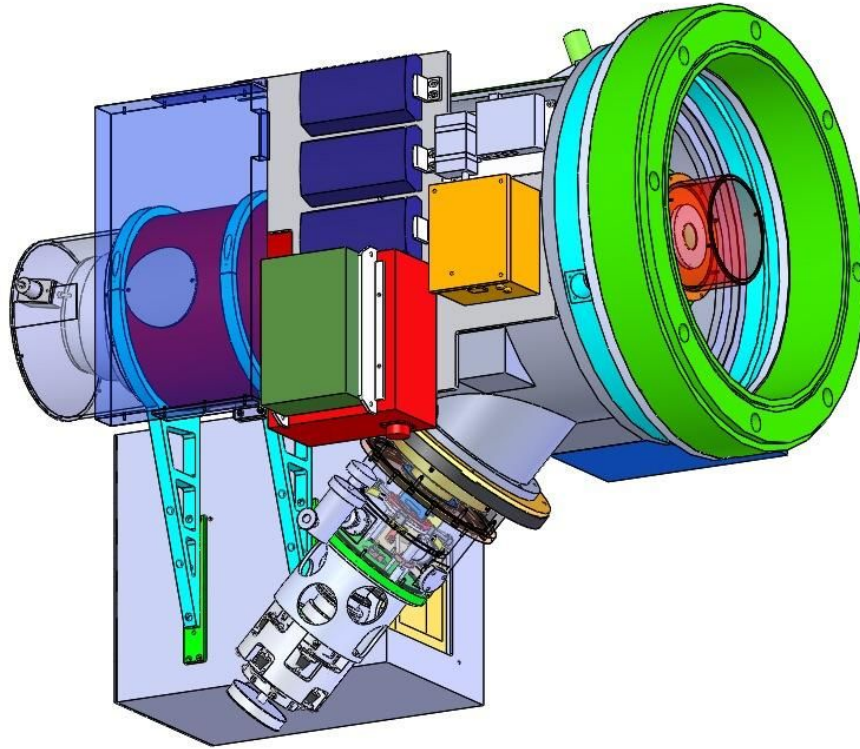# DeVeny Spectrograph
Discovery Channel Telescope
Reference and Operations Guide

v1.3   21 April 2017   T. Pugh, T. Bida, S. Levine

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, decker, 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 ~ 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 1st-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 1st-order blazed plane reflection gratings. The Lowell DeVeny grating complement is shown in Table I. A preliminary assessment of instrumental efficiency vs. grating is shown in Figure 1.

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

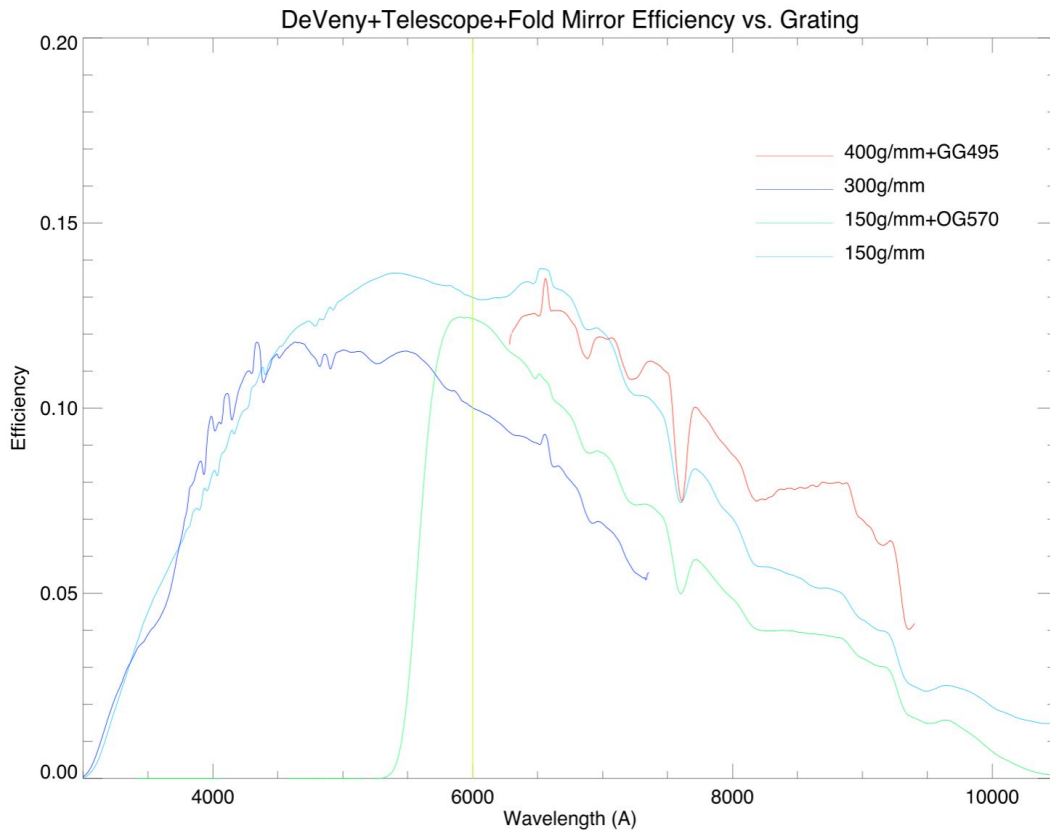| g/mm	Blaze Wavelength (Å)	Dispersion (Å/pix)	Free Spectral Range (Å)	R (2.5-pixel, on-blaze)	Comments
150	5000	4.3	8800	450	KPNO 201
300	4000	2.17	4440	920	
400	8500	1.66	3400	2850	
500	5500	1.33	2720	1500	KPNO 240
831	8000	0.80	1630	4000	KPNO 47
1200	5000	0.58	1180	3450	
2160	5000	0.33	670	5250	4630 Å red tilt limit

Figure 1. On-sky measured DeVeny efficiency vs. wavelength for several gratings.   The vertical line at 6000 Å shows where 2nd-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 DeVeny 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 DeVeny 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 (see a sample relative response curve from the manufacturer in Figure 6). The read noise is nominally less than 10e-, and full well is greater than 50,000 e- (per the manufacturer's literature). Typical gain is 0.4 e-/ADU. The camera is uncooled so the hot pixel count increases with exposure time.
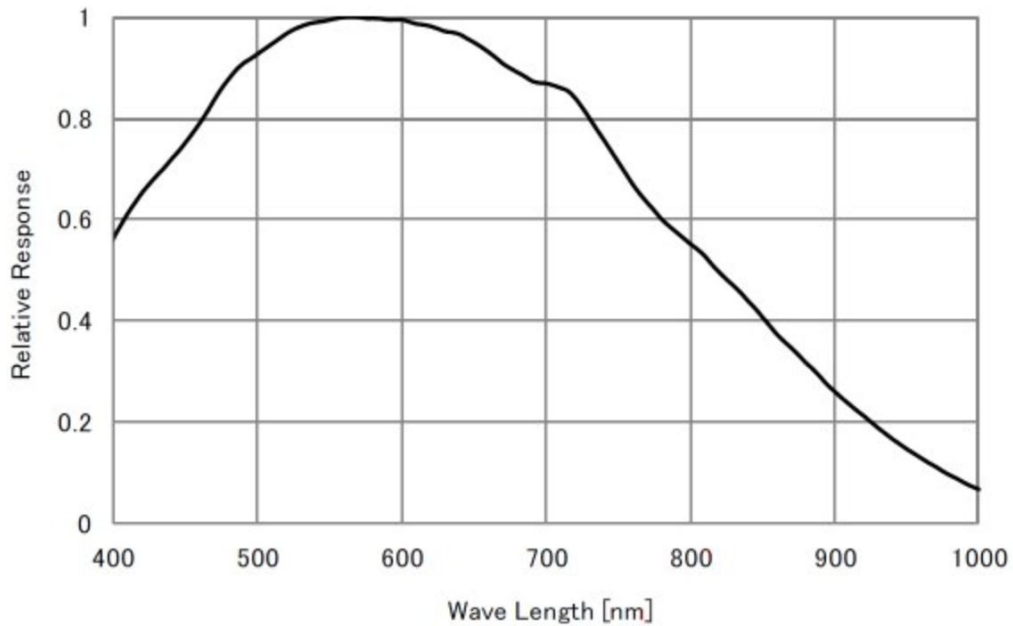

Figure 3. Typical CCD response curve for a Lodestar X2.

The camera is USB-based and is run by a linux machine using the GoQat software package, and operated for observing by a custom IDL GUI (see §4.d). Typical image download times are roughly 0.2 s using USB2. The camera is always operated binned 2x2 to provide seeing appropriate spatial sampling, and reduce overhead.

Table IV. Slit Viewing Camera Specifications

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

f) CCD camera:

A major component of the DeVeny/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$^-$/ADU
Read Noise	4.9 e$^-$
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 to *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 *baggins* 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).

Figure 4. Results of an `st` command run in the *deveny* terminal window when all process are running (LOIS, NTDP, 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 ⏻ *Exit LOIS*
   - 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.
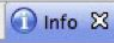

   - Initialize lois - in the top right of the LOUI press ⬅ *Initialize LOIS*

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4. Set-up the data storage pathway.

  • In the ⓘ Info ⊠ 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.

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.
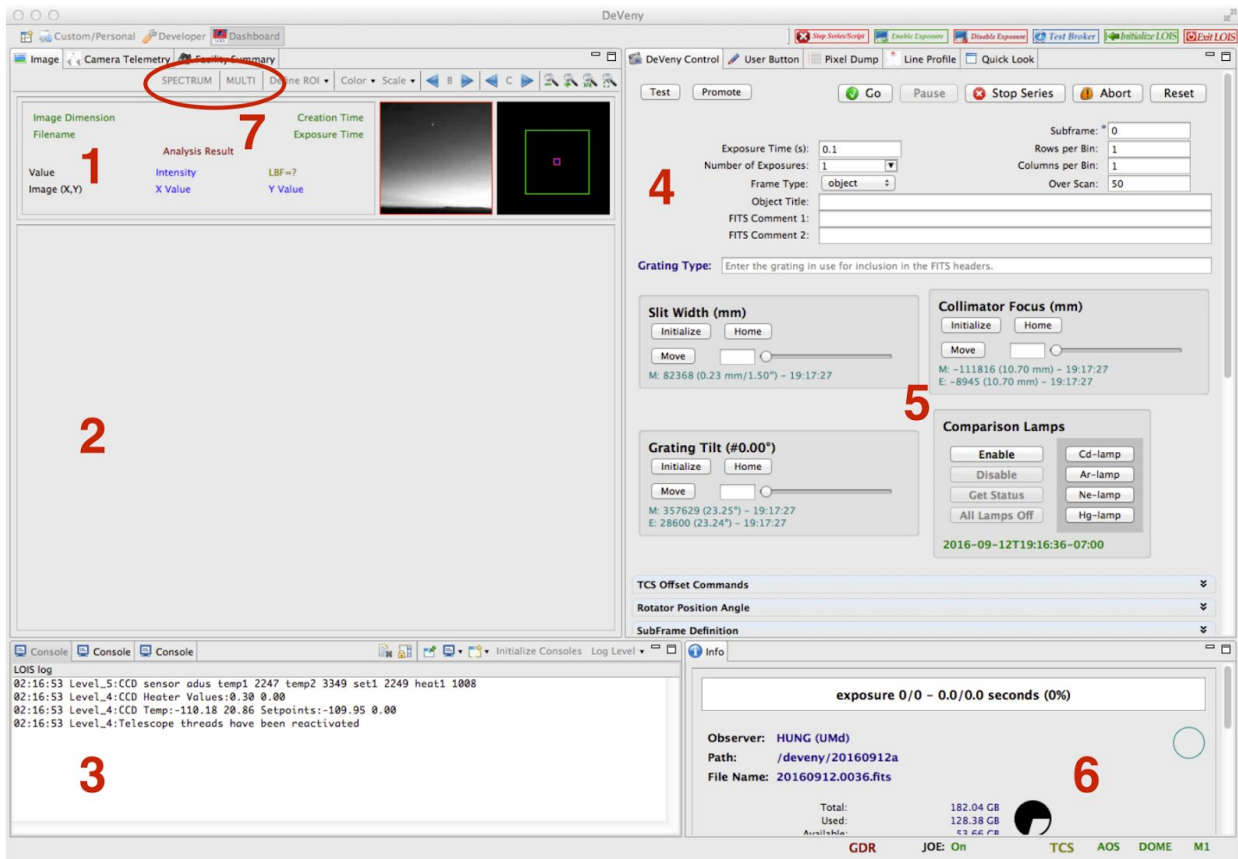
Figure 5. The layout of the DeVeny LOUI. *1:* This area gives information about the currently displayed (i.e., previously exposed) image. *2:* Displays the spectral images, blue on the right, red on the left. *3:* LOIS log. *4:* CCD/Instrument control panel. *5:* Control for spectrograph set-up and comparison 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

Image acquisition
- To take an image to be saved as test.fits, press "Test" in the DeVeny Control tab (#4 in Figure 5).
- To add an image to your numerical file sequence, press "Go" in the DeVeny 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 DeVeny-specific LOUI features of note:
  1) In the Image perspective, there are two graphical functions (#6 in Figure 5):
      a) SPECTRUM: After clicking this you select a region of interest on the displayed image. A spectrum is then plotted in the Quick Look tab

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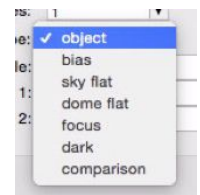
b) MULTI: After selecting this tool you select individual spectral lines of interest. When your selection is complete you hit the M key. This will open a new plot for each line selected, under the Quick Look tab and perform a fit, giving the FWHM of the selected line. (This tool is useful for determining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

Figure 6. Use of the SPECTRUM tool. In the top portion DeVeny 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.
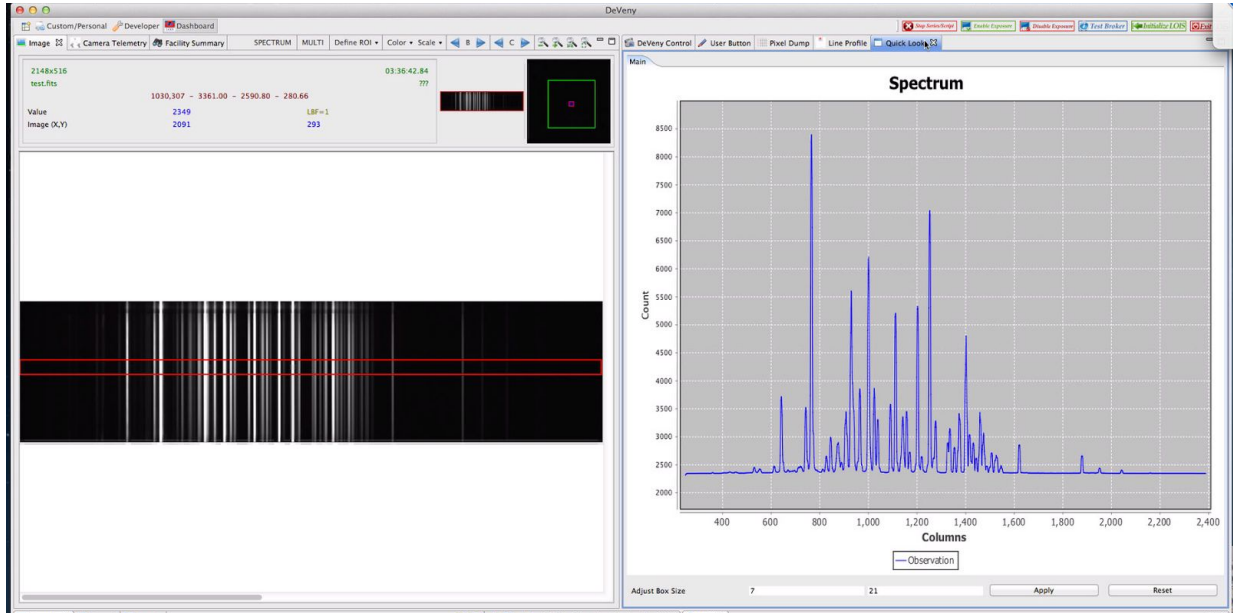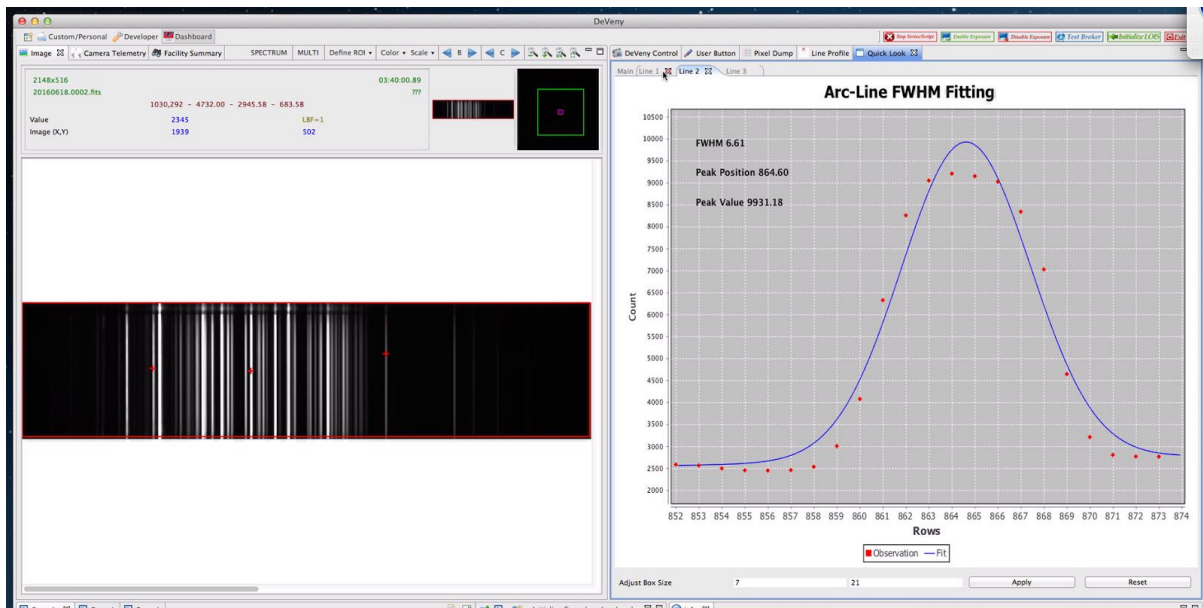

Figure 7. Use of the MULTI tool. In the top portion DeVeny LOUI, in the left panel several lines have been selected. In the right panel the Quick Looks tab is selected and each line is plotted in its own tab. The tabs display the data points, a fit to the selected line and a few statistics.

2) In the DeVeny Control tab there are four widgets that allow interaction with the instrument (#5   in Figure 5; see §3 for instructions):

a) the Comparison Lamps widget provides access to arc lamp power controls; click Enable for access,
b) the Slit Width widget sets the slit width in mm (1" = 0.153mm),
c) 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),
d) 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:

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

(See the LMI user manual — www2.lowell.edu/users/massey/LMIdoc.pdf — for more discussion of camera operations and LOUI and IRAF quick-look software, as DeVeny camera operations are very similar.) — This will be included in an appendix as time allows.

b) Set-up of the Spectrograph

The slit width, grating tilt, and collimator focus are controlled from the DeVeny LOUI (as discussed above). When the LOUI is started, if joe is running, the positions of all 3 motorized stages (slit width, grating tilt, and collimator focus) should automatically update in their respective widgets. Since the motor control power will only rarely be cycled the previous values should be retained. If joe is not running be sure to ask your TO to start it for you, as the motors cannot be moved without it. If any part does not update to a real value (slit width: 0.075-15 mm, grating tilt: 0-47°, collimator focus: 7.75-19 mm), initialize and then home that stage. 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 E(ncoder) and M(otor step) values will update. The values in parentheses are the computed physical values and they should be approximately the same. The slit is in position when the physical value equals the input value.
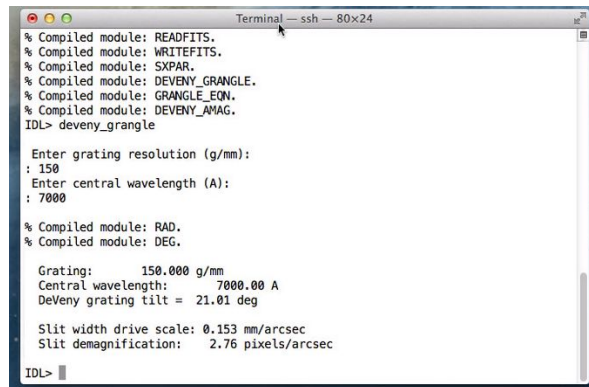

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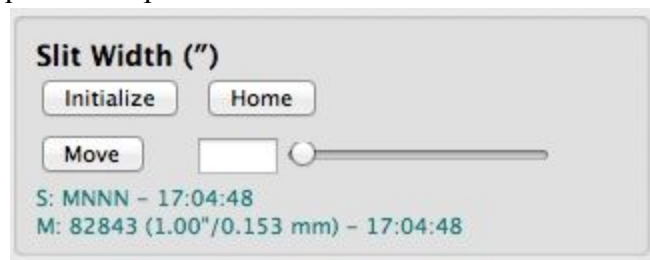
2. Setting the grating tilt:

   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 *baggins.*
   b. Type "idl" to launch idl, and the code automatically compiles.
   c. At the idl promp, type deveny_grangle
   d. At the prompts 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 they should be the same. The grating is in position when the tilt value equals the desired value.

   The grating position should be checked against a DeVeny arc line atlas plot for the imaged spectral central wavelength and/or range.
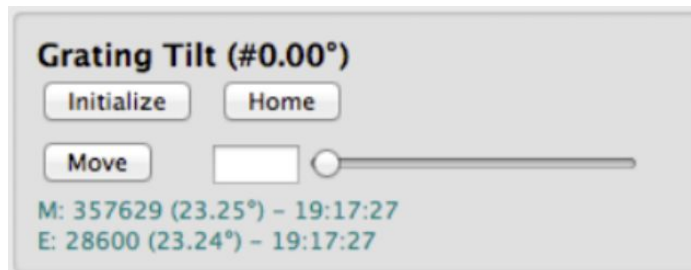
Table VI. Example grating settings (approximate)

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	22.58	2880-7350 (5110)		
300	22.28	3600-8000 (4800)	Clear	11.25
400	26.20	4900-8300 (6620)		
400	27.17	6280-9700 (7360)		
500	26.75	4340-7060 (5700)	GG420	11.5
1200	31.6	3000-4180 (3590)	Clear	
1200	39.75	5010-6190 (5600)	GG420	8.9 (with GG420)
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.

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).

3. Changing 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 arcsec x 2.76 pixels/arcsec = 4.1 pixels. The collimator focus is changed with it's widget, shown below; input units are mm.
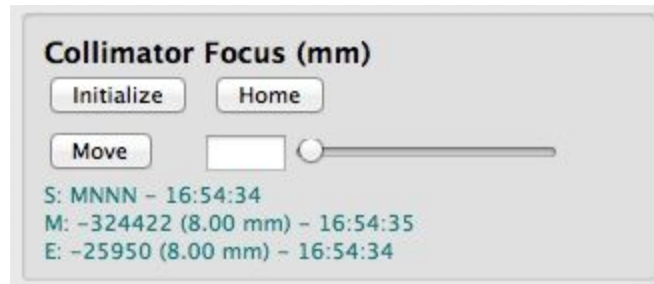
It is suggested to focus the spectrograph using a slit width that projects to about 2.5-3 pixels on the CCD. For example, the 300/5000 grating tilted for a central wavelength of 5000 A will image the slit at a scale of 2.7 pixels/arcsec. So, the slit width can be set to 1 arcsec for the focus run. Afterwards, the slit is changed to the observational on-sky width.

To measure and adjust focus:
a. 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.**
b. 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. The status of these components is shown on the LOUI.
c. 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): `8`   Step Size (mm):   `0.5`

Number of Steps: `13`   [Focus Sequence]   [Abort]

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 baggins terminal window move to the correct directory 'cd /deveny/UTDATE/focus' (where UTDATE is the current UT date in the form YYYYMMDD). 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 IRAF too if desired).

    g. In this directory start IDL and run 'dfocus': IDL> dfocus. In about 15 s a 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).

    h. 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.
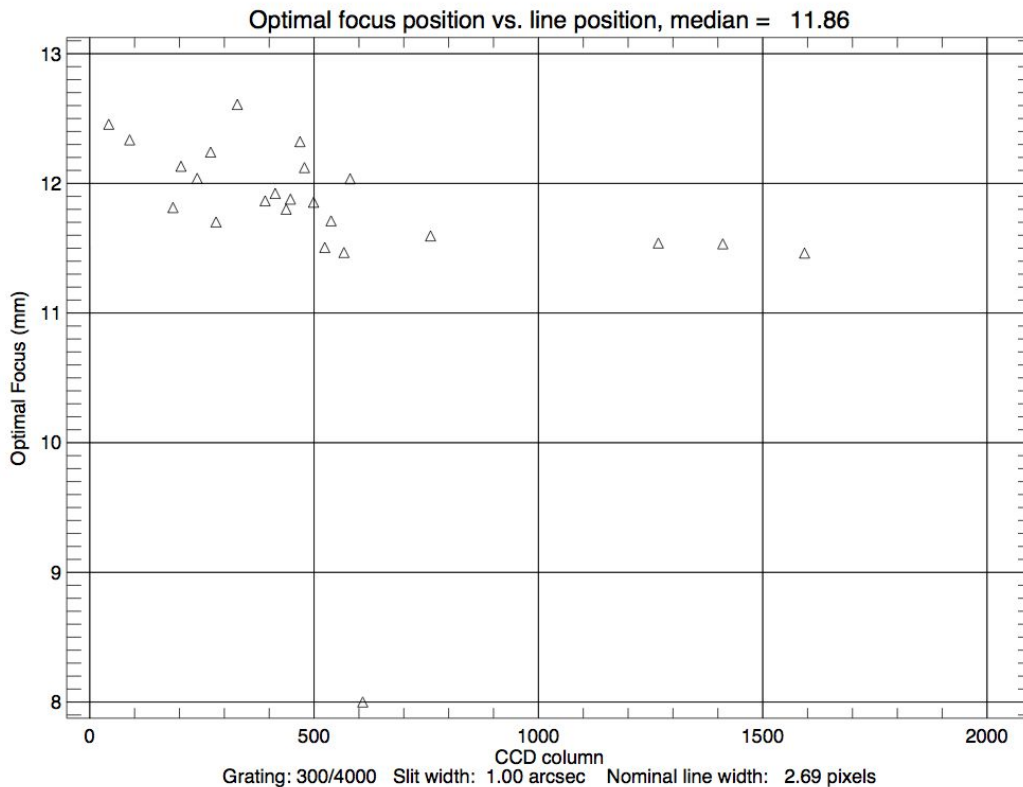
Figure 8. Example optimal focus vs. line position curve for the 300 g/mm grating.   The median value is 11.9 mm.

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

c) Taking Calibration Data

With the software and hardware both set-up you are now ready to acquire your first set of 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.
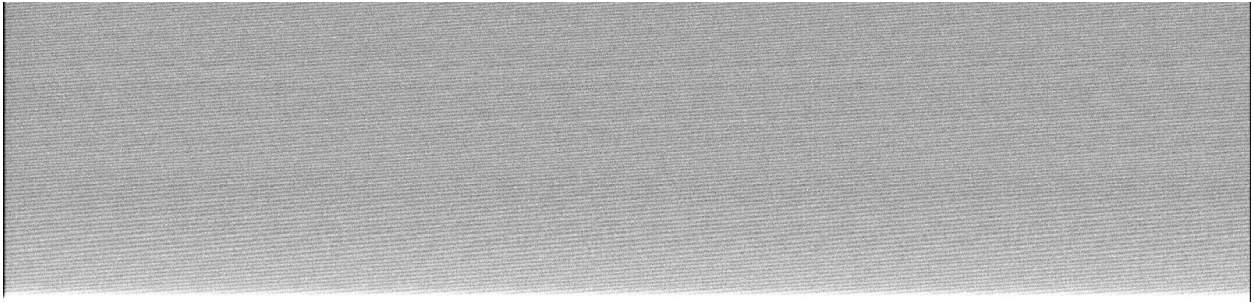
Figure 9. Example bias frame.

2. 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.
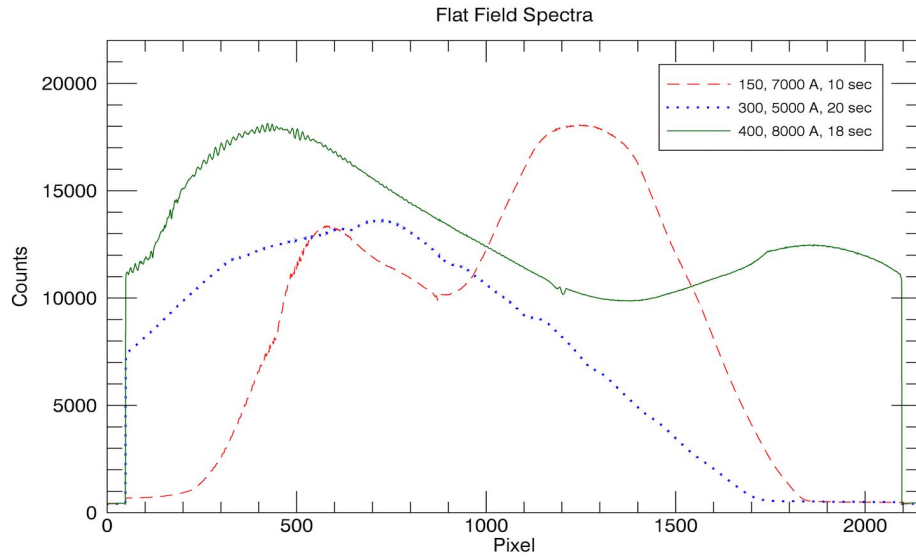
Figure 10. Example flat field spectra for the 150 g/mm, 300 g/mm and 400 g/mm gratings. Note: spectra are not wavelength corrected, thus red is on the left and blue is on the right. The legend gives the central wavelengths and exposure times (exposure times were varied to give 10000 - 20000 counts) . Fringing is seen in the red end of the spectra. These were taken using the top-ring lamps at a setting of 12V.
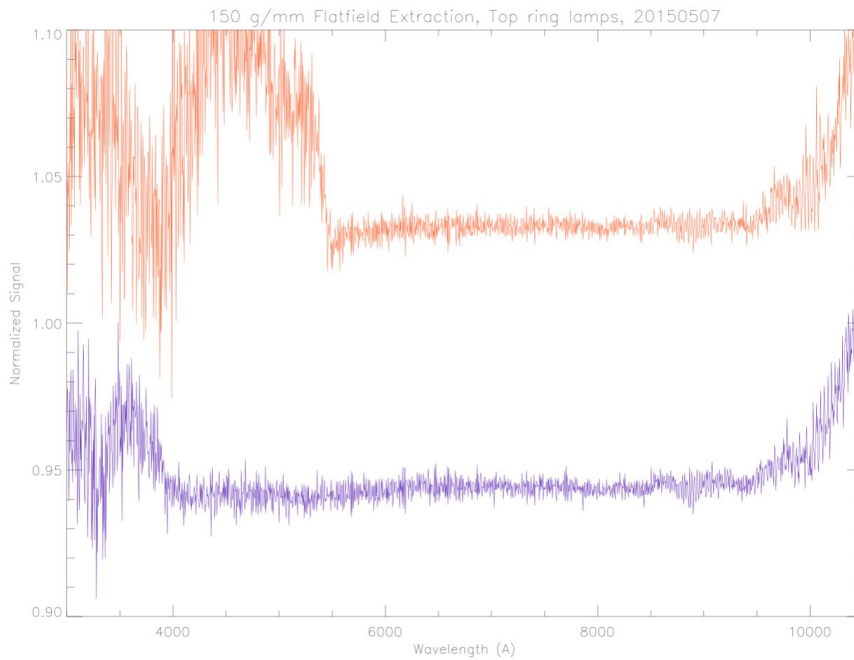

Figure 11. Normalized and offset flatfield profiles for the 150g/mm grating, with no blocking filter (purple), and with GG495 (orange), which show the emergence of fringes of approximately 1% amplitude redward of about 8000-8400 Å.

Fringing in the CCD with the deep depletion device is significantly reduced from the thinned CCD 42-10. For example, Figure 11 shows normalized flatfield profiles extracted from 150g/mm top end dome flatfields where approximately 1-3% fringe amplitudes emerge redward of about 8400Å. 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.

3. 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). Nominal exposure time for the arcs with the low-dispersion gratings is about 20 s when the lamps are warmed up.
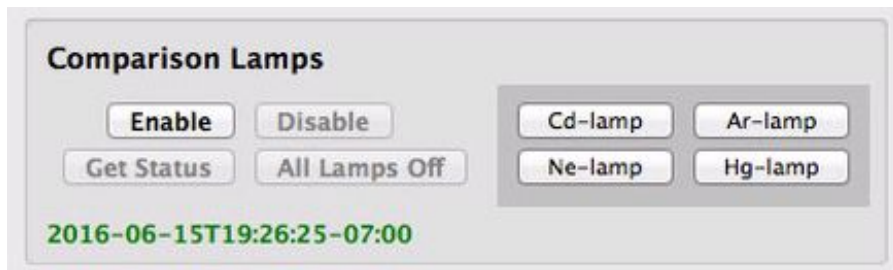
Cadmium (Cd) lines occur primarily from 3200 to 5500 Å, including 3 lines in the 'green gap' around 5000 Å. Mercury (Hg) covers roughly 3300 to 5800 Å, neon (Ne) covers roughly 5800 to 8600 Å, and argon (Ar) covers roughly 6900 to 9700 Å. A sample spectrum is shown in Figure 12. Appendix A shows blue and red-side arc line identifications for the 300g/mm and 400g/mm gratings; the line list is also tabulated there.

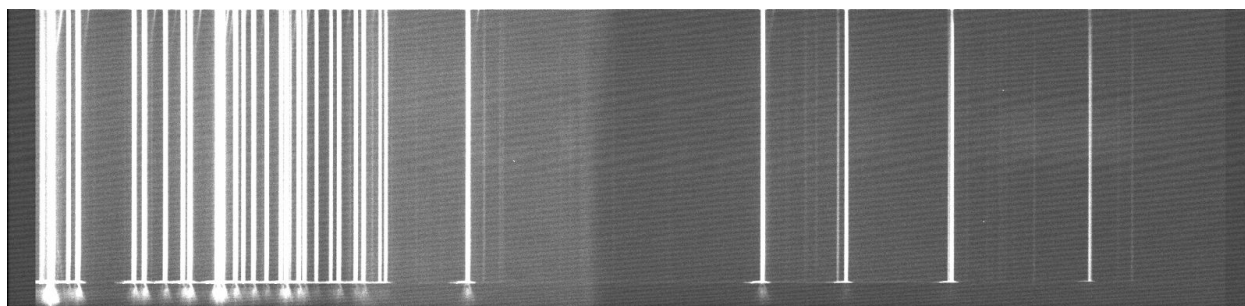**Figure 12. Example arc spectrum, taken with the 300 g/mm grating at a central wavelength of 5000Å**
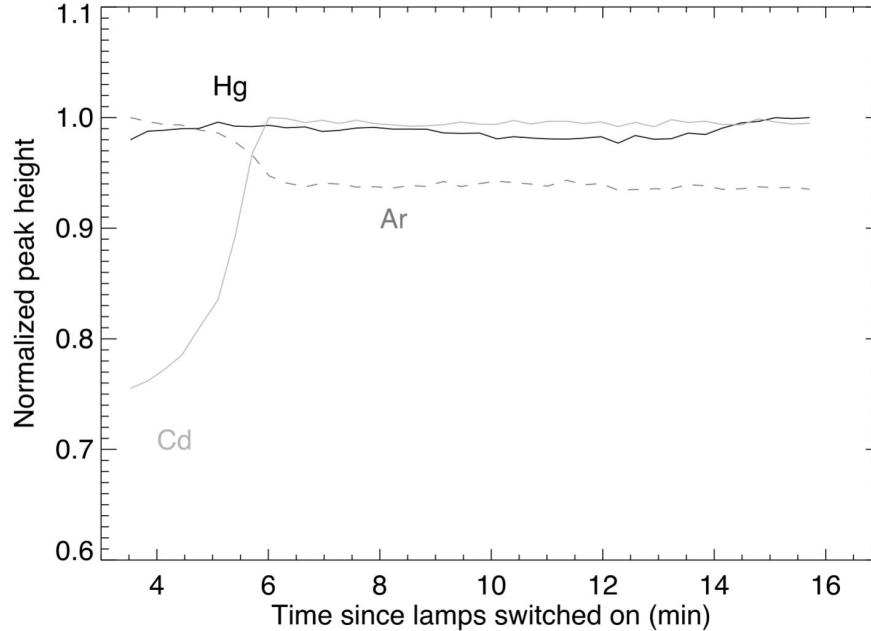
Figure 13. Arc lamp warm up curves. Ne stabilizes within a minute, Hg in 1-3 minutes, Ar, in 4-6 minutes and Cd in about 6 minutes. They may well be usable before they have fully stabilized, but caveat emptor.

d) Slit viewing camera operation

1) Starting the control software: GoQat and slitviewg:
The slit viewing camera is operated through USB connections on both the instrument and computer room ends, connected by a fiber-based extender; the extender unit on the telescope has a separate DC power supply.

The camera is controlled by the computer *vishnu,* through the GoQat software package, and operated on-sky through the locally-developed IDL 'slitview' package.

To start up the slit viewing camera and software GoQat:
  i.   From a local terminal window on *baggins,* login to the control computer *vishnu*:
       `ssh -X lois@vishnu`, password: ask TO
  ii. In this terminal, type `goqat.start` this script will check for and create a data
       directory titled with the current UT date, and start up GoQat . The script is:
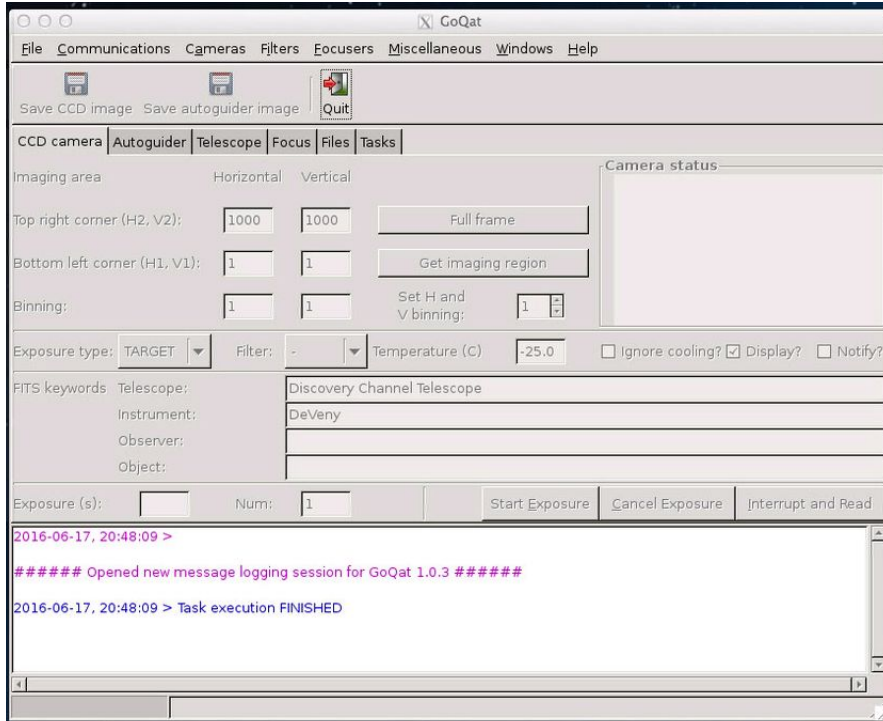   /home/lois/bin/goqat.start
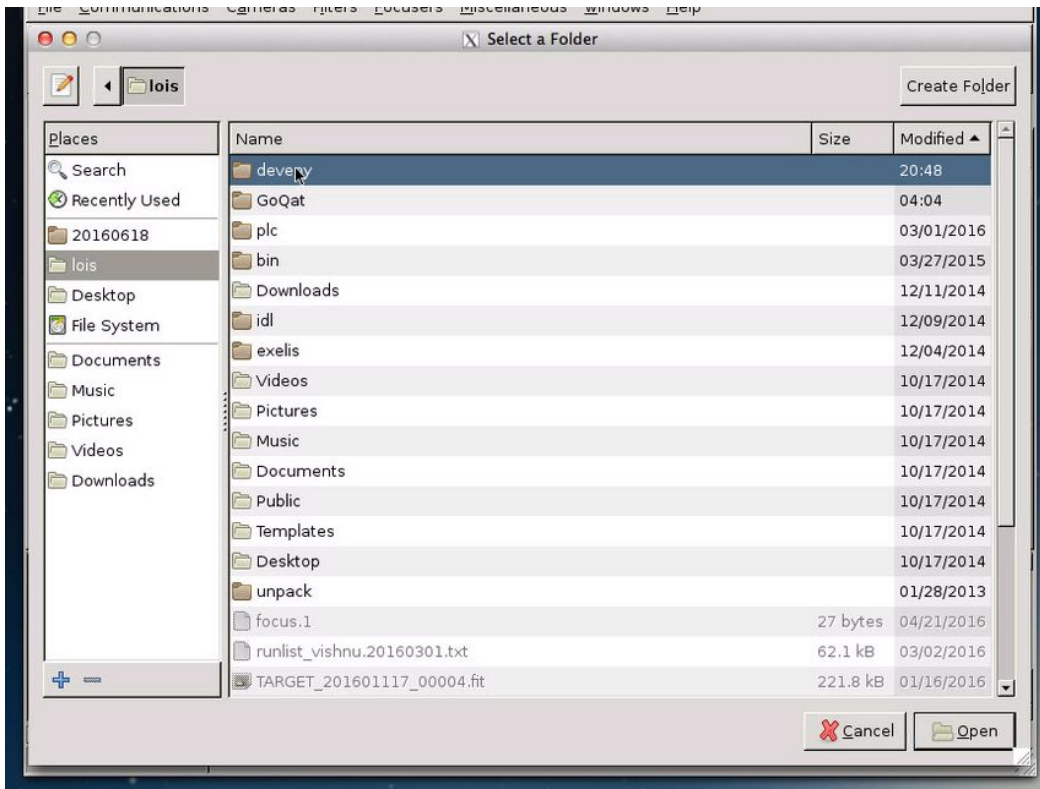
Figure 14. GoQat camera software interface.

Figure 15: GoQat directory selection. *Top:* **Directory selection window, appears after selecting 'other' from the 'Folder for saving CCD image:' drop down menu.** *Bottom:* **A cut from the 'Files' tab showing 'Autosave each image?' selected, the UT date directory selected, and the UT date filled as the 'Base filename for CCD image:'**

iii. In the GoQat GUI (Figure 16):
    Connect to CCD camera using the Cameras drop down menu
    Set H and V binning to 2, in the CCD camera tab
    Set exposure time to 1sec, in the CCD camera tab
    Files tab: i.e. lois/deveny/yyyymmdd
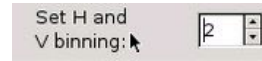   (Figure 18)   Autosave each image: check
                          Base file name for CCD image: enter i.e. 'yyyymmdd'
                          Save files with number starting from:
                                start at 1 and adjust as necessary.
    Take an image, hit start exposure, when the image is complete a ds9 window will
    pop-up with an image of the slit. The ds9 window is not needed but **do not** close it.
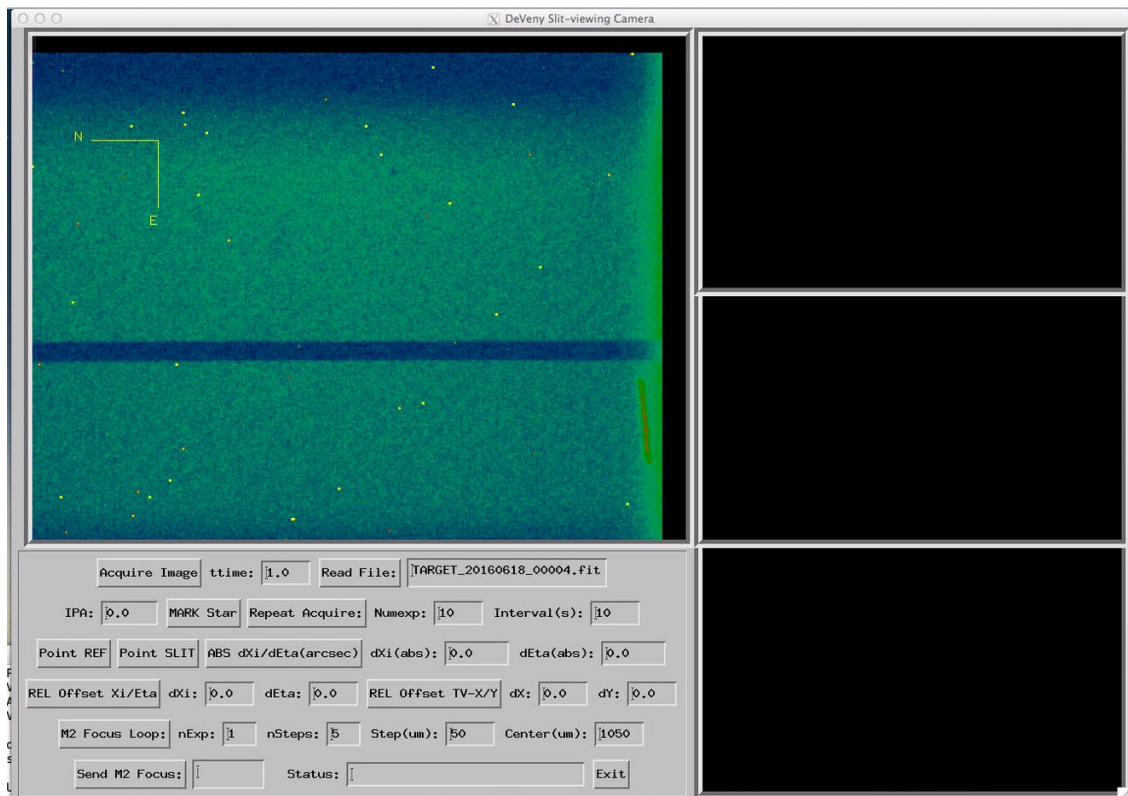
2) IDL slitview package:

Figure 16. IDL slitviewg control GUI.

i.   Open a second terminal window to vishnu, logging in as above.
ii. Change directory to the working data directory for the night:
     i.e. /home/lois/deveny/yyyymmdd
iii. Type "idl" to launch idl. The slitview code automatically compiles.

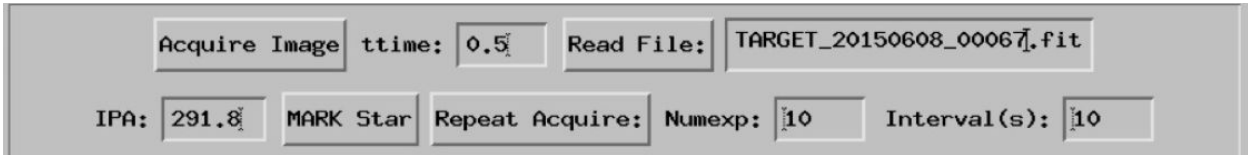iv. At the idl prompt: type slitviewg'. this launches the slit viewing camera top level control GUI (Figure 19).

Acquire Image ttime: 0.5   Read File: TARGET_20150608_00067.fit

IPA: 291.8   MARK Star   Repeat Acquire: Numexp: 10   Interval(s): 10

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

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

2) **Read File**:   TARGET_20150608_00067.fit   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. Set the IPA, to the correct sky angle (details to follow), upon taking the next image the compass rose position will be updated.If you are observing at the parallactic angle then the IPA should be set to the parallactic angle. If you are keeping the sky fixed on the slit this should be set to the current rotator IPA Both of these angles can be found the Facility Summary tab of the LOUI (Figure 21). You will need to update this angle every time you change the rotation angle of the spectrograph.
4) **MARK Star**: Fits a 2-D Gaussian function to a selected star in the field of view. (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.)
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.
Images are currently 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.

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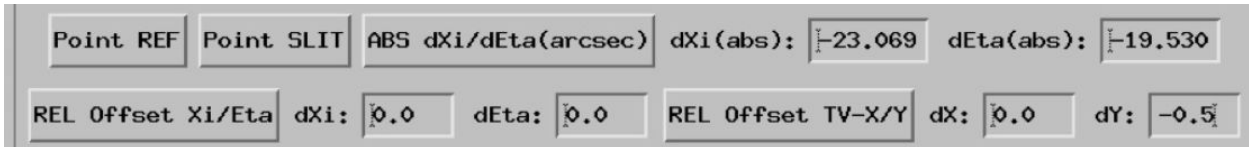
Figure 19. Cut-out section of the slitviewg GUI showing the offset selections.

6) **Point REF**: Moves the telescope to put the star ~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 23).

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 23).

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

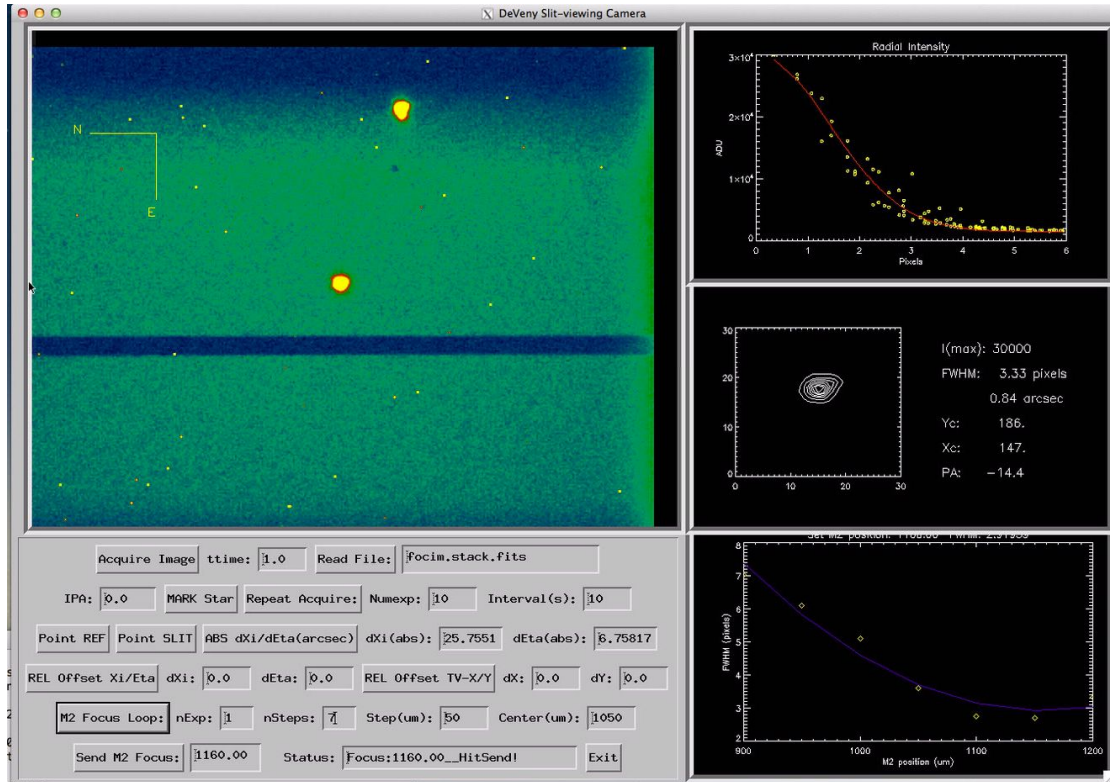8) **ABS dXi/dEta**: Sends an absolute telescope offset in arcseconds in TPLANE dXi/dEta coordinates (~RA/DEC directions). The offset shown is absolute with respect to the original science target position.

    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

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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. Value defaults to 1050 μm.
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 25).
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.
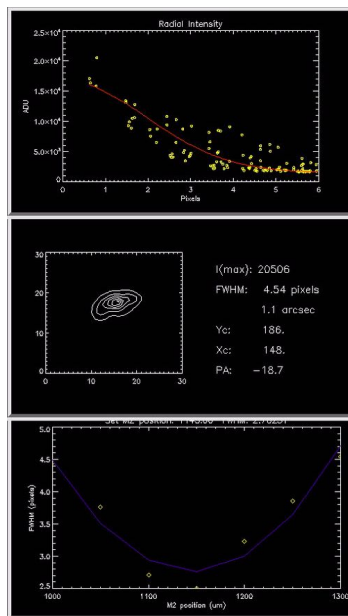

Figure 22. Right panel of the GUI showing the radial plot and contour plot for the final step of the focus loop. The lower panel shows the focus plot and the fitted curve used to give the final focus value.

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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.

```
Status:  Focus:1145.00__HitSend!        Exit
```
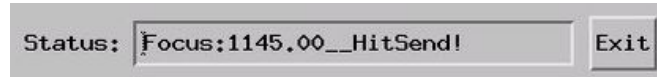
e) Focusing the Telescope

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 μm. Use a 13th magnitude star (approx.) for focusing, with ttime=1s. 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.
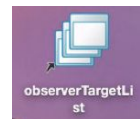
5) Setting up for Object Spectra

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 26) 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 DeVeny 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 (GDR). 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 *baggins* from the corresponding data directory on *deveny* itself, where LOIS writes the original data. The naming convention yyyymmdd 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 *baggins*, 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 *baggins* with the command 'loiscopy status'. There is also a pdf of the loiscopy document ('Fast Copy Support') in the Documents directory on *baggins*.

8) Troubleshooting notes for Observers

a) If the IDL widget hangs:

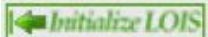Images are not updated, offsets are not sent, etc.

At the IDL prompt in the terminal that launched the IDL widget, type
        @recover
Repeat if necessary.

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

If the DeVeny 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 ⏻ Exit LOIS
- 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.

- Initialise lois - in the top right of the LOUI press ◀ Initialize LOIS

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.
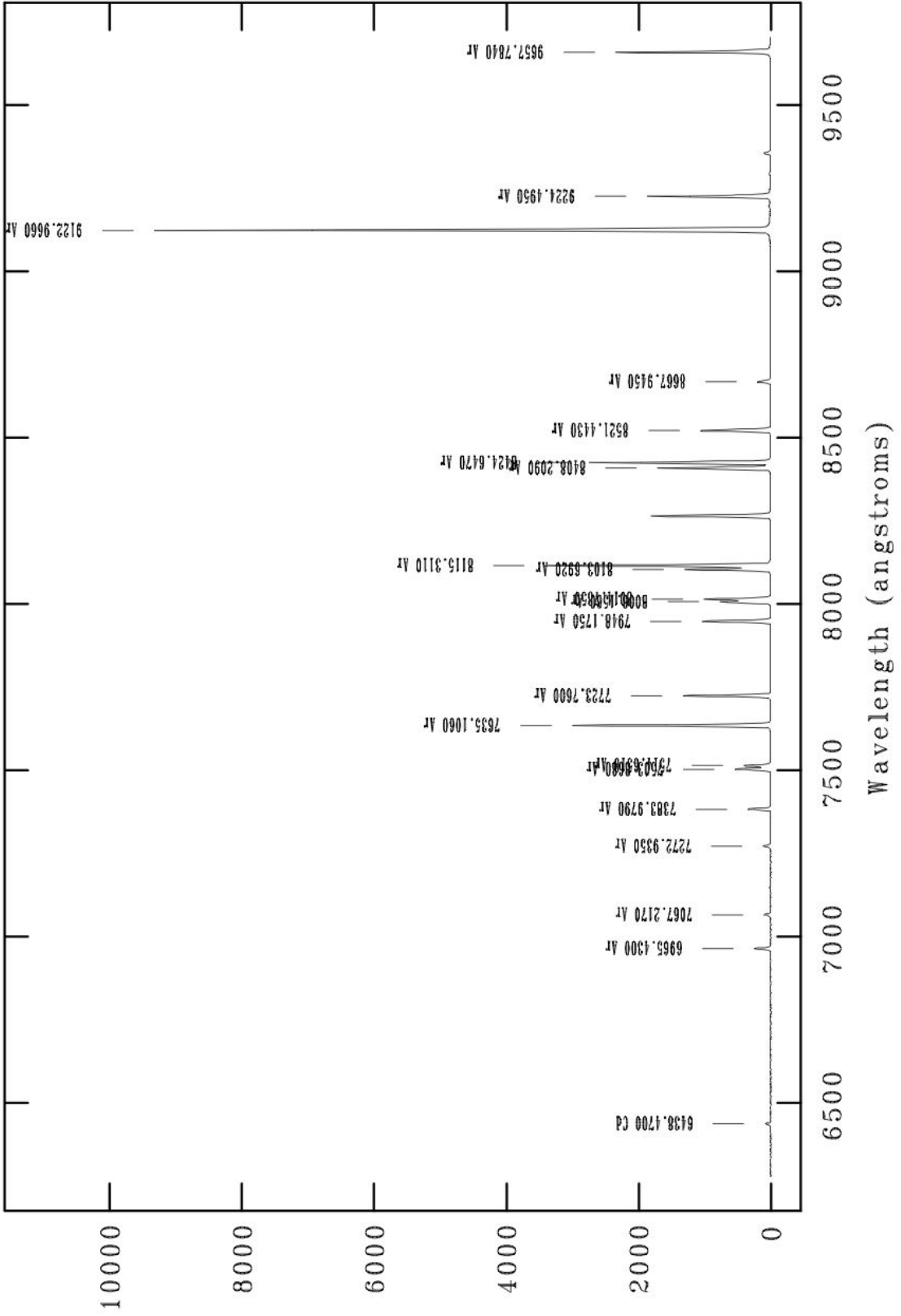
Appendix A: Arc Line Identification

The line list for the DeVeny arc lamps is given in table AI and the spectra are shown in Figures A1 - A3.
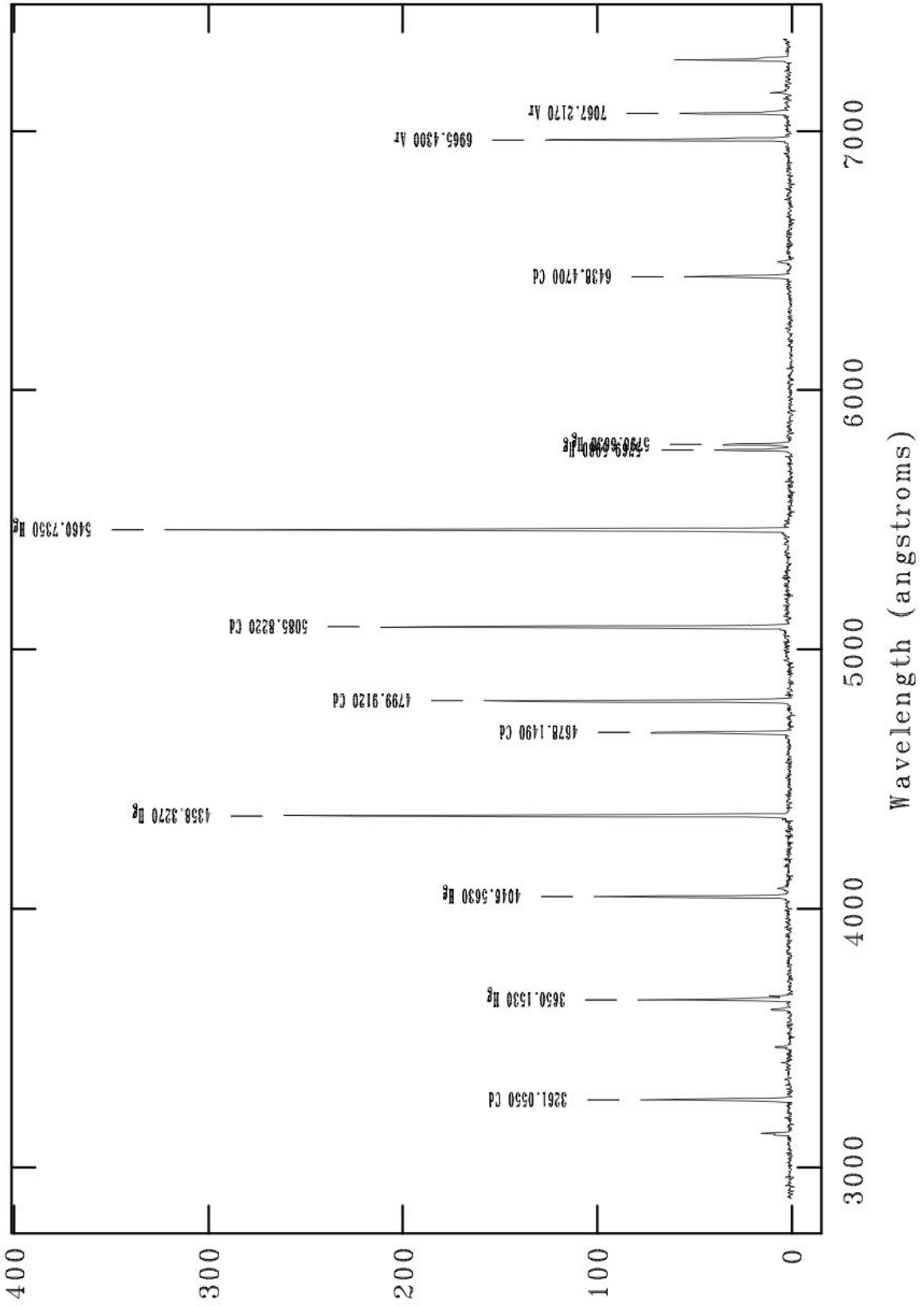
Table AI. Arc Line Identification by Species

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

Wavelength (angstroms)

9657.7840 Ar

9224.4950 Ar

9122.9660 Ar

8667.9150 Ar

8521.4430 Ar

8408.2090 Ar 8424.6470 Ar

8115.3110 Ar 8103.6920 Ar

8006.1560 Ar 8014.7860 Ar

7948.1750 Ar

7723.7600 Ar

7635.1060 Ar

7503.8690 Ar 7514.6520 Ar

7383.9790 Ar

7272.9350 Ar

7067.2170 Ar

6965.4300 Ar

6438.4700 Cd

NOAO/IRAF V2.16.1 tbida@tapeats.local Thu 11:48:15 21-May-2015
identify arc300_cl_all - Ap 1

Wavelength (angstroms)

3261.0550 Cd
3650.1530 Hg
4046.5630 Hg
4358.3270 Hg
4678.1490 Cd
4799.9120 Cd
5085.8220 Cd
5460.7350 Hg
5769.5980 Hg
5790.6030 Hg
6438.4700 Cd
6965.4300 Ar
7067.2170 Ar

NOAO/IRAF V2.16.1 tbida@tapeats.dfrc.nasa.gov Mon 18:49:34 18-May-2015
identify arc150_cl_all - Ap 1

Wavelength (angstroms)

37
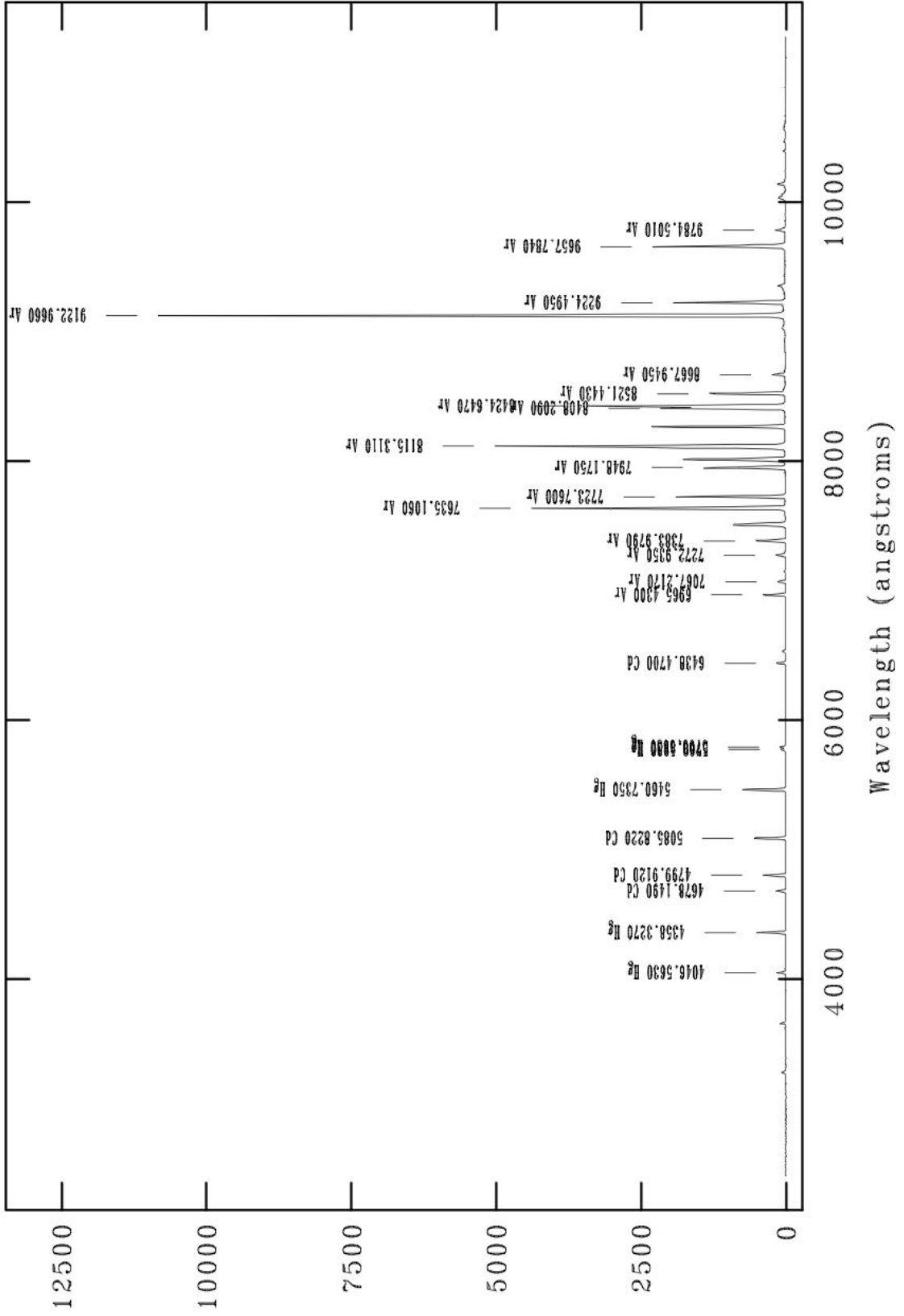
Appendix B: Nominal blocking filter data sheets

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).
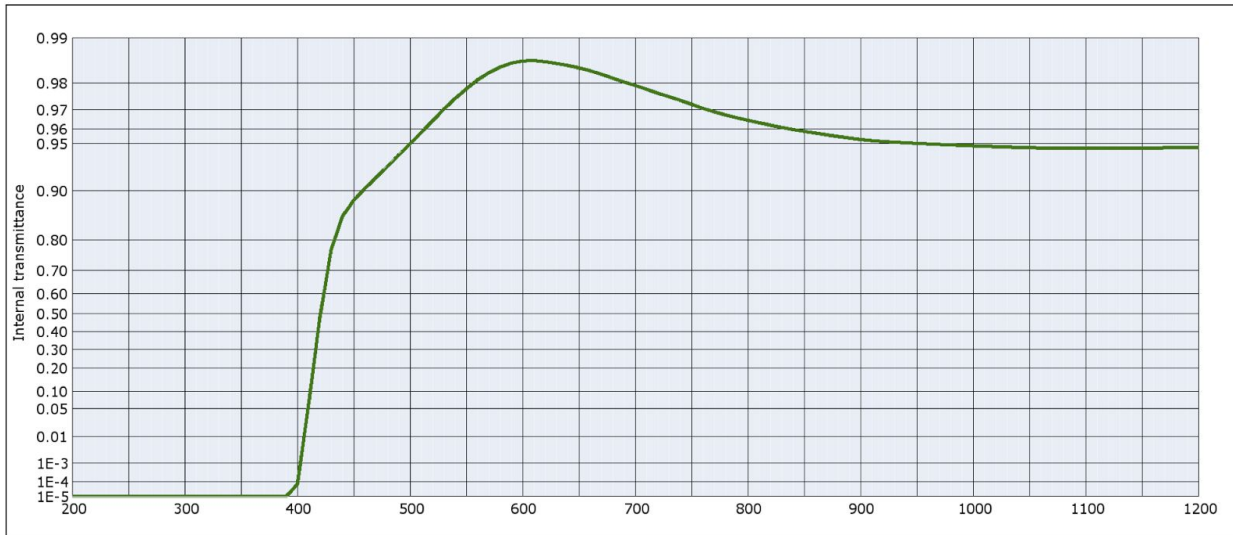
2. GG495 filter transmission curve (from Schott)
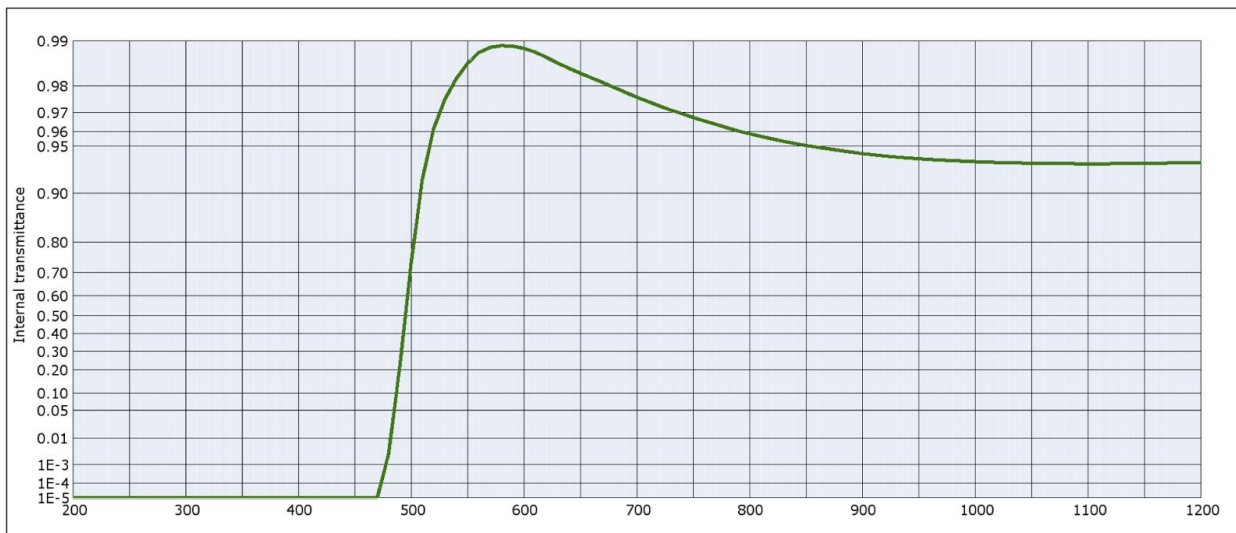
3. OG570 filter transmission curve (from Schott)

Appendix C: The Observer Target List Tool

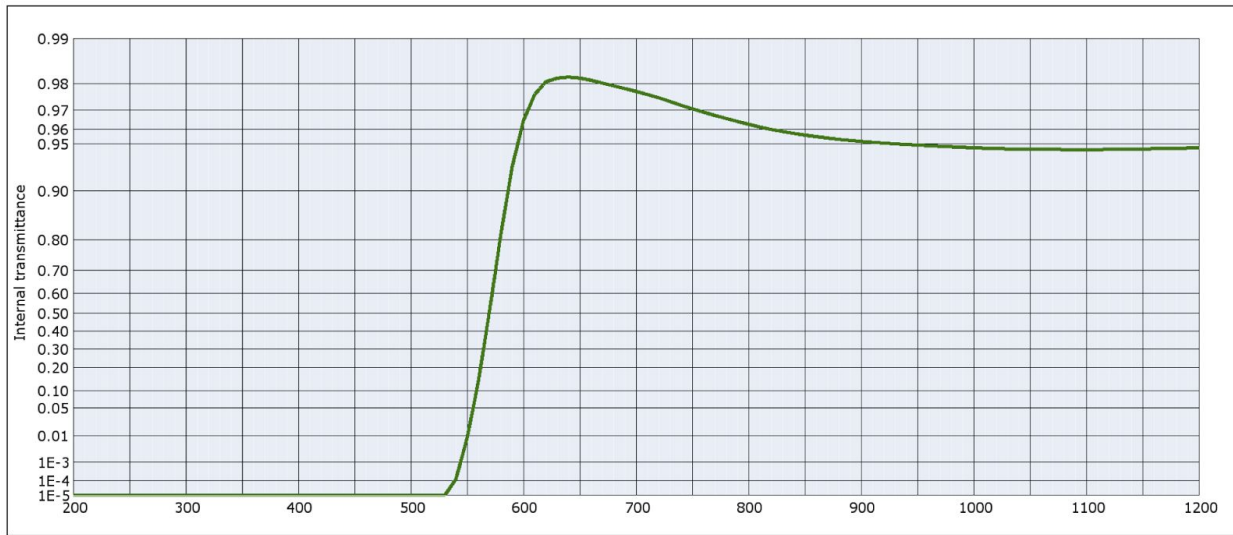As mentioned in §5, above, the telescope may be controlled through the use of the Observer Target List Tool. To use this tool a Target List must be provided. These lists are provided in the form of a text file, saved with the extension .tls. The files must contain meta data, such that the GUI/widget 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 Postion 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., emacs) as the UI does not recognise smart characters.

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 3rd '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).