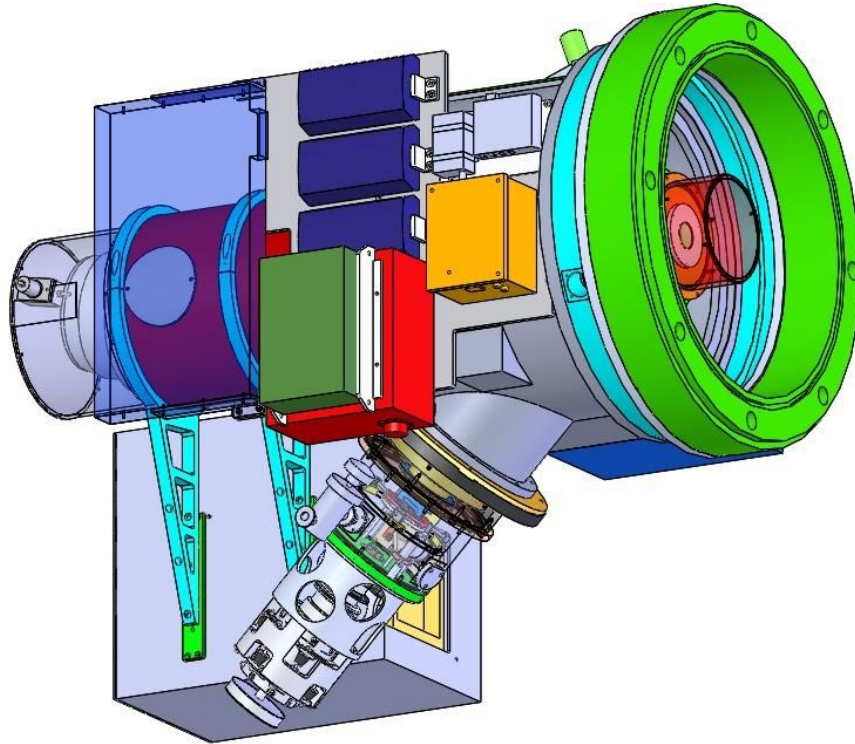


# DeVeny Spectrograph Discovery Channel Telescope Reference and Operations Guide

v1.4 16 May 2018 T. Bida, T. Pugh, S. Levine



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## 1. History/Overview

The DeVeny spectrograph was built and known at Kitt Peak National Observatory (KPNO) as the KPNO White Spectrograph, and had a long career at the 36" telescope there before being retired. Lowell Observatory acquired the spectrograph from KPNO on indefinite loan in 1998. A new CCD camera was built for it, and the instrument was further modified for installation on the 72" Perkins telescope in 2005. Following 8 years of service there, it was removed in 2013 for upgrades for installation on the DCT instrument cube in February 2015, where it has been located since. The spectrograph was designed for f/7.5 telescope optics, and new re-imaging optics were designed and fabricated to match the spectrograph with DCT's f/6.1 beam.

The DeVeny/DCT Spectrograph system introduces the f/ratio matching optics, a deep depletion version of the e2v CCD42-10 CCD (2048x512 13.5 micron pixels) mounted in a new dewar with a Stirling cycle cooler, and a slit-viewing acquisition camera. Behind the shutter, decenter, and slit-jaws there is a pupil-matching lens, order-blocking filters, an off-axis parabolic collimator, and a grating carriage that holds one of a set of 128x154mm plane reflection gratings. The image is formed on the CCD by the f/1.25 Wynne camera, which has two powered reflective surfaces and a series of weak fused silica refractive correction surfaces. The secondary 'mirror' (an aluminized rectangular spot on a key surface) introduces a substantial central obscuration in the camera. Four spectral calibration lamps (Hg, Ne, Cd, and Ar) are mounted on the spectrograph front plate and are remotely controllable.

The spectrograph provides low-resolution optical spectra at resolving power  $R \sim 500$  -- 4000 over a wavelength range from 3200 Å to 1 micron. The slit length is up to 2 arcmin on the DCT. The grating complement currently includes several 1<sup>st</sup>-order blazed gratings, from 150g/mm up to 2160g/mm (see [Table I](#) below for details; other stock rulings are commercially available). An upgrade project has just been completed (Summer of 2016) to motorize and implement remote control of the slit width, grating tilt, and collimator focus.

The CCD detector is operated by a Gen III ARC (aka Leach) controller from a Linux computer. The software that interfaces directly with the controller is called LOIS, and the user interface software is called LOUI. Both LOIS and LOUI were developed at Lowell and are under active maintenance and development.

## 2. Quick reference specifications and operating options

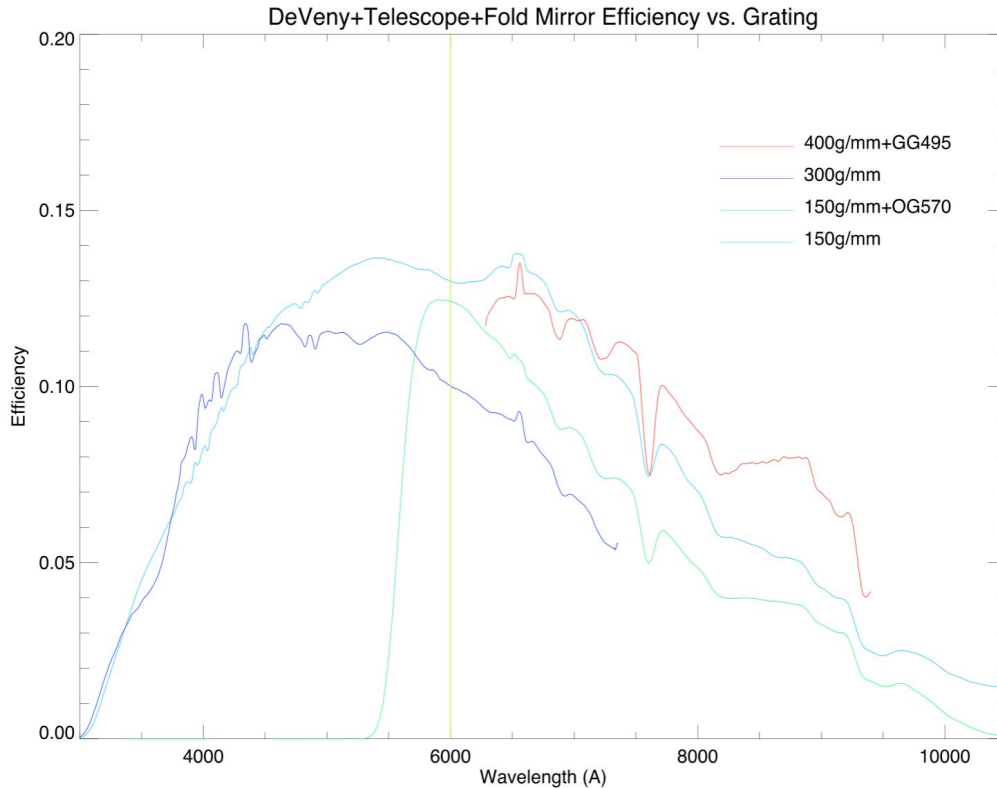
### a) Gratings:

All the gratings are 128 x 154 mm 1<sup>st</sup>-order blazed plane reflection gratings. The Lowell DeVeny grating complement is shown in [Table I](#). A preliminary assessment of instrumental efficiency vs. 3 gratings is shown in Figure 1. Estimated system signal-to-noise ratio and point source count rates for select gratings are shown in Appendix E.

The grating tilt is controlled with a stepper motor attached to the stage drive shaft, with an encoded resolution of <0.001 deg. The grating tilt angle is modified using a widget on the DeVeny LOUI (see Figure 2). The angles are given by the grating equation, and should position the spectral format centred within a small number of pixels.

**Table I. DeVeny Gratings**

| g/mm          | Blaze Wavelength (Å) | Dispersion (Å/pix) | Free Spectral Range (Å) | R (2.5-pixel, on-blaze) | Comments         |
|---------------|----------------------|--------------------|-------------------------|-------------------------|------------------|
| 150           | 5000                 | 4.3                | 8800                    | 450                     | KPNO 201         |
| 300           | 4000                 | 2.17               | 4440                    | 920                     | KPNO 9           |
| 300           | 6750                 | 2.17               | 4440                    | 1250                    | KPNO 32          |
| 400           | 8500                 | 1.66               | 3400                    | 2850                    |                  |
| 500           | 5500                 | 1.33               | 2720                    | 1500                    | KPNO 240         |
| 600 (Note 1)  | 4900                 | 1.14               | 2320                    | 1400                    | KPNO 26new       |
| 600           | 6750                 | 1.14               | 2320                    | 2370                    | KPNO 35          |
| 831           | 8000                 | 0.80               | 1630                    | 4000                    | KPNO 47          |
| 1200          | 5000                 | 0.58               | 1180                    | 3450                    |                  |
| 2160 (Note 1) | 5000                 | 0.33               | 670                     | 5250                    | 4630 Å red limit |



**Figure 1. On-sky measured DeVeny efficiency vs. wavelength for several gratings. The vertical line at 6000 Å shows where 2<sup>nd</sup>-order leakage would begin for unfiltered spectra. The spectra were taken with a 5 arcsec wide slit, on 20150507, of the spectrophotometric standard stars Feige 66 (using the 150 and 300g/mm gratings) and Feige 34 (using the 400g/mm grating). The absorption and emission features are relics of the stellar spectrum, not actual efficiency variations.**

***b) Shutter and filter wheels:***

The iris shutter is made by Uniblitz (model CS-45). A new shutter was installed for the DCT upgrade. It is positioned above the slit assembly, therefore, the slit-viewing camera will be blocked from the sky and the images will be blank when the CCD is reading out. The photometric accuracy of the new shutter has not yet been measured.

The order blocking filters are installed in the rear filter wheel. These are 1.75in diameter x 2mm thick circular filters fabricated from Schott glasses, polished to 1 wave/inch with 1 arcmin wedge maximum, and broad-band AR coated on both sides. Both filter wheels are 5-position, with an

empty position available in each. Representative transmissions curves from Schott are shown in [Appendix B](#).

**Table II. Filter Wheel Positions (ND = neutral density grade)**

| Wheel         | Position C | Position 1 | Position 2 | Position 3 | Position 4 |
|---------------|------------|------------|------------|------------|------------|
| Front filters | Clear      | 2.5mag ND  | 5mag ND    | 7.5mag ND  | Empty      |
| Rear filters  | Clear      | GG420      | GG495      | OG570      | Empty      |

**c) Slit and Decker:**

The slit width is controlled by a stepper-motorized micrometer made by PI (model M-229.26S), with 0.08 micron resolution and 10 microns backlash. The maximum slit length without the decker is about 2.5 arcmin. With the decker, the maximum slit length is 1.9 arcmin. The decker plate is **not** currently installed. The slit-jaws that are installed are aligned end to end within a pixel. The slit width is adjustable from a widget in the DeVeney LOUI, described in §.4b.

**Table III. Slit Width Drive Specifications**

|                         |                                            |
|-------------------------|--------------------------------------------|
| Focal plane plate scale | 0.153 mm/arcsec                            |
| Minimum slit width      | ~0.5 arcsec (0.075 mm)                     |
| Maximum slit width      | 98 arcsec (15 mm)                          |
| Slit position angle     | 0 - 360 degrees via the Cassegrain rotator |

**d) Calibration lamps:**

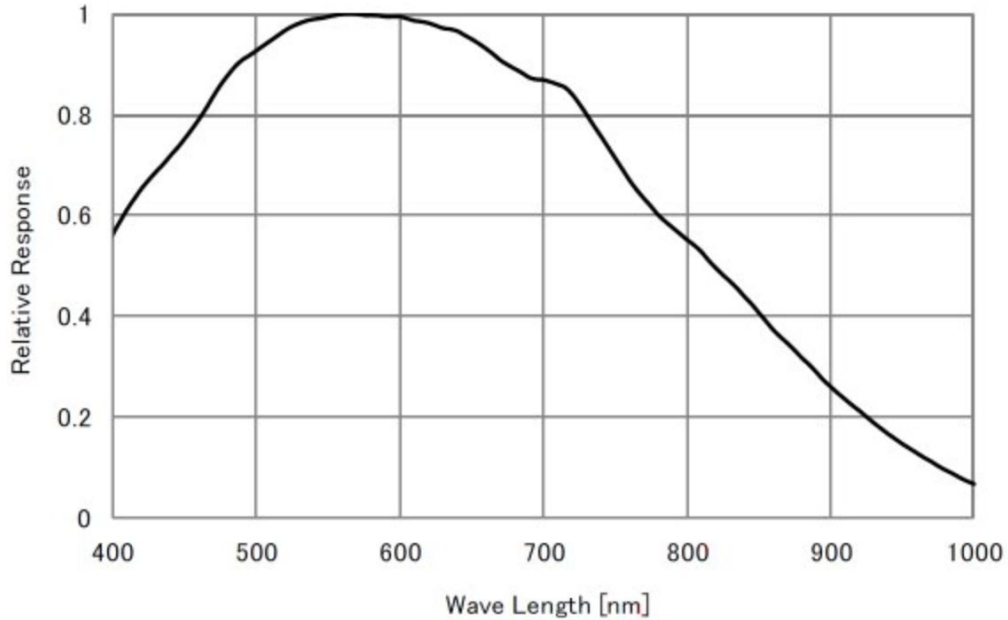
The arc calibration sources are AC-powered pencil-style lamps, installed on the front end of the spectrograph and switched with the DeVeney PDU through a LOUI widget, described in §.3b. The lamp emission backscatters from the instrument cover and fold mirror to illuminate the slit. The lamps installed are Hg, Ne, Ar, and Cd; sample spectra are shown in Appendix A.

There are two sets of dome-illuminating flats lamps available; the brighter top-ring mounted lamps are best suited for spectroscopy, and are operated by your Telescope Operator. A sample of flat field spectra are shown in Figure 10. Brightnesses can be adjusted with the DC power supplies.

**e) Slit viewing camera:**

The slit viewing camera is a Lodestar X2 made by Starlight Xpress. The detector is a Sony ICX829AL ExView2 interline CCD, with 752 x 580 pixels. The camera is always operated binned 2x2 to 376 x 290 pixels. The pixels are 8.6 x 8.3 microns with embedded vertical antiblooming circuitry. The QE peaks at about 77% at 620nm, and drops to 45% at 400 and

770nm; a manufacturer’s relative response curve is shown in Figure 6. The read noise is less than 10e-, full well is greater than 50,000 e-, and typical gain is 0.4 e-/ADU (per the manufacturer’s literature). The camera is uncooled so the hot pixel count increases with exposure time. Typical image download times are roughly 0.2 s using USB2.



**Figure 3. Typical CCD response curve for a Lodestar X2.**

The slit viewing camera is USB-based, connected by a fiber-based extender from the instrument, and run by a linux machine using the GoQat software package. It is operated on-sky by a custom IDL GUI (see §4.d).

**Table IV. Slit Viewing Camera Specifications**

|               |                               |
|---------------|-------------------------------|
| Pixel Scale   | 0.253 arcsec/binning-2x pixel |
| Image Size    | 376 x 290 16-bit pixels       |
| Field of View | 95 x 73 arcsec                |

**f) CCD camera:**

A major component of the DeVeney/DCT upgrades is the new CCD camera, developed at Lowell, and operated with ARC Gen-III control electronics. The CCD is an e2v CCD42-10 deep depletion device, which replaced a similar e2v standard silicon CCD, to reduce fringing in the red end of the spectrum. The CCD has 2048 x 512 13.5 micron pixels. The device is AR coated with e2v’s 4-layer Astro-broadband AR coating.

**Table V. CCD Camera Specifications**

| Gain                | 1.52 e <sup>-</sup> /ADU                                      |
|---------------------|---------------------------------------------------------------|
| Read Noise          | 4.9 e <sup>-</sup>                                            |
| Linearity           | tbd                                                           |
| Fringing            | 1-3% fringe amplitudes, redward of 8000 Å (Figures 10 and 11) |
| Operating T         | -110 C                                                        |
| Dark current        | tbd                                                           |
| Readout time        | 8 s                                                           |
| Spatial pixel scale | 0.34 arcsec/pixel                                             |

### 3. Quick-start Guide

#### 1. The LOUI

- a. Start LOUI and restart lois (4.a.1 - 4.a.3)
- b. Set storage pathway (4.a.4)
- c. Check joe is running (4.a.5)
- d. Take a test image to confirm everything is working (4.a.6)

#### 2. The Spectrograph

- e. Check grating tilt, slit width and collimator focus initial values (4.b.1 - 4.b.2)
- f. Confirm requested grating and filters
- g. Update telemetry
- h. Focus collimator (4.b.4)
- i. Bias, arc lamps, flats (4.c)

#### 3. The Slit Viewer (*ssh -Y lois@vishnu.lowell.edu*)

- j. Start slit viewing camera, GoQat (4.d.1)
- k. Set-up storage pathway (4.d.1)
- l. Start IDL slit viewing GUI, *slitviewg* (4.d.2)
- m. Take a test exposure (4.d.2)

### 4. Set-up (hardware, software and calibrations)

#### a) *The CCD camera UI (LOUI & lois)*

The instrument user interface software (LOUI) is operated from *dct-obs1* or *dct-obs2* in the control room. The camera control software (*lois*) runs on the host machine *deveny*.



1. Verify that lois, the ntp client, and sequester are running.
  - Log in to deveny using ssh:
 

```
ssh obsdeveny@deveny
```

 (the password is on the whiteboard or can be given by your TO)
  - Check the status of the various required process: Type `st`. This will provide the status of the processes (see Figure 7).
  - To tell if the NTP daemon is running, look for the line that starts “NTPD:” If there is a number after the NTPD, that is the process ID number, and means that the local NTP daemon is running. If there is NOT a number, you need to start the daemon.
  - If NTPD is not running type `./timefix`
  - Similarly, to check if the sequestor process is running, look to see if there is a number after the line that starts “Sequestor Proc:” If yes, it is ok.
  - If sequester is not running the host machine will need to be rebooted (check with your TO, they will do this, or they will contact a member of the instrument group).

```

obsdeveny:~>st
Fri Jun 17 05:37:35 UTC 2016
user obsdeveny logged in as obsdeveny

ActiveMq Broker: joe.lowell.edu (loisMachine deveny)
LOIS:           8192 (script 8181)
NTPD:           8469
Sequestor Proc: 7875
Archiver Link:  Running /home/obsdeveny/20160617

Currently logged in:
loisdata pts/1      2016-06-16 17:11 (rook.lowell.edu)
obsdeveny pts/3      2016-06-11 18:33 (baggins.lowell.edu)
obsdeveny pts/4      2016-06-16 22:37 (10.11.131.225)

CCD config file  devenyexper.cfg camera name  deveny Setpoint  -110.00
CCD TIM DSP     /opt/LOIS.test/dsp/gwaves/exper/tim_shutter lod.deveny
                SI_DELAY  880000 INT_TIM  520000 VOD
CCD UTIL DSP    /opt/LOIS.test/dsp/gwaves/exper/util.lod.genii
HTMAX           1 800034
HTMAX value is 000C00

DISK SPACE Used Available Use% Mounted on
            5284664 43700036 11% /
            117165100 55624676 68% /home
obsdeveny:~>


```

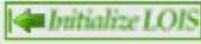
**Figure 4. Results of an `st` command run in the *deveny* terminal window when all process are running (LOIS, NTPD, and Sequester Proc). All processes have process IDs.**

2. Start the user interface LOUI (the LOUI icon is shown to the right):
  - If there is a DeVeny LOUI in the dock, exit it.
  - Double-click the DeVeny LOUI icon on the desktop (shown right).




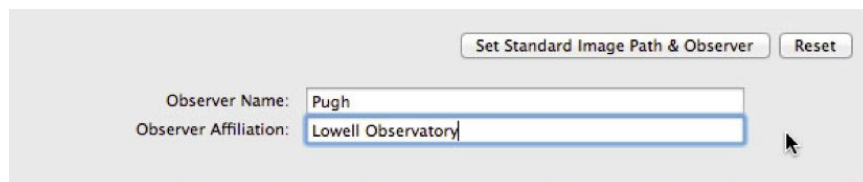
3. Restart lois:

- If lois is running, then stop it. In the top right of the LOUI press 
- Type `st` in the *deveny* terminal window to confirm lois is no longer running.
- Then (or if lois isn't running) type `lois &` in the *deveny* terminal window. A series of lois startup messages will be printed in both the terminal and the lois console on LOUI.

- Initialize lois - in the top right of the LOUI press 

#### 4. Set-up the data storage pathway:

- In the  tab (bottom right) enter you name and affiliation and press 'Set Standard Image Path & Observer'



- You should see your name, affiliation, and the directory structure displayed:



- If both lois and temperature logging are running, there should be CCD temperature and heater readouts appearing in the log.

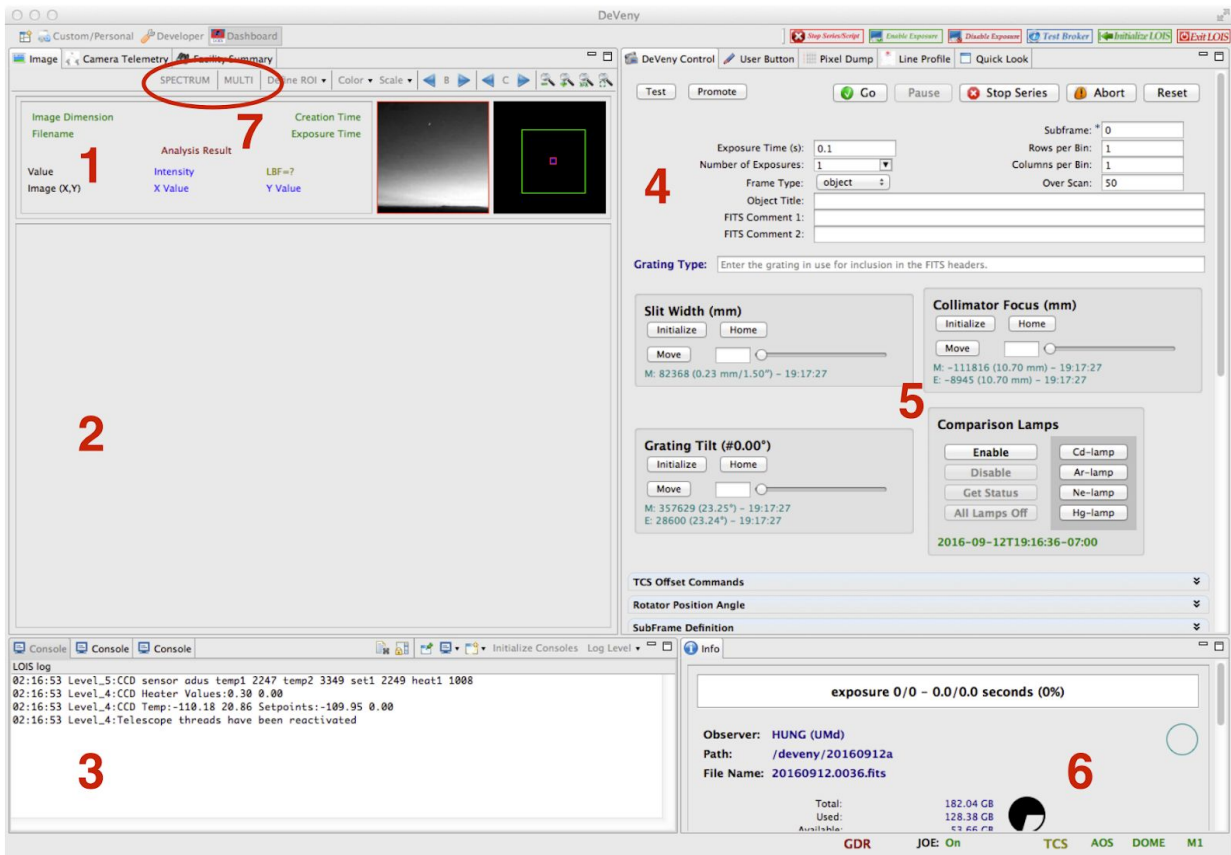
#### 5. Check that JOE (Java Operations Executive) is on:

- Either ask your TO or check the status line on the bottom of the main LOUI window.

**JOE: On**

#### 6. Update the telemetry: This is done by moving one part of the instrument (e.g. changing the slit width, the grating tilt or the collimator focus) and/or entering a grating identification. Items 4 and 5 marked in red in Figure 8.

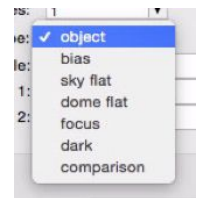
The camera software is now set-up and you can take images. Taking a test frame now will allow you to confirm that everything is working correctly.



**Figure 5.** The layout of the DeVeney LOUI. 1: This area gives information about the currently displayed (i.e., previously exposed) image. 2: Displays the spectral images, blue on the right, red on the left. 3: LOIS log. 4: CCD/Instrument control panel. 5: Control for spectrograph set-up and comparison lamp power. 6: Info tab, contains directory information and information about the current exposure. 7: Analysis tools. For more information on the LOUI see <https://jumar.lowell.edu/confluence/display/DCTIC/User+Interface+Elements>

### 7. Image acquisition:

- To take an image to be saved as test.fits, press “Test” in the DeVeney Control tab (#4 in Figure 5).
- To add an image to your numerical file sequence, press “Go” in the DeVeney Control tab (#4 in Figure 5)
- The type of image can be set from the drop down menu. Selecting bias (or dark) will not open the shutter, and bias sets a 0 sec exposure time.

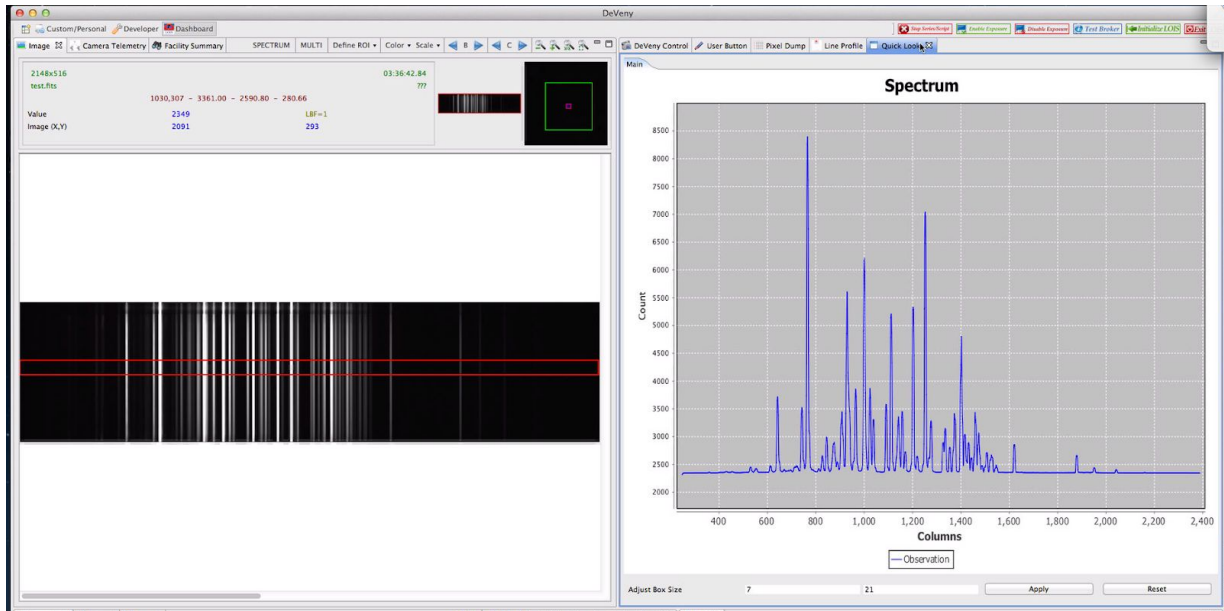


There are several DeVeney-specific LOUI features of note:

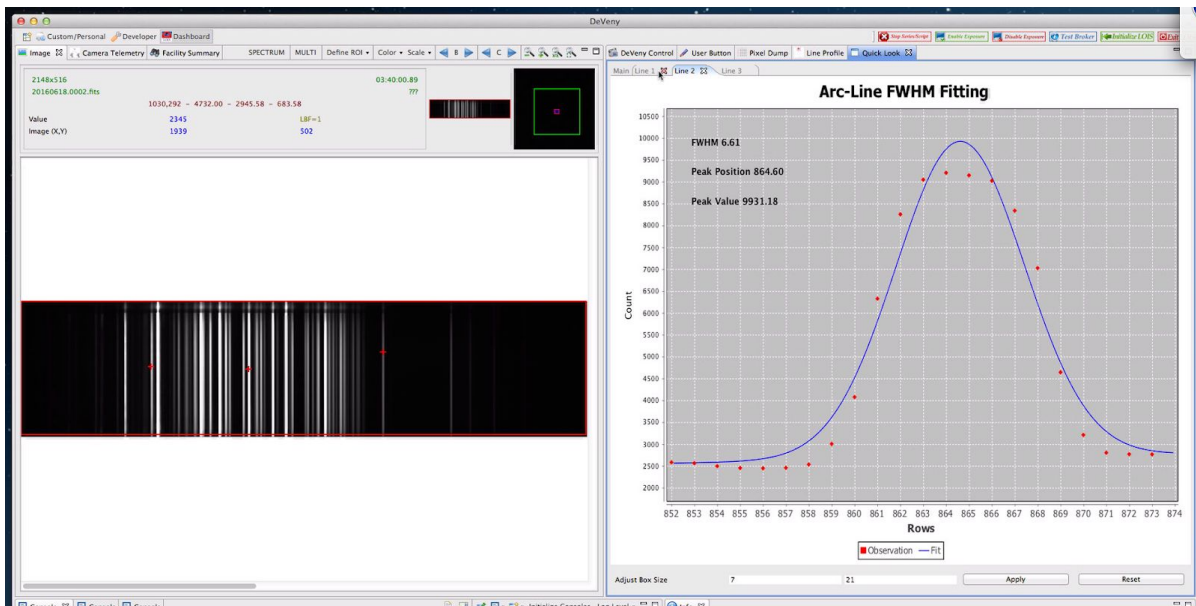
In the Image perspective, there are two graphical functions (#6 in Figure 5):

- **SPECTRUM:** After clicking this you select a region of interest on the displayed image. A spectrum is then plotted in the Quick Look tab

- **MULTI:** After selecting this tool you select individual spectral lines of interest. When your selection is complete you hit the M key. This will open a new plot for each line selected, under the Quick Look tab and perform a fit, giving the FWHM of the selected line. (This tool is useful for confirming correct collimator focus).



**Figure 6.** Use of the SPECTRUM tool. In the top portion DeVeney LOUI, in the left panel a region has been selected. In the right panel the Quick Looks tab is selected and the spectrum for the selected region is displayed here.



**Figure 7.** Use of the MULTI tool. In the top portion DeVeney LOUI, in the left panel several lines have been selected. In the right panel the Quick Looks tab is selected and each line is plotted in its own tab. The tabs display the data points, a fit to the selected line and a few statistics.

In the DeVeny Control tab there are four widgets that provide control of instrument functions (#5 in Figure 5; see §3 for instructions):

- the Comparison Lamps widget provides access to arc lamp power controls; click Enable for access;
- the Slit Width widget sets the slit width in mm (1" = 0.153mm);
- the Grating Tilt widget sets the grating tilt in degrees (the desired tilt may be computed using the idl function `deveny_grangle` on vishnu — see section b below);
- the Collimator Focus widget sets the position for the collimator focus in mm and is used to determine the collimator focus.

At the end of the observing session:

- In the Comparison Lamps widget, 'Enable' the lamps. Then, click 'All Lamps Off'.
- Exit the application with the top-level pull down menu.

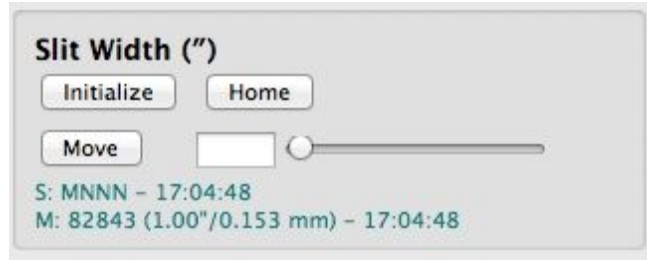
See the LMI user manual — [www2.lowell.edu/users/massey/LMI doc.pdf](http://www2.lowell.edu/users/massey/LMI doc.pdf) — for more discussion of camera operations and LOUI and IRAF quick-look software, as DeVeny camera operations are very similar.

### ***b) Set-up of the Spectrograph***

The slit width, grating tilt, and collimator focus are controlled from the DeVeny LOUI (as discussed above). When LOUI is started and if joe is running (ask the TO to start joe if it is not), the positions of all 3 motorized stages (slit width, grating tilt, and collimator focus) should automatically update in their respective widgets. If any stage does not update to a real physical value (slit width: 0.075-15 mm, grating tilt: 0-47°, collimator focus: 7.75-19 mm), initialize and then home that stage. Since motor control power will only rarely be cycled the previous values should be retained. However, power cycling does occur on occasion, requiring initialization and homing of all 3 stages. The home position for slit width is 13.1 mm, the grating tilt is 0°, and collimator focus is 12.1 mm. Homing and resetting any stage position will take 2-4 minutes total. Filter moves are performed manually at the instrument.

#### 1. Setting the slit width:

In the Slit Width widget (below), enter the width in arcsec in the open field, and click 'Move'; the M(otor step) values will update. The values in parentheses are the computed physical values. The slit is in position when the physical value equals the input value.



## 2. Setting the grating tilt:

Some commonly used grating tilt angles are given in [Table VI](#). The tilt angle is determined with the *deveny\_grangle* IDL procedure, which computes the angle based on the grating in use and the desired central wavelength (example calculation is shown below):

- a. Open a terminal window on *dct-obs1/obs2*.
- b. Type "idl" to launch idl, and the code automatically compiles.
- c. At the IDL> prompt, type *deveny\_grangle*.
- d. Enter the grating resolution and central wavelength.
- e. Using the computed grating tilt angle, set the angle using the LOUI grating tilt widget, shown below (and Fig. 5, item 5).
- f. Enter the desired grating tilt (0 - 48°); click 'Move'.

The E and M values will update as the motor moves. The values in parentheses are the computed tilt angles and should approximately be the same. The grating is in position when the tilt value equals the input value.

The grating position should be checked with an arc line image against a DeVeney arc line atlas plot for the imaged spectral central wavelength and/or range.

```
Terminal -- ssh -- 80x24
% Compiled module: READFITS.
% Compiled module: WRITEFITS.
% Compiled module: SXPARG.
% Compiled module: DEVENY_GRANGLE.
% Compiled module: GRANGLE_EQN.
% Compiled module: DEVENY_AMAG.
IDL> deveny_grangle

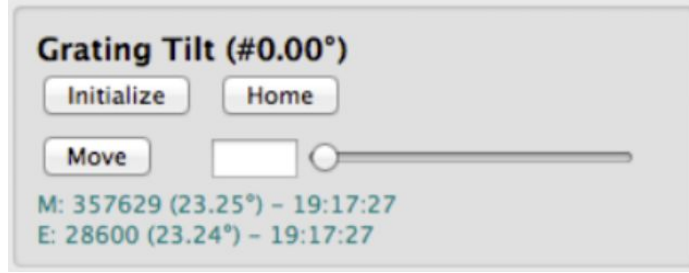
Enter grating resolution (g/mm):
: 150
Enter central wavelength (A):
: 7000

% Compiled module: RAD.
% Compiled module: DEG.

Grating:      150.000 g/mm
Central wavelength: 7000.00 A
DeVeney grating tilt = 21.01 deg

Slit width drive scale: 0.153 mm/arcsec
Slit demagnification: 2.76 pixels/arcsec

IDL> █
```



**Table VI. Example grating settings (approximate)**

| Grating (g/mm) | Grating Tilt (degrees) | Wavelength Range (center) (Å) | Filter | Collimator Focus (mm) (for nominal line width) |
|----------------|------------------------|-------------------------------|--------|------------------------------------------------|
| 150            | 20.95                  | 2500-11300 (6870)             |        |                                                |
| 150            | 21.30                  | 3200-12000 (7600)             | Clear  | 10.9                                           |
| 300            | 22.46                  | 2820-7350 (5110)              | Clear  | 9.4                                            |
| 300            | 22.16                  | 2600-7100 (4850)              | Clear  | 9.5 - 11.25                                    |
| 400            | 26.20                  | 4900-8300 (6620)              | Clear  | 8.5                                            |
| 400            | 26.20                  | 4900-8300 (6620)              | GG495  | 9.1                                            |
| 400            | 27.17                  | 6280-9700 (7360)              | Clear  | 8.0                                            |
| 500            | 26.75                  | 4340-7060 (5700)              | GG420  | 11.5                                           |
| 600            | 25.28                  | ????                          | Clear  | 9.1                                            |
| 600            | 30.70                  | 5200-7250 (6220)              | OG 570 | 8.0                                            |
| 1200           | 31.6                   | 3000-4180 (3590)              | Clear  |                                                |
| 1200           | 39.75                  | 5010-6190 (5600)              | GG420  | 8.9                                            |
| 1200           | 46.65                  | 6200-7300 (7200)              | GG420  | 7.8 (see Note 1)                               |

**Notes: 1. Due to the high angle of incidence with the 1200 g/mm red setting, the collimator position moves to its negative limit before optimum focus is reached.**

3. Changing the order blocking filter:

This is a manual operation, which your TO will perform. The available filters are listed in [Table II](#). Please let them know what filter(s) you will need when you arrive or (preferably) before your run. (TOs see Appendix).

4. Setting the decker: the decker is not currently installed.

## 5. Setting the collimator focus (focusing the spectrograph):

The DeVeny is focused by pistoning the collimator. The recommended focus values in [Table VI](#) should be tested prior to making adjustments, and these values should also be used as a starting point. Focus will vary with temperature, trending to smaller values in colder temperatures. Measuring focus requires the use of arc lamp spectra, described in the following section. The optimum line width in pixels on the CCD for a given slit width is a function of the grating dispersion and the central wavelength of the setting, through anamorphic magnification of the imaged slit, and is determined by multiplying by the slit width in arcsec by the slit demagnification (pixels/arcsec) as given by the *deveny\_grangle* procedure described above.

For example, if an observation with the 150 g/mm grating requires a 1.5 arcsec slit on-sky, line widths in the spectral image should be approximately  $1.5 \text{ arcsec} \times 2.76 \text{ pixels/arcsec} = 4.1 \text{ pixels}$ . The collimator focus is changed with its widget, shown below; input units are mm.



It is suggested to focus the spectrograph using a slit width that projects to about 2.5-3 pixels on the CCD. For example, the 300/5000 grating tilted for a central wavelength of 5000 Å will image the slit at a scale of 2.7 pixels/arcsec. So, the slit width can be set to 1 arcsec for the focus run. Afterwards, the slit is changed to the observational on-sky width.

To measure and adjust focus:

- Determine the slit width in arcsec for a line width between 2.5-3 pixels for the grating setting in use, and set the slit width to this value. If an order blocking filter is used, make sure the filter wheel has been set to the proper position. **Please ensure that the correct grating and blocking filters are selected from the LOUI drop-down menus.**
- Turn on an appropriate arc lamp(s); Ne reaches full brightness in a few seconds, Ar in < 1 min, Hg in 2-3 minutes, and Cd in 3-6 min, the latter 2 taking longer to brighten if it is colder. The focus process can be conducted with the fold mirror in the beam path or stowed, but the instrument cover must be closed. Exposure times will be decreased if the fold mirror is stowed. The status of these components are shown on the LOUI.
- Take a test image of length 15 s, and make a line plot in LOUI or IRAF to check line brightness. The fainter Cd and Hg lines will peak at a few hundred counts at 15 s, while Ar and Ne will be a thousands of counts. This is a good compromise if both Cd/Hg and Ne/Ar sets are used. If only Ne/Ar are used, then the exposure length can be reduced to 2-5 s.



- d. Make sure that the number of exposures selected in LOUI is 1, otherwise the script will take as many exposures as entered at each position, and ultimately fail while consuming lots of time.
- e. In DeVeny LOUI there is a drop down tab labeled “Focus Sequence”, which will take a series of exposures interleaved with collimator moves. In the Focus Sequence tab enter the initial position (8.5 mm is a good starting point), step size (0.5 mm), and the number of focus steps (9-13). The coloured text will show the progress through a sequence.

**Focus Sequence**

Initial Position (mm):  Step Size (mm):

Number of Steps:

Focus Sequence has ended. Last exposure started.

- f. Once the image sequence has completed an IDL routine is available to analyze the images and determine the optimal collimator focus position. From a *dct-obs1/obs2* terminal window move to the correct directory, e.g.: ‘cd /deveny/20180421/focus’. Then ‘ls’ to check for a file of the form ‘deveny\_focus.UTDATE.UTTIME’. The image files are stored one level above, and can be examined with ds9, IRAF, or other tools.
- g. In this directory start IDL and run ‘dfocus’: IDL> dfocus. In about 15 s three windows will appear:
  - i. an arc line plot showing lines found and marked with a peak value above a default threshold of 150 DN. This is a good threshold for spectra that includes Hg and/or Cd. For spectra of Ne and Ar that are well-distributed across the CCD image, the number of lines utilized can be reduced by increasing the threshold, like so: IDL> dfocus, thresh=1000.
  - ii. the full set of focus curves for the lines analyzed. If there are more than 30 lines the plots will wrap in the window; the full set will be plotted in the hardcopy (.ps) file in the focus directory.
  - iii. nominal collimator focus for each analyzed line plotted vs column number. The median value is highlighted with a purple horizontal line and printed in the plot title.
- h. window will appear that shows the distribution of nominal focus vs. column (see Figure 8), and the median value is printed in the title. If the result looks good (fairly flat distribution, often higher at the left), set the collimator focus to the median value. (A full output of the focus analysis is saved in the file ‘[deveny.xx.xx.ps](#)’ file in the focus directory, where one can examine the focus curves in detail to see if the range needs to be extended).
- i. It is important that the image headers have valid telemetry for the slit width and collimator focus, so if the analysis bugs up with -9999 values in the focus curves, that is why.

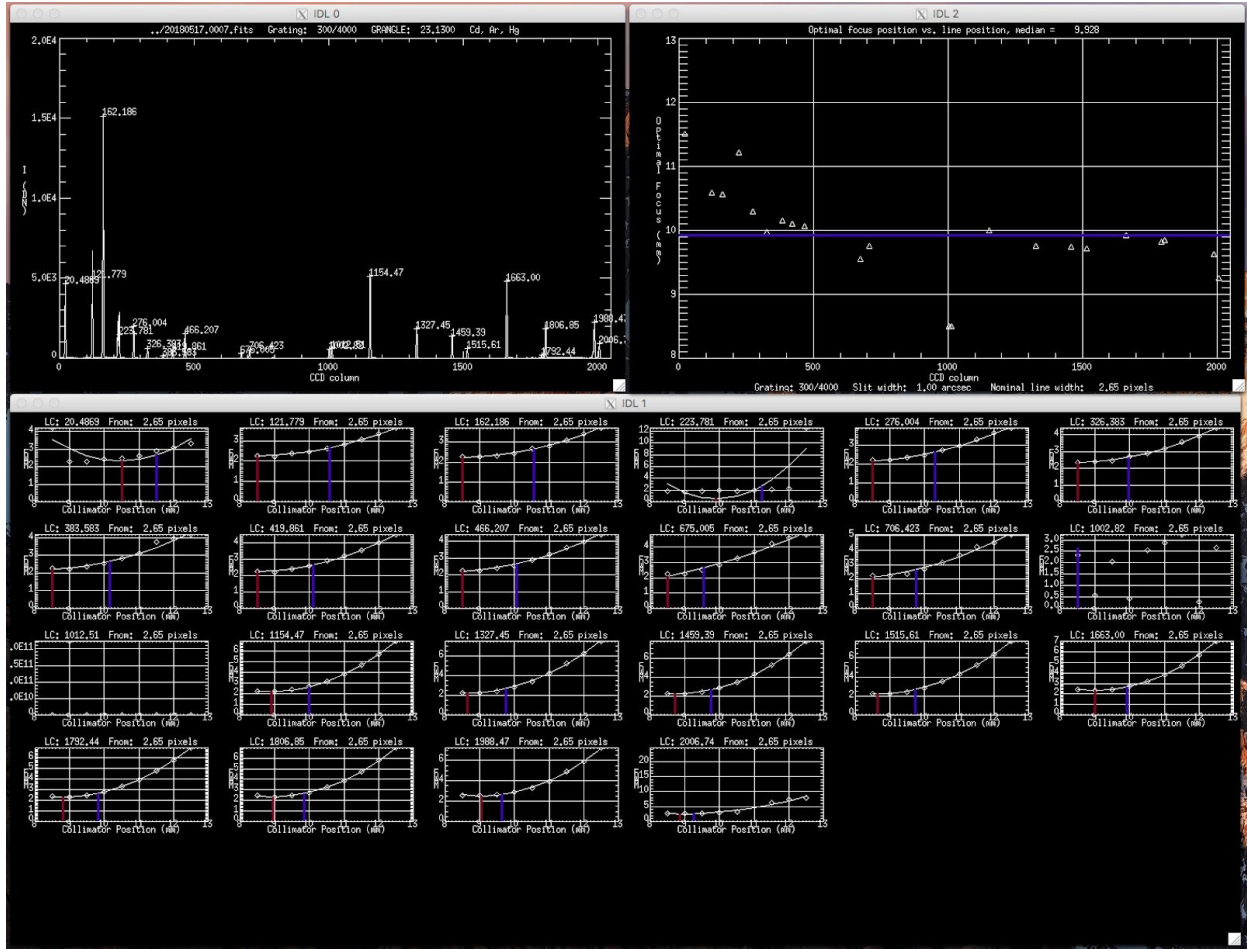


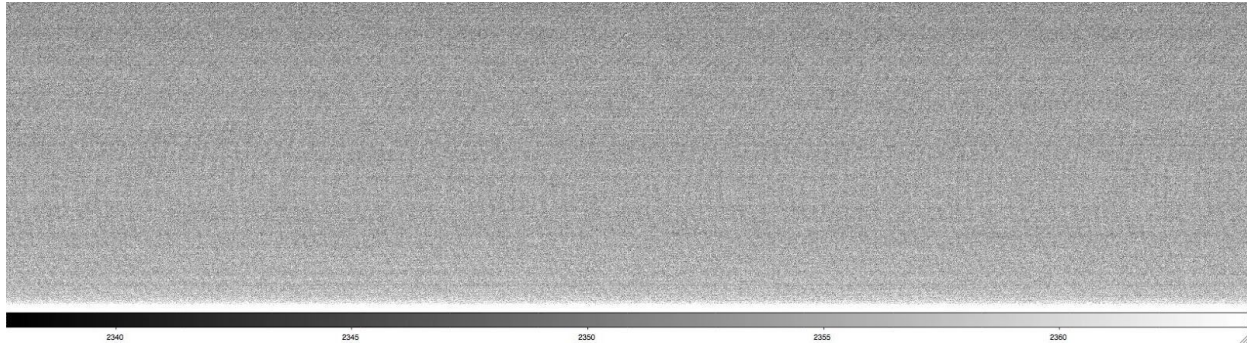
Figure 8. Example output from dfocus analysis for the 300 g/mm grating. Upper left panel: arc line plot; Lower panel: line focus curves; Upper right panel: optimal focus vs. line position curve. The median value is 9.9 mm.

### c) Taking Calibration Data

#### 1. Bias Frames:

To take bias frames in the LOUI interface, select the Camera Control tab, select Frame Type 'bias', set the number of exposures required, and click "Go." The exposure time setting is ignored when Frame Type is bias.

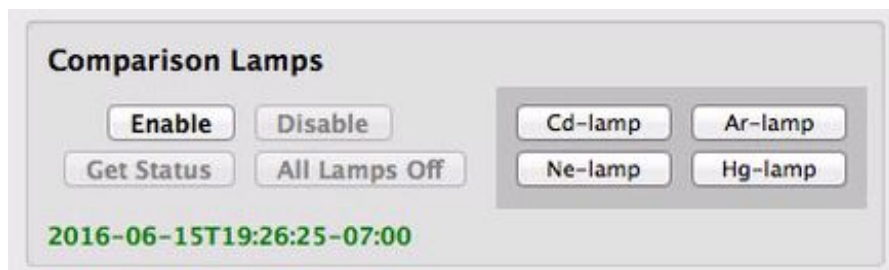
Figure 9 shows an example bias frame. In January 2018 a significant ground loop was broken, eliminating the formerly prominent 'corduroy' noise pattern. Bias images may still contain another pickup mode: low-level ( $\pm 2$  DN), time-variable scalloped noise pattern as shown, which may affect low SNR spectral extractions.



**Figure 9. Example bias frame. Image readouts display a remaining low-level (+/- 2 DN), time-variable noise pattern, which may affect low SNR spectral extractions. The former strong ‘corduroy’ noise has been eliminated (January 2018).**

## 2. Arc Lamp Spectra:

To take arc spectra, turn on the desired lamps with the Comparison Lamps widget (below), and **CLOSE** the instrument cover. Arcs can be taken with the fold mirror either stowed or extended. The underside of the cover is white and is used as a scattering surface for the arc lamps. It takes about 6 minutes for all the lamps to stabilize, as shown in Figure 13 (courtesy N. Moskovitz). When warm, nominal exposure times for Hg and Cd arcs with the low-dispersion gratings is 15-20 s, and about 2-8 s for Ar and Ne.



Cadmium (Cd) lines occur primarily from 3200 to 5500 Å, including 3 lines in the ‘green gap’ around 5000 Å. Mercury (Hg) covers roughly 3300 to 5800 Å, neon (Ne) covers roughly 5800 to 8600 Å, and argon (Ar) covers roughly 6900 to 9700 Å. A sample spectrum is shown in Figure 12. [Appendix A](#) shows blue and red-side arc line identifications for the 300g/mm and 400g/mm gratings; the line list is also tabulated there.

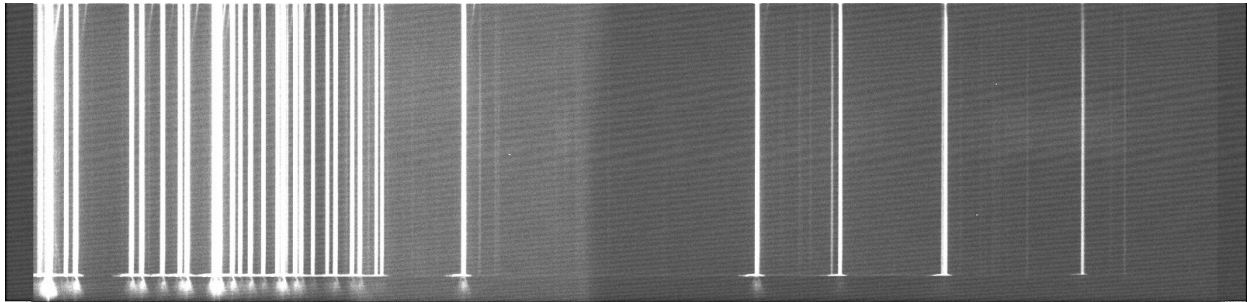


Figure 12. Example arc spectrum, taken with the 300 g/mm grating at a central wavelength of 5000Å

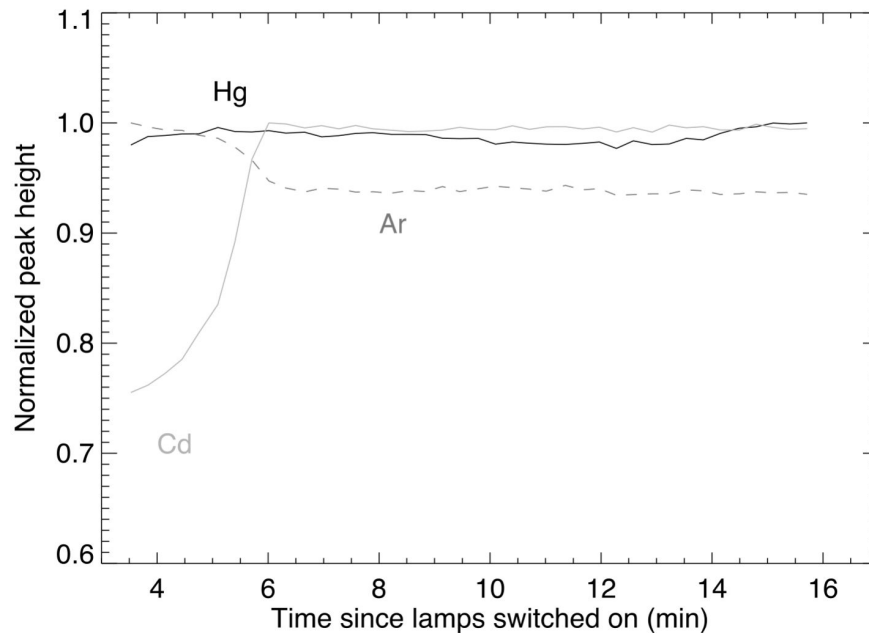


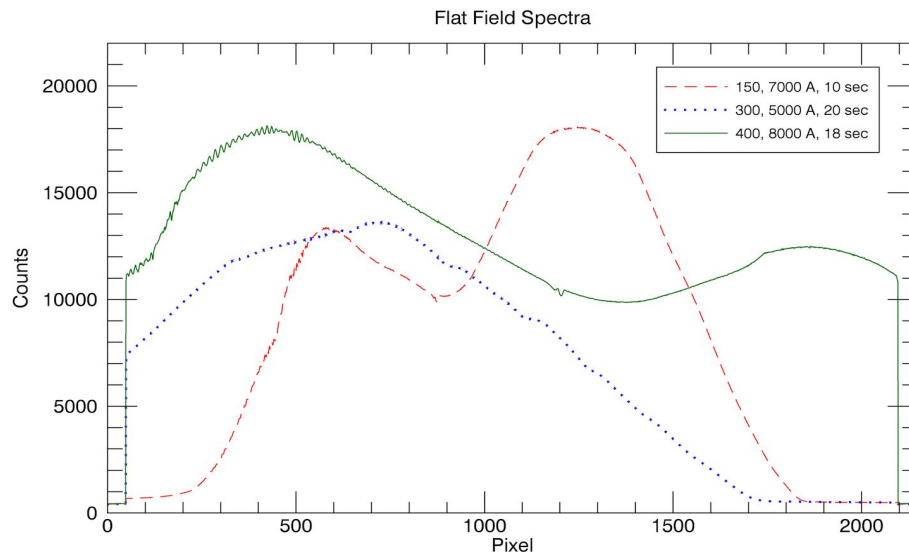
Figure 13. Arc lamp warm up curves. Ne and Ar brightnesses stabilize within a minute, Hg in 1-3 minutes, and Cd in about 6 minutes. They may well be usable before fully stabilized, but caveat emptor.

### 3. Flat Field Spectra:

For dome flats, ask your TO to insert the fold mirror that feeds the spectrograph into the beam, and open the instrument cover. There are 2 sets of dome flat lamps: the boom lamps that are used for LMI and controlled by your TO, and the ring lamps that are controlled by a dedicated power supply on the mount. Ask the TO to point the telescope at the flat field screen, and to turn on the dome flat lamps.

Example count rates for the lamps were shown in Figure 10. Flux in the UV with both lamp sets is very low; the low bank lamps can be used with long exposures to avoid saturation which occurs when using the top end lamps redward of 4000Å. We are looking into installation of UV-emitting lamps in the top end fixtures.

There is evidence of significant instrumental flexure at large zenith distance when coupled with large rotation angles. For this reason, observers may want to take arc line spectra and flat fields near observed sky angles. The top ring dome flat lamps may be used for this purpose by rotating the dome in front of the telescope; the amount of returned scattered light will be lower than that obtained with the flat field screen.



**Figure 10. Example flat field spectra for the 150 g/mm, 300 g/mm and 400 g/mm gratings. Note: spectra are not wavelength corrected, thus red is on the left and blue is on the right. The legend gives the central wavelengths and exposure times (exposure times were varied to give 10000 - 20000 counts). Fringing is seen in the red end of the spectra. These were taken using the top-ring lamps at a setting of 12V.**

Fringing in the CCD with the deep depletion device is significantly reduced from the thinned CCD 42-10, now about 1-3% amplitude redward of about 8200Å. Small amplitude fringes can also be seen redward of 8000Å in Figure 10's 400g/mm flatfield profile. In comparison, the old thinned CCD exhibited 5% fringing at 7000Å, rising to 20% at 8000Å and 40% at 9000Å.

#### **d) Slit viewing camera operation**

The camera is controlled by the computer *vishnu*, through the GoQat software package, and operated on-sky with the IDL *slitviewg* interface.

1. Camera control software: *GoQat*

To start up the slit viewing camera and software *GoQat*:

- a. From a local terminal window on *dct-obs1*, login to the control computer *vishnu*:  

```
ssh -Y lois@vishnu, password: ask TO
```

b. In this terminal, type `goqat.start`; this script (`/home/lois/bin/goqat.start`) will start GoQat and nominally set the following parameters automatically; verify that the commands are printed in the goqat console with no errors (as in Figure 14):

- Open the CCD camera connection.
- Set autosave to true.
- Set the output directory: `/home/lois/deveny/UTDATE`, and and base filename (UTDATE): `'TARGET_UTDATE_file-number.fit'`.
- Set binning to 2x2.

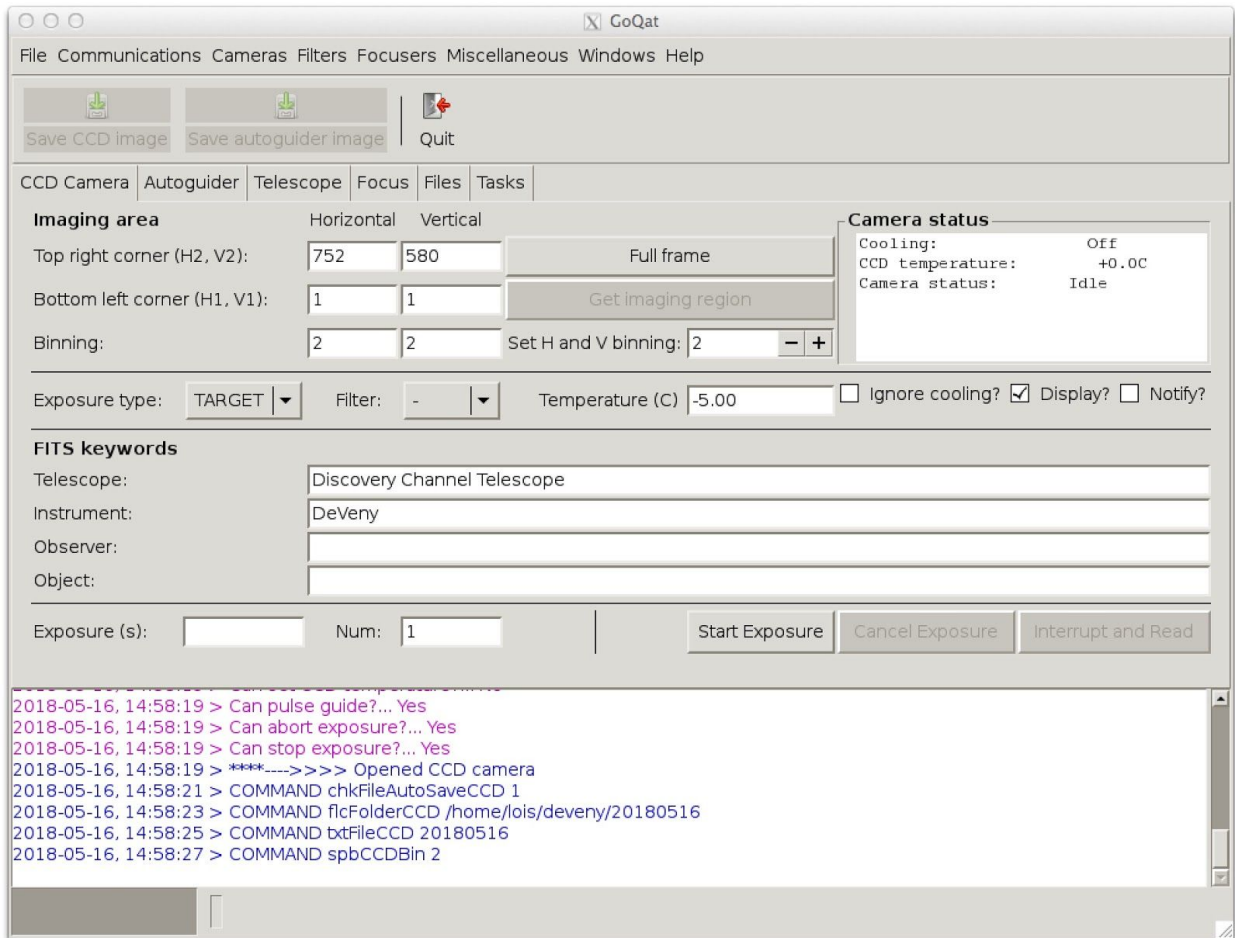
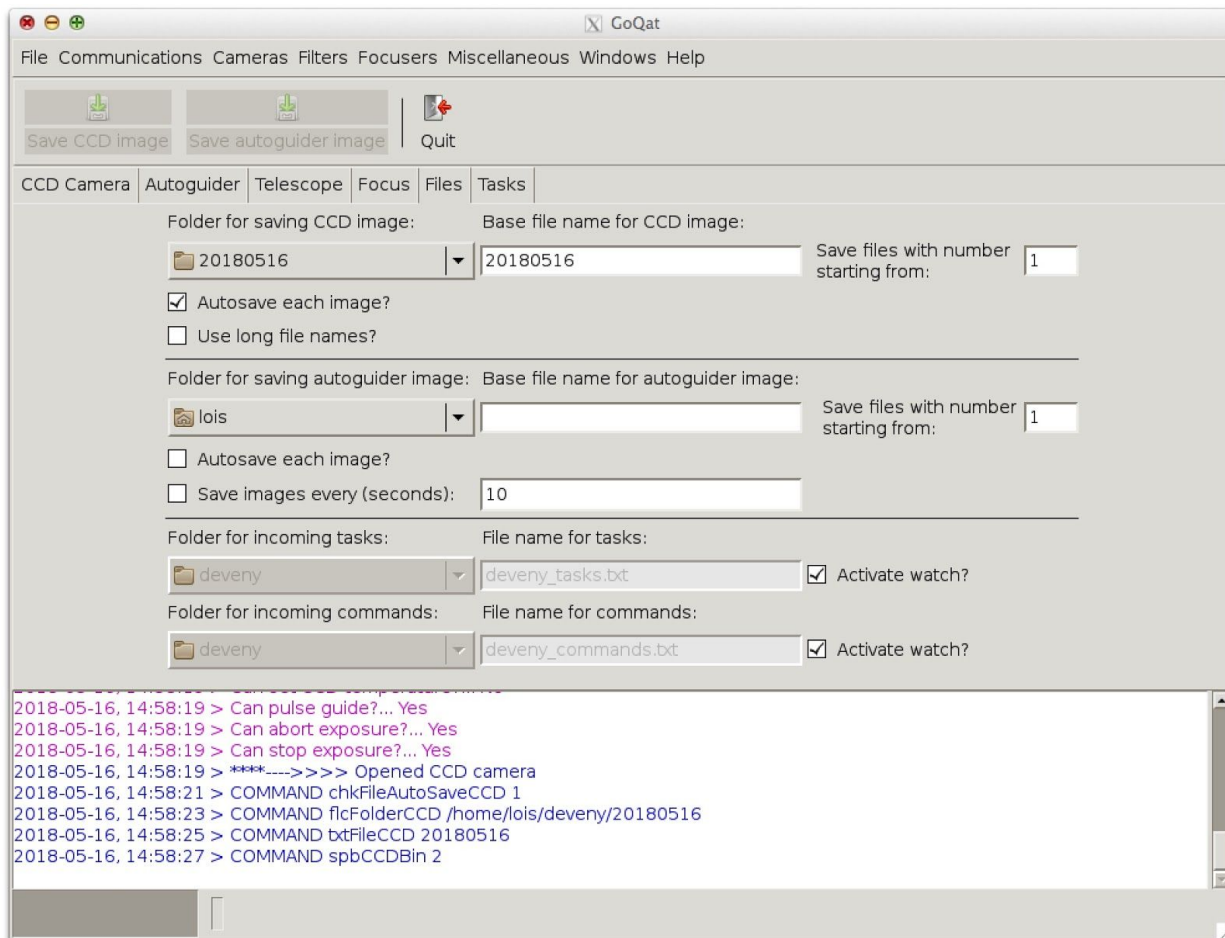


Figure 14. GoQat camera software graphical user interface, CCD Camera tab.



**Figure 15: GoQat Files tab.** This panel provides manual selection of directory and base filename (UTDATE), first file number, and autosave files.

- In the event that any of the automatic settings don't take, make the proper settings manually in the CCD Camera and Files tabs. Note that if goqat should require restarting, the file number should be set to the next in sequence when the restart happened.
- When ready, take an image with Start Exposure to start the frame counter, and it will appear in a new copy of ds9. The ds9 display can be used separate from the IDL operational interface to adjust contrast and conduct other image interpretive actions.

2. IDL *slitviewg* package:

- a. *goqat.start* completes with an automatic start of IDL, and compilation of *slitviewg*.
- b. At the IDL> prompt, type *slitviewg*. This launches the slit viewing camera top level control GUI (Figure 16).

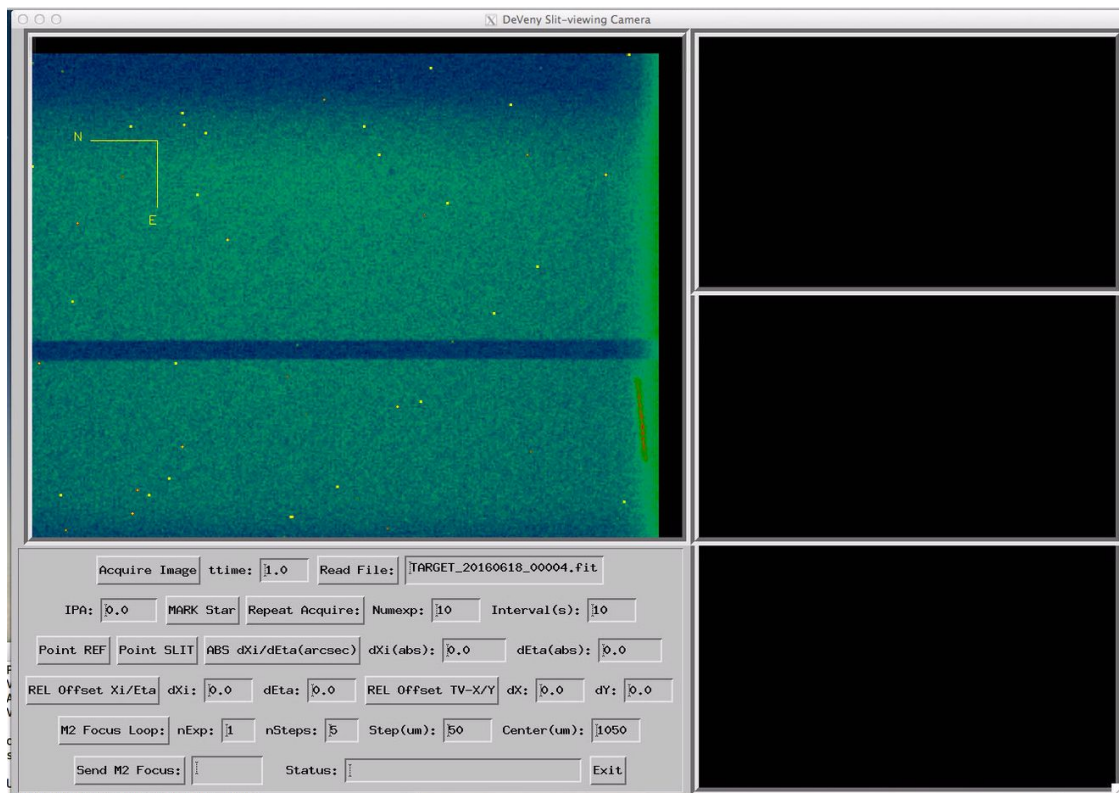


Figure 16. IDL *slitviewg* control GUI.

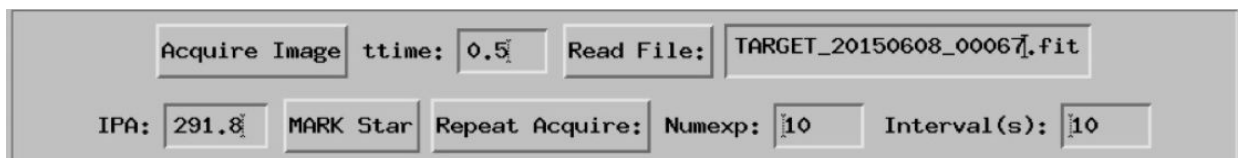


Figure 17. Cut-out section of the slitviewg GUI showing the image controls.

Running *slitviewg*:

- 1) **Acquire Image**: Takes an image, with integration time set in 'time'. The file name is written to the following field. The usual format is:

TARGET\_20150608\_00067.fit

- 2) **Read File**: Loads the image file name in the field into the display.
- 3) **IPA**: To correctly apply offset commands from this UI the compass rose seen in the top left corner of the image must be correctly oriented. If you are observing in position angle mode (slit fixed with respect the sky), set the IPA field to 'Current Rotator IPA' seen in



the LOUI Facilities Summary tab (Figure 18); upon taking the next image the compass rose position will be updated. If you are observing in fixed-rotator mode (slit fixed with respect to the horizon, i.e. atmospheric dispersion along the slit) set IPA to ‘Current Parallactic Angle’. You will need to update this angle every time the rotation angle of the spectrograph is changed.

- 4) **MARK Star**: Fits a 2-D Gaussian function to a selected star in the field of view; the center of the PSF is utilized for offsetting operations. Click the button, then select star with the cursor and click. Note: the Status field will change to say Markstar! and the cursor will change.

After the fit is calculated, a 1-D radial plot with the fitted curve is displayed in the upper right window, with a contour plot of the selected star and fit parameters displayed in the middle-right window.

- 5) **Repeat Acquire**: Takes ‘Numexp’ images in sequence with the specified interval in-between. This function can be used to monitor tracking. All of the images are saved, so caution is advised when executing long sequences. To interrupt the sequence, regain focus in the IDL session window, and type ^C, followed by ‘@recover’. To avoid buffer overflow crashes of GoQat on the server, set the interval between exposures to 5 s or longer.

|                                    |                     |                                    |                     |
|------------------------------------|---------------------|------------------------------------|---------------------|
| LST:                               | 00:55:44            | UTC:                               | 08:18:53 2016-09-21 |
| Current $\alpha$ :                 | 00:55:07.130        | Current $\delta$ :                 | +34:38:24.40        |
| Demand $\alpha$ :                  | 21:28:14.000        | Demand $\delta$ :                  | +10:14:48.10        |
| Hour Angle:                        | -00:00:19           | Zenith Distance (°):               | 0.00                |
| Current Azimuth (°):               | 110.00              | Current Elevation (°):             | 90.00               |
| Demand Azimuth (°):                | 110.00              | Demand Elevation (°):              | 90.00               |
| Air Mass:                          | 1.00                | Guide Mode:                        | NoTrack             |
| Target Name:                       | unspecified         | Mirror Cover:                      | Closed              |
| Target Time To Set (minutes):      | 158.0               | Time To Blind Spot (minutes):      | Never Reaches Limit |
| Time To Rotator Limit (minutes):   | Never Reaches Limit | Time To Azimuth Limit (minutes):   | Never Reaches Limit |
| Mount Dome Azimuth Difference (°): | ---                 | Dome Occultation Warning:          | false               |
| Current Parallactic Angle (°):     | 53.94               | Julian Date:                       | 2457652.8465        |
| Azimuth current Wrap:              | -1                  | Rotator Current Wrap:              | 1                   |
| Current Rotator PA:                | 360.00              | Current Rotator VPA:               | 185.20              |
| Demand Rotator PA:                 | 300.80              | Current Rotator IPA:               | 0.00                |
| Sun Distance (°):                  | -1.00               | Sky VPA:                           | 88.80               |
| Moon Distance (°):                 | -1.00               |                                    |                     |
| equinox:                           | 2000.0              | Time To Blind Spot Exit (minutes): | -1.0                |
| In Blind Spot:                     | false               | Elevation Zenith Limit:            | 89.30               |
| External Target Command Preview:   | true                |                                    |                     |
| Fold Mirror:                       | Open                | Instrument Cover:                  | CLOSED              |
| Focus Offset ( $\mu$ m):           | 3525.0              | Current LMI Filters:               | ---                 |

Figure 18. Facility Summary tab from the LOUI. The red lozenges high-light the parallactic angle and the IPA.

**NOTE:** The following section discusses offsets. The IPA must be correctly set and a reference image with the compass rose correctly oriented for the offsets to work correctly. If the compass rose is incorrectly oriented the offsets will be applied in incorrect directions.

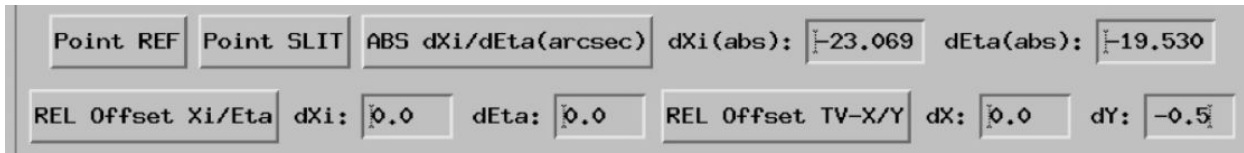


Figure 19. Cut-out section of the slitview GUI showing the offset selections.

- 6) **Point REF**: Moves the telescope to put the star  $\sim 5$  arcsec above the center of the slit. A verification image is automatically taken following the offset. After pressing the Status field will change to say Markstar! and the cursor will change. A radial and contour plot will be generated (see Figure 20).
- 7) **Point SLIT**: Moves the telescope to put the star approximately at the slit center position. A verification image is automatically taken following the offset. After pressing the Status field will change to say Markstar! and the cursor will change. A radial and contour plot will be generated (Figure 20).

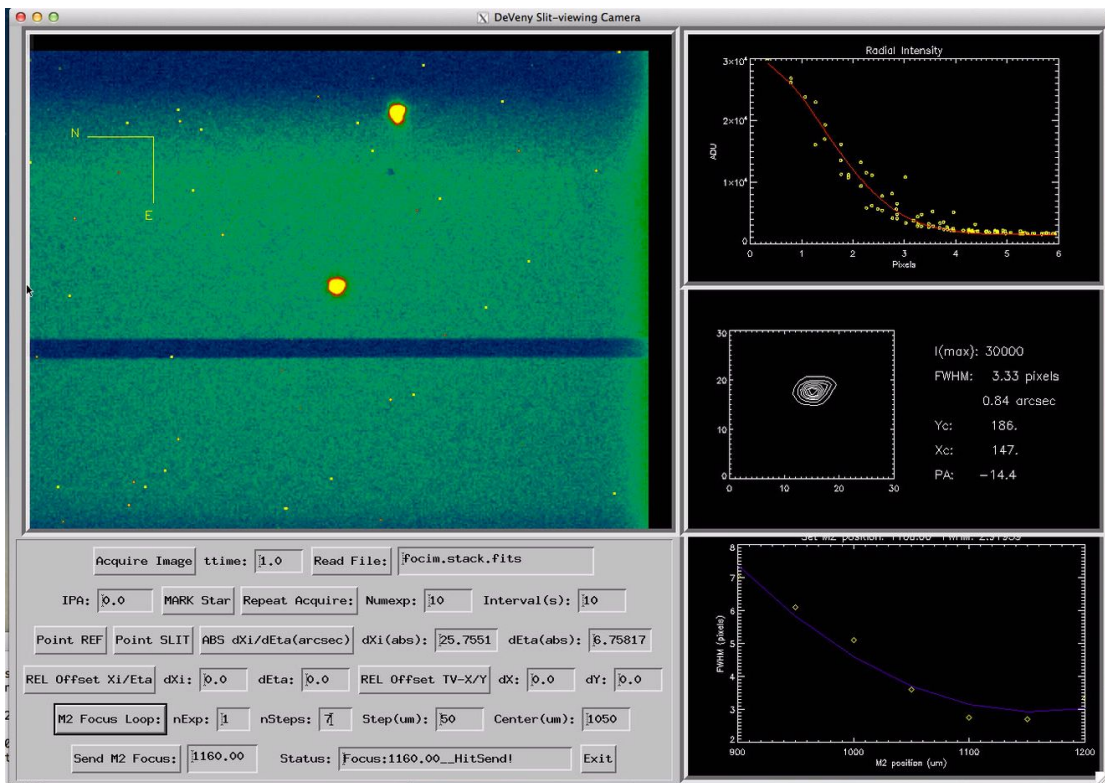


Figure 20. IDL slitview control GUI. A star can be seen at the reference location. In the right hand panel a contour and radial plot have been produced.

- 8) **ABS dXi/dEta**: Sends an absolute telescope offset in arcseconds in TPLANE dXi/dEta coordinates ( $\sim$ RA/DEC directions). The offset shown is absolute with respect to the original science target position.

The field values actively accumulate relative offsets applied through the two REL offset buttons. An absolute offset of 0,0 should always put the target back in the original position.

In order to establish a new origin after a non-zero absolute offset, ask the TO to absorb the current offsets, and set these fields to 0. Any subsequent offset will be a new absolute offset from the new origin.

If there is any confusion regarding what your offsets are compare these values with what the TO has on the telescope software.

- 9) **REL Offset Xi/Eta:** Sends a relative telescope offset in TPLANE coordinates of the values in the fields. These offsets are accumulated in ABS dXi/dEta.
- 10) **REL Offset TV-X/Y:** Sends a relative telescope offset in the camera's X/Y coordinates. These offsets are also accumulated in ABS dXi/dEta. This function can be used to dither along the slit, as well as make fine adjustments in the object position on the slit. See also the discussion in §6 on open loop vs. guided offsets, and why open loop offsets are preferred for target set up.

For those offset commands that also take an image there is no delay added, thus the image is sometimes taken while the telescope is in motion. This is evident from non-circular star images (elongated or crescent shaped). It is advised that a follow-up image is taken to confirm the current pointing.



Figure 21. Cut-out section of the slitviewg GUI showing the focus controls.

- 11) **M2 Focus Loop:** Executes a focus loop with an imaged star on the slit plane by piston of the secondary mirror (M2) using the telescope active optics system (AOS). Pressing this takes a reference image, after which the Status changes to Markstar!

*nExp* - number of images to be stacked at each step in the focus loop

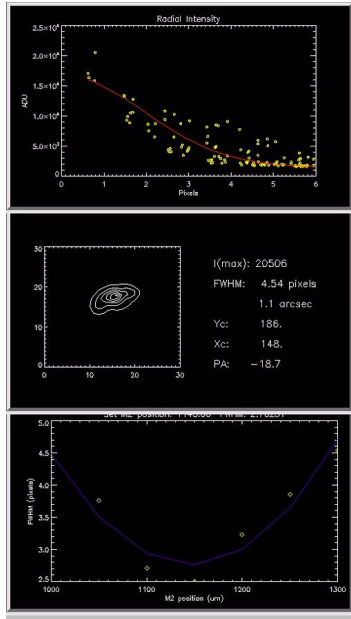
*nSteps* - number of steps taken during the focus, this value defaults to 5 but in practice 7 works better

*Step* - size in microns of each step, default value is 50. This should be altered depending on sky and seeing conditions

*Center* - the focus value around which the nSteps will be made; the value defaults to 2780  $\mu\text{m}$  (fall 2017).

The focus loop can be monitored through the psf fitting output and messages printed to the terminal window, and via the radial and contour plots on the right hand side of the GUI (Figure 22).

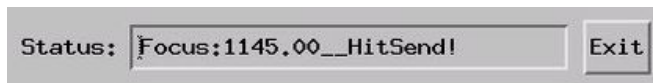
The focus curve data and fit is plotted in the lower right window. M2 is left at the end of travel, and the predicted position for minimum focus is printed in the 'Send M2 Focus' field, which must be clicked to send the move to the AOS.



**Figure 22.** Right panel of the GUI showing the radial plot and contour plot for the final step of the focus loop. The lower panel shows the focus plot and the fitted curve used to give the final focus value.

Status bar will indicate when the focus loop is complete

- 12) **Send M2 Focus:** Send a focus offset value to the Active Optics System. The value is entered in microns. This field is auto-filled after running a focus loop.



### **e) Focusing the Telescope**

At this point all of the software should be set-up and the beginning of the night calibration images collected. Once your TO has completed their start of night checks, you will be ready to focus the telescope before moving on to your object spectra.

The telescope is focused on the DeVeny slit by pistoning the telescope's secondary mirror. The most straightforward way to do this is via the slit viewing camera GUI, as described in that section above. Spatial focus of a dispersed star should be checked following a focus run. The DCT M2 focus offset for the DeVeny is roughly 1050 to 1150  $\mu\text{m}$ . Use a 13<sup>th</sup> magnitude star (approx.) for focusing, with  $t_{\text{time}}=1\text{s}$ . If the seeing is poor or highly variable, stack several (3, say) images at each focus position. The camera saturates at 65,000 counts, so for optimal focus the star used should have 10,000 to 20,000 counts in the peak.

## **5) Setting up for Object Spectra**

There are several ways to send the telescope to your targets of interest:

1. You may give the coordinates to your TO who can then manually enter them into the telescope controls.
2. You can create an Observer Target List and then send your targets directly.
3. You can supply ephemeris files or have the TO generate them (using the telescope control software's inbuilt JPL Horizons interface).

Observer target lists are a text file containing object names and coordinates along with other astrometric information (sample files are shown in the appendix).

They are accessed using the Observer Target List UI, which is started using the icon on the desktop. Once the software (Figure 23) has loaded target lists can be loaded using the 'File' drop down menu.

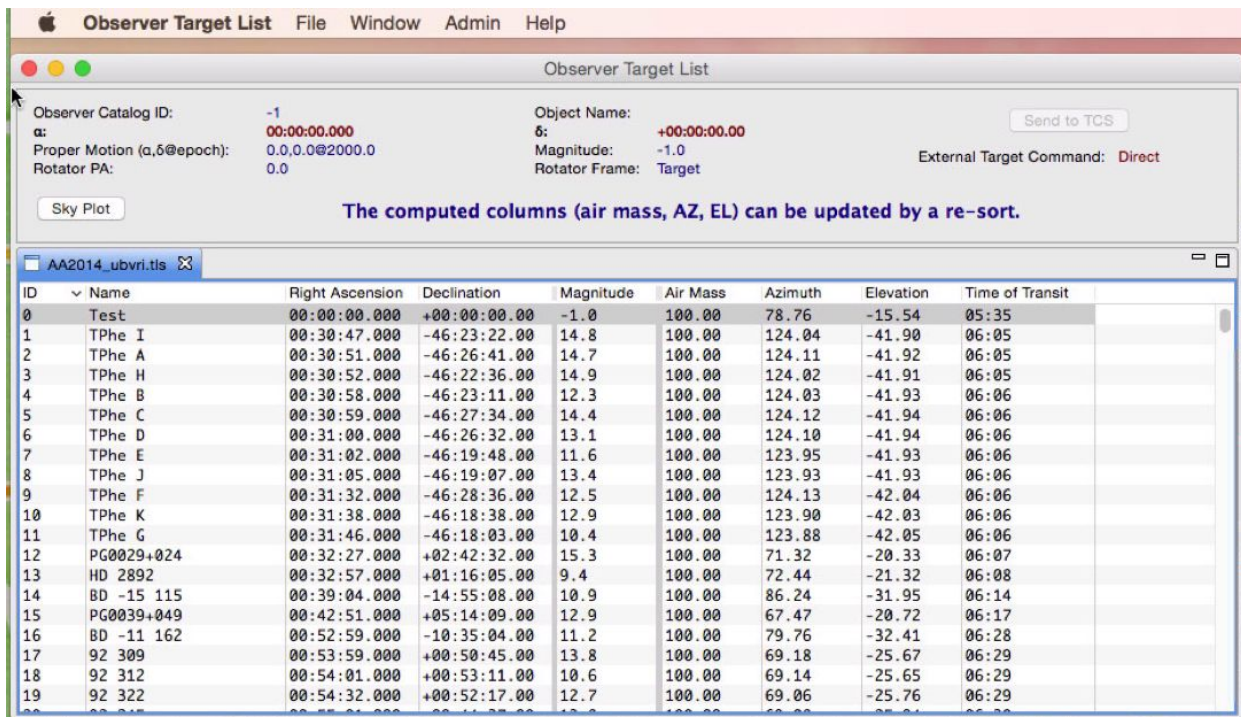
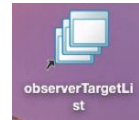


Figure 23. The Observer Target List UI. The four right-most columns are automatically generated and do not appear in the base file. The rows are editable to allow for corrections and/or sending of additional targets.

In cases where you supply files (target lists or ephemeris) it is recommended that you have these ready before your observing run starts. Regardless, you will need to inform your TO of how you would like the sky to move on the slit (slit fixed with stars rotating or slit rotating and the stars appearing fixed upon the slit) — if you are using a target list this distinction can be made in the target list, see [Appendix C](#) for details.

When the telescope is in position all four status indicators ( **TCS** **AOS** **DOME** **M1** ) at the bottom of the DeVeney LOUI should be green.

- TCS - Telescope Control System
- AOS - Active Optics System

DOME - Dome shutter position

M1 - Mirror Cover


Red indicates that the status is bad (e.g., the light path is blocked, the telescope is still in motion,...); yellow indicates that the status is unknown (this is usually seen at the beginning of the night before any commands have been sent or received); green indicates that all is well.

Use the slit viewing camera to identify and offset targets onto the slit. As mentioned above, to correctly apply offsets, the IPA must be filled in correctly. If you have trouble identifying which angle you require, ask your TO for assistance.

It is recommended to place objects near the center of the visible slit in the image display. Once the target is centered on the slit you are ready to begin exposing. If desired, your TO can set-up guiding for you once you are happy with the pointing (see below for more information on guiding).

To take object exposures, select Frame Type 'object', enter the exposure time, and click Go. It is important to note that at this time, an image in progress **can only be aborted**, with loss of the image. A future upgrade to the CCD control software will provide the means to stop and read out an exposure in progress.

## 6) Guiding

Guiding is done by inserting a pick-off mirror into the beam off-axis, below the instrument pick-off mirror. Your TO will set this up, doing so takes 30 seconds to a minute depending upon the local star field and sky conditions. When guide lock is established, the GDR indicator on the LOUI will turn green (  ). Like the other status indicators it has three states: red indicates that the telescope is parked, yellow indicates that it is tracking unguided (open loop) and green indicates that the telescope is guiding (closed loop).

It is most efficient to make telescope offsets for setup while tracking open loop, i.e. while not guiding. Applying a pointing offset, say to ensure that your target remains in the slit, breaks guide lock which takes ~15 seconds to establish. As mentioned earlier there is no delay in the automatically issued exposure command, thus if offsets are made during a guide sequence it is advisable to take another image when guide lock is re-established (indicator is green).

It is important not to issue pointing offsets in rapid sequence, while guiding, to avoid out of sequence messages to the guider and TCS. Rather, confirm completion of any guided offset before issuing the next offset.

## 7) Data access for local analysis

A fast copy daemon controlled by the script 'loiscopy' will copy the Deveny spectra files to the directory /deveny/yyyymmdd on *dct-obs1* from the corresponding data directory on *deveny* itself, where LOIS writes the original data. The naming convention yyyyymmdd is the UT date of the night, which is set on LOUI via 'Set Standard Image Path And Observer' in the Info Tab.

The fast copy daemon runs on *dct-obs1*, and is started and stopped with a cron job, and will be enabled between 1615 and 0815 MST every night. This operation will be updated in the near term future for greater adaptability. For daytime operations the daemon may be enabled manually with 'loiscopy'. The daemon status can be checked at any time on *dct-obs1* with the command 'loiscopy status'. There is also a pdf of the loiscopy document ('Fast Copy Support') in the Documents directory on *dct-obs1*.

## 8) Troubleshooting notes for Observers

### a) If the IDL widget hangs:

Images are not updated, offsets are not sent, etc.

At the IDL prompt in the terminal that launched the IDL widget, type

@recover


Repeat if necessary.

### b) If the DeVeney image pixels are uniformly railed at a single value:


If the DeVeney images appear to be railed to a single, high value (like 22,000 ADU), this is most likely because the analog power supply to the Leach controller has dropped out.

This can occur, for example, through RF interference when operating devices on the spectrograph, such as the grating tilt drive, or switching the arc lamps.

The solution is to quit, restart, and re-initialize lois.

- In the top right of the LOUI press 
- Type `st` in the *deveney* terminal window to confirm lois is no longer running.
- Then (or if lois isn't running) type `lois &` in the *deveney* terminal window. A series of lois startup messages will be printed in both the terminal and the lois console on LOUI.

```
LOIS log - All
Lois Log Module Initialized
01:27:17 Level_5:Opening Active MQ message log LOUI.RC2.loisLog
01:27:17 Level_5:Opening Active MQ message log LOUI.RC2.loisImage
01:27:17 Level_5:Opening Active MQ message log LOUI.RC2.loisAnalysis
01:27:18 Level_3:LOIS Telemetry Functions Initialized
01:27:18 Level_3:Lois Started, Waiting for Initialization
01:27:18 Level_3>Loading Script dummyvat.tcl
01:27:18 Level_3>Loading dummy copy gettemp for external poll attempts
01:27:21 Level_1:Error Unable to identify the Cmd command: lois status anv.
```

- Initialise lois - in the top right of the LOUI press 

### c) If the slit viewing camera will not open:

We recommend that your TO troubleshoot this.

### d) If the lois log shows Telemetry Damaged

This is a result of the new stages not having been moved (grating tilt, slit width, and collimator focus) or the telemetry not having been set (grating type).

If the observer desires good telemetry then the stages need to be moved and/or the grating type needs to be set. If any one of these is not done then the telemetry will continue to register as damaged.

The telemetry will become damaged at any time that JOE is restarted.



## Appendix A: Arc line identification

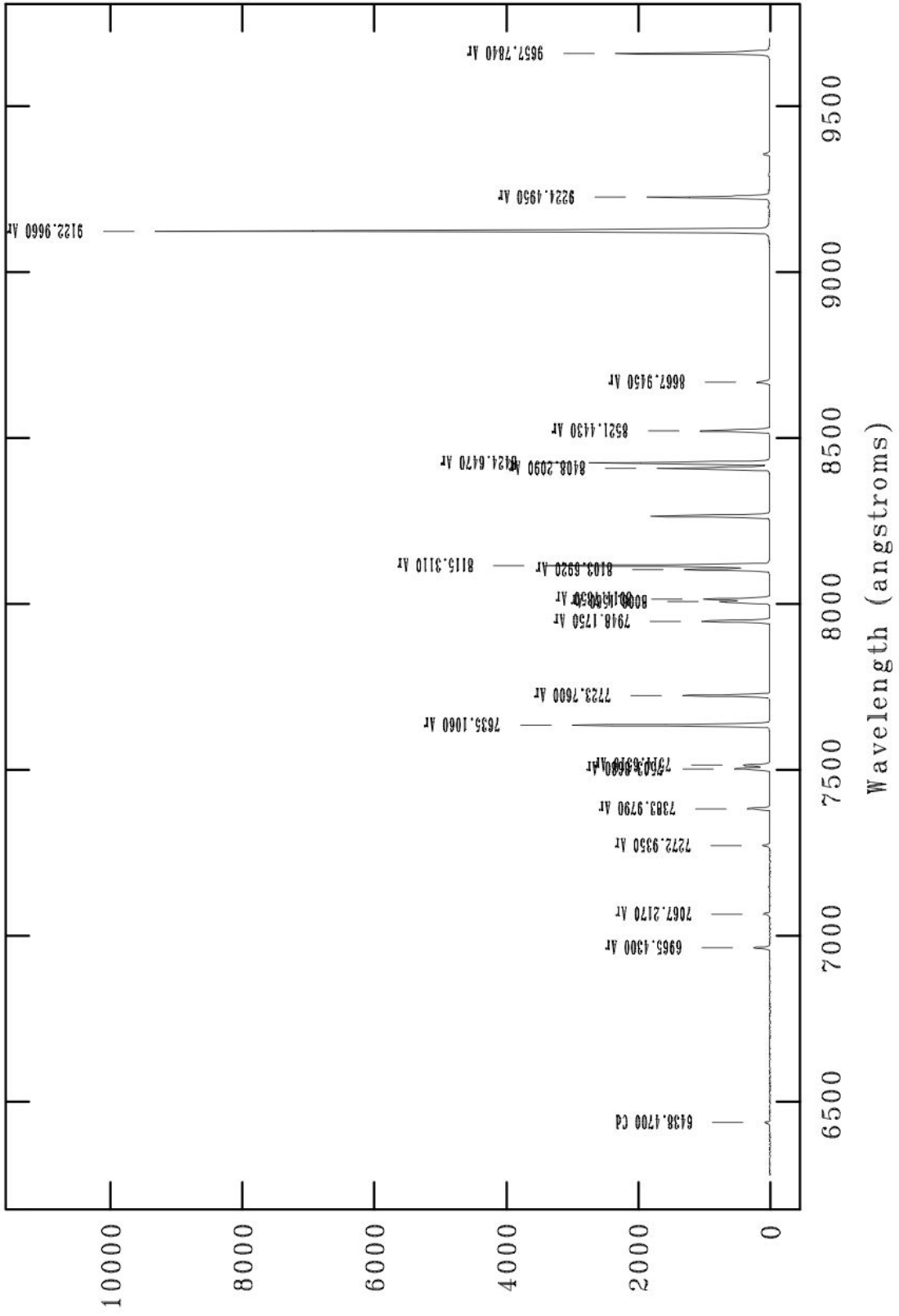
The line list for the DeVeney arc lamps is given in table AI and the spectra are shown in Figures A1 - A3.

**Table AI. Arc Line Identification by Species**

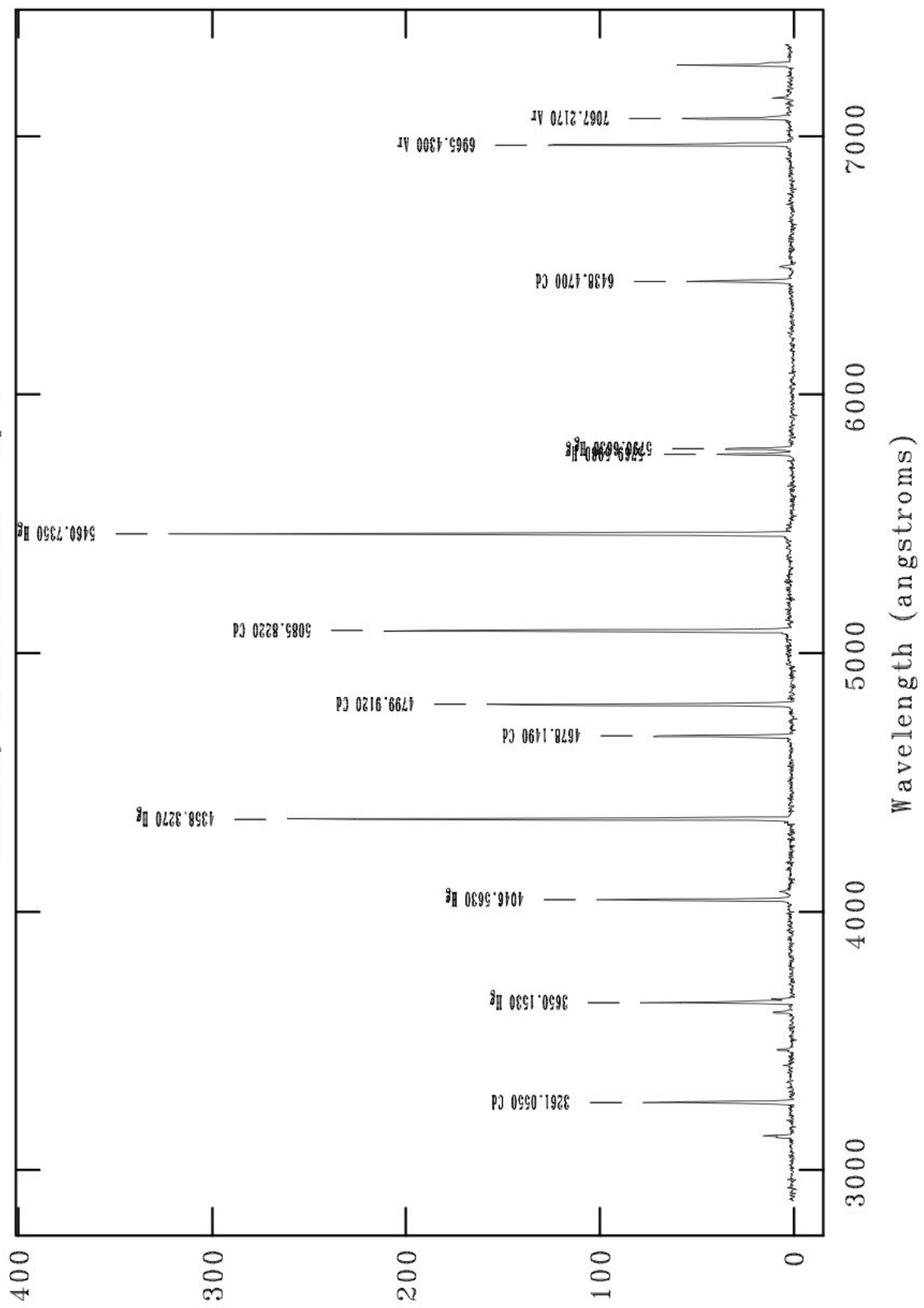
| Wavelength (Å) | Species | Wavelength (Å) | Species | Wavelength (Å) | Species | Wavelength (Å) | Species | Wavelength (Å) | Species |
|----------------|---------|----------------|---------|----------------|---------|----------------|---------|----------------|---------|
| 3125.67        | Hg      | 5852.488       | Ne      | 7535.774       | Ne      | 6965.430       | Ar      | 3080.822       | Cd      |
| 3131.70        | Hg      | 5881.895       | Ne      | 7544.044       | Ne      | 7067.217       | Ar      | 3082.593       | Cd      |
| 3341.48        | Hg      | 5944.834       | Ne      | 7943.180       | Ne      | 7147.041       | Ar      | 3133.167       | Cd      |
| 3650.153       | Hg      | 5975.534       | Ne      | 8082.457       | Ne      | 7272.935       | Ar      | 3252.524       | Cd      |
| 3654.84        | Hg      | 6029.997       | Ne      | 8136.406       | Ne      | 7383.979       | Ar      | 3261.055       | Cd      |
| 3663.279       | Hg      | 6074.337       | Ne      | 8300.324       | Ne      | 7503.868       | Ar      | 3403.652       | Cd      |
| 4046.563       | Hg      | 6096.163       | Ne      | 8377.606       | Ne      | 7514.651       | Ar      | 3466.200       | Cd      |
| 4077.831       | Hg      | 6128.450       | Ne      | 8418.426       | Ne      | 7635.106       | Ar      | 3467.655       | Cd      |
| 4358.327       | Hg      | 6143.062       | Ne      | 8495.359       | Ne      | 7723.760       | Ar      | 3499.952       | Cd      |
| 4916.068       | Hg      | 6163.594       | Ne      | 8591.258       | Ne      | 7948.175       | Ar      | 3610.508       | Cd      |
| 5460.735       | Hg      | 6217.281       | Ne      | 8634.647       | Ne      | 8006.156       | Ar      | 3612.873       | Cd      |
| 5769.598       | Hg      | 6266.495       | Ne      | 8654.384       | Ne      | 8014.785       | Ar      | 3614.453       | Cd      |
| 5790.663       | Hg      | 6304.789       | Ne      | 8853.867       | Ne      | 8103.692       | Ar      | 3649.558       | Cd      |
|                |         | 6334.428       | Ne      | 8865.756       | Ne      | 8115.311       | Ar      | 3981.926       | Cd      |
|                |         | 6382.991       | Ne      | 8919.499       | Ne      | 8408.209       | Ar      | 4140.500       | Cd      |
|                |         | 6402.246       | Ne      | 8988.58        | Ne      | 8424.647       | Ar      | 4306.672       | Cd      |
|                |         | 6506.528       | Ne      | 9148.68        | Ne      | 8521.443       | Ar      | 4412.989       | Cd      |
|                |         | 6532.882       | Ne      | 9201.76        | Ne      | 8667.945       | Ar      | 4662.352       | Cd      |
|                |         | 6598.953       | Ne      | 9300.85        | Ne      | 9122.966       | Ar      | 4678.149       | Cd      |
|                |         | 6652.092       | Ne      | 9313.98        | Ne      | 9224.495       | Ar      | 4799.912       | Cd      |
|                |         | 6678.276       | Ne      | 9326.52        | Ne      | 9657.784       | Ar      | 5085.822       | Cd      |
|                |         | 6717.043       | Ne      | 9354.218       | Ne      | 9784.501       | Ar      | 5154.660       | Cd      |
|                |         | 6929.467       | Ne      | 9425.38        | Ne      | 10470.51       | Ar      | 6099.142       | Cd      |

|  |  |          |    |          |    |  |  |          |    |
|--|--|----------|----|----------|----|--|--|----------|----|
|  |  | 7024.050 | Ne | 9459.21  | Ne |  |  | 6111.490 | Cd |
|  |  | 7032.413 | Ne | 9486.680 | Ne |  |  | 6325.166 | Cd |
|  |  | 7173.938 | Ne | 9534.167 | Ne |  |  | 6330.013 | Cd |
|  |  | 7245.166 | Ne | 9547.40  | Ne |  |  | 6438.470 | Cd |
|  |  | 7438.898 | Ne | 9665.424 | Ne |  |  | 6778.116 | Cd |
|  |  | 7488.871 | Ne |          |    |  |  | 7345.670 | Cd |

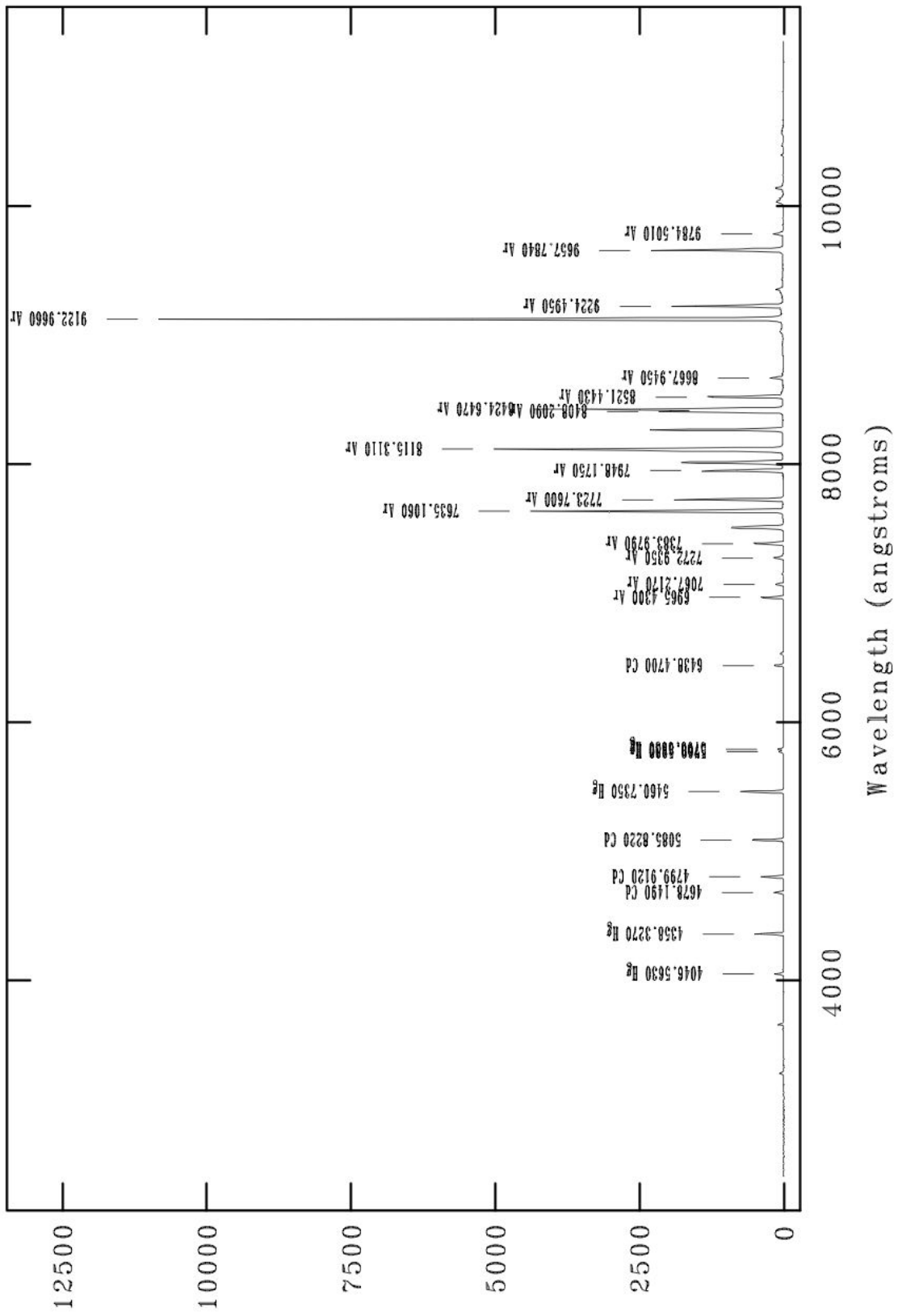
NOAO/IRAF V2.16.1 tbida@tapeats.local Thu 12:22:40 21-May-2015  
identify arc400\_175\_gg495 - Ap 1



N0A0/IRAF V2.16.1 tbida@tapeats.local Thu 11:48:15 21-May-2015  
identify arc300\_cl\_all - Ap 1



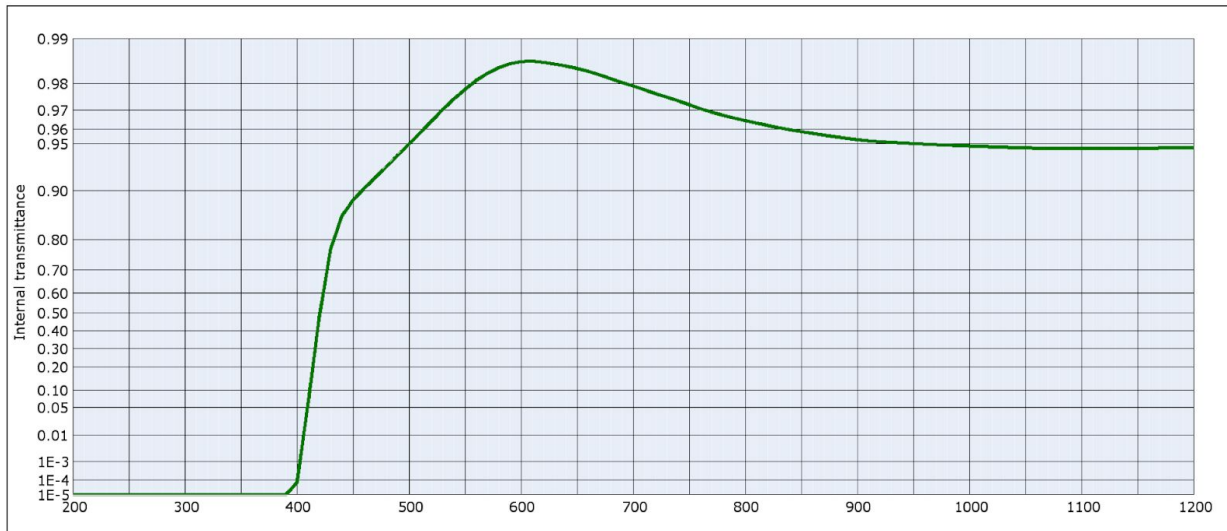
NOAO/IRAF V2.16.1 tbida@tapeats.dfrc.nasa.gov Mon 18:49:34 18-May-2015  
identify arc150\_cl\_all - Ap 1



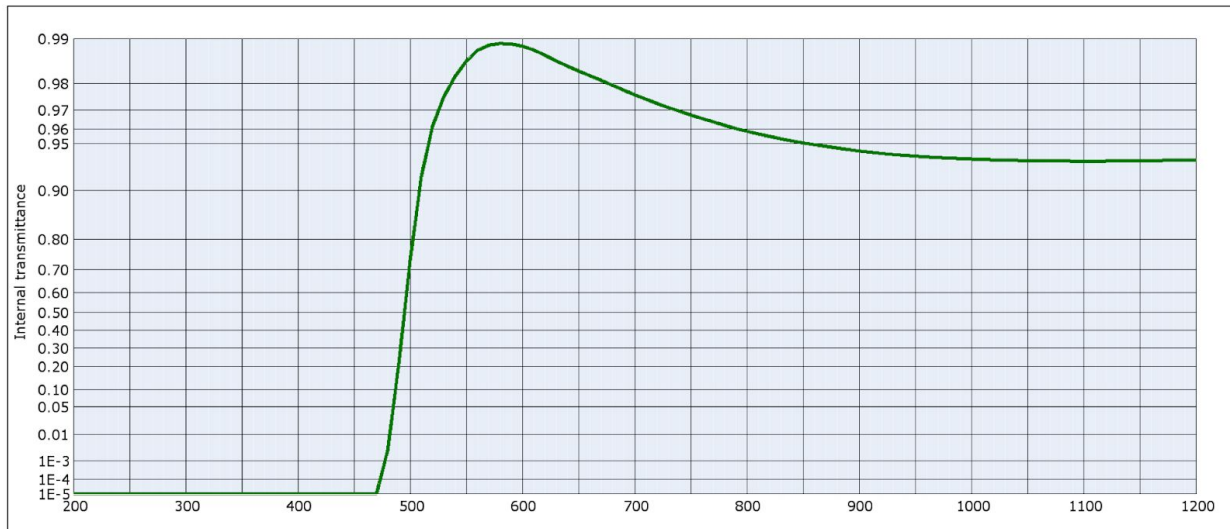
## Appendix B: Nominal blocking filter data sheets

The following data sheets are from Schott to give a sense of the typical transmission curves for the blocking filters mounted in the the DeVeny spectrograph. We have not directly measured transmission of the actual filters in the spectrograph itself.

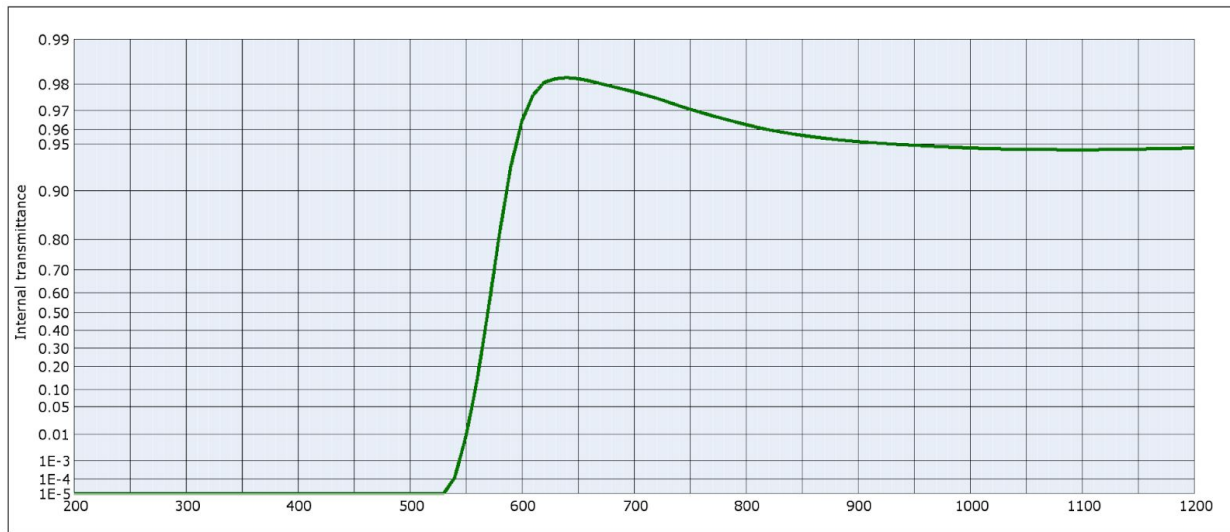
1. GG420 filter transmission curve (from Schott).



2. GG495 filter transmission curve (from Schott)



### 3. OG570 filter transmission curve (from Schott)



## Appendix C: The Observer Target List Tool

As mentioned in §5, above, the telescope may be controlled through the use of the Observer Target List Tool. To use this tool a Target List must be provided. These lists are provided in the form of a text file, saved with the extension .tls. The files must contain meta data, such that the GUI/widget can identify which columns to create and what data to expect. A number of sample files are shown below. For a full description please see <https://jumar.lowell.edu/confluence/display/DCTIC/Observer+Target+List>

1. File to load a target list that contains name, RA, and Dec only.

```
#title=true ra=true dec=true epoch=false muRA=false muDec=false
magnitude=false dRA=false dDec=false rotatorPA=false
rotatorFrame=false
#
"187799" 12:16:38.99 +00:33:58.3
"30512" 16:03:58.72 +14:55:08.0
"3552" 10:08:05.70 +19:19:07.2
"2016_EE156" 08:45:13.69 +59:34:02.4
"248590" 11:32:16.42 +68:19:08.2
```

2. File to load a target list that contains name, RA, Dec, and differential track rates. (Note: track rates must be entered in arc seconds per hour).

```
#title=true ra=true dec=true epoch=false muRA=false muDec=false
magnitude=false dRA=true dDec=true rotatorPA=false
rotatorFrame=false
#
"uranus 11UT" 01:28:50.65 +08:39:22.3 3.920 1.521
"Makemake 04UT" 12:50:49.36 +25:38:34.7 -0.261 -1.402
"Makemake 05UT" 12:50:49.34 +25:38:33.3 -0.254 -1.406
"Makemake 06UT" 12:50:49.33 +25:38:31.9 -0.245 -1.409
"Makemake 07UT" 12:50:49.31 +25:38:30.5 -0.234 -1.412
"Haumea 04UT" 14:01:41.50 +17:40:55.3 -1.075 -0.919
```

3. File to load a target list that contains name, RA, Dec, and Rotator position. (A file of this format will set you up to observer at the parallactic angle with the sky rotating).

```
#title=true ra=true dec=true epoch=false muRA=false muDec=false
magnitude=false dRA=false dDec=false rotatorPA=true
rotatorFrame=true
#
"uranus 11UT" 01:28:50.65 +08:39:22.3 180 Fixed
"Makemake 04UT" 12:50:49.36 +25:38:34.7 180 Fixed
"Makemake 05UT" 12:50:49.34 +25:38:33.3 180 Fixed
"Makemake 06UT" 12:50:49.33 +25:38:31.9 180 Fixed
"Makemake 07UT" 12:50:49.31 +25:38:30.5 180 Fixed
"Haumea 04UT" 14:01:41.50 +17:40:55.3 180 Fixed
```



The available variables that can be set are:

- title or name (surrounded in double quotes) - **required** - it will be sent to the TCS as the science target name and cannot be blank. NB: the double quotes should be ASCII character 0x22 ("), **not** the matched left and right double quote ( “ and ” ) that a word processor is likely to embed. You may need to use a simple text editor to get this right.
- Right Ascension (hh:mm:ss.sss) - **required** - the seconds can be either integer or float
- Declination (+/-dd:mm:ss.ss) - **required** - plus sign is optional for the degrees, and arc-seconds can be either integer or float
- Proper Motion in RA (mas/yr) - this is the angular measurement used by most catalogs:  $\mu\alpha\times\cos(\delta)$
- Proper Motion in Dec (mas/yr) -  $\mu\delta$
- Magnitude
- differential tracking rate in RA (arc seconds/hour)
- differential tracking rate in DEC (arc seconds/hour)
- rotator Position Angle (degrees)
- rotator Frame ("Target" or "Fixed") - a literal string without the quotes

One item of note is that target lists should be created in a basic editor (i.e., vi or emacs) as the UI does not recognise smart characters, and will reject lines with characters outside the ASCII set.

## Appendix D: TO troubleshooting section

### ***a) If the slit viewing camera will not open:***

If GoQat does not show an available CCD camera, then this means that the computer is not connecting to the slit viewing camera. The most likely problem is that there has been a break in the USB connection to the camera. Check the following:

(i) On *vishnu*, type 'lsusb'. Look for a return like:

```
Bus 001 Device 012: ID 1278:0507 Starlight Xpress Lodestar autoguider
```

If there is no such return, then the camera is not visible, and go to step (ii). If it is visible, then check that the device file is world read and write accessible:

```
ls -al /dev/bus/usb/001/012
```

(with 001/012 to be replaced by whatever numbers show up on the response to lsusb). Look for a listing like:

```
crw-rw-rw- 1 root root 189, 11 Apr 14 00:37 /dev/bus/usb/001/012
```

If the 3<sup>rd</sup> 'w' (world writable) is missing in the permissions, i.e.

```
crw-rw-r-- 1 root root 189, 11 Apr 14 00:37 /dev/bus/usb/001/012
```

then this must be modified with 'chmod', with the following command:

```
sudo chmod 0666 /dev/bus/usb/001/012
```

'sudo' will then prompt for the lois password.

If the USB connection has been re-made and is therefore not world-writable, the device file ID can also be seen in the 'goqat.start' terminal when attempting to connect to the camera during the start up procedure.

(ii) If the camera is not visible, then check that the USB extender and camera have power (devenypdu, socket 6). The USB extender connection to *vishnu* can be checked next, followed by the LC fiber connections on both ends. If power, or any of the USB or fiber connections have been disturbed, the permissions on the new USB connection will still need to be changed as in (i).

## Appendix E: DeVeny Signal-to-noise and count rate estimates

The following 2 plots provide estimates of instrumental signal performance:

E1. The signal-to-noise ratio (SNR) of the spectrograph, telescope, and gratings expected at 5400 Å, with a 100 s exposure in 1 arcsec seeing, and no slit losses. To estimate SNR at other wavelengths, utilize the efficiency plots of Figure 1, and scale the SNR in this plot by the square root of the ratio of the desired grating wavelength efficiency to that printed here at 5400 Å.

E2. The estimated count rate at 5400 Å of gratings under the same conditions; scale this plot for other wavelengths in the same fashion.

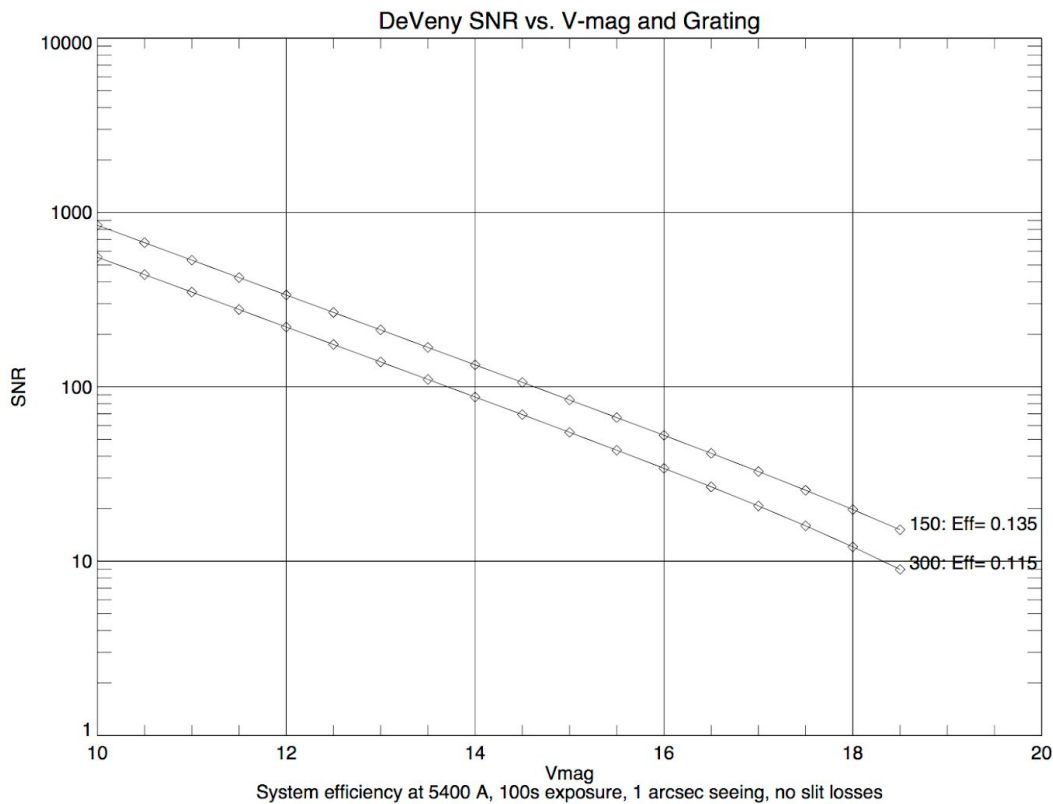


Figure E1. SNR vs. V-mag and grating, at 5400 Å system efficiency and 100 s exposure time.



**Figure E2. Count rate (e-/s) vs. V-mag and grating, at 5400 Å system efficiency.**