spectral coverage (although higher orders can still be placed on the array by rotating the grating turret), and therefore loss in observing efficiency. The disadvantage of this format is increased light loss. Since the wavelength spacing between orders is reduced, prism angles must be increased to produce more dispersion, and working at higher angles increases reflection losses (see Section 5.9). Additional losses occur at the gratings since they work more efficiently in lower orders.

3.7 Example Observing Programs

Example observing programs are used to to develop efficient observing procedures and observing mode requirements. One of the best ways to do this is to examine the procedures required to execute specific scientific programs with SpeX. The examples chosen illustrate the use of likely observing modes.

3.7.1 General observing procedure

For standard nighttime observing instrument checkout will be done during the afternoon with the telescope parked at zenith. The rigidity of the instrument and the reproducibility of the mechanisms is designed so that flat field and wavelength calibrations taken at zenith can be used for observations taken at any normal telescope position. An additional variable in the optical path is the position of the image rotator but since this is located closely behind the fixed cold stop, flat fielding and wavelength calibration should be independent of rotator angle. In the event that the effects of flexure or rotator angle are significant, or for particularly sensitive calibration, calibration can always be done immediately before or after an observation at the same air mass and rotator angle as the object. Wavelength calibration is easily obtained from appropriate sky frames.

SpeX has two flat field sources: a QTH lamp for 0.8-2.5 μm, and an infrared source for 2-5.5 μm. Although wavelength calibration can be done on sky lines in both the non-thermal and thermal infrared, use of an argon lamp allows wavelength calibration in the range 0.8-4.1 μm at any time, a feature which is very useful for instrument checkout (mechanism position, focus, signal level etc.). These lamps are located in the calibration unit (see Section 5.7) and are selected by moving a pick-off mirror into the beam above the window. With the exception of the pick-off mirror and rotator, flat field and wavelength calibrations are taken with the spectrograph set up identically to that used on the object (dichroic, filter, slit, grating turret, and detector focus positions; and detector readout parameters). Integration times (on-chip times and coadds) are chosen as necessary to achieve the required S/N.

The slit wheel and grating turret positions can be selected as the telescope slews to the astronomical target. Targets are found and positioned on the slit by using the slit-viewer like a simple infrared camera. If desired the orientation of the slit on the object can chosen by adjusting the image rotator. Several guiding options are available to keep the object in the slit: optical tip-tilt, infrared guiding on objects in the slit-viewer field (including the object), or unguided telescope tracking. Depending on the angular size of the object, sky frames can be taken by either nodding the object up and down the slit, or by offsetting to a nearby piece of sky. It is important that good focus be maintained of the image field on the slit. The focus will depend on whether or not the dichroic is used. If infrared guiding is selected then it is optically more efficient (although not essential) to remove the dichroic from the beam, in which case the telescope must be refocused. The instrument is designed such that with the slit-viewer in focus, images on the slit and in the spectrograph are also in focus. Also, if infrared guiding is selected then both filter wheels need to be positioned before guiding can start (see Figure 2.1a). Once guiding is started spectra can be taken. For telluric cancellation object observations are interleaved with standard star observations relatively close in air mass and in time.

Medium and high-resolution infrared spectroscopy is often limited by the ability to correct for atmospheric transmission, which varies significantly with wavelength (for example see Figure 3.1), and also with air mass and time depending on conditions. These telluric features are normally removed by dividing the object spectra by a standard star of suitable spectral type nearby on the sky. In practice no standard stars are featureless and as a consequence the final spectrum contains psuedonoise from features in the standard star. For restricted wavelength ranges it is sometimes possible to select standard stars which have few features in the range of interest. Unfortunately this is not suited to wide-band spectroscopy and so we are faced with the prospect of using multiple standard stars of different spectral types. Fortunately, Maiolino et al. (ApJ 111, 537, 1996) have developed a working solution to this problem. In this procedure main sequence early G or late F stars nearby in the sky are used for telluric cancellation, and an atmospheric- transmission corrected solar spectrum, convolved to the resoution of the spectrograph, is then used to correct for standard star features. The technique works best for standard stars closest to solar spectral type (dG2).

The slit-viewer may also be used as an optimized infrared imager. In this mode any combination of filters in the two filter wheels can be used. Flat fielding of the slit-viewer can be done to better than 2% to the edge of the $60\times60\,\hat{''}$ FOV using the QTH and IR lamps in the calibration unit. For precise imaging photometry it may be better to use dome flats or sky flats, but this will need to be measured. For now it will be assumed that the internal flats are satisfactory. It is unlikely that slit-viewer flat fields will be affected by instrument flexure or rotator angle. Both fast and slow guiding are available with the tip-tilt system, as well guiding with the off-axis camera.

Some observing programs will require (absolute) spectrophotometry. In principle this is most simply accomplished by using a very wide slit to let all the light from the object into the spectrograph (at the cost of reduced spectral resolution.) The low resolution spectrum can then be used to scale the intensity of the high resolution spectrum. The widest slits available in SpeX are $3.0\,\hat{''}$ wide. Depending on seeing conditions this may not always be sufficient to transmit all of the object signal into the spectrograph. Given the lack of spectrophotometric standards in the infrared, the best alternative is to calibrate the spectrum by imaging the object with the slit-viewer through an appropriate filter. Knowing the filter profile and the absolute imaged brightness the absolute intensity of the object spectrum can then be calculated. For wide-band spectra it is probably best to use more than one filter to correct for light loss at the slit as a function of wavelength.

Many of the instrument set-up and observing procedures will be coded into high-level command files (macros).

3.7.2 M-dwarf Program

One of NASA's long range goals is the program to Explore Neighboring Planets (ExNPS). ExNPS will evolve from a ground-based to space-based search for earth-like planets orbiting the nearest 1,000 stars - stars closer than about 13pc. Of these main-sequence (dwarf) stars, there are 12 A stars, 20 F stars, 70 (sun-like) G stars, 200 K stars and 700 M stars. Although M dwarfs are common in the solar neighborhood, they are not well-studied due to their intrinsic visible faintness. However, since M dwarfs are brightest at 1-2 μm they are well-suited to wide-band spectroscopy with SpeX. Such a survey will make a valuable contribution to the ExNPS data-base.

Understanding the atmospheres of these low mass hydrogen-burning stars is also important because of the probable overlap in atmospheric properties with the highest mass non-hydrogen burning stars (brown dwarfs), such as GL229 B. The near-infared is also a logical place to obtain spectra of low-mass stars and brown dwarfs since it contains many features which are sensitive to surface gravity and temperature (CO, H_2O, Ca I, Na I). M-dwarf atmospheres are also dominated by deep water absorption at 1.4, 1.9, 2.7 and 4.4 μm, features which lie between the infrared photometric bands. Measurements of these features are essential to a establish a reliable temperature (and therefore mass) scale. Only with a wide-band cross-dispersed spectrograph on a dry site like Mauna Kea can this be done.

The magnitudes of typical M2 and M7 dwarfs at 10pc are estimated from the colours and absolute K magnitudes measured by Leggett (ApJ Supplement 82, 351, 1992). The magnitudes of GL229B (distance 5.7pc) are from Matthews et al. (IAU Circular 6280, December 1995):

Table 3.3. Typical M-dwarf magnitudes at 10pc

Approx. Filter	dM2	dM7	GL229B
V (0.52-0.60 μm)	10.0	17.9	-
R (0.61-0.69 μm)	9.2	15.7	-
I (0.73-0.88 μm)	8.0	13.5	-
Z (0.95-1.11 μm)	-	-	15.3
J (1.15-1.40 μm)	6.8	10.8	14.2
H (1.50-1.80 μm)	6.3	10.4	14.3
K (2.00-2.45 μm)	6.0	10.0	14.3
L' (3.40-4.00 μm)	5.8	9.5	13.4

Fast tip-tilt operation at ~10Hz is predicted for M stars brighter than about $R = 17$. Table 3.3 indicates that most M dwarfs are bright enough for fast tip-tilt guiding using a dichroic mirror which reflects light shortward of 0.8 μm, while transmitting light into the spectrograph at wavelengths longer than about 0.8 μm. Such a dichroic maximises the spectral range available to the spectrograph. Fainter objects require more visible signal for tip-tilt, and in these cases a second dichroic which cuts off at 1.0 μm can be used. Since M dwarfs are relatively bright at K it should also be possible to guide using the slit-viewer (at ~1Hz) on spill-over flux from the object in the slit. Guiding can also be done on any other bright objects in the 90×90 $''$ FOV of the tip-tilt camera or in the 60×60 $''$ FOV of the slit-viewer.

For the M-dwarf project the smallest slit width/highest resolving power is desirable for optimum detection of atomic absorption lines. A 100σ detection of the continuum is chosen to improve detection of low contrast lines. Although the estimated throughput of SpeX is about 15% (see section 5.9), a 5% throughput is used in this case to allow for seeing losses at the 0.3 $''$ slit. Conservative values for read noise (20 e^- RMS) and dark current (0.5 e^-/sec) are also used. Point-source limiting magnitudes for a 100σ detection of the stellar continuum at R=2000 (and R=1500 at 3.8 μm) as a function of integration time are as follows; the maximum on-chip integration time is 2 minutes:

Table 3.4. Point-source limiting magnitudes for R=2000 at 100σ

λ	1 min	2 min	5 min	10 min	20 min	30 min	60 min
0.80 μm (I)	11.90	12.65	13.30	13.65	14.05	14.30	14.70
1.00 μm (Z)	11.70	12.45	13.10	13.45	13.85	14.10	14.50
1.25 μm (J)	11.50	12.25	12.90	13.25	13.65	13.90	14.30
1.65 μm (H)	10.90	11.65	12.30	12.65	13.05	13.30	13.70
2.20 μm (K)	10.30	11.05	11.70	12.05	12.45	12.70	13.10
3.80 μm (L')	7.80	8.15	8.50	8.85	9.20	9.45	9.80

Clearly for M dwarfs as faint as dM7 the required S/N can be obtained in only one or two minutes in the range 1-2.5 μm. However, it is certainly desirable to also cover the region down to the Na I line at 0.82 μm, since it contains several important atomic and molecular lines and also overlaps the visible. This requires integration times of bewteen five to ten minutes but only one setting (0.8-2.5 μm, see Figure 2.2). Given the time to acquire and position the object and standard star (minutes), taking the extra few minutes to get good spectra down to 0.8 μm is operationally efficient even though there is little multiplex advantage in covering 0.8-2.5 μm simultaneously. To obtain the same spectral resolution and S/N at 3.8 μm requires about one hour, so this would only be done on a sub-sample of M dwarfs, with the instrument set up to cover the 2.1-4.2 μm range (see Figure 2.3b) for overlap with the K-band. If GL 229B is typical, medium-resolution high S/N spectra of brown dwarfs in the range 1-2.5 μm will need one hour of integration time. For the purposes of this exercise instrument set up and calibration will be considered for 0.8-2.5 μm spectroscopy of M dwarfs:

- Instrument checkout (daytime)
  1. Move mechanisms
  2. Check noise and signal levels and order positions using calibration lamps
- Calibration (daytime)
  1. Calibration unit set-up for flat fielding
     - Move calibration unit mirror in
     - Select QTH (0.8-2.5 μm) lamp
  2. Spectrograph set-up for flat fielding
     - Select 0.8 μm dichroic
     - Select PK-50 blocker in order sorter (blocks $\lambda > 2.5\,\mu$m)
     - Set image rotator to default angle
     - Select $0.3 \times 15''$ slit
     - Select 0.8-2.5 μm XD grating turret position (fine tune position?)
     - Set up spectrograph detector for QTH lamp (itime, coadds, cycles)
  3. Spectrograph integrate (Object minus Sky, ie. lamp on minus lamp off)
  4. Calibration unit set-up for wavelength calibration
     - Select Argon lamp
  5. Spectrograph set-up for wavelength calibration
     - Set up spectrograph detector for Argon lamp (itime, coadds, cycles)
  6. Spectrograph integrate (Object, ie. lamp on)
- Observation (nighttime)
  1. Slew to object
  2. Spectrograph set-up (do first since dichroic and order sorter shadow slit-viewer)
     - Move calibration unit mirror out
     - Select 0.8 μm dichroic (blocks $\lambda > 2.5\,\mu$m)
     - Select PK-50 blocker in order sorter

- Set image rotator angle to parallactic angle of object (slit normal to horizon)
- Select 0.3×15″ slit
- Select 0.8-2.5 μm XD grating turret position (fine tune position?)
- Set up spectrograph detector for object (itime, coadds)

3. Slit-viewer set-up
   - Select K-filter in slit-viewer (M dwarfs are brightest at K)
   - Set up image detector for object (itime, coadds)
4. Slit-viewer integrate
5. Move telescope to place object in slit, focus telescope, set telescope nod position along slit
6. Tip-tilt set-up for guiding on object. Start guiding
7. Spectrograph integrate (Object minus Sky)
8. Spectrograph set-up for flat fielding at position of object (if required)
   - Move calibration unit mirror in
   - Select QTH lamp
   - Set up spectrograph detector for QTH lamp (itime, coadds, cycles)
   - Spectrograph integrate
   - Move calibration unit mirror out
9. Slew to standard and repeat. Interleave object and standard observations

3.7.3 Cometary Dust Grains

Studies of the 0.8-5.5 μm spectra of cometary dust grains in the coma will complement the direct study of the nucleus. It has been suggested that weakly sublimating organic grains provide a "distributed source" of many of the gaseous species identified in the coma (c.f. the CN and C_2 jets in Comet P/Halley). This idea can be tested by studying the radial distribution of organic solids along the slit (for example, the 3.4 μm C-H stretch feature) in active comets. Two features most likely arising from refractory organics, the 3.29 μm "PAH" and 4.62 μm "X-C-N" bands, have been detected in comets, but are neither well-observed nor understood.

Some comets display a coma of solid grains at large heliocentric distance, where water ice is stable. Icy grains can be searched for via their transitions at 1.5 μm, 2.0 μm and 3.0 μm. (Broad shallow bands at 1.5 μm and 2.05 μm are attributed to water ice were detected in comet Hale-Bopp at 7 AU.)

In this exercise we will use the 2.0-4.1 μm cross-dispersed mode to probe the radial distribution of the 2.0 μm, 3.0 μm, 3.4 μm and 3.29 μm features, for a bright comet which is visible only during daylight. Daylight or twilight rules out the use of visible guiding/tip-tilt, and we will assume that the comet is bright enough to guide on in the K filter. The slit-viewer will also be used for imaging the coma.

- Instrument checkout (daytime)

  1. Move mechanisms
  2. Check noise and signal levels and order positions using calibration lamps

- Calibration (daytime)

  1. Calibration unit set-up for flat fielding
     - Move calibration unit mirror in
     - Select IR lamp
  2. Slit-viewer set-up for flat fielding
     - Select open position in dichroic turret
     - Select required filter combination in order sorter and slit-viewer filter wheels
     - Set image rotator to default angle
     - Select imaging mirror in slit wheel
     - Set up image detector for IR lamp (itime, coadds)
  3. Slit-viewer integrate (Object minus Sky, ie. lamp on minus lamp off)
  4. Repeat slit-viewer imaging for other filters
  5. Spectrograph set-up for flat fielding
     - Select open position in dichroic turret
     - Select Fused Silica blocker (short pass $\lambda < 4.2\,\mu$m) in order sorter
     - Set image rotator to default angle
     - Select $0.5\times 15\,\widehat{''}$ slit
     - Select 2.0-4.2 μm XD grating turret position
     - Set up spectrograph detector for IR lamp (itime, coadds, cycles)
  6. Spectrograph integrate (Object minus Sky, ie. lamp on minus lamp off)
  7. Calibration unit set-up for wavelength calibration
     - Select Argon lamp
  8. Spectrograph set-up for wavelength calibration
     - Set up spectrograph detector for Argon lamp (itime, coadds, cycles)
  9. Spectrograph integrate (Object, ie. lamp on)

- Observation (daytime or twilight)

  1. Slew to object
  2. Slit-viewer set-up for science imaging
     - Move calibration unit mirror out
     - Select open position in dichroic turret
     - Select required filter combination in order sorter and slit-viewer filter wheels
     - Select imaging mirror in slit wheel
     - Set up image detector for object (itime, coadds)
  3. Slit-viewer integrate (Object minus Sky)
  4. Move telescope to position object in 60×60 FOV, focus telescope, set telescope nod, select image rotator angle - all as necessary
  5. Repeat slit-viewer imaging for other filters
  6. Spectrograph set-up

  - Select Fused Silica blocker in order sorter (blocks λ >4.2 μm)
  - Set image rotator to desired position angle on object
  - Select 0.5×15 $''$ slit
  - Select 2.0-4.2 μm XD grating turret position
  - Set up spectrograph detector for object (itime, coadds)

7. Slit-viewer set-up for guiding
   - Select K-filter in slit-viewer
   - Set up image detector for object (itime, coadds)
8. Slit-viewer integrate
9. Move telescope to place object in slit, focus telescope, set telescope nod position (out of slit for extended object)
10. Start slit-viewer guiding on object (spill-over from slit or coma surrounding slit)
11. Spectrograph integrate (Object minus Sky)
12. Spectrograph set-up for flat fielding at position of object (if required)
    - Move calibration unit mirror in
    - Select IR lamp
    - Set up spectrograph detector for IR lamp (itime, coadds, cycles)
    - Spectrograph integrate
    - Move calibration unit mirror out
13. Slew to standard and repeat. Interleave object and standard observations

3.7.4 Cometary Nuclei

Because they are the least evolved bodies in the solar system, the nuclei of comets provide us with a remarkable window into the physical and chemical properties of primitive planetary matter, and the formative processes which are active in star- and planet-forming regions today. The comets also play a role as carriers of volatiles to the terrestrial planets. An understanding of the composition and nature of comets will constrain existing models of the origin of the atmospheres of Earth and other planets. To date, the ground-based study of the composition of comets has been confined largely to the gaseous species which emit strongly in the optical and UV via resonance fluorescence, and molecules which absorb strongly at wavelengths longer than 3 μm. Using the low resolution (R = 150) prism mode, SpeX will have the capability to measure directly the surface composition of cometary nuclei at heliocentric distances where a strong dust coma does not obscure the view. Spectral resolutions of R$\sim$100-200 are optimum for deriving the parameters (band centres, widths, intensities, shape/profile) required to characterize of the surface materials of most solid bodies. Of particular interest will be a comparison between Oort Cloud comets, thought to have originated in the region of the outer planets, and the short-period comets likely to have originated in the Kuiper belt beyond the outer planets.

For this program we will use the the low resolution (R = 150) prism mode and a 60 $''$-long slit. The tip-tilt sensor will be used in its slow guide mode since distant comets are most likely to be too faint for tip-tilt correction. Using a long slit will allow the source to be successively stepped along the slit to allow for improved subtraction of skylines in the reduction process. Science imaging with the slit-viewer using tip-tilt will also be required.

- Instrument checkout (daytime)
  1. Move mechanisms
  2. Check noise and signal levels and order positions using calibration lamps
- Calibration (daytime)
  1. Calibration unit set-up for flat fielding
     - Move calibration unit mirror in
     - Select QTH lamp
  2. Slit-viewer set-up for flat fielding
     - Select 0.8 μm dichroic
     - Select required filter combination in order sorter and slit-viewer filter wheels
     - Set image rotator to default angle
     - Select imaging mirror in slit wheel
     - Set up image detector for IR lamp (itime, coadds)
  3. Slit-viewer integrate (Object minus Sky, ie. lamp on minus lamp off)
  4. Repeat slit-viewer imaging for other filters
  5. Spectrograph set-up for flat fielding
     - Select 0.8 μm dichroic
     - Select PK-50 blocker in order sorter
     - Set image rotator to default angle
     - Select $0.5\times60''$ slit
     - Select 0.8-2.5 μm low-res prism in grating turret position
     - Set up spectrograph detector for IR lamp (itime, coadds, cycles)
  6. Spectrograph integrate (Object minus Sky, ie. lamp on minus lamp off)
  7. Calibration unit set-up for wavelength calibration
     - Select Argon lamp
  8. Spectrograph set-up
     - Set up spectrograph detector for Argon lamp (itime, coadds, cycles)
  9. Spectrograph integrate (Object, ie. lamp on)
- Observation (nighttime)
  1. Slew to object
  2. Slit-viewer set-up for science imaging ($ZJHK$ photometry)
     - Move calibration unit mirror out
     - Select 0.8 μm dichroic
     - Select open position in order sorter
     - Select imaging mirror in slit wheel
     - Select filter in slit-viewer filter wheel
     - Set up image detector for object (itime, coadds)

3. Slit-viewer integrate (Object minus Sky)
4. Move telescope to position object in 60×60 FOV, focus telescope, set telescope nod, select image rotator angle - all as necessary
5. Tip-tilt set-up for guiding on object. Start guiding
6. Slit-viewer imaging for $ZJHK$ filters (dither if required)
7. Spectrograph set-up
   - Select PK-50 blocker in order sorter
   - Set image rotator to parallactic angle of object
   - Select 0.5×60 $\hat{''}$ slit
   - Select 0.8-2.5 μm low-res prism in grating turret position
   - Set up spectrograph detector for object (itime, coadds)
8. Slit-viewer set-up for positioning on slit
   - Select Z-filter in slit-viewer (best S/N for guiding on distant comets)
   - Set up image detector for object (itime, coadds)
9. Slit-viewer integrate
10. Move telescope to place object in slit, focus telescope, set telescope nod position
11. Tip-tilt set-up for guiding on non-sidereal object (speed depends on brightness). Start guiding.
12. Spectrograph integrate (Object minus Sky)
13. Successively step object along slit.
14. Spectrograph set-up for flat fielding at position of object (if required)
    - Move calibration unit mirror in
    - Select QTH lamp
    - Set up spectrograph detector for QTH lamp (itime, coadds, cycles)
    - Spectrograph integrate
    - Move calibration unit mirror out
15. Slew to standard and repeat for imaging and spectroscopy.

3.7.5 Jovian Aurorae

The discovery of the molecular ion H_3^+ in the auroral regions of Jupiter is one of the highlights of recent solar-system infrared astronomy. H_3^+ has also been detected in Uranus and Saturn. The hundreds of tabulated infrared ro-vibrational transitions of this ion provide a major new diagnostic of atmospheric, ionospheric, auroral, and magnetospheric physics and chemistry in Jupiter. Since the emission is highly time-variable, as is its spatial distribution, and since Jupiter rotates rather rapidly, there will be no instrument in the world capable of studying Jovian aurorae via this ion that is competitive with SpeX. For example, at $R = 2500$ SpeX can reach $S/N = 50$ in 120 seconds. During this time a point crossing Jupiter's meridian at a latitude of 60° would move 0.3 $\hat{''}$, the width of the slit. Using SpeX in single-order mode allows use of the 60 $\hat{''}$-long slit and so the entire disk of Jupiter can be monitored. Thus, it would be possible with SpeX to obtain spatially and temporally resolved spectra of these highly variable emissions. Similar observations of H_3^+ in Saturn and Uranus are also feasible. Investigating the spatial distribution of H_3^+ on Uranus as the northern hemisphere moves into view would help lead to a fundamental understanding of the nature of Uranus's magnetosphere and upper-atmospheric chemistry

For this program we will use the 2.0-5.5 μm single-order turret position with the $Los6$ (3.06-3.6 μm) order sorting filter and a $0.3\times60\,\widehat{''}$ slit. The slit will be aligned along the central meridian of Jupiter using the image rotator. Guiding will be done on the limb of Jupiter using the tip-tilt system. To keep track of auroral features moving into the slit spectroscopy will be interleaved with imaging in the 3.534 μm H_3^+ line.

- Instrument checkout (daytime)
    1. Move mechanisms
    2. Check noise and signal levels and order positions using calibration lamps
- Calibration (daytime)
    1. Calibration unit set-up for flat fielding
        - Move calibration unit mirror in
        - Select IR lamp
    2. Spectrograph set-up for flat fielding
        - Select 1.0 μm dichroic
        - Select $Los6$ in order sorter (3.06-3.6 μm)
        - Set image rotator to default angle
        - Select $0.3\times60\,\widehat{''}$ slit
        - Select 2.0-5.5 μm single-order grating turrer position
        - Set up spectrograph detector for IR lamp (itime, coadds, cycles)
    3. Spectrograph integrate (Object minus Sky, ie. lamp on minus lamp off)
    4. Calibration unit set-up for wavelength calibration
        - Select Argon lamp
    5. Spectrograph set-up wavelength calibration
        - Set up spectrograph detector for Argon lamp (itime, coadds, cycles)
    6. Spectrograph integrate (Object, ie. lamp on)
- Observation (nighttime)
    1. Slew to object
    2. Spectrograph set-up
        - Select $Los6$ in order sorter
        - Set image rotator to position angle of Jovian meridian
        - Select $0.3\times60\,\widehat{''}$ slit
        - Select 2.0-5.5 μm single-order grating in turret
        - Set up spectrograph detector for object (itime, coadds)
    3. Slit-viewer set-up for positioning on slit
        - Select 3.534 μm filter in slit-viewer (H_3^+ emission line)

- Set up image detector for object (itime, coadds)

4. Slit-viewer integrate
5. Move telescope to place object in slit, focus telescope, set telescope nod position
6. Tip-tilt set-up for guiding on limb of Jupiter. Start guiding.
7. Spectrograph integrate (Object minus Sky)
8. Spectrograph set-up for flat fielding at position of object (if required)
   - Move calibration unit mirror in
   - Select IR lamp
   - Set up spectrograph detector for IR lamp (itime, coadds, cycles)
   - Spectrograph integrate
   - Move calibration unit mirror out
9. Slit-viewer integrate (Object minus Sky)
10. Interleave spectroscopy and imaging
11. Slew to standard and repeat for imaging and spectroscopy.

3.8 Observing Modes

An observing mode describes how the instrument needs to be configured to perform a particular type of observation. These configurations are used to define requirements for fundamental engineering needs such as array control, and software design. The listing of the different observing modes and requirements is the starting point of these designs:

3.8.1 Imaging 0.8-5.5 μm

Infrared imaging is used for object acquisition and for scientific imaging. In this mode the slit-viewer is used as a standard imager with a selection of filters. A $60\times60\,\widehat{''}$ field is directed into the slit-viewer by mirror-slits. Using the slit-viewer in Image mode, the object is positioned in the slit, and the telescope nod position is set up. For point sources the source is nodded up and down the slit. The rotator position angle is also set by viewing the slit field. To minimize the effects of differential atmospheric dispersion on spectroscopy in the range 0.8-2.5 μm, the slit position angle should be set to the local vertical. Once the source is positioned in the slit guiding can be started.

Imager readout in Image mode:

- one quadrant only
- minimum on-chip itime = 0.25 sec
- maximum on-chip itime = 300 sec
- multiple reads for itimes > 0.25 sec
- co-adding for itimes 0.1-10 sec
- sub-arraying for itimes < 0.25 sec