Photometry with the 16-inch Telescopes at Wallace Observatory

Summer 2009 PAL UROP: Summary Report

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1. INTRODUCTION

My summer UROP project consisted of obtaining photometry data for calibration of the 16-inch telescopes at MIT's Wallace Astrophysical Observatory. I worked with fellow student Matt Sooknah in taking series of images of stars of varied magnitudes at a range of different exposure times. With this data, it would be possible to determine the capabilities of each telescope in resolving faint stars at certain exposure times. We took data of three different star fields, on three telescopes, in three different filters, with exposure times ranging from 0.5 seconds to 5 minutes. We used our results to produce three different types of graphs: (1) Signal-to-noise vs. exposure time, (2) Limiting magnitude vs. exposure time, and (3) Dark current vs. exposure time.

2. TAKING DATA

Before going to the Wallace Astrophysical Observatory, I chose three star fields that would be optimal for taking data. I determined which fields to use depending on the range of magnitude stars they contained, whether they consisted of any bright stars that would become oversaturated in short exposure times (eg. Magnitudes smaller than 8), the presence of easily recognizable reference stars, and position in the sky. I chose three fields centered on the stars SAO 66888, GSC 2029:1022, and GSC 3878:1084. It should be noted that the field containing SAO 66888 includes stars of magnitudes of 8, which would be oversaturated at the longer exposures. As a result, we avoided using this field with the Clear filter. Another reason why we chose to use one field for taking data that night rather than another may be the availability of reference magnitudes for stars in certain filters. The choice of field may also have depended on the position of it in the sky on that night, such as in the case where clouds may be obstructing the view of one field but not the other. In some other situations, the choice of field may have been at random.

In The Sky software, readjustments the default settings may be required to display stars of greater magnitudes and labels for the magnitude of each star. To display stars of certain magnitude ranges in The Sky, select a star in the program, right click it, and select "Display properties." This option will present a menu that offers the option of entering magnitude ranges to display. I usually entered an upper limit of 20 or so, in order for the higher magnitude stars in the catalogue to be shown in the program. To display magnitude labels, it is necessary to go into the extended labels menu and manually select the option to view magnitudes.

The actual process of data taking involved taking five images of the star field at each of the following exposure times: 0.5s, 1s, 2.5s, 5s, 10s, 20s, 30s, 60s, 90s, 120s, 180s, 240s, 300s. Often the 90s or the 300s times were omitted because of lack of time in the night or, more so in the case of 300s, it was not necessary because many stars were becoming oversaturated. I typically took 10 darks at each exposure time, from 0.5s to 30s, and 5 darks at the remaining exposure times. Again, this was done as a result of lack of time in the night. I continued to take data until I had a data set for Clear, R, and V filters.

3. ANALYSIS

After reducing the data, I ran photometry on the images in IRAF. I used the imexam command to find the values for the full-width-at-half-max and standard deviation of background sky for each image and ran daofind on all the data to generate .coo files, coordinates for all the stars in the images. Then, I ran the phot command, which generates .mag files containing data about the stars such as measured instrumental magnitudes. I extracted this data using txdump into a spreadsheet. Before doing all of this, I had to make changes to certain parameters, which are shown here in bold:

```
PACKAGE = daophot
   TASK = centerpars

(calgori=          centroid) Centering algorithm
(cbox   =                8.) Centering box width in scale units
(cthresh=                0.) Centering threshold in sigma above background
(minsnra=                1.) Minimum signal-to-noise ratio for centering algo
(cmaxite=                10) Maximum iterations for centering algorithm
(maxshif=                1.) Maximum center shift in scale units
(clean  =                no) Symmetry clean before centering
(rclean =                1.) Cleaning radius in scale units
(rclip  =                2.) Clipping radius in scale units
(kclean =                3.) K-sigma rejection criterion in skysigma
(mkcente=                no) Mark the computed center
(mode   =                ql)
```

Bold (changed): (calgori= centroid) Centering algorithm; (cbox = 8.) Centering box width in scale units

```
PACKAGE = daophot
   TASK = fitskypars

(salgori=              mode) Sky fitting algorithm
(annulus=               15.) Inner radius of sky annulus in scale units
(dannulu=                5.) Width of sky annulus in scale units
(skyvalu=                0.) User sky value
(smaxite=                10) Maximum number of sky fitting iterations
(sloclip=                0.) Lower clipping factor in percent
(shiclip=                0.) Upper clipping factor in percent
(snrejec=                50) Maximum number of sky fitting rejection iteratio
(sloreje=                3.) Lower K-sigma rejection limit in sky sigma
(shireje=                3.) Upper K-sigma rejection limit in sky sigma
(khist  =                3.) Half width of histogram in sky sigma
(binsize=               0.1) Binsize of histogram in sky sigma
(smooth =                no) Boxcar smooth the histogram
(rgrow  =                0.) Region growing radius in scale units
(mksky  =                no) Mark sky annuli on the display
(mode   =                ql)
```

Bold (changed): (annulus= 15.) Inner radius of sky annulus in scale units; (dannulu= 5.) Width of sky annulus in scale units

```
PACKAGE = daophot
   TASK = photpars

(weighti=          constant) Photometric weighting scheme
(apertur=          8,10,12) List of aperture radii in scale units
(zmag   =               25.) Zero point of magnitude scale
(mkapert=                no) Draw apertures on the display
(mode   =                ql)
```

Bold (changed): (apertur= 8,10,12) List of aperture radii in scale units

PACKAGE = daophot
TASK = phot

image = 00000155*.FIT Input image(s)
coords = default Input coordinate list(s) (default: image.coo.?)
output = default Output photometry file(s) (default: image.mag.?)
skyfile = Input sky value file(s)
(plotfil=) Output plot metacode file
(datapar=) Data dependent parameters
(centerp=) Centering parameters
(fitskyp=) Sky fitting parameters
(photpar=) Photometry parameters
(interac= no) Interactive mode ?
(radplot= yes) Plot the radial profiles?
(icomman=) Image cursor: [x y wcs] key [cmd]
(gcomman=) Graphics cursor: [x y wcs] key [cmd]
(wcsin =)_.wcsin) The input coordinate system (logical,tv,physical
(wcsout =)_.wcsout) The output coordinate system (logical,tv,physica
(cache =)_.cache) Cache the input image pixels in memory ?
(verify =)_.verify) Verify critical phot parameters ?
(update =)_.update) Update critical phot parameters ?
(verbose=)_.verbose) Print phot messages ?
(graphic=)_.graphics) Graphics device
(display=)_.display) Display device
(mode = ql)

PACKAGE = daophot
TASK = datapars

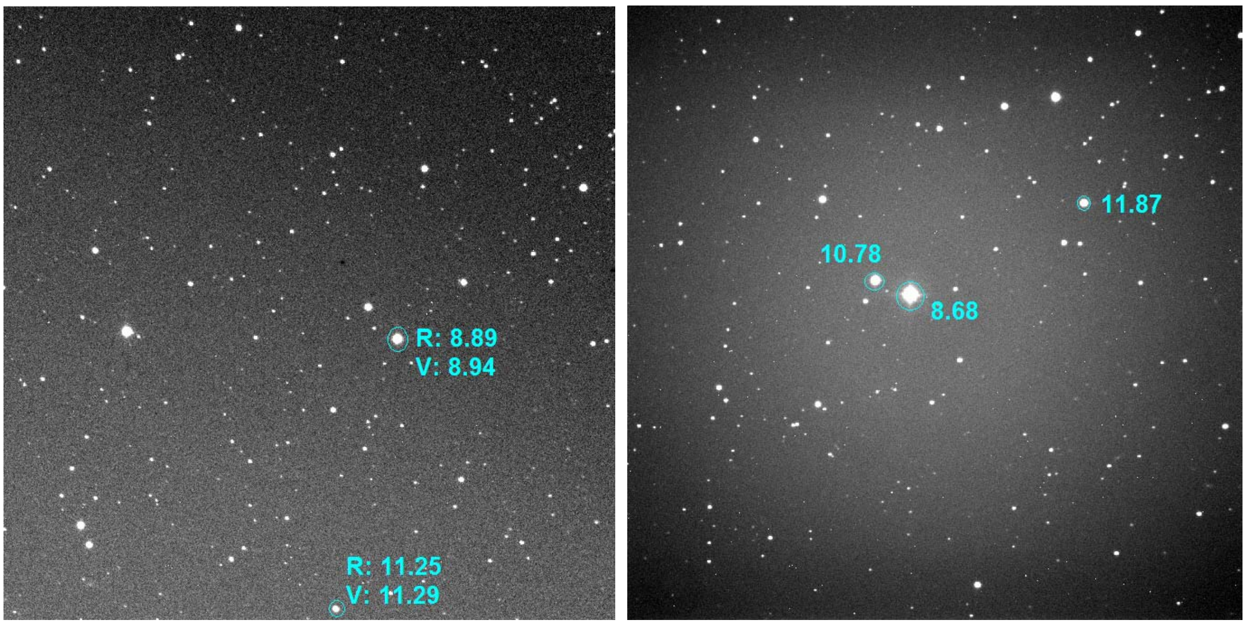
(scale = 1.) Image scale in units per pixel
(fwhmpsf= 2.5) FWHM of the PSF in scale units
(emissio= yes) Features are positive ?
(sigma = 0.) Standard deviation of background in counts
(datamin= INDEF) Minimum good data value
(datamax= INDEF) Maximum good data value
(noise = poisson) Noise model
(ccdread=) CCD readout noise image header keyword
(gain = EGAIN) CCD gain image header keyword
(readnoi= 0.) CCD readout noise in electrons
(epadu = 1.) Gain in electrons per count
(exposur= EXPTIME) Exposure time image header keyword
(airmass= AIRMASS) Airmass image header keyword
(filter = FILTER) Filter image header keyword
(obstime= TIME-OBS) Time of observation image header keyword
(itime = 1.) Exposure time
(xairmas= INDEF) Airmass
(ifilter= FILTER) Filter
(otime = 0) Time of observation
(mode = ql)

PACKAGE = daophot
TASK = txdump

textfile= 000001*.mag.1 Input apphot/daophot text database(s)
fields = image,ifilter,itime,xairmass,xcenter,ycenter,mag,merr Fields to be extracted
expr = yes Boolean expression for record selection
(headers= yes) Print the field headers ?
(paramet= no) Print the parameters if headers is yes ?
(mode = ql) Mode of task

Note that in though we chose three apertures—8, 10, and 12—we only used the results we got from using 10, which showed less error on a whole than either 8 or 12.

I calibrated the instrumental magnitudes into their actual magnitudes by looking at star charts and choosing a reference star of known magnitude. I compared the charts to my images and determined the coordinates at which these stars were located. Because I had extracted the coordinates of each identified star from the .mag files, it was simple to find my reference stars in my data and figure out the factor by which I would have to subtract from the instrumental magnitudes to obtain the actual magnitude.



Reference charts with actual magnitudes.
Left: SAO 66888 with R and V magnitudes. Right: GSC 3878:1084 with magnitudes in the Clear filter.

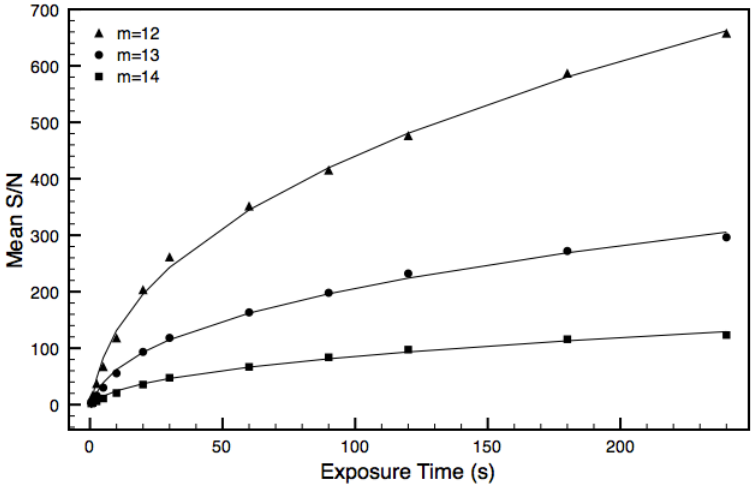
To calculate signal-to-noise, I estimated it as equivalent to the reciprocal of the magnitude error. Because this estimate is only accurate for small errors, I did not use any data with magnitude errors larger than 0.5. The graphs display the mean signal-to-noise at each exposure time, for a certain magnitude, on a certain telescope, and in a certain filter.

I also went through the data to find the highest magnitudes resolved in each image. Because I took five images at each exposure, I took the median of these magnitudes and plotted them against exposure time. These graphs were then linearized to confirm the trend fit of the data.

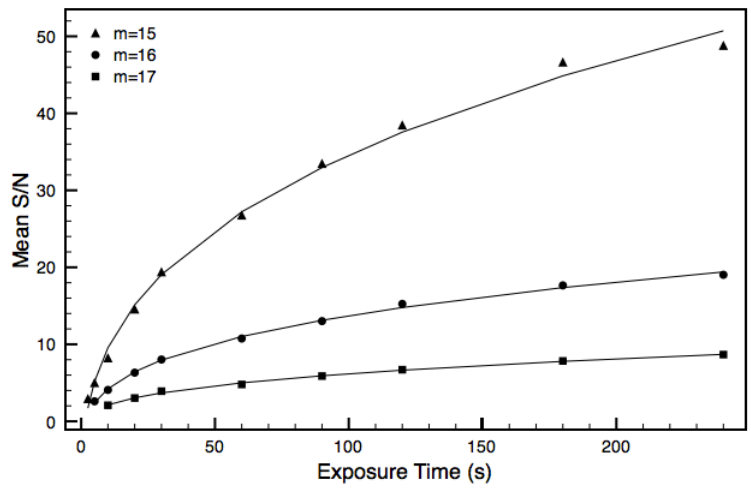
Finally, I found the counts in the darks I took and graphed them against exposure time.

4. RESULTS

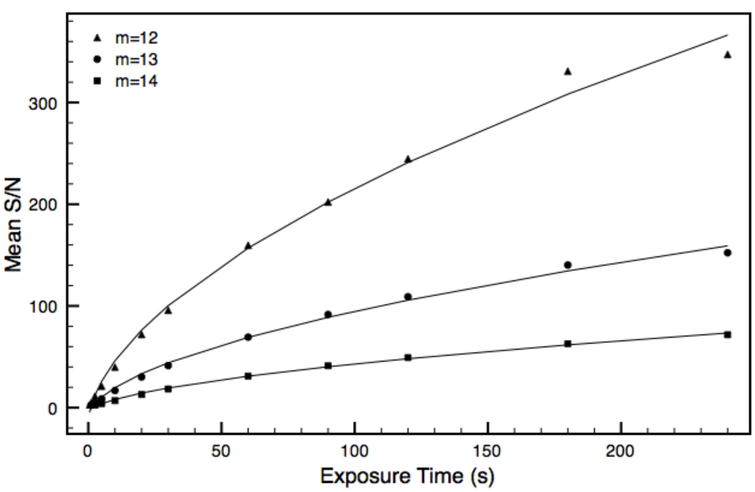
S/N - Pier 2, Clear



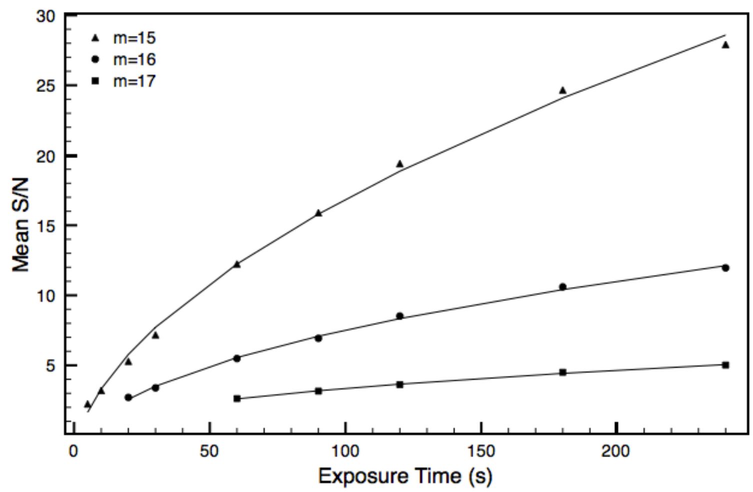
S/N - Pier 2, Clear



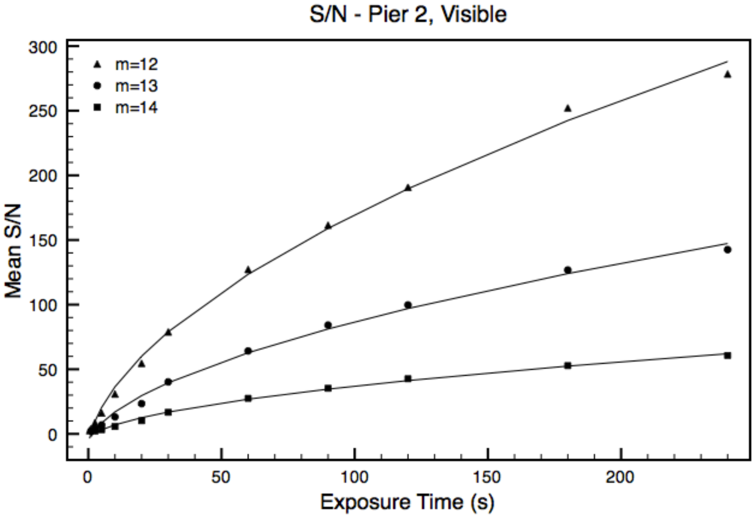
S/N - Pier 2, Red



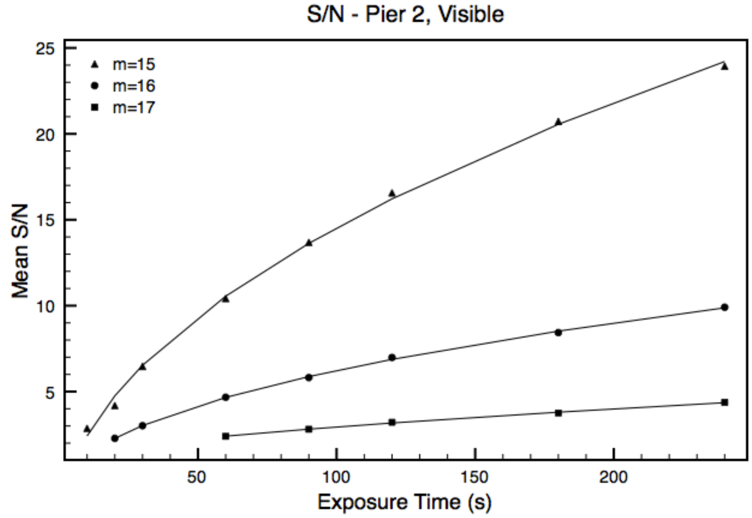
S/N - Pier 2, Red

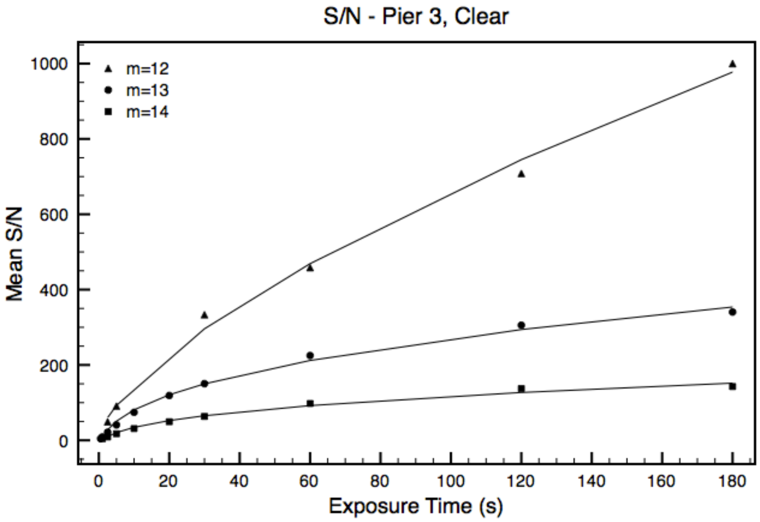


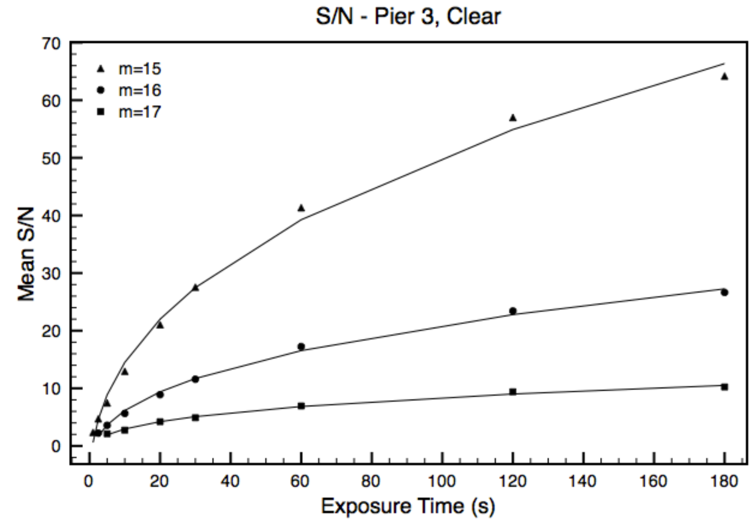
S/N - Pier 2, Visible

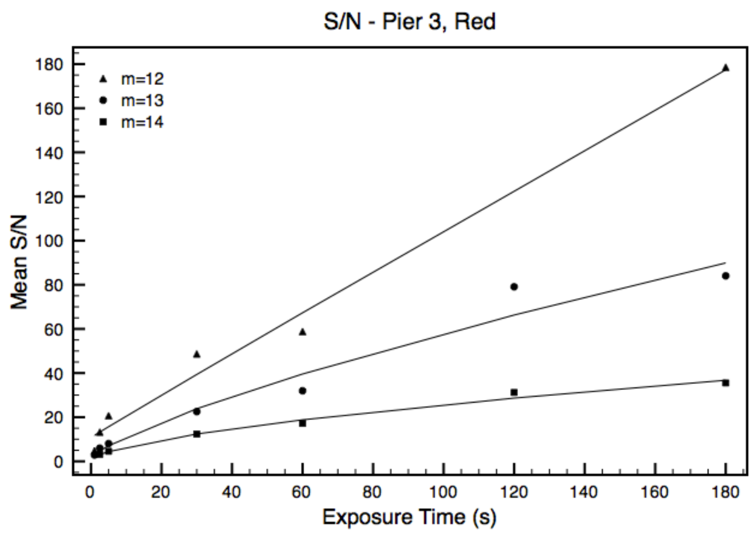


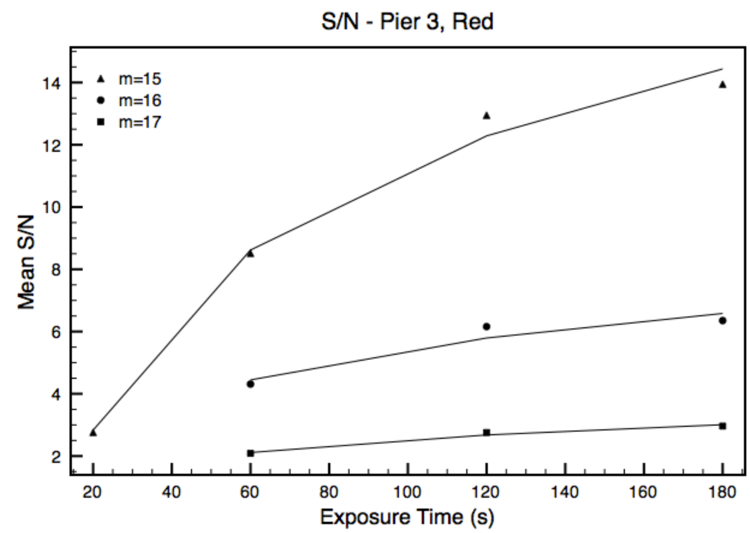
S/N - Pier 2, Visible

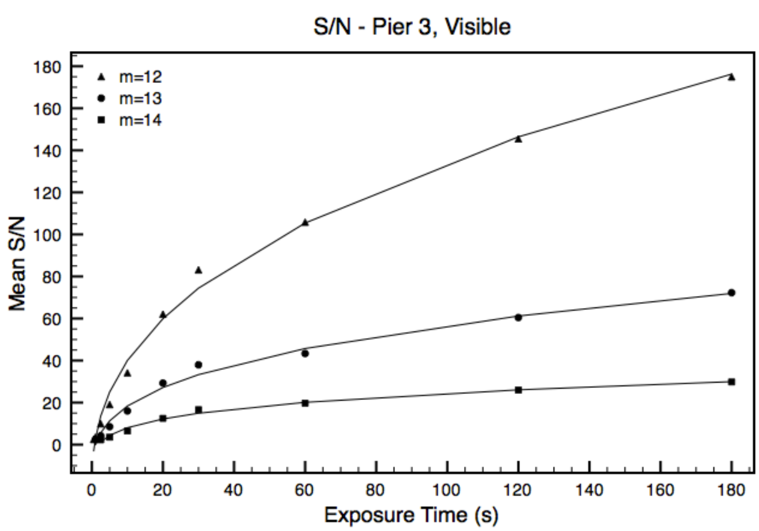


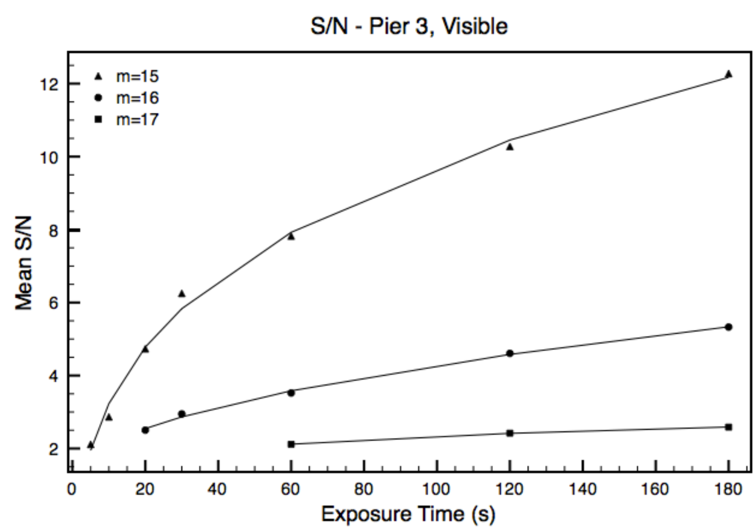

S/N - Pier 3, Clear
m=12
m=13
m=14
Mean S/N
Exposure Time (s)

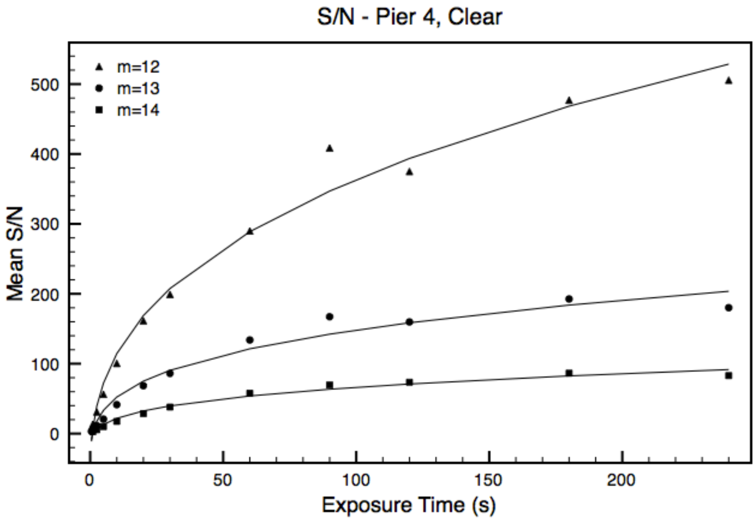

S/N - Pier 3, Clear
m=15
m=16
m=17
Mean S/N
Exposure Time (s)

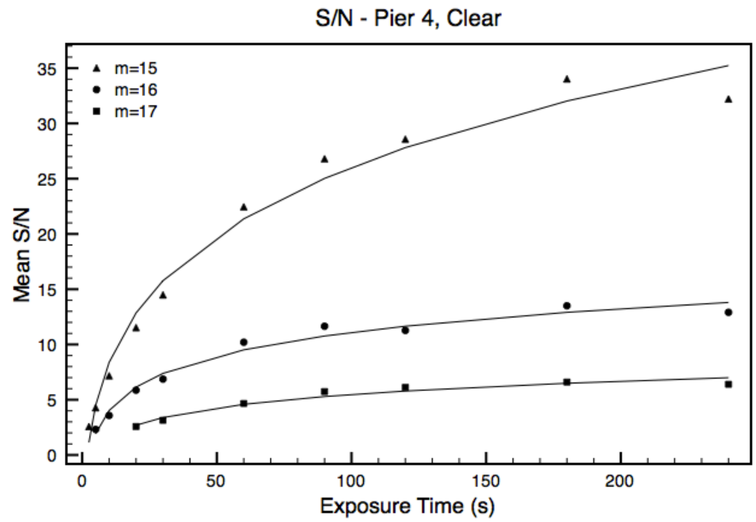

S/N - Pier 3, Red
m=12
m=13
m=14
Mean S/N
Exposure Time (s)

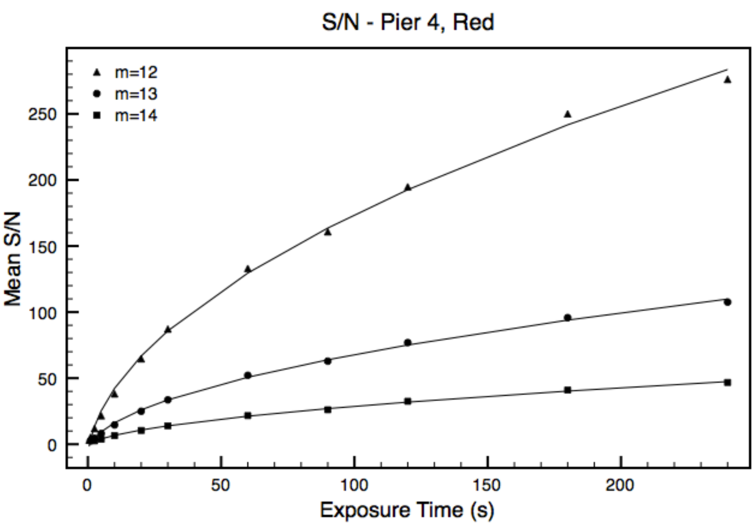

S/N - Pier 3, Red
m=15
m=16
m=17
Mean S/N
Exposure Time (s)

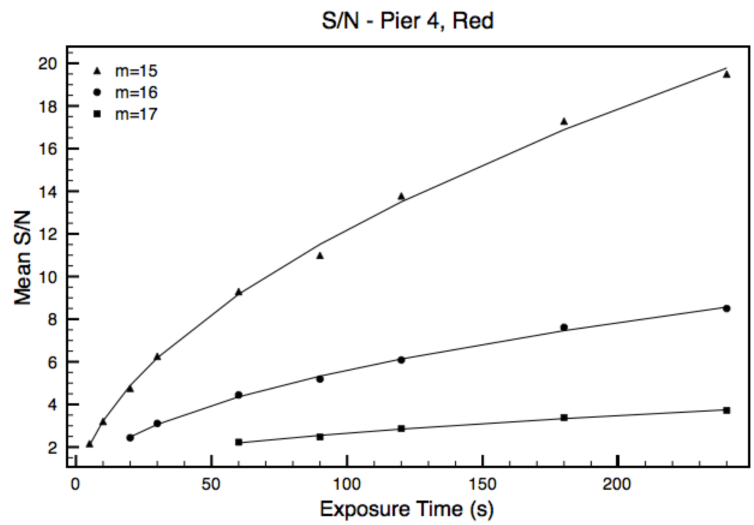

S/N - Pier 3, Visible
m=12
m=13
m=14
Mean S/N
Exposure Time (s)

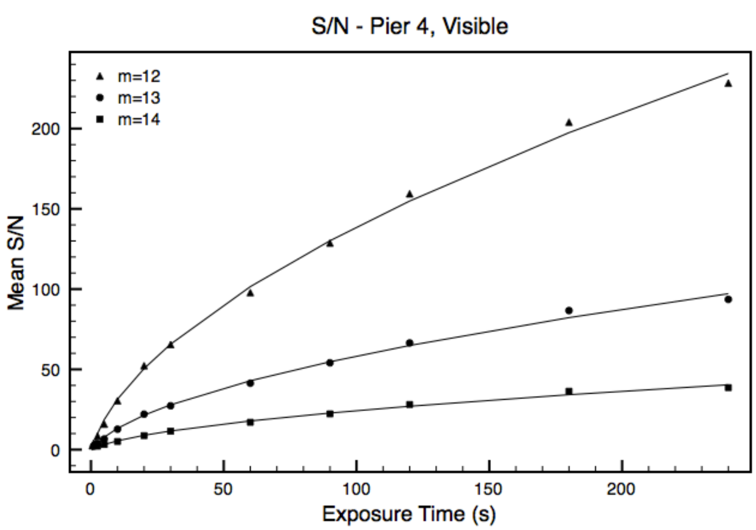

S/N - Pier 3, Visible
m=15
m=16
m=17
Mean S/N
Exposure Time (s)

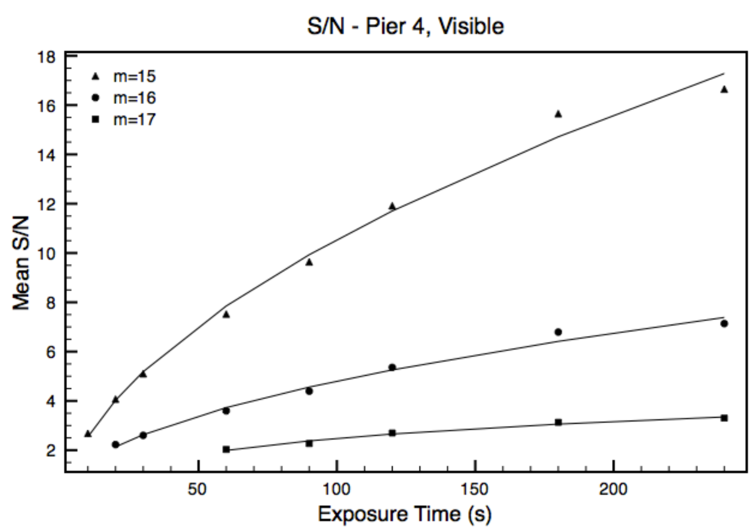

S/N - Pier 4, Clear
m=12
m=13
m=14
Mean S/N
Exposure Time (s)

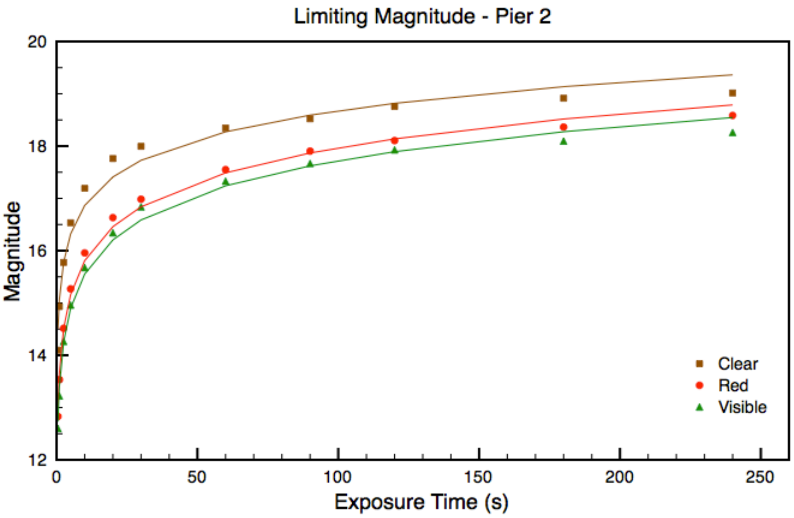

S/N - Pier 4, Clear
m=15
m=16
m=17
Mean S/N
Exposure Time (s)


S/N - Pier 4, Red
m=12
m=13
m=14
Mean S/N
Exposure Time (s)

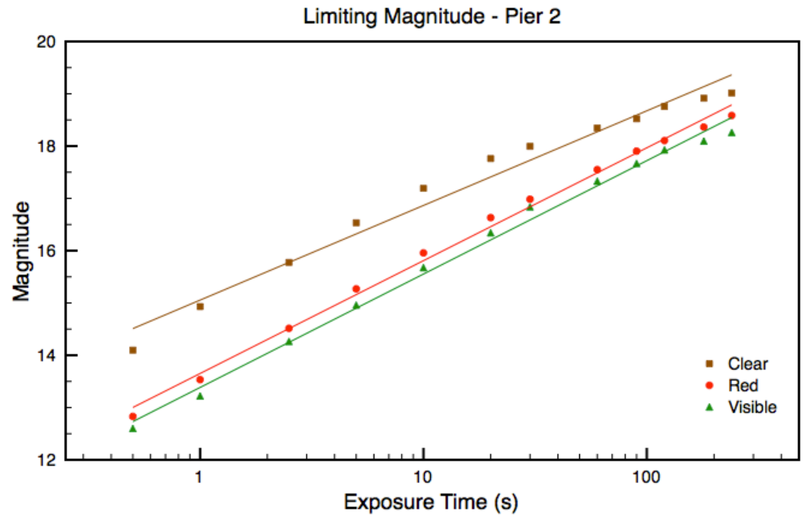

S/N - Pier 4, Red
m=15
m=16
m=17
Mean S/N
Exposure Time (s)


S/N - Pier 4, Visible
m=12
m=13
m=14
Mean S/N
Exposure Time (s)

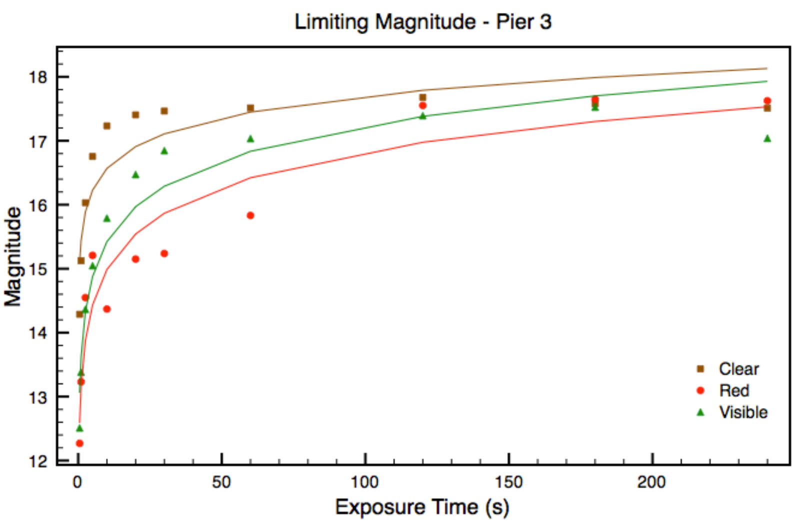

S/N - Pier 4, Visible
m=15
m=16
m=17
Mean S/N
Exposure Time (s)



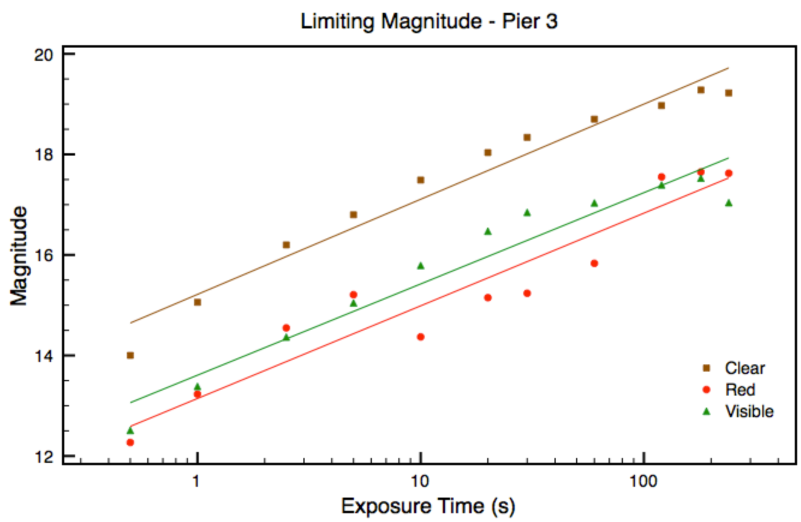
Limiting Magnitude - Pier 2
Magnitude
Exposure Time (s)
20
18
16
14
12
0
50
100
150
200
250
Clear
Red
Visible



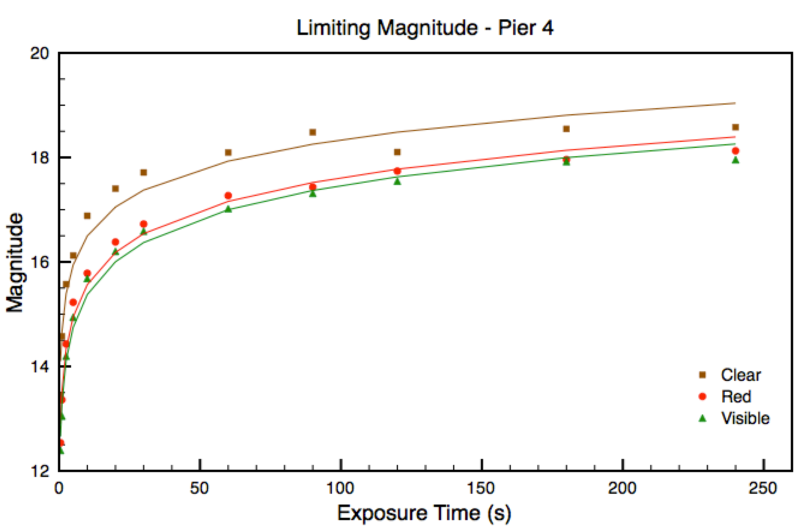
Limiting Magnitude - Pier 2
Magnitude
Exposure Time (s)
20
18
16
14
12
1
10
100
Clear
Red
Visible



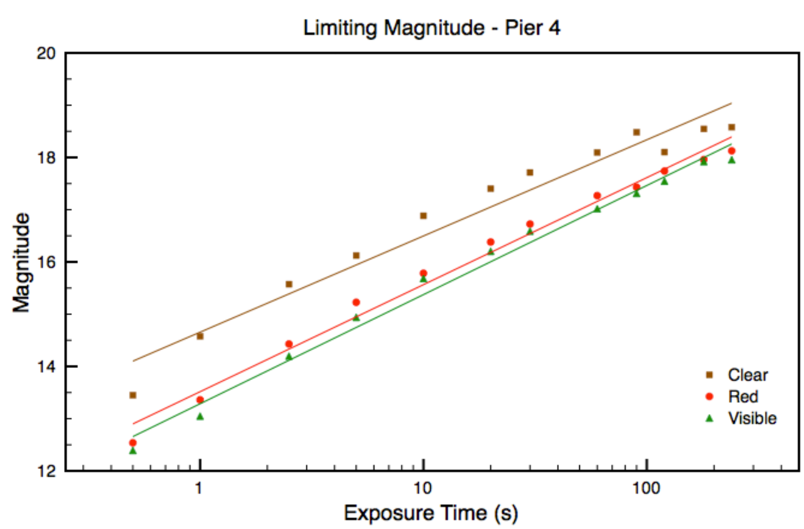
Limiting Magnitude - Pier 3
Magnitude
Exposure Time (s)
18
17
16
15
14
13
12
0
50
100
150
200
Clear
Red
Visible



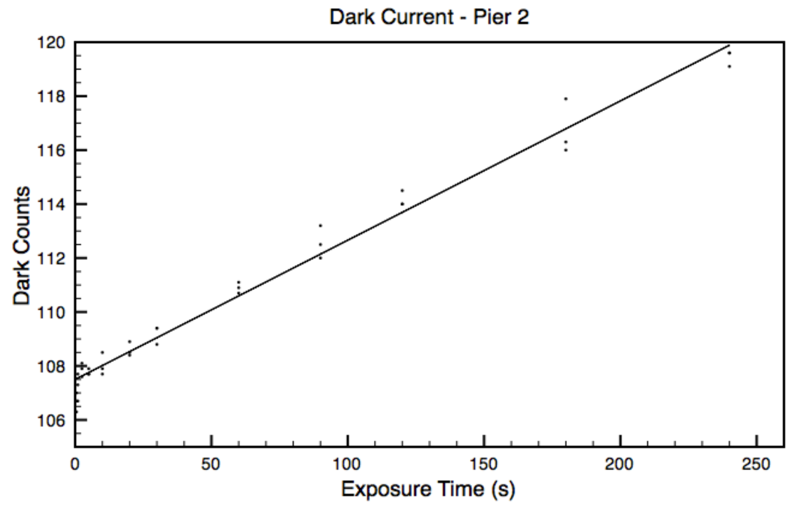
Limiting Magnitude - Pier 3
Magnitude
Exposure Time (s)
20
18
16
14
12
1
10
100
Clear
Red
Visible

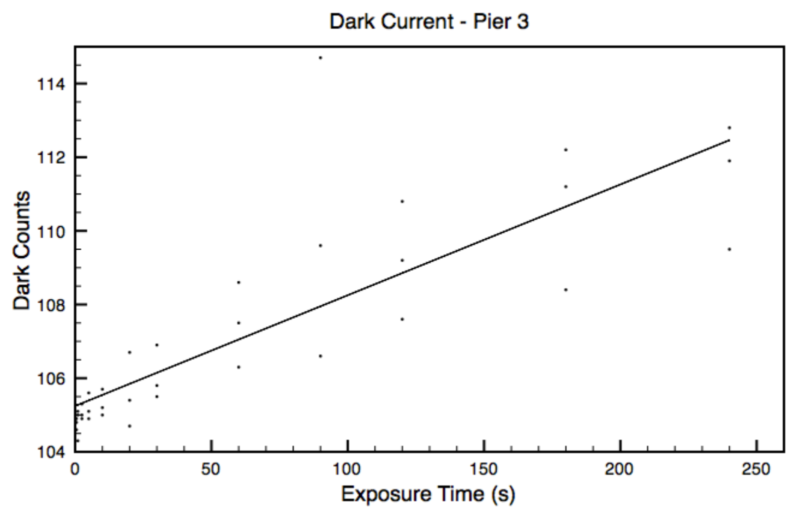


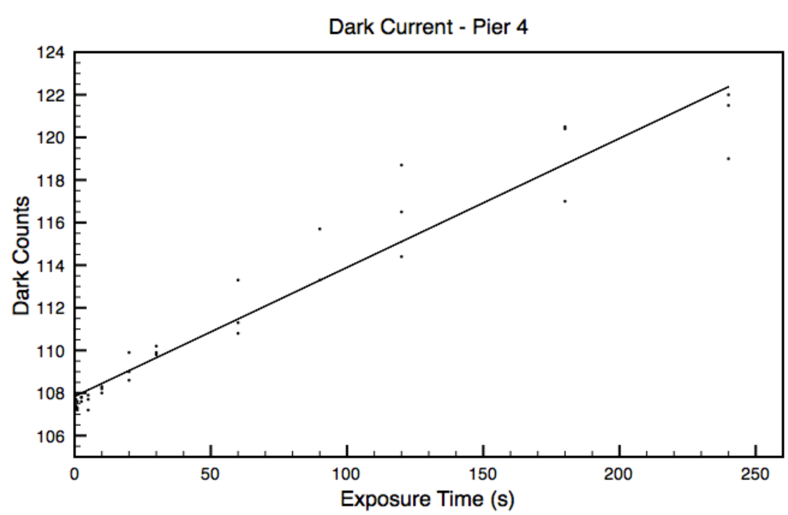
Limiting Magnitude - Pier 4
Magnitude
Exposure Time (s)
20
18
16
14
12
0
50
100
150
200
250
Clear
Red
Visible



Limiting Magnitude - Pier 4
Magnitude
Exposure Time (s)
20
18
16
14
12
1
10
100
Clear
Red
Visible


Dark Current - Pier 2
Dark Counts
Exposure Time (s)
120
118
116
114
112
110
108
106
0
50
100
150
200
250


Dark Current - Pier 3
Dark Counts
Exposure Time (s)
114
112
110
108
106
104
0
50
100
150
200
250


Dark Current - Pier 4
Dark Counts
Exposure Time (s)
124
122
120
118
116
114
112
110
108
106
0
50
100
150
200
250

5. CONCLUSIONS

The data from Piers 2 and 4 are very good and show the expected trends. However, data from Pier 3 proved to be more problematic, which is something I'm quite aware of, having taken and worked with the data myself. The data I used for this project was taken in June, and it was not until the end stages of analysis that I realized there could be problems with it. I can provide several explanations for the less-than-perfect results above.

First of all, the dark current from Pier 3 is slightly lower than those of Pier 2 and Pier 4. On June 20, the night I took data in the R and V filters, despite clear weather forecasts, a sudden cloud cover interrupted my data taking. I had to stop in the middle, at which time I started to take my darks, and then continued a half an hour later. I commented in a summary report:

> Sometime during 11:00 PM, in the middle of the 30s exposures, a sudden cloud cover appeared. At 11:30 PM, I retook another 30s exposure series. Frames after this point may fluctuate in quality because of the cloudiness.

The data in the R filter suffers more from this cloudiness than the V filter, because I had taken those images later in the night after the sky had cleared up more.

On June 29, the night I took data in the Clear filter, I took a series of darks that produced very irregular results. The dark current vs. exposure time graph showed a drop in the later exposure times, rather than the expected linearly increasing trend. In a last minute attempt to save the data in the Clear filter, I used darks from another night to reduce the data. The results were much better than the original.