Observer’s Guide for KSPEC

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1 System Description

The University of Hawai‘i (UH) K-band spectrograph (KSPEC) utilizes a cross-dispersed echelle design to provide medium-resolution spectra of the 1–2.5 μm region, optimized for 2.2 μm. The instrument uses two arrays, a HAWAII 1024 × 1024 array as the detector for the spectral information, and a 256 × 256 NICMOS array as a slit-viewing array which images the region of the sky surrounding the slit. The control software runs on a unix workstation and is similar to the QUIRC camera.

The KSPEC dewar has two LN\textsubscript{2} reservoirs— one large capacity (4.92 liter) which cools the radiation shields, central cold plate, optics, and imaging detector, and one smaller (2.46 liter) reservoir which is thermally connected to only the spectral array. The hold time for the large reservoir is approximately 17 hours; the hold time for the smaller one is several days because of the low heat load. The dewar contains no moving parts, other than the externally mounted shutter. The electronics consists of separate driver boards, preamps, and A/D boards for the two arrays, and a Leach DSP controller that clocks the arrays and provides the data link to the workstation.

1.1 Filling the Dewar

There are two fill tubes, one for each of the nitrogen reservoirs. The tubes are located on the top of the dewar, and have right-angle fittings so that the fill tube is accessible from the side while the dewar is bolted to the telescope. In the normal orientation of the dewar, the open ends of the fill tubes face N (towards the control room). There are two tubes for each reservoir; one is the actual fill tube which goes all the way into the can, the other is a vent tube so that boiloff N\textsubscript{2} can escape when filling. The fill tubes are the smaller tubes in the center of the fittings, the larger tube are the vents. If one is facing the dewar, the right side tubes are for the large reservoir, the left tubes are for the small (spectrometer) reservoir. The large reservoir should be filled once every twelve hours. The spectrometer reservoir has a much longer hold time and so needs to be filled no more than once approximately every 5 days, if the large one has been kept properly topped off. When pumping on the spectrometer reservoir, one must fill more often, about every 3 days, because of the higher boil-off.

The fill tubes extend approximately halfway into the dewar cans. The large can must be completely filled in order to reach the full hold time. The best way to complete the fill is by attaching a funnel to the dewar fill tube opening using a short piece of flexible tubing. Normally this funnel and tube will be left attached to the dewar. The LN\textsubscript{2} can then be poured into the funnel and allowed to slowly fill the reservoir. The dewar is full when one starts to see LN\textsubscript{2} starting to come out of the vent tube. If one tries to blow the LN\textsubscript{2} directly into KSPEC using the pressurized storage dewar, the dewar cannot be completely filled because LN\textsubscript{2} begins blowing out of the vent tube when the can is only about half full. An alternative way to fill is to run the tube from the pressurized storage dewar to the funnel. There is not much space between the funnel and the bottom of the telescope, so it is sometimes difficult to pour from the hand-held flask into the funnel.

When pumping on the inner can, it must be refilled more often, about every 2-3 days. Usually the day crew will be responsible for this task. First, the pumping hose should be valved off and the inner can should be brought to atmospheric pressure. Then the pumping hose is removed and the dewar filled in the usual way with the funnel and short tube, filling until LN\textsubscript{2} begins spilling out the other tube. Then the pumping tube is reconnected and pumping resumed. An alternative technique is to do the fill while still pumping, allowing the vacuum to help pull the LN\textsubscript{2} into the can. However, it is impossible to tell when the inner can is full, and this is believed to have resulted in a loss of vacuum at the telescope on one occasion. This happens when the O-ring at the fill tube freezes and causes the seal to fail.
1.2 Electronics and Computer

The camera electronics are located in the two rectangular boxes below the dewar. The white box contains the imaging detector electronics; the red box contains the spectrometer electronics. The smaller gray box mounted on the back contains the Leach controller and driver boards. The electronics are powered by supplies that are located in a rack-mounted unit on the telescope. Two separate Lakeshore temperature controllers monitor the temperatures of the detectors, and are also mounted in this rack.

The instrument is linked to the workstation via a fiber optics interface. Commands from the workstation are sent to the DSP and data and other information are read by the workstation.

2 Instrument Parameters

2.1 Imaging Detector

The imaging detector views the region of the sky surrounding the slit. The pixel scale is 0.24 arcsec/pixel; the field of view along the longest dimension is $\approx 1$ arcmin. The slit in the image plane is almost the same length as the full field, but is masked off to allow about 15 arcsec to pass to the spectrograph section. A $K$ filter is permanently mounted in the imaging optics. The slit-viewing capability facilitates the source acquisition and centering operations. Since the user can see the region of the sky around the slit, it is easy to find the source and place it at the desired slit position. The image can be stored as a record of the slit position, and images taken during the spectral integration will confirm that the telescope is guiding properly. Figure 1 shows a typical image.
2.2 Spectrograph Detector

The spectrograph detector is a science-grade HAWAII device with relatively few pixel defects in the regions used. For most pixels, the dark current is less than 0.1 electrons/sec and the read noise is about 12 electrons. The current device has pixels with high dark current near the bottom edge of the array. The spectrograph section is operated at 73K to reduce the dark current from these pixels and minimize their impact on the data. The pixel scale for the spectrograph detector is 0.167 arcsec/pix, and the useable slit length is approximately 17 arcsec.
Table 1 gives the approximate wavelength ranges and resolutions for the six orders. Sensitivity values are also given. These are $1\sigma$ values for a 3 minute on-source integration, after subtracting a similar 3 minute integration. If moving the source along the slit, then the total on-source time equals the total integration time and the numbers in Table 1 can be used to estimate this. If moving the object off the slit for sky frames (e.g., when observing an extended object), then the total integration time required will be two times the total on-source time.

Table 2 gives the resolution of each KSPEC slit, based on the measured resolution of slit #4 at the 2.2-meter telescope at 2.2 $\mu$m in the $K$ order. The width of the slit on the spectrograph is about 3 $\AA$ wider than the physical size of the slit due to a slight defocus of the spectrograph optics. The defocus is different in each of the orders. For example, with slit #4 the resolutions in the orders are: 650 ($K$), 665 ($H$), 674 ($J_2$), 585 ($J_1$), and 571 ($I_2$).

Note that the sensitivities given here do not include overhead time necessary to make the observations, including acquiring the source, centering on the slit, detector readout, and telescope motion. When estimating the time necessary to perform an observation, additional time must be included for these tasks.

For the imaging detector, the noise equivalent magnitude was measured to be 18.1 (in $K$) in one minute of integration (1 minute total, using a median-filtered sky image to subtract the background).
Table 1. KSPEC Orders (0.96 arcsec slit, UH 2.2m telescope, 3 minute exposure)

<table>
<thead>
<tr>
<th>Order Name</th>
<th>Range (μm)</th>
<th>Scale (μm pixel(^{-1}))</th>
<th>Continuum (10(^{-14}) W m(^{-2}) μm(^{-1}))</th>
<th>Sensitivity Mag.</th>
<th>Line Flux (10(^{-16}) W m(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1</td>
<td>0.81–0.95</td>
<td>0.00014</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>I2</td>
<td>0.84–1.08</td>
<td>0.00022</td>
<td>11.0</td>
<td>...</td>
<td>43</td>
</tr>
<tr>
<td>J1</td>
<td>0.98–1.27</td>
<td>0.00029</td>
<td>9.5</td>
<td>...</td>
<td>12</td>
</tr>
<tr>
<td>J2</td>
<td>1.18–1.52</td>
<td>0.00034</td>
<td>9.6</td>
<td>11.1</td>
<td>22</td>
</tr>
<tr>
<td>H</td>
<td>1.47–1.90</td>
<td>0.00042</td>
<td>2.7</td>
<td>11.4</td>
<td>1.8</td>
</tr>
<tr>
<td>K</td>
<td>1.96–2.54</td>
<td>0.00056</td>
<td>0.94</td>
<td>11.5</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Table 2. Available Slits for KSPEC

<table>
<thead>
<tr>
<th>Slit #</th>
<th>2.2-meter (arcsec)</th>
<th>CFHT (arcsec)</th>
<th>Resolution (K order) (λ/Δλ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.33</td>
<td>0.19</td>
<td>1570</td>
</tr>
<tr>
<td>2</td>
<td>0.56</td>
<td>0.32</td>
<td>1030</td>
</tr>
<tr>
<td>3</td>
<td>0.79</td>
<td>0.45</td>
<td>760</td>
</tr>
<tr>
<td>4</td>
<td>0.96</td>
<td>0.56</td>
<td>650</td>
</tr>
<tr>
<td>5</td>
<td>1.08</td>
<td>0.62</td>
<td>570</td>
</tr>
<tr>
<td>6</td>
<td>1.47</td>
<td>0.85</td>
<td>430</td>
</tr>
<tr>
<td>7</td>
<td>1.65</td>
<td>0.95</td>
<td>390</td>
</tr>
<tr>
<td>8</td>
<td>1.92</td>
<td>1.10</td>
<td>335</td>
</tr>
<tr>
<td>9</td>
<td>2.11</td>
<td>1.22</td>
<td>310</td>
</tr>
<tr>
<td>10</td>
<td>2.61</td>
<td>1.50</td>
<td>250</td>
</tr>
</tbody>
</table>
A raw spectral image is shown in Figure 2. The $K$ order is on the bottom, with $H$, $J2$, etc. above it. Wavelength increases from right to left in all orders, and from top to bottom. The spectrum shows a short integration of a standard star. Note how the thermal continuum rises sharply at the long wavelength end of the $K$ order.

3 Observing Technique

It is assumed that the observer is familiar with the standard techniques for observing with the UH QUIRC camera; see the document “Observers Manual for QUIRC” for more information. Also see Appendix 2 for a list of the program commands and instructions. The standard methods for using the IR camera can be used to observe and reduce images obtained with the imaging detector.

The general method for taking spectroscopic data is similar to the imaging data – one usually takes data in pairs of “on” and “off” integrations of equal time using the telescope nod. For fairly bright point sources and standard stars, the object can be chopped along the slit and the images differenced to subtract the sky. For extended sources, the slit is not quite long enough for nodding along the slit with the source in both beams. In those cases, it is better to move the source entirely off the slit for the integration on the sky. The ideal off-source position is different for various objects. If one is looking at an isolated point source or a point source with background nebulosity, one should use a sky position as near as possible to the object of interest to properly sample the surrounding background. This can typically be a few arcsec in a direction perpendicular to the long direction of the slit. If one is observing an extended source, the “off” nod must move completely off the source to properly measure the sky background, and in crowded fields, care must be taken so that the sky position is not on some other source.

The best way to center a star on the slit and keep it positioned is by using the autoguider. Once an object is acquired in the KSPEC image, the guide star should be found and guiding started. Take another image after guiding starts because the guider will move the telescope slightly. Calculate the necessary offset to center the object on the slit (use $v_f$ as described below) and move the telescope with a guided offset (see below). Then mark the position as base, making this the reference position for further offsets. After this, the telescope should be moved with guided offset commands with a command file or by typing commands at the kspec program prompt.

3.1 Detector Saturation Levels

The saturation levels are different for each array. For the spectrometer, the counts should be kept below 20,000 counts per sample to avoid non-linearity. The system gain is roughly 4.3 electrons per ADU for the spectrograph. The multiple sampling mode sums the counts from each sample, and does not normalize by the number of samples. For example, if the peak flux has a value of 2000 in one sample, if the number of samples is changed to 8, then the peak will be 16000. Currently, the data are stored as two-byte integers, which gives a digital maximum of 32767. Therefore, one can be in “digital saturation" when using multiple samples well before the device is actually saturating. For the example of a peak of 2000 ADU’s, if one were to set the number of samples to 20, the sum of the samples would be 40000 which would exceed the range of the 2-byte integers. Note that the overall flux level can be within the saturation limits, but the brightest emission lines can be many times the continuum level. Therefore if one is interested in measuring these lines, the pixels at the location of the emission lines should be checked for saturation.

The saturation level on the imaging detector is 12,000 counts per sample. It is not used in the multiple
sample mode. It is a good idea to check the numbers when starting to observe a new standard or object to
insure that the array is not saturating. If the saturation is severe, the counts can actually begin to be reduced
as flux is increased further. If there is any doubt, several exposure times should be tried to check the state
of the detectors.

3.2 Calibration

There are three different types of calibration data that must be taken during the course of observing. Dome
flats and darks must be taken to correct for pixel-to-pixel variations in gain, and to help locate bad pixels.
Standard stars must be observed for flux calibration and correction for telluric absorption. Finally, spectra
of the argon lamp must be obtained to determine the wavelength calibration for the data. Alternatively, one
could use the night sky lines present in the data, or observe a source such as a planetary nebula with many
bright lines in all orders to obtain the wavelength calibration.

3.2.1 Dome Flats

Dome flats and darks are taken in much the same way as is done for QUIRC. The bright flood lamp should
be used for the spectrograph dome flats so that sufficient flux is obtained in a short time period. Alternating
exposures with the lights on and off are taken with the same operating parameters (number of samples) as
will be used when performing the astronomical integrations. A 30 second integration time provides good
illumination while staying well below saturation. Dividing the data by the difference between the lights
on and off integrations will correct for the pixel gain variations, as well as non-uniform illumination of the
array caused by the telescope, KSPEC optics, or other effects. Figure 3 shows an example of a dome flat.

There is a fringing effect that the observer should be aware of. This manifests itself as a sinusoidal variation
of intensity in the dome flats (and also in the source spectra) with a period of about 10-12 pixels at the
long wavelength end of the $K$ band, and decreasing towards shorter wavelength. To remove this effect, the
dome flats must have adequate S/N over all wavelengths of interest. Therefore one should take care that
the flux level of the dome flats is high enough over the full range of the orders. This may require taking
longer exposures for certain spectral orders. Also, variations of the object’s position along the width of the
slit can change the fringing pattern. This will be more severe for brighter stars where the integration time
is short and therefore the FWHM of the star is small and can be less than the slit width. In these cases, it
may be better to slightly defocus the star to fill the slit width, or choose fainter standards where one can use
integration times comparable with the sources of interest.

3.2.2 Calibration stars

Standard stars must be observed during the night to correct for telluric absorption. Calibration stars can be
found in the Yale Bright Star catalog; the Hipparcus and SAO catalogs are other sources with more stars.
One must choose stars of a spectral type with few spectral features at wavelengths where there are features in
the objects to be observed. For example, if one is trying to observe the Br $\gamma$ feature in the source, one should
not choose a standard star with Br $\gamma$ absorption. When in doubt, standards of two different spectral types
(e.g., A0 and G0 dwarfs) can be observed and compared to identify lines in the standard star spectra. The
standards must be observed at a minimum of two different airmasses to determine the airmass-dependence
of the corrections.
The HAWAII arrays have a relatively high filling factor, and coupled with the better sampling due to its smaller pixels, will not have problems with short exposures of bright standard stars. Using exposure times of one second or more is recommended to reduce the shutter timing uncertainty for the flux standards. The shutter timing is uncertain to about 10 ms, so a longer integration time insures that this is a small effect. Also, bright sources that drive the detector into hard saturation will leave residual images which require 10–15 minutes to completely purge. Additional readouts will not help speed up the recovery process. In practice, stars greater than 5 magnitude can usually be observed with integration times of 1 second or more with no saturation problems.

Figure 3. Spectral image of the dome. The dark dome image of the same integration time has been subtracted. This shows the separation between orders, and their relative transmission.

3.2.3 Wavelength calibration

The wavelength calibration data is obtained by illuminating the instrument with an argon lamp. Figure 4 shows a typical calibration spectrum integration. The lines can later be identified and the wavelength position and scaling can be determined. Since there are no moving optical components in the dewar, the wavelength calibration should remain constant. In principle, there is no need to take new data, one could use the calibration data already obtained. However, slight shifts in the calibration are possible over long
periods of time and from thermal cycling of the dewar, so it is probably a good idea to do this calibration once during a run. The argon lamp has many lines throughout the orders that can be used for calibration; however, the intensity is different for each of the bands, so that at least two different integrations must be used to get well-exposed lines in all bands without saturation. There are some lines that will go into hard saturation during this process and will take long periods to purge, so the calibration process should be done at the end of a night, or during the day before the start of the run. See Appendix 3 for an example of an argon lamp calibration of a KSPEC spectrum.

Figure 4. Calibration spectrum of argon. Note the overexposed lines in the $I$ orders appear with dark centers. A shorter integration must be used to get proper calibration data for those wavelengths.

Another option for wavelength calibration is to use the night sky lines (OH$^{-}$emission lines). There are many lines in the $J1$, $J2$, $H$, and $K$ bands that are strong in any exposure of $\sim 60$s or more, as can be seen in Figure 2. The wavelengths of these lines are known to sufficient accuracy (e.g., Ramsay, Mountain, and Geballe 1992, MNRAS, 259, 751). One advantage to using these lines is that the calibration data are taken at the same conditions as the object data. No separate observations are necessary; a calibration spectrum can be extracted from any long exposure taken during the night. One problem with this method is that not enough bright sky lines may be visible over the whole range of wavelengths of interest.
4 Software

4.1 Starting the Software

The program is run on halley or wekiu and is called kspec. It is very similar to the qedcom program that is used to operate QUIRC. These programs are based on the ccdcom program and corresponding DSP programs written by Mark Metzger. The programs were modified by Metzger, J. Hora, and E. Irwin for their use with KSPEC. See Appendix 1 for a list of all commands. There are some differences, as outlined below and in Appendix 1. The program can be started by typing kspec at the unix prompt, usually after setting the default directory to be where one wants the data stored. The default directory can be changed after starting the program as well.

The dsp code to use will be called kspec.lod, in the default dsp code directory, so the command

df kspec

will load the proper dsp program into the instrument.

The file prefix is set using the fp command. The spec and image file prefixes must be set. For example, one could set them as follows:

fp ks950831. ki950831.

to have different names for the images and spectra.

4.2 Taking data

The go command will take an observation. Since there are two detectors in KSPEC, there are two modes of operation, set by the commands image and spec. The command set image on or off is also valid. When a go is done, a spectrum (1024x1024) or image (256x256) is taken. There is a third mode where a long spectral integration is taken, and one or more shorter image frames are taken at the same time. This is done by doing the spec command to set to the spectrum mode, and then turning on the switch to take simultaneous data. This is done via the auto command. Several other basic operational parameters are set with this command. Below are the usual defaults:

Number of times to reset chip before exposure [1]:
Open shutter for exposure? [yes]:
Read detector after exposure? [yes]:
Turn on continuous reset after readout? [no]:
Do double-correlated read? [yes]:
Simultaneous spectrum and image? [no]:

The integration time is set with the et command. The SPEC and IMAGE times are set separately. The et command will set the integration time for the particular mode one is in. Alternatively, one can set the integration time directly using the spec or image commands, for example, spec 10 will set the spectral integration time to 10 seconds.

There are several other parameters that are stored separately for the spec and image modes, these are accessed using the sauto or iauto commands. These parameters are the number of frames to read out, whether
to save the data automatically to disk, the chop mode, and whether to write a difference frame (useful to display data). Below is the sauto:

Number of samples [4]:
Write data to file after read? [yes]:
Subtract previous dither frame from current? [yes]:
Do telescope chop? [no]:

and iauto:

Number of samples [1]:
Write data to file after read? [no]:
Subtract previous dither frame from current? [no]:
Do telescope chop? [no]:

In the simultaneous mode, the minimum image integration time is around 4s because of the readout and other delay times. The shutter is of course open during the entire spectral integration, so this cannot be used to control the image integration time. As many images as possible will be completed, the program stops taking images at a conservative time before the spectral integration time runs out. In practice, the imaging detector saturates fairly quickly in the simultaneous mode, so only short integrations are possible.

If the auto save is off, and vfout is set on to display data using vf (see below), the data is written to a file ending in .chop and displayed. This allows one to do things like focus, center up the image, etc., without saving a lot of useless files.

4.3 Moving the telescope

Commands for telescope motion can be sent using the kspec program just as with qcdcom. The commands are aoff, aroff for unguided absolute and relative offsets, and goff, groff for guided absolute and relative offsets. Telescope commands are entered using the tel command in kspec. For example,

tel goff 5 -3

will stop guiding, move the telescope to the position (5,-3) relative to base, move the guider to reacquire the star, and resume guiding. The command

tel aroff 0 7

will move the telescope 7 arcsec North from the current position. Most observing should be done using “source” files with kspec commands to move the telescope, guide, and take data. Point sources can be “chopped” along the slit, keeping the object on the slit at all times. For extended sources one should alternate taking object and sky data for background subtraction. Below is the beginning of a sample source file for chopping along the slit (slit oriented N-S, with 0,0 at the center of the slit):

go
tel goff 0 -3.5
5 Using vf to display images and spectra

The vf program which was developed by Tony Denault at the IRTF has been adapted for use with KSPEC. See the vf manual (available on galileo in ~88inch/mkoman/quirc/vf.ps.gz or from the IRTF ftp and web site) for general information on running the program. It is set up properly on halley and wekiu so someone logged on using the obs account will simply type

```
vf &
```

from the obs home directory to run the program.

5.1 Automatic image display

To automatically display images from ks pec, one must do the command

```
set vfout
```

from ks pec and also have vf running. The default data directory in vf (can be set from the Options/Setup menu or the File menu in vf) must be the same as the directory where ks pec is saving the data. If vf is running when the set vfout command is given, the ks pec program sends a command to vf to set the data directory to the current default directory that the ks pec program is using.

The spectra are automatically displayed in buffer B4 (E), one must click on the “E” button to pop this window up. The images are displayed in the B0(A) buffer. The x.5 scale will display the whole spectral image in the B4 buffer. The x1 scale will display the entire slit image in its canvas. See Figure 5 for a sample vf display.
Figure 5. Sample $\nu f$ screen. A slit image is displayed in canvas B0, a spectrograph image of a star is shown in the big canvas B4.

### 5.2 Zooming on object

The “Zoom on ObjBox” is a useful feature to zoom in on a source. After the image has been displayed, make a box around it by moving to the lower left corner and press & hold the middle mouse button, then move to the upper right corner and release. Note that this is different from the original IRTF version of $\nu f$. Then left click on the “Zoom on ObjBox” button and it will magnify it. You can use the slider bars to adjust the zoom location. Click on the .5x button to go back to full scale. When zoomed in, you can use the LineCut display mode to show the profile in the X and Y directions. When zoomed out, you can use the left mouse button to change the position of the box you have defined.

### 5.3 Sending TCS commands to move telescope

The TCS coordinate window can be used to center a source or move it around the array (when running at the 88-inch). The platescale defaults to the f/10 scale. You will have to set it to the proper scale (0.24 arcsec/pix
for f/31 88-inch) and the rotation angle of the instrument, with the angle putting North “up” defined as zero. (In that orientation, East is to the left). This is at a rotator angle of 0, which is 90 degrees from the usual QUIRC rotator position (the rotator will actually be set for 0.2 at the “zero” position). The rotation value entered in vf is actually the position angle, defined as [360 - (rotator value)] mod 360. The two most common values will be rotator of 0 (= 0 in vf) and 270 (=90 in vf). The instrument can be set to any angle, but currently the autoguider will not guide for settings other than 90 degree increments.

First move to the source and press the “f” key, it will grab the pixel location as the “From” coordinates (you may need to click left with the mouse on the source before hitting the F key). Then move to the center or wherever and hit the “t” key to grab the “To” location. You can also set these positions by holding the shift key and pressing the middle mouse button, then drag and release to set the “To” position. A line is drawn on the image marking the two positions. Click on “calculate offset” and then on “Offset TCS” to actually move the telescope (the 88-inch). This sends an offset command directly to the TCS, so should not be used when the autoguider is actively guiding or tip/tilting. Once the “To” location has been defined, then when centering other objects, only the new “From” positions need be entered. The center of the slit is near (133,124) on the image array.

The best way to offset an object to the slit is to do a guided offset. If the star is visible in the imager, do the following steps: move to the object and take an image while the TO is finding a guide star to make sure that the object is somewhere in the field of view. Start the guiding and take another image (because the object will jump a fraction of an arcsec when guiding is started as it moves the star to the center of the quad cell). Use vf to calculate the offset to the center of the slit, and then do the offset using the command tel groff (raoff) (decoff) which does a guided relative offset from the current position. Take another image to confirm you are on the slit, some small adjustments may have to be made. Then call that the base position (zero the telescope offsets).

If the object is not visible, then the best way to center it on the slit is to know its RA and Dec offsets from some nearby source that is visible in the imaging detector. Do the above procedure to center that object on the slit, then do another guided relative offset to move to the source. Make sure that there is enough room in the guider’s field to move to the new position and keep guiding on the star.

5.4 Plotting spectra

There is a new spectra display mode added for KSPEC, called “SpectraK”. This is similar to the “SpectraB” mode in the original IRTF vf program. This will do a quick extraction of the spectrum and display a plot. The user defines a range of pixels to sum, for the “object” and/or “sky”, and the program can display these spectra as well as their difference. This is slightly different than just doing a cut along the X axis – the dispersed orders are curved on the HAWAII array, so this mode follows the curve to extract the entire order.

Here is how to run the SpectraK display: first, while looking at the image, determine where on the array you want to look at the spectrum. One way to do this is to note the Y pixel values of the locations of the object and sky areas. All these must be determined at the left edge of the array, where the orders are least curved. One can also define the object and sky areas by using the Stats window and the middle mouse key to define boxes on the array, first choosing the sky area and clicking on “SetSky” in the Stats window, then define the object box.

Once the areas of interest are determined, switch to the Spectra K display mode. Set the ObjBin and SkyBin values, either by typing in the pixel values or by clicking on the Set ObjBin and Set SkyBin buttons if you have used the boxes to define the areas. The spectrum is then displayed in the canvas, and the X range and
Y scaling can be set. The wavelength values are displayed along the bottom of the plot, below the pixel numbers. These are set automatically, depending on which order you have chosen to display. Figure 6 shows a sample printout from the SpectraK mode.

Figure 6. A sample output of a stellar spectrum from the SpectraK mode. The K order has been extracted. At the bottom the pixel and approximate wavelength scale are shown. The file header information is printed at the top of the page.

At present only the lower 5 spectral orders are defined for the wavelength scale in the SpectraK plot.

5.5 Focusing

Focusing should ideally be performed on an SAO star located close to the object being studied. The focus is at approximately 1110 (at a tube temperature of 0°C) with the hexapod on the 2.2m telescope with the f/31 secondary. The imaging and spectral detectors have been positioned so that if the image of the field and slit is in focus, the spectral image will also be in focus. The relative focus setting has actually been optimized for the H and K bands, so the shortest wavelength I bands are at a slightly poorer focus.
The observer can focus the image on the imaging array, using the \texttt{vf} program to examine the image. One can zoom in on the source to see it better, and use the Linecut display option to look at the stellar profile. The focusing can usually be performed good to 2 pixels FWHM, although occasionally, poor seeing prevents this. The seeing is always better in the near-infrared than at visible light wavelengths. Focusing of the telescope is made easier by small aberrations in the optics, which usually allow the direction of focus change to be unambiguously determined from an out of focus image. Specifically, an out of focus image takes on an elliptical appearance, and the position angle of the major axis of this ellipse reveals the direction of focus change required. If the image is extended in the NE-SW direction, then the focus should be changed to smaller numbers (on the 2.2m telescope). On the other hand, if the image is extended in the NW-SE direction, the focus should be changed to higher numbers. The focus setting also changes with temperature. As the tube temperature drops, the focus setting must also decrease, at roughly 60 units per degree C. When focusing on a bright star, using a short integration time, it may be necessary to take multiple exposures at each focus position in order to properly ascertain the focus quality (because of short time scale variations in seeing).

### 5.6 Mismatch of Image and Spectrum focus

There is currently a mismatch between the focus for the spectral and imager detectors. If the observer optimizes the focus for the image of a star as described above, the spectrum is slightly out of focus in the spatial direction (along the slit), leading to a wider profile. If one minimizes the profile of the stellar spectrum, then the image will be slightly out of focus. This problem will be addressed in future engineering work; for now, the observer must choose what to optimize. If getting more light down the slit or in-focus images are more important, the imager focus should be optimized. If spatial resolution along the slit is more important, then the spectral detector focus should be optimized.

### 6 Data Reduction

The KSPEC images and spectral data can be reduced using any software that can import FITS format images and extract spectra from 2-D array data. For a “quick-look” reduction while observing, several IRAF macros and files have been set up to do an extraction using the \texttt{apall} task in the \texttt{noao.twodspect.apextract} package. To use these commands, the following files can be defined:

- \texttt{mask.imh} – Image showing bad pixels, where 1=good, 0=bad. This file is optional.
- \texttt{flat.imh} – flat field to divide by, made from difference of dome on and off integrations. This file is optional.
- \texttt{refstar.imh} – reference star where the apertures have been defined. This file is required if extracting a point source.
- \texttt{calib.imh} – the wavelength calibration image. This file is required.
refextd.imh –
the reference image for a spatially extended source. Not required if only extracting point sources.

refstar.ms.imh –
exttracted spectrum of reference star. This is required.

./database/aprefstar –
aperture definition for point source. Required if using refstar.imh.

./database/aprefextd –
aperture definition for extended source. Required if using refextd.imh.

./database/idcalib –
wavelength information for the calibration image. This is required.

There are also a number of scripts with the extension .cl that should be present in the default directory for a quick-look reduction. These are available in a file named reduce.tar.gz, which also contains the required files from the above list. This file is located in ~88inch/mkoman/kspec on galileo.ifa.hawaii.edu, and in the anonymous ftp area of hubble.ifa.hawaii.edu in ~88inch/mkoman/kspec. On galileo, these files can be copied and extracted into your working data reduction directory by issuing the following commands from the data directory:

```
cp ~88inch/mkoman/kspec/reduce.tar.gz .
gunzip reduce.tar.gz
.tar xvf reduce.tar
```

For a full guide to using IRAF to extract and reduce spectra, read the IRAF documentation and on-line help. Especially useful is the document “A User’s Guide to Reducing Slit Spectra with IRAF”, Massey, Valdes, & Barnes 1992. A brief overview is given in the following sections, with some details on the KSPEC reduction.

### 6.1 Basic tasks in the reduction

The first task in the reduction process is to get the spectral data from the two dimensional image to a one dimensional spectrum. The procedure is dependent on the details of the observation, whether a point or extended source has been observed, whether beam switching off the source has been done, etc. First the case of the point source will be discussed.

In the simplest case, the slit aperture would be centered on a single row of the array, so the extraction procedure would consist of simply summing the counts in a particular range of rows across the array to obtain the source flux at each wavelength. As can be seen from Figure 2, the case is not so simple. The aperture is curved across the array, and this curvature is different at points along the aperture, and for each order. The reduction procedure must perform the following tasks:

1. Find the different orders on the array, select the ones to extract.
2. Select the source and background regions on each aperture.
3. “Trace” the apertures, or determine what the curvature is for each order.
4. Sum the source pixels, subtract the background flux if any, and write the extracted data to a 1-D image file.

The apall task performs all of these procedures, or any subset of them, in either interactive or batch mode. Steps 1 and 3 are necessary only for the first object done; on subsequent images, the first image can be used as a reference image to guide the source finding and selection steps. The following steps are then performed on the extracted spectrum:

5. Wavelength calibration - using a previously defined wavelength scale, the wavelength calibration is associated with the data and dispersion corrected.
6. Correct for the atmospheric absorption by dividing the spectrum by one from a standard star.
7. Flux calibration or normalization - if spectrophotometric standards have been observed, the data can be scaled to absolute flux units. Or one may perform a fit to the continuum and divide to normalize by the continuum level.

Step 5 is useful to do when at the telescope so that one can identify lines that have been detected. Steps 6 and 7 are more involved and one may choose not to do it for the quick reduction at the telescope.

6.2 Using rrs.cl for quick-look extraction

There is an IRAF script named rrs.cl defined that performs a quick-look spectral extraction that is useful while observing. The script contains the commands to read them into IRAF format, subtract the sky frames, flat field the data, multiply by a bad pixel mask, then extract the spectra in each of the three apertures, apply the proper wavelength scale to the spectra, divide by a reference star to correct for atmospheric absorption, and display the data.

A number of things must be prepared before this procedure is executed. If desired, the mask, flat field, and spectrum to divide by must be prepared and stored in the iraf image names mask.imh, flat.imh, and divstar.imh, respectively. Also, a reference star extraction must be done and the results stored in refstar.imh. This defines the default aperture positions and the size and shape of the apertures. If extended sources are to be extracted, then another reference extraction named refextd.imh must be saved. The calibration spectrum must have its lines identified and the wavelength scale fitted. Also, a number of IRAF packages are used by rrs.cl to perform the reduction. The necessary tasks can be loaded using the init.cl script, using the following command:

```
cl < init.cl
```

The following are the necessary parameters for the rrs script:

datadir - the directory of the raw data files
rootname - the part of the raw data filename before the image number
stype - source type, 1=point source, 2=extended source
divbystar - 1=true (divide by "divstar"), 0=false (do not divide by star)
imnum - image number of the on-source raw KSPEC image
subnum - image number of the sky frame to subtract (enter 0 if none)
The procedure is run as in the following example: the files ks951123.051 and ks951123.052 are the on-source and sky frames for a point source. Then the following command line should reduce these data:

```
rrs /scr/obs/data ks95nov23. 1 1 51 52
```

The iraf image names of these data are `ks951123.051.imh` and `ks951123.052.imh`, extracted spectrum is stored as `ks951123.051.ms`. The first “1” in the command line specifies that a point source is to be extracted, and the second “1” indicates that the extracted spectrum should be divided by the reference spectrum `divstar.imh`. Examine the file `rrs.cl` to see how the IRAF commands are called to perform the reduction.

After performing these operations, the data is displayed using the IRAF function `splot`, in the package `noao.onedspec`. See the IRAF documentation for a detailed description of this command. The basic useful keys you must know are “q” = quit, and the parentheses keys switch between apertures within a data file.

### 6.3 Using `apall`

For certain unusual spectra, and for the final data reduction, one should use `apall` directly. See Appendix 1 for typical default parameters for using `apall` for the KSPEC reduction.

The task is started with the following:

```
c1> apall tstar
Find apertures for tstar? (yes):
Number of apertures to be found automatically (3):
Resize apertures for tstar? (yes):
Edit apertures for tstar? (yes):
```

Then the cut perpendicular to the dispersion axis is displayed which shows the location and width of the spatial profile. This is shown in Figure 7. While in the `apall` task, one can press the “?” at any point to receive on-line help on the cursor commands. As one performs the reduction steps while in `apall`, the “q” key is used after every step when one is finished and ready to proceed with the next function within the task.
The S/N is high enough so that apall has automatically found the orders, and has set the profile widths. If this had not happened, one could center the cursor on the desired positions and manually mark the order positions with the “m” command. Orders can be deleted with the “d” cursor command. Once the orders have been located, then the background and source regions should be set if one is subtracting a background. Figure 8 shows the display for setting the background, which is accessed using the “b” command. The profile of the aperture is shown, along with the regions on either side that are used for fitting the background level. The regions can be interactively redefined and fitted. The “t” command clears the background definition. The “s” command defines the fit regions. Press it once on one edge and again on the other edge of the region being defined. This can be done for several regions. Then the “f” command fits a background based on the chosen type and displays the fit. The “q” command exits and returns to the order location display (Figure 7).
The next step is to trace the aperture along the dispersion direction on the array. The `apall` routine does this by moving along the aperture and determining the center of the profile for that column. These center points are then used in fitting a curve for the aperture shape. The result of such a fit is shown in Figure 9. The aperture is fit well by a 4th order Legendre polynomial. Each aperture must be fit separately because the curvature is different. One should perform the trace for high S/N data, such as the standard stars, and use these as reference definitions for subsequent data, since the tracing algorithm can get lost or make errors when tracing low S/N data.

Figure 8. The background fitting display.
Finally, after each aperture has been traced, the data is extracted and written to a file that contains the 1-D spectra from each of the orders. One can preview the spectra as the data is extracted. Figure 10 shows sample raw spectra from the extracted $K$ order. The spectrum is dominated by three factors: the spectral shape of the star being observed, the sensitivity of KSPEC as a function of wavelength, and the atmospheric transmission.
Figure 10. Sample extracted spectrum from the KSPEC K order aperture.

Each spectrum from the dataset should be extracted in this way. The extracted spectra can then be coadded. The task identify is used to define the argon calibration lamp wavelength scale (see Appendix 3). The tasks refspec and dispcor apply the wavelength calibration to the extracted spectra. Dividing the object spectra by the standard star can be done with sarith; use this instead of imarith because the latter can strip out some spectral information from the image headers. See the iraf documentation for more information on the reduction process.
Appendix 1. kspec Command Summary

This appendix contains excerpts from the QUIRC manual (Metzger, Hora, & Hodapp), as well as additional commands specific to KSPEC. These programs are based on the ccdcom program written by Metzger. See the QUIRC manual for additional useful information.

When you first start kspec you should be aware of two self explanatory commands:

> help () Help help lists the currently recognized commands. Angle brackets indicate arguments, and square brackets indicate optional arguments.

> quit () Quit quit terminates kspec. Control-D will also do this.

In general, you will need to initialize the DSP processor in the Leach electronics after power-up or after a DSP reset, because its cold-reset state is not appropriate for running the instrument. In order to do this you need to read a file of compiled DSP code, and then download it to the DSP. (Note that DSP assembler code in a .asm file is compiled by the a56 compiler into binary code in a .lod file. For example, a56 quircop1 will read quircop1.asm and write quircop1.lod.)

Note that while you may see several different versions of the code for KSPEC in the dsp directory, you can always find the current version of the code as kspec.lod. (It is maintained as a symbolic link to the working code.) Thus to download the current version of the code, after a power cycle or DSP computer reset, you can always use df kspec to load correct code. Remember that it is not necessary (and even undesirable) to download code when kspec is restarted. Quitting and re-starting kspec in itself has no effect on the on-board DSP computer, which runs independently.

> df {file} Read and download DSP code

df is a combination of ll and dl, and is the normal command to use for sending code to the DSP. It will fill in a .lod extension if it is missing, and it will look in directories according to the environment variable LODPATH, which can be set to a list of directories separated by colons. Thus, the visitor account has been provided with: setenv LODPATH .:/aux/inst/dsp:/mydspcode

Example: df kspec

> ll {file} Read DSP code .lod file

ll reads a DSP code binary file into the Sparcstation memory.

> dl () Download DSP code

dl sends the DSP code to the DSP electronics, and then causes the DSP to start executing this code. dl also asks the DSP to recalibrate its A/D converter, which takes about 2 seconds.

kspec takes exposures and writes data files according to various parameters which you can set. The basic sequence that kspec follows is to

1. Reset the chip
2. Do dummy read to stabilize array
3. Perform first data read of double-correlation pair, store image in memory
4. Turn off output amplifiers
5. Open the shutter and wait for a predetermined exposure time
6. Close the shutter
7. Turn on output amplifiers
8. Do dummy read to stabilize array
9. Perform second data read, subtract the first from it, store in memory
10. Write the contents of memory into a FITS format data file
11. Put the controller into reset idle mode

These actions are performed by the fundamental command \texttt{go}, which is described below. First, the commands which tailor the sequence followed by \texttt{go} are given.

Not all of these steps may be taken, and the actual sequence followed depends on how the automatic actions are set, as described below. The operations can be different for the spectrograph and image arrays. There are a number of ways to set the parameters which govern what the \texttt{kspc} program does. Several commands are available which can be used to set integration time, object name, object type (a FITS header item), and default automatic actions. None of these does anything more than setting parameters to be used later—only \texttt{go} takes an exposure.

\begin{verbatim}
> object \{[time [name]]\} Setup for object

    object prepares to take an exposure of a general target. You can specify integration time as the first argument and an object name as the second. The object command sets the automatic actions: # of resets: 1, shutter on, readout on.

    Example: object 300 N3031 (set integration time to 300 sec and object name to N3031)
    Example: object 0.18 (set integration time to 0.18 sec)

> auto () set automatic action

    auto goes through the choices for the automatic actions, and allows you to set each. These parameters are common for both the spectrograph and image channels. The automatic actions are:

    \begin{itemize}
    \item \#reset: n Number of times to reset the chip before starting the exposure. Should usually be set to 1.
    \item Shutter on/off Controls whether the shutter should be opened for the exposure. Usually set to ON, otherwise no flux from sky gets to detector.
    \item Readout on/off Controls whether the chip should be read out at the end of the exposure. Usually ON.
    \item idle on/off If on, at the end of a readout the chip is placed in a continuous reset, or idle, mode.
    \end{itemize}

    Currently this setting causes some problems with the imaging channel in that it will sometimes fail when reading out the imaging detector, so this must be left off.
\end{verbatim}
double correlated read on/off Controls whether the device is read out before and after the shutter opening, or only after. If reading before and after, the difference between the two are taken, and this difference is written to the FITS file. Double correlated read ON is the normal operating mode.

For experienced users: note that if you want to use auto from a script, you can specify the complete set of parameters, in the order above, as numeric arguments. Be careful not to skip any, and use 1 for on and 0 for off. For example, for the sauto command, you could type *sauto 4 1 1 0* to set the parameters to their usual default values.

> sauto ()
> iauto () These auto commands set the parameters associated with the spectrograph or image detectors. The auto parameters are:

- Number of samples n controls how many frames to co-add in the double correlated read. For each exposure, the chip will be reset and read n times before opening the shutter, and read n times after the shutter closes. Usually set to 1 for the image channel and more for the spectrograph, e.g., 4.

- Write on/off Controls whether a FITS file should be written after the chip is read out. Usually ON to save data. This can also be set using the command *set save*. If set off and vfout is on, then the data are written to a file with a name ending in "chop" which is displayed by vf.

- dither subtract on/off This option, when turned on, will subtract the previous image from the current one and store the result in a file with a "chop" added to the normal data file name instead of the file number. The name is the same as the chop mode described above. This is often useful when dithering on a faint source that cannot be seen without subtracting the sky/array background from the image.

- chop on/off Controls whether a beamswitched pair of integrations is performed for each go command. If at the UH 88-inch, the beamswitch is done automatically. Use with caution. The on and off source frames are differenced and the result is stored in a file with the name constructed from the data file name plus "chop" added instead of the file number. This file is overwritten every time a new chop is done.

> clear ([num]) Clear (reset) array

  clear resets the detector num times, default 1. If you have CTRL-C'd out of an integration, you should do a clear to reset the device and kspec. If you do not use clear after CTRL-C, on typing the next go the program will assume you want to continue the previous exposure.

> comment (text) Adds a comment to the obs.log file, and to the FITS header of the image file.

> et (seconds) Set exposure time

  et sets the exposure time. Any floating point value is accepted; the accuracy of the exposure timing is somewhat better than 0.01 second, but it is ultimately limited by the mechanics of the shutter. et uses Unix to compute the exposure time, and an exposure which is based on Unix timing can be interrupted. Some care is taken to make sure that the unix timed exposures are correct, but the machine running kspec is heavily loaded it is possible for the shutter to stay open slightly longer. The exposure time recorded in the header, however, will reflect the true amount of time the shutter was open.
The `et` command sets the exposure time of the current mode, SPEC or IMAGE. The exposure time can also be set with the `image` or `spec` command.

> **fn** \{fileno\} Set running file number

`kspec` writes files of the form `filename.xxx`, where `xxx` is a file number. `fn` allows you to specify the file number. `kspec` uses the current file number as a prompt, and automatically increments the file number as each file is written.

> **fp** \{specprefix\} \{imagprefix\} Set file prefix

`fp` allows you to specify what the output file name will be. `kspec` expects to write a file of the form `prefixNNN`, where `NNN` is the frame number. `fp` is how you specify `prefix`. Note that if you want a decimal point as a separator you must specify it. KSPEC’s default file prefixes are `ks` and `ki`.

Example: `fp ks940811`. `ki940811`.

> **go** \{[num]\} Start exposure

`go` is the command to take an exposure. As described above, according to the parameters which are set, `go` may reset the chip, open the shutter and close it a predetermined time later, read out the data into memory, write the data to disk, and set the controller into idle mode. An exposure which has been started with `go` and Unix timing (`et`) can be interrupted by control-C. This will close the shutter and return you to the `kspec` command level. You can then alter parameters while you are in the paused mode. For example, you can change the exposure time with `et`, or the eventual output file name with `fp` or `fn`. You can set or unset automatic flags to specify what `go` will do when it finishes. If you want to continue the exposure, you can reissue a `go` command. If you want to read out the device, you can issue an `rc` command. If you want to abort the exposure, use the `clear` command. You can take multiple identical exposures with the \{num\} argument.

> **idle** () Put camera in idle mode

`idle` starts an infinite loop of resetting the detector every 5 seconds. It is a good idea to leave the system in this state when not observing, so that the detector does not saturate. If the auto idle mode is set, the camera is put into idle mode after every exposure.

> **image** \{time\} set image mode

and optionally the integration time. When this is set, the `go` command starts a readout of the image detector.

> **name** \{objname\} Set object name

`name` is used to set the object name which will be written to the FITS header.

> **rc** \{[Xnx Xny]\} read array

`rc` reads out the array, and if the auto-write flag is set, `rc` will write the resulting image to a disk file.

> **set** \{param\} [n] Set parameter

Certain program parameters can be set or unset with this command. To set a parameter, for example “save”, one issues the command `set save`. To unset, the command `set nosave` is used. Alternatively, one can type `set save 1` and `set save 0` to turn it on or off. Below are the available parameters:
- clobber – If on, existing files will be automatically overwritten. If off, the program will ask for confirmation from the user before overwriting files.
- chop – Turns chopping on or off. Also can be set via the auto command.
- beep – Causes the program to beep after each detector readout, and other operations. Can be annoying.
- vfout – Directs kspec to send commands to vf to display the most recent image.
- save – Turns auto save on or off. Also can be set via the auto command.

> shutter \{ (open|close) \} Commands the specified shutter action.

> spec \{ time \} set spec mode
and optionally the integration time. When this is set, a go command starts a readout of the spectrograph detector.

> status \{ \} Show status
status shows the current parameters.

> sound \{ \} Toggle fancy sounds
kspec will use distinctive sounds for various operations. If you don’t want to listen to them you can turn them off with the sound command.

> synch \{ \} “Ping” the DSP by sending it data and asking it to send it back. This is useful to check to see whether the controller is alive and receiving commands properly from kspec, or if the electronics may need a hardware reset.

> wf \{ [ file ] \} Write FITS file
kspec reads out the array into memory, and maintains the image there. The wf command puts together a FITS header for the image and writes it to a disk file. If the write fails (for example because the disk is full) wf will abort, but the program will keep the data in memory and you can save your data after rectifying the problem that prevented the write.
Appendix 2. APALL default parameters

IRAF
Image Reduction and Analysis Facility

PACKAGE = apextract
TASK = apall

input = k4f List of input images
(output = ) List of output spectra
(format = multispec) Extracted spectra format
(referen= ) List of aperture reference images
(profile= ) List of aperture profile images

(interac= yes) Run task interactively?
(find = yes) Find apertures?
(recente= yes) Recenter apertures?
(resize = yes) Resize apertures?
(edit = yes) Edit apertures?
(trace = yes) Trace apertures?
(fittrac= yes) Fit the traced points interactively?
(extract= yes) Extract spectra?
(extras = yes) Extract sky, sigma, etc.?
(review = yes) Review extractions?

(line = 600) Dispersion line
(nsum = 50) Number of dispersion lines to sum

# DEFAULT APERTURE PARAMETERS

(dispaxi= 1) Dispersion axis (1=along lines, 2=along columns)
(lower = -20.) Lower aperture limit relative to center
(upper = 20.) Upper aperture limit relative to center
(apidtab= ) Aperture ID table (optional)

# DEFAULT BACKGROUND PARAMETERS

(b_funct= legendre) Background function
(b_order= 1) Background function order
(b_samp= -25:-15,15:25) Background sample regions
(b_naver= 1) Background average or median
(b_niter= 0) Background rejection iterations
(b_low_r= 3.) Background lower rejection sigma
(b_high = 3.) Background upper rejection sigma
(b_grow = 0.) Background rejection growing radius

# APERTURE CENTERING PARAMETERS

(width = 20.) Profile centering width
(radius = 50.) Profile centering radius
(thresho= 0.) Detection threshold for profile centering

# AUTOMATIC FINDING AND ORDERING PARAMETERS

nfind = 5 Number of apertures to be found automatically
(minsep = 50.) Minimum separation between spectra
(maxsep = 1000.) Maximum separation between spectra
(order = increasing) Order of apertures

# RECENTERING PARAMETERS

(apertur= ) Select apertures
(npeaks = INDEF) Select brightest peaks
(shift = yes) Use average shift instead of recentering?

# RESIZING PARAMETERS

(llimit = INDEF) Lower aperture limit relative to center
(ulimit = INDEF) Upper aperture limit relative to center
(ylevel = 0.1) Fraction of peak or intensity for automatic width
(peak = yes) Is ylevel a fraction of the peak?
(bkg = no) Subtract background in automatic width?
(r_grow = 0.) Grow limits by this factor
(avglimi= no) Average limits over all apertures?

# TRACING PARAMETERS

(t_nsum = 5) Number of dispersion lines to sum
(t_step = 10) Tracing step
(t_nlost= 50) Number of consecutive times profile is lost before
(t_funct= legendre) Trace fitting function
(t_order= 4) Trace fitting function order
(t_sampl= *) Trace sample regions
(t_naver= 2) Trace average or median
(t_niter= 0) Trace rejection iterations
(t_low_r= 3.) Trace lower rejection sigma
(t_high_= 3.) Trace upper rejection sigma
(t_grow = 0.) Trace rejection growing radius

# EXTRACTION PARAMETERS

(backgro= none) Background to subtract
(skybox = 1) Box car smoothing length for sky
(weights= none) Extraction weights (none|variance)
(pfit = fit1d) Profile fitting type (fit1d|fit2d)
(clean = no) Detect and replace bad pixels?
(saturat= INDEF) Saturation level
(readnoi= 0.) Read out noise sigma (photons)
(gain = 1.) Photon gain (photons/data number)
(lsigma = 4.) Lower rejection threshold
(usigma = 4.) Upper rejection threshold
(nsubaps= 1) Number of subapertures per aperture
(mode = ql)
Appendix 3. Argon Calibration Spectra

The following plots are examples of calibrated Argon spectra taken with KSPEC. The line wavelengths are marked; the wavelengths greater than 11000Å are taken from the IRAF argon.dat line list file, which are vacuum wavelengths from "Wavelength Standards in the Infrared", K.N. Rao et al., 1966. Wavelengths shorter than 11000Å are taken from "Atomic Transition Probabilities", W.L. Wiese, M.W. Smith, & B.M. Miles, 1969, National Stand. Ref. Data Ser., Nat. Bur. Stand. (US), 22, 189. This reference lists the wavelengths as measured in air; these values were corrected to vacuum wavelengths using the dispersion for standard air of \( (n - 1) \times 10^8 = 8342.13 + 2406030(130 - \sigma^2)^{-1} + 15997(38.9 - \sigma^2)^{-1} \), where \( \sigma \) is the vacuum wavenumber in \( \mu m^{-1} \) (see B. Edlen 1965, Metrologia, v. 2, p. 71). The vacuum wavelength is then given by \( \lambda_{vac} = n\lambda_{air} \).
Figure A3.1 Argon spectrum for the $K$ order.
Figure A3.2 Argon spectrum for the $H$ order.
Figure A3.3 Argon spectrum for the $J_2$ order.
Figure A3.4 Argon spectrum for the J1 order.
Figure A3.5 Argon spectrum for the I2 order.