935 11.861 10460.1 768.3452 11 79.6 3.37 1.506
0.336
9 2 6360239302e+01 8.9731077375e+01 829.005 7.734 5389.68 626.0877 6 66.2 3.56 1.694
0.410
10 3 2627380904e+02 8.8989134465e+01 1007.110 6.651 5883.159 663.9305 6 72.0 2.64 1.395
0.283
11 3 3268158890e+02 8.9343446525e+01 935.370 2.903 50238.82 1491.59 42 -0.9 6.17 1.359
0.264
12 3 1403578122e+02 8.4290022238e+01 1941.347 1.960 9179.856 767.5115 10 -27.9 5.60
1.210 0.174
```

13.31505013389e+02 8.6044907015e+01 1592.487 1.785 6285.056 699.6644 8 -2.5 5.06 1.373  
0.272

14.12148432853e+02 8.8701992906e+01 564.523 2.180 13887.2 990.1401 10 0.2 6.12 2.707  
0.631

15.10657971253e+02 8.9275122039e+01 686.315 17.328 16382.86 966.7205 16 70.3 3.49  
1.379 0.275

16.32023120678e+02 8.7767635077e+01 1248.824 21.639 19798.46 1040.643 19 88.4 4.52  
1.439 0.305

17.35646014091e+02 8.9543279310e+01 878.671 19.939 16640.43 991.5295 17 72.5 4.83  
1.440 0.306

18.31562238508e+02 8.5539867121e+01 1691.696 16.340 8551.783 734.9296 11 -66.1 5.44  
1.369 0.269

19.31522456289e+02 8.4172527926e+01 1963.294 26.777 21152.03 1232.563 26 63.7 9.85  
1.487 0.327

20.12679130989e+02 8.6445201661e+01 120.513 17.037 5504.732 626.1796 5 2.4 3.27 1.138  
0.121

21.12725760125e+02 8.6087888489e+01 50.120 16.867 5295.161 626.0122 7 45.9 4.46 1.309  
0.236

22.31691579927e+02 8.6415413899e+01 1517.500 20.492 5101.134 543.1834 6 -71.2 3.67  
2.165 0.538

23.11849013482e+02 8.8454760084e+01 520.068 26.350 16930.82 1062.259 19 86.2 5.69  
1.374 0.272

24.32671601826e+02 8.8685415472e+01 1064.319 23.577 8898.229 735.1652 9 83.2 5.24  
1.653 0.395

25.12558379682e+02 8.6668830444e+01 165.598 26.966 13515.31 939.8705 17 69.3 5.27  
1.655 0.396

26.12596567942e+02 8.6436839891e+01 119.857 27.218 25961.62 1234.513 26 -53.0 6.97  
1.278 0.218

27.11070318890e+02 8.9086642159e+01 647.809 21.191 4634.342 542.7535 5 -45.5 3.87 1.358  
0.264

28.31765492840e+02 8.6542849350e+01 1491.530 26.964 6404.932 626.8979 8 -78.5 4.32  
2.649 0.623

29.35892920663e+02 8.9443792610e+01 889.131 36.970 45394.17 1457.171 37 71.8 4.16  
1.320 0.242

30.32529892871e+02 8.8422685690e+01 1116.077 29.505 8674.102 767.182 9 83.9 3.65 1.668  
0.400

31.90943379582e+01 8.9429393874e+01 730.258 30.028 11558.47 858.1527 11 61.3 3.96  
1.469 0.319

32.31785685476e+02 8.5698279973e+01 1657.249 47.171 43564.21 1568.372 45 85.2 6.78  
1.418 0.295

33.12625727005e+02 8.5974034393e+01 29.096 32.371 6911.819 733.8129 8 73.4 5.24 1.396  
0.284

34.10640339516e+01 8.9439161503e+01 871.779 51.149 184436.9 2036.43 72 81.5 5.63 1.253  
0.202

35.32444668508e+02 8.7793170834e+01 1237.839 52.285 153701.8 2075.96 75 85.0 6.33  
1.239 0.193

36.12551102332e+02 8.6325280602e+01 98.701 35.119 7253.686 700.3562 8 39.3 5.12 1.659  
0.397

37.10217352320e+02 8.9076529724e+01 657.461 46.291 43849.96 1371.197 36 85.2 4.82  
1.384 0.278

38.11221379135e+02 8.8635046814e+01 562.741 46.390 53077.56 1508.643 41 -84.4 4.75  
1.221 0.181

39.11481774280e+02 8.8461840888e+01 526.461 44.719 20164.48 1086.256 21 88.8 4.87  
1.683 0.406

40.12433157815e+02 8.6334741737e+01 102.358 49.626 39291.23 1421.477 36 -89.2 6.75  
1.250 0.200

From this information we acquire numerous columns of data, which we have chosen to receive by changing the parameters of SExtractor in the

default.param file. The ones which are most relevant to us are Right ascension and Declination, counts and error in counts.

Using this information we constructed a spreadsheet. The spreadsheet uses only the 19 brightest stars, starting with Polaris, which we received from our .phot file. We then placed the Right ascension and Declination we had received and placed them into the SIMBAD Astronomical database. This gave us a set of stars in this region and we would have to pick the one that is our star that we had received information on, and the one we would pick out of the list in SIMBAD would be the brightest. From this we got the identifier and real magnitude (V magnitude) of the star in question. Using the information we were able to work out the instrumental magnitude (Minst):

$$\text{Minst} = -2.5 \log (\text{counts} / \text{exposure time})$$

For example the instrumental magnitude for POLARIS:

$$\text{Minst} = -2.5 \log (9884146 / 18) = -14.349$$

The error in this would be  $-2.5 * (\text{error} / \text{counts})$  and as for POLARIS equals 0.002. Now we could proceed to working out something most important the constant c from the equation

$$\text{Mv} = -2.5 \log (\text{counts} / \text{error} ) + C$$

We gathered the constant c for the 19 brightest stars and made an average. This average was 18.0988783. However once a graph of magnitude against constant C was constructed, Scatter graph of Magnitude (Mv) against Constant (c) for 19 identified stars of greatest brightness within image 128\_20071219\_12, we could see that the first 7 brightest starts could be ignored as the pixels had been saturated.

This was shown by their absence in correlation with the other plots, and as they were saturated the values received for them were incorrect. So using

this information we made a new more accurate measurement for C which was 18.1019576. Now having acquired this value for C we could now use it for the rest of the objects in the image along with their instrumental magnitude. We then worked out a calibrated magnitude for these 19 brightest objects. This was compared to the official magnitude of the SIMBAD astronomical database. This difference in magnitude between calibrated magnitude and the official magnitude is represented by the column Delta M in the first spreadsheet of the 19 brightest stars. As you can see the error is very slight.

With this information we were able to construct a spreadsheet "Calibrated magnitude of all objects of image 128\_20071219". This gives us the final magnitude of every object within the image.

I then constructed a graph with the magnitudes that I calibrated and the SIMBAD Astronomical Database magnitudes for the stars in a particular image. It is graph "2008 08 22 03 05 Magnitude in image against Magnitude from SIMBAD Astronomical Database" and as you can see there is correlation. However as the stars go fainter the amount of error becomes greater and they begin to scatter from the correlation. I then did a graph for the same image called "2008 08 22 03 05 positional error against magnitude". This is a graph of its positional error against the magnitude within SIMBAD to observe is this was a factor involved. I then proceeded to create a light curve "2008 08 21: HD 76990". This is a light curve for the star HD 76990 which we followed through our results. The blue dots are the actual magnitude against time and the red dots at the bottom are the error, measured from 0 on the y axis.

## Conclusion

Foremost my concluding results had excellent correlation with what they were supposed to be officially. The official magnitude, obtained from SIMBAD Astronomical database, and the calibrated photometric magnitude were very close. This illustrated that my acquired values were somewhat correct. Obviously there will be error within the results although for this

data the error was incredibly small as shown by the column Delta M in the first spreadsheet. Delta M is the difference between the official magnitude and my calibrated magnitude. These acquired values show us the magnitude of each star. This will allow us to further assist in identifying particular stars. This is also required for the overall goal of this project. This project is but a small component of the overall creation of variable star and light pollution monitor. Though these were the final results of project we had a large part in the overall data-stream of information required for the final output of this experiment. To examine the variable star they will be acknowledging the magnitude of a particular variable star as it makes its way across the sky. The magnitudes which I have proceeded to work out and the method will be used in the further development of this project.

By means of using the error values I had produced I came to the conclusion that the tools which we used were reasonably accurate in are photometry. They had minor error in the results it gave use i.e. star position and calibrated magnitude matched up with the official values. Obviously, as with any scientific experiment, there are going to be factors which cause error. The error here however were very slight showing the accuracy of the software and are processing. Using XEphem and the Palomar Photographic Star Atlas I was able to conclude that that information was correct that I was working with. As it provided me coordinates which I used on SIMBAD to attain identifiers. Then proceeded to match these up with the starts on the Palomar Sky Atlas, and they matched successfully.

I acquired various values using the equation below:

$$Mv = -2.5 (\text{counts} / \text{exposure time}) + C$$

The accuracy of using this equation was revealed by the calibrated magnitude matching up with the catalogue magnitude exceedingly closely with only a slight difference between them. This equation allowed me to work out my results. These results include the constant C in the magnitude

equation, instrumental magnitude and calibrated magnitude. The use of this equation was necessary in my research.

In my results I displayed two percent of the information which is contained within a .phot file, and this was a great amount of information. During one night there will be hundreds of these images taken. So in order to process this information a software tool had to be developed which would automate and allow this to be done successfully. So I proceeded to learn the basics of C++ and start the creation of a program which would do this, illustrated below.

```
#include <iostream>
using namespace std;

#include <fstream>
using std::ifstream;

const int data_max=10000;
int read_phot(float data_ra[data_max], float data_dec[data_max], float data_cts[data_max], float
data_ctserr[data_max], float data_seq[data_max], float data_flag[data_max]);

int main () {
int iread;
int data_max=10000;
float phot_ra[data_max];
float phot_dec[data_max];
float phot_cts[data_max];
float phot_ctserr[data_max];
float phot_seq[data_max];
float phot_flag[data_max];

iread=read_phot(phot_ra, phot_dec, phot_cts, phot_ctserr, phot_seq, phot_flag);
cout << phot_ra[1] << phot_ra[2] << phot_ra[10];
cout << endl;
cout << phot_dec[1] << phot_dec[2] << phot_dec[10];
cout << endl;
cout << phot_cts[1] << phot_cts[2] << phot_cts[10];
cout << endl;
cout << phot_ctserr[1] << phot_ctserr[2] << phot_ctserr[10];
cout << endl;
cout << phot_seq[1] << phot_seq[2] << phot_seq[10];
cout << endl;
cout << phot_flag[1] << phot_flag[2] << phot_flag[10];
cout << endl;
return 0;
}

int read_phot(float data_ra[data_max], float data_dec[data_max], float data_cts[data_max], float
data_ctserr[data_max], float data_seq[data_max], float data_flag[data_max])
{

ifstream indata ; // indata is the input data
```

```
int seq, flag, i;
float ra, dec, x, y, cts, ctserr;
string line;
char tail[90];

indata.open("test.phot"); // open the data file
if(!indata) { // file couldn't be opened
    cerr << "Error: file could not be opened";
    return 1;
}

// indata >> seq >> ra >> dec >> x >> y >> cts >> ctserr;//
// indata.getline(tail, 90, '\n');
// cout << seq << ' ' << ra << ' ' << dec << ' ' << x << ' ' << y << ' ' << cts << ' ' << ctserr << endl;

while ( !indata.eof() ) { // keep reading until end-of-file
    indata >> seq >> ra >> dec >> x >> y >> cts >> ctserr;//
    indata.getline(tail, 90, '\n');
    i=seq;
    data_ra[i]=ra;
    data_dec[i]=dec;
    data_cts[i]=cts;
    data_ctserr[i]=ctserr;
    data_flag[i]=flag;
    cout << seq << ' ' << ra << ' ' << dec << ' ' << x << ' ' << y << ' ' << cts << ' ' << ctserr << endl;
}

indata.close();
cout << "End-of-file reached.." << endl;

return 0;
}
```

This program allows for the contents of a .phot file to be processed and can be modified accordingly to what you want to receive as output, but you choose the rows, brightness etc you wish to be shown. This is necessary in order to follow a star across the sky and to analyse its variability. This tool will be further developed to provide a lot more functions. One of the subsequent steps is to eliminate any information for stars that are inaccurate, i.e. saturated stars or stars located at the very edge of the image using flag values. We also eventually want the program to send queries the SIMBAD Astronomical database. This program will then be joined by a set of “standard stars”, this is a set of identifier stars we will choose that will allow us to identify other stars. We will be in other words creating are own catalogue. By doing this the observatory will hopefully be able to identify stars that have not been discovered and add them to the SIMBAD Astronomical database.

I then went on to create a graph called “2008 08 22 03 05 Magnitude in image against Magnitude from SIMBAD Astronomical Database”. This graph showed us correlation between the two magnitudes, however greater correlation at the beginning. As the stars got fainter the error got greater and the plotting began to scatter. Showing that accuracy of weaker stars is not that good although of bright stars is excellent.

I then constructed a graph, 2008 08 22 03 05 Magnitude in image against Magnitude from SIMBAD Astronomical Database, to see if the positional error of the star was an affecting factor by plotting it against the magnitude of SIMBAD, there was no correlation. Showing us that it was not a factor.

Using the software, that was partially further developed, we were able to follow one star through the set of data of images took over night by the polar bear telescope. I then proceeded to create a graph with this data called “2008 08 21: HD 76990. The star we choose to follow was HD 76990. In this image we seen that the greater the error in the star the less accurate and more scattered the plot is. As can be seen greater than 22.05 t/day and less than 22 t/day. Between these times there is perfect correlation. These stars also have the least error. This shows that we were able to follow a specific star through are data and observe its variability against time, this was one of my goals. This will be done further with greater steps of analyse in order to observe a variable star crossing the sky with more scrutiny.

## Evaluation

I felt that my results and recordings were fairly accurate but as with any experiment or investigation there are factors which cause error. There are a number of instrumental effects which come into the camera itself. One is vignetting, which is a reduction of an image brightness or saturation at the periphery compared to the image centre. This means when measuring certain things, if the image gets fainter as it gets closer to the edge, the results will be affected. Also image motion comes into play as when there is moving, even slowly, the image is blurred. There can also be errors within the CCD itself. The detector collects photons, converts them to electrons then to "counts". Photons fall at random and there is not a 1-1 relationship between electrons and "counts". However the effect of these factors would be minor as it was taken with a fairly modern camera.

Also all the light from the star does not hit the CCD some is lost. These can be described as two factors, seeing and extinction. Extinction is when light makes its way through the atmosphere, photons of light collide with atom and other particles and objects. This light may be reflected or absorbed by the objects and particles. Seeing is the blurring effect of the atmosphere. The amount of blur depends on the properties of the atmosphere through which that light passes. Also photons obey the "Poisson" statistics, which means that they arrive at random intervals.

The success in any experiment is how accurate measurements of error are recorded and also how these are taken into account. A big source of error within this experiment is the ability of the software to be accurate, but as I stated earlier the software was accurate at identifying positions of the stars in right ascension and declination as I compared results with XEphem and the Palomar photographic sky atlas. Also the software measured the

“counts” accurately, excluding the 7 that were saturated, and we know this as the final calibrated magnitude matched up to the official results with an average error of 0.074. This shows the accuracy of our results.

## Acknowledgements

I would like to thank Nuffield bursary for allowing me a place within their scheme. I would also like to thank all the Observatory staff for all their patience, help and for being so welcoming. Additionally a special thanks to Dr Simon Jeffery for taking me for my bursary and for his guidance.