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IRSPEC

I R S P E C

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Chapter 1

Introduction

This manual replaces the description of the operation of the Infrared Spectrometer (IRSPEC) written by Alan Moorwood in October 1986. The revision was necessary because of the replacement of the old 1-D array by a 58 × 62 Santa Barbara Research Center (SBRC) array and the transfer of IRSPEC to the New Technology Telescope (NTT) to which it is now permanently attached. The upgrade of IRSPEC has brought a number of operating features, such as long-slit spectroscopy, not available with the old setup.

The observer who has no experience with IRSPEC is urged to read this manual carefully. It contains all the information required to successfully carry out an observing program and includes a number of useful hints for observations in the infrared.

A description of the spectrometer, the detector, and the data acquisition system is given in Chapter 2. Chapter 3 summarizes a typical observing session with IRSPEC. It includes suggestions for daytime preparations as well as hints for astronomical observations. Chapter 4 contains miscellaneous comments and advice that may help to carry out an observing run efficiently. IHAP commands and batches available for on line data reduction are listed in Appendix A. The procedure for changing the IRSPEC wavelength calibration is described in Appendix B which also contains a Neon spectrum in the range 1 - 2.5 μm. The atmospheric transmission between 1 μm and 5 μm is shown in Appendix C. A few commands related to the operation of the NTT are given in Appendix D.

Users of IRSPEC are invited to make comments and suggestions concerning this manual in order to improve it. Please pass them on to the introducing astronomer or write them up in your final observing report after your observing mission to La Silla.

Chapter 2

System Description

2.1 General Description

IRSPEC is a cryogenically cooled grating spectrometer equipped with a 58 × 62 pixel SBRC InSb array with 76 μm pixel size. It covers the 1 μm to 5 μm wavelength range at resolving powers of 1000 to 5000 with a nominal slit length of 2 arcmin. The instrument is attached permanently to one of the F/11 Nasmyth focii of the New Technology Telescope (NTT) and hence free of instrumental flexure effects. It employs an optical de-rotator in front of the slit to counter the field rotation at the telescope focus and to permit orientation of the slit at any position angle on the sky.

IRSPEC is remotely controlled from the HP A900 'New Technology Instrument' (NTI) host computer via form filling and 'mouse' clicking on a menu bar. An on-line display of standard instrument and detector status parameters is available on a RAMTEK screen.

Data acquisition is performed through the pre-processing system (PPS) which receives commands from the host. Images and 1-D traces can be displayed in real time on a monitor connected directly to the pre-processor. The display can be used for infrared 'peaking-up'. Brighter objects are centered using the NTT guide probes or the IRSPEC slit viewer.

Final data are sent to the A900 where they are stored as individual 2-D IHAP files. IHAP is available on-line on the A900 with a RAMTEK monitor for image display and a graphics terminal for obtaining 1D spectrum plots, traces, etc.

2.2 The Spectrometer

2.2.1 Optics

Figure 2.1 is a schematic view of IRSPEC illustrating the overall concept and showing the optical arrangement.

Light enters the spectrometer via the de-rotator which is installed between the NTT

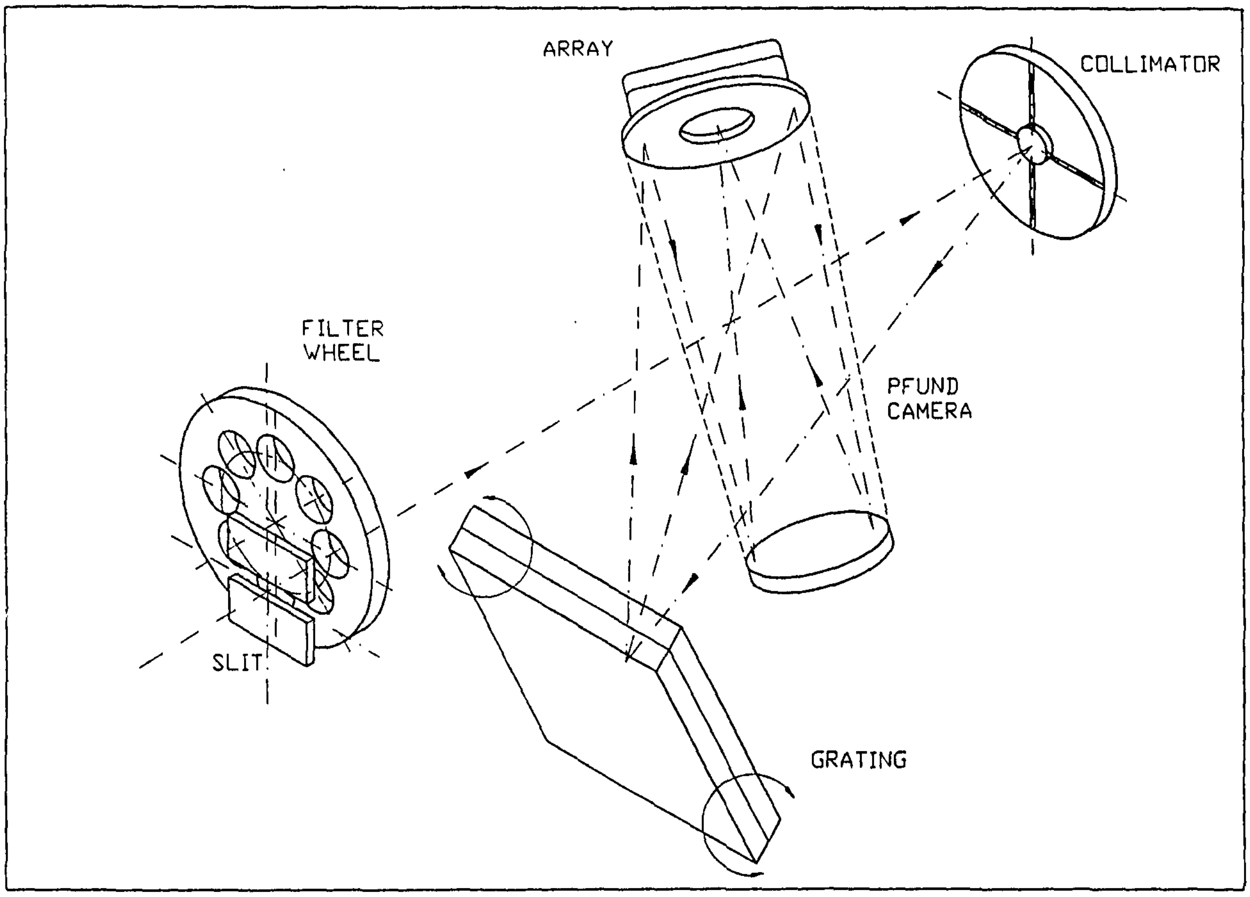


Figure 2.1: Schematic of IRSPEC

adapter A and IRSPEC. The de-rotator converts the NTT F/11 beam to F/8 at the slit. After passing through the entrance window, the F/8 beam is converted to F/7.4 by a field lens located immediately in front of the slit which also re-images the pupil onto a cold stop at the off-axis parabolic collimator. The latter directs the 10 cm diameter collimated beam towards one of the two 'back-to-back' mounted diffraction gratings (12 × 15 cm ruled area) operated in the Littrow mode. Grating # 1 (300 lines/mm) is used in the middle infrared and grating # 2 (600 lines/mm) in the near infrared. The F/2 Pfund type camera then focuses the spectrum on the detector array.

The gratings are supported in a cradle mount which permits their interchange by a 180° rotation about an axis parallel to the ruled surface and orthogonal to the rulings. Both gratings have blaze angles ≈ 37° and can be rotated through ≈ 25°.

The slit is a continuously variable moving blade system. Magnification between the detector and the slit is 3.7 so a 76 μm pixel corresponds to 280 μm on the slit or 2.2 arcsec. The slit blades are polished and slightly tilted to permit slit viewing with a TV camera. Behind the slit is a 8 position wheel containing the order sorting filters.

The Littrow mount is off-axis by 10° and the slit is tilted by 15° relative to horizontal coordinates. This particular spectrometer arrangement causes a pronounced spectrum line tilt and curvature. The tilt angle ω_{tilt} is given by

$$\omega_{tilt} = arctan(sin\ \gamma_0\ \times 2\ tan\ \omega) - \Theta \quad (1)$$

where

$$sin\ \omega = \frac{m\lambda}{2D cos\ \gamma_0} \quad (2)$$

with

Θ	≈ 15°, slit tilt
γ_0	≈ 10°, off-axis angle of Littrow mount
m	grating order
λ	center wavelength
D	grating constant

2.2.2 Mechanics and Cryogenics

All the cooled optical functions are supported by, but thermally isolated from, a rigid optical bench which remains close to room temperature. The optical bench supports pass through stainless steel vacuum bellows attached to the vacuum vessel in order to decouple the latter from the spectrometer. Cooling of the optics to ≈ 80 K is by means of silver straps or copper braids attached to the radiation shield which, in turn, is cooled by a continuous flow of liquid N_2 (LN_2) through a tube attached to its bottom plate. LN_2 also passes through a heat exchanger sandwiched between the two gratings. The LN_2 is supplied from an internal storage tank which is refilled twice a day. Temperature sensors automatically control the nitrogen flow to limit temperature gradients during cool down and to maintain the final steady state temperature. The detector array is cooled to 30K by a closed cycle cooler.

2.3 The SBRC Array

The new detector at IRSPEC is a 58 × 62 pixel array from SBRC with 62 pixels aligned along dispersion direction. It is a hybrid type detector with backside illuminated InSb diodes bump-bonded to an X-Y addressed switched FET output multiplexer. The array has a quantum efficiency of 0.89 at 2.85 μm, 99.7% of pixels operable, and a well capacity of 1×10^6 e^-. The array is operated in DC mode which is possible because of its high stability. The ADU to electron conversion factor is 85 e^-/ADU.

2.3.1 Dark Current and Noise

Two major sources of dark current are present. The diffusion current, due to thermally generated charge carriers in the semiconductor, and the generation-recombination current due to emission of charge carriers through mid-band traps, add up to up to $\approx$ 200 e^-/sec at 30K. The internal background of the instrument increases the dark current to $\approx$ 400 e^-/sec.

Individual pixels exhibit noise which is due to Shot (Poisson) noise, Johnson noise, and 1/f noise. Shot noise is associated with statistical variations in the arrival rates of photons (i.e. the rate of generation of photo current) and in the generation and drift of dark current carriers across the semiconductor. Johnson noise is thermodynamically fundamental to all resistances, including that of the detector. 1/f noise increases as the sampling frequency is lowered. Its origin is not understood. Read noise is defined as the RMS deviation of the signal read out of a pixel after zero integration time. Spatial noise, *i.e.* pixel to pixel variations present *after* flat fielding, determines the ultimate S/N that can be achieved.

Two read out schemes are implemented for the SBRC array. Before an integration, a reset switch is closed and the detector is set to an initial voltage V_i. This causes the detector and FET capacities to be charged up. An integration is started by opening the reset switch. The effective capacitances are discharged by the photon and dark currents. In **triple correlated read out**, the detector voltage is sampled at reset (R1), at the beginning (S1), at the end (E1), and at second reset (R2) after the end of the integration. The main contribution to the read noise results from the video line (kTC noise). It varies on timescales longer than typical detector integration times. This allows an interpolation of the noise during the integration; the signal voltage is thus obtained by V_S = (E1 - R2) - (S1 - R1). The read noise in triple correlated read out is $\approx$ 680 e^- RMS.

The read noise is significantly reduced by **non destructive read out**. In this option, the output voltage is continuously sampled at a rate of 28/sec without resetting the detector. The final signal voltage El is obtained by a least squares fit through the individual measurements. For detector integration times around 10 sec, the combined dark and read noise is $\approx$ 150 e^- RMS. Figure 2.2 shows the read noise as a function of the detector integration time. It increases for integration times above one minute due to the the internal background.

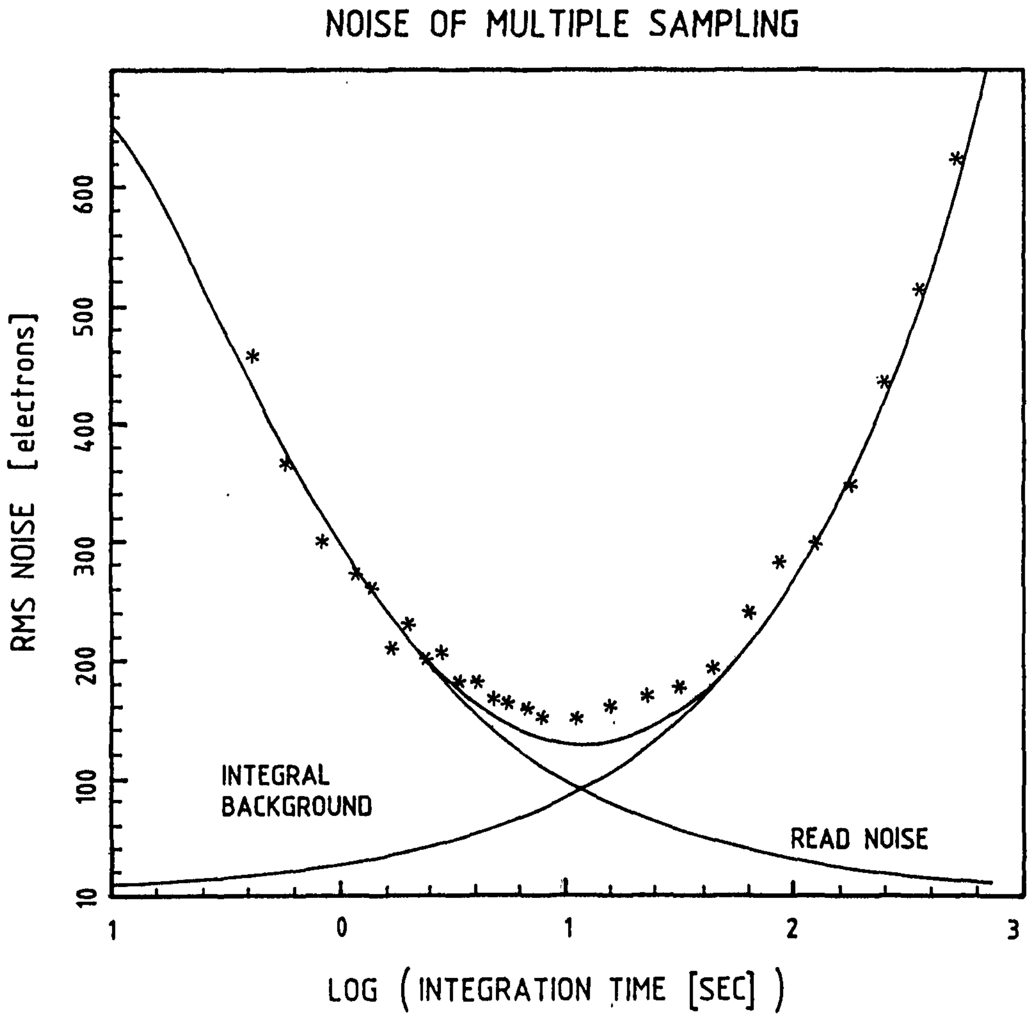


Figure 2.2: Noise of Multiple Sampling

2.3.2 Detector Response

Pairs of columns are read out simultaneously via two independent output lines. A pronounced odd - even effect between adjacent columns appears in the detector response because the output lines have different gains. The difference is corrected to first order by software.

There is an intrinsic non-linearity of the discharge of the total capacitance because both I_{dark} and C_{det} are functions of the the bias voltage which changes during integration. The present software does not correct for the nonlinearity which is estimated to amount to 10% at maximum (McCaughrean 1988).

2.4 Data Acquisition and Storage

A simplified layout of the data acquisition system hardware is illustrated in Figure 2.3.

The central unit is the NTI A900 computer on which the IRSPEC tasks are implemented. Data acquisition on the SBRC array is controlled through the pre-processor (PPS). Commands and replies from the A900 host system are sent via a simple RS232 connection. Final data are sent back to the A900 via a fast fiber link and stored as 2-D IHAP files. All IRSPEC commands are issued from the LU54 instrument console. Two RAMTEKs, LU38 and LU39, and a graphics terminal, LU72, are used to display final images, instrument and detector status parameters, and 1-D spectra.

2.4.1 The Pre-Processing System

The pre-processing system is based on VME hardware. It contains a MC68030/25 MHz CPU board (Eltec E6) and a RAM board with 2 × 0.5 MBytes solid RAM disk cartridges. The software works under the OS-9 operating system. It handles the data acquisition, the host communication and the real-time display. On the PPS, the interface program CI waits for commands from the host, checks the correctness and triggers one or more programs depending on the command.

After initialization of the acquisition hardware at start detector data are continuously read out upon an interrupt of the sequencer. The data are stored in an input-ring-buffer as pixel values. The mean and standard deviation are calculated and the result is stored into an output-ring-buffer. Individual measurements and final averaged data are sent on request to the NTI A900 host system.

The PPS software contains a real-time graphics display task. It displays data frames, 1-D plots, and various integration parameters. The task has facilities like autocut (median filtered), display of pixel values for the various data frames, 'keeping images' for later display, subtract fixed pattern frame, etc.

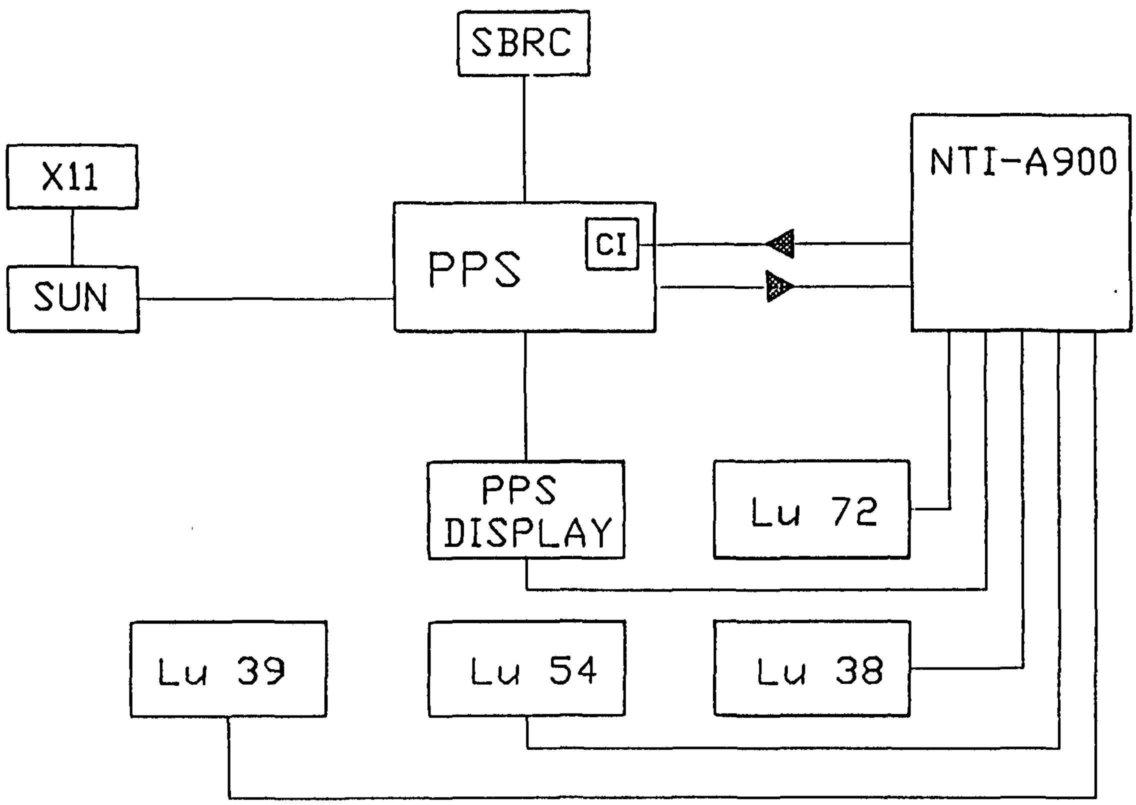


Figure 2.3: Data Acquisition

2.4.2 IRSPEC Software

The IRSPEC software on the NTI-A900 consists of several programs: The observation task IRSPC executes commands from the user or external programs . Its main functions are to set up the instrument and detector, to start exposures and transfer final data to tape. The spectrometer control task ICTRL receives commands related to the setting of spectrometer parameters sent by IRSPC. The detector control task IDTRL executes detector commands. Commands from the terminal are sent to the various destination programs via the Terminal Handler (TH). The display of messages on the terminal screen is handled by the Screen Handler (SH). It divides the terminal screen into two parts: in lines 1 to 5 replies from any destination program are displayed. Scrolling is disabled because of the need to write asynchronous replies. The instrument control task IRSPC communicates with the NTT computer via an Ethernet link. Both NTI and NTT computers keep the same, updated parameters in their respective memory (twin-pool). From IRSPC, any program, both on the NTI and NTT computers, can be accessed by typing its name.

Chapter 3

Observing

Detector and instrument parameters such as the integration time or the central wavelength are entered via form filling. The forms are accessed through the <F1> to <F8> function keys of the NTI-LU54 terminal. Parameters are set by filling in the highlighted, inverse video parameter fields. The cursor is moved forward with the <TAB> key and backward with <SHIFT><TAB>. Forms are exited and updated with <ENTER>. To quit from a form without updating its content, press <SHIFT><DEL> followed by <ENTER>. Instrument parameters can be specified by typed commands as well.

Detector status displays are selected by mouse clicking of respective fields in a menu bar displayed on the NTI-LU39 RAMTEK. Measurement control such as starting and pausing integrations is provided through the same menu bar. 2-D images as well as 1-D traces in or perpendicular to the dispersion direction can be displayed in real time on the PPS monitor. Fixed pattern frames can be automatically subtracted. Final images are displayed on the NTI-LU38 RAMTEK after storage as IHAP files on the NTI A900 computer. A graphics terminal (NTI-LU72) is available to display 1-D spectra obtained in IHAP.

3.1 Starting Up

To start up the IRSPEC software, log on as `IRSPEC` on the NTI-LU54 instrument console and hit the <ENTER> key when asked for the password. Type `IRSPECON` in response to the `CI.54>` prompt. This starts the Terminal Handler and Screen Handler and calls the startup form shown on the following page. Enter your name in the first field. Unless there are specific problems, the remaining parameters should be specified as shown in Table 3.1:

Table 3.1: IRSPEC Startup Form

```
Enter name of user                    [A. Moorwood]
During this run is access required to:

Telescope ("device TELNTT")?                              [TRUE]
Telescope ("device ADAPTA")?                              [TRUE]
Mirror#4 ("device DIFA")?                                 [TRUE]
Detector ("device IRDET")?                                [TRUE]
Instrument ("device IRSPEC")?                             [TRUE]

Please make sure that simulation mode is FALSE for
Detector                              [FALSE]
INSTRUMENT                            [FALSE]
```

Press <ENTER> to exit from the form.

If for some reason the link between the NTT and NTI computer crashes during observations and cannot be recovered, specify FALSE in the two fields

Telescope ("device TELNTT") and
Telescope ("device ADAPTA")

In this case, observations are still possible but no telescope parameters are stored in the data header. To call the startup form again, type /e followed by IRSPECON.

Exiting the form causes on line IRSPEC tasks to be initialized and started. Among the various messages displayed in the upper half of the LU54 terminal screen are

```
IRSPEC started
Initializing IDTRL software and Pre-Processing System
IDTRL> Program Start
ICTRL> Program start
initializing ICTRL software and IRSPEC motor functions
Testing communication with telescope program
Testing communication with adapter A (NTT computer)
Testing real time database (Twin Pool:  NTT - NTI) access
```

Watch these messages carefully to ensure everything is alright. Errors during startup such as initialization failures are indicated. If errors occur, press <EXIT> followed by <SHUTDOWN> to log off. Remove the cause of the error and start up again. Do not hestitate to call the introducing astronomer for help. With the proper termination of the startup command file the observing task IRSPC is ready to receive commands. The initial assignment of the <F1> - <F8> softkeys is indicated on the NTI-LU54 screen.

To get the instrument and detector status display, click the field `Window Up` on the menu bar that appears on NTI-LU39. Both `Window Up` and `Window Down` are selected with the right button of the mouse. All other fields are clicked with the center button. Click `Detector Status` to get the detector status display in the upper part of the NTI-LU39 RAMTEK. Now click `Window Down` and `Instrument status` to get the instrument status display in the lower part. The detector and instrument status displays are reproduced in Figure 3.2 on the following page.

If an exposure is active, the message `active` appears on a highlighted, yellow background field in the detector status display. Other important messages such as `NO TAPE` or `SBRC ARRAY NOT INITIALIZED` are enhanced as well.

Instrument and exposure parameters are set through the `IRSPEC Set Up Forms` and `Exposure Parameters Form` (Tables 3.4 and 3.5, respectively). The various exposure parameters defined are DIT, NDIT, NINT, and FINAL. DIT (*i.e.* detector integration time) is a single detector integration, NDIT is the number of DITs per measurement and NINT is the number of measurements. FINAL is the average of NDIT×NINT frames with DIT seconds of integration time each. By default, it is only the FINAL that is transferred to the NTI-A900 and stored as a 2-D IHAP file. As an option, the final average, the intermediate INTs and standard deviations can be stored as 1-D scanlines in the same file. To change the default storage mode, access the `Installation parameters form` by pressing the `Maintenance` softkey followed by `Installation Parameters`. Step through the form with the `<RETURN>` key and change the parameter `Data-Storage: Store all INT data:` to `TRUE`.
Among the installation parameters are the CAMAC LUs, the RS232 link LUs etc. Access this form only if you know what you are doing!

Click the `Observing Menu` field on the NTI-LU39 RAMTEK to call a new menu that contains the various options to control the integration. It is self-explanatory. For instance, click the field `Start Exposure` to start an exposure. A typical observation is descibed in section 3.1.2.

Note

Before filling in a form, wait until the previous exposure is finished and the data are transferred to the A900 and written onto tape. Being too hastily in changing the parameters may result in the loss of the parameter specified or it may leave the PPS in a strange configuration.

All programs that run on the NTT computer (see a brief selection in Appendix D) can be called from the observing task `IRSPC` by typing the program name, including the > sign. To come back to the observing task, either type `IRSPC>` or press the softkey `Back to IRSPC>`.

All commands entered are saved in the HP stack. To call the stack, type /. The last 20 commands are listed. Move the cursor to the command you want to execute and hit `<ENTER>`. Use `<SHIFT>` <↑> or `<SHIFT>` <↓> to scroll through the commands. Type /n to recall the last n commands.

Table 3.2: Status Display on NTI-LU39

IRSPEC Status

Detector SBRC 62 X 58
Identifier H2 2.122
Total Time = DIT*NDIT*NINT 5 sec
Temperature 30 K
IHAP File # 128
Exposure Active

Detector Integration Time DIT 0.97 sec

INT 5 2 done

Selected Options

FITS Format
TAPE Recording
SCI Exposure type
2-D frame Storage Mode

# of DITs per measurement NDIT 5 3 done
# of measurements NINT 1 0 done
# of Dummy Readouts 0
IHAP Batch k
Access Disabled for TELNTT ADAPTA

Instrument Parameters

Slit
Width 560 microns
0 arcsec

Decker
Position 21

Filter
Name H
Position 3

Range 1.53 to 1.80 um

Grating

Selected Grating 2
Wavelength from 2.11623 to ... 2.14564
Grating Encoder 3544
Order 1
Wavelength Center 2.12200 um
Range 0.02941 um

Cryogenic Status

Grating temperature 77 K
Pressure Gauge 0.18 V
Nitrogen level OK
Delta Temp. 1 OK
Vacuum Pressure OK

Detector temperature 30 K
Diff T1 0.2 Diff T2 0.1
Steady State OK
Delta Temp 2 OK
Cable Lock OK

3.1.1 The PPS Display

The PPS Parameters Form, shown in Table 3.3, provides control of the on line display on the PPS screen. Press the [PPS menu] softkey. A new menu appears. Press [PPS parameters] to access the form.

Table 3.3: PPS Parameters Form

```
PPS: plot mode [TRUE]
if T: average lines [28] to [30] ...  in dispersion direction? [T]
PPS: set autocut? [T]
if F,                  HCUT1 [100]       HCUT2 [100]
                       HCUT2 [800]       HCUT2 [800]

PPS: Display mode [1]
                       1 = every DIT signal
                       2 = don't use
                       3 = every INT signal + noise
                       4 = every FINAL data after every INT
                       0 = until 1st INT every DIT, then every INT
```

The right window on the PPS screen shows a 1-D spectrum plot of some horizontally or vertically averaged lines if the PPS plot mode is set to TRUE. To display the 2-D NOISE, set the plot mode to FALSE and chose display mode 3. The left display window shows individual data frames (DITs or INTs) as obtained during integration, depending on the parameter PPS Display mode. Cut levels can be chosen explicitly if the parameter PPS autocut it set to FALSE.

The DIT, NDIT and NINT, the number of DITs and the number of INTs done and the remaining integration time in seconds are displayed in the lower part of the PPS monitor. An arrow driven by a mouse connected to the PPS can be moved to any pixel within the 2-D frame or the 1-D plot. The X and Y coordinates of the arrow position are displayed as well as the pixel value and the pixel values of the eight or two neighbors. The color lookup table can be changed pressing the left button of the PPS mouse. The respective color bar is displayed left to the 2-D frame where the low and high cut levels are indicated as well.
Note: *Do not confuse PPS and NTI-LU39 mice!*

The currently displayed frame can be stored as a fixed pattern if the softkey [STFP] (store fixed pattern) is pressed. The softkey is defined in the [PPS menu]. The fixed pattern is automatically subtracted from every subsequent frame. The fixed pattern can be cleared with [CLFP] (clear fixed pattern). Whether a fixed pattern frame is stored or not is indicated. To set the cut levels properly, press [PPS autocut].

3.1.2 Check of Wavelength Calibration

The wavelength to grating position conversion is made automatically via a stored polynomial fit to measurements of a spectral line lamp. This 'master' curve is revised occasionally by ESO staff. The following procedure to check the wavelength calibration is in general only required once and preferentially done in the afternoon before your first night. The procedure is as follows:

- Type `AGA LACM> CLON 2` to switch on the Ne calibration lamp on the NTT adapter A.
- Type `ADA ADCM> CAIN` to move in the calibration unit.
- Set the instrument to a prominent Ne emission line (e.g. λ_{center} = 2.1708 μm). To do so, press `Instrument Parameters` and fill in the `IRSPEC Instrument Set Up Form` shown in Table 3.4:

Table 3.4: IRSPEC Instrument Set Up Form

Grating number	2	
Grating order	1	
Center wavelength	2.1708	um
Filter Name	K	
Auto Filter Selection	TRUE	
Slit width	280	um
Decker position	21	21=open, 22=closed

- Press `<ENTER>` to exit from the form.
- Set the detector integration time DIT to one second. To do so, press the `Exposure Parameters` softkey and fill in the form shown in Table 3.5:
- Click `Observation menu` on the menu bar displayed on NTI-LU39. Click `Start Exposure` to start the exposure. The following messages are displayed on the NTI-LU54 terminal:

```
IRSPC> Exposure "Neon 2.1708" started
IDTRL> Detector integration done.  Passing control to IRSPC
IRSPC> Data stored in IHAP file # nnn
IRSPC> Saving exposure data on tape in FITS format
IRSPC> OK. Data saved on tape. Exposure done
```

Watch these messages during your run. Error messages result if commands inadmissible to the current state of IRSPEC are selected.

Table 3.5: Exposure Parameters Form

Identifier	Neon 2.1708	
Tape Recording	TRUE	
Exposure type	CAL	SCI, DK, CAL, FF-SKY, SCRATCH
DIT	1	the exact DIT will be displayed after start
NDIT	2	DIT$\star$NDIT should be > 3sec if NINT>10
NINT	1	
Comment		Check of IRSPEC wavelength calibration
Sampling method	0	0=automatic, 1=non-destructive, 2=correlated
# of dummy DITs	0	
Store noise data	TRUE	into IHAP file #2 and #4
IHAP batch	k	

Note

If no emission line is visible, check the IRSPEC wavelength setting again. In particular, be sure to use the right combination of grating number, grating order, and filter for the selected wavelength. Possible combinations are given in Table 3.8. Make sure that the Ne lamp is turned on, that the calibration unit is in, and that the Decker is open. Check if both the NTT mirror M3 and the DIFA mirror are in the right position. Check if the calibration lamp is still working.

- Check the centering of the Ne emission line by moving the mouse driven arrow displayed on the PPS monitor to the center of the Ne line. The wavelength calibration is correct if the line is centered between pixels 31 and 32. Note that because of the tilt of the spectral lines the calibration is only defined for the middle between rows 28 and 29. If the line is not centered, call the introducing astronomer for help or follow the procedure described in section B. A Neon spectrum is shown in B.1 and B.2
- Type `AGA LACM> CLOF 2` to turn the calibration lamp off
- Type `ADA ADCM> COUT` to move the calibration unit out.

3.2 Calibration Exposures

3.2.1 Dark Current and Noise Measurements

The actual dark current may vary due to thermal radiation that originates within the cryostat. Dark measurements are also necessary if the sky is used for flat - fielding (see section 3.2.2). To perform dark measurements, enter the `IRSPEC Instrument Set Up Form` (Table 3.4) and set the grating number, the grating order, the center wavelength, and the filter name desired for the dark measurement. Close the Decker (position 22) and exit from the form. Obtain a series of darks with varying DITs, specified in the `Exposure Parameters Form` (Table 3.5).

3.2.2 Flat Fielding

In a procedure similar to that employed for optical CCDs, reasonable flat field corrections are obtained at wavelengths $\lambda < 2.5$ μm using a halogen lamp. It is in general sufficient to obtain flat field exposures at the beginning and at the end of the night. To account for the non - linearity of the array, take flat fields at an exposure level similar to that of the objects. The halogen lamp is bright at wavelengths between 1 μm and 2.5 μm and the detector saturates for DITs larger than 5 sec. Perform flat field measurements for the instrument settings used for the science exposures, including the various central wavelengths, grating number/orders, and filters.

The use of standard stars as flat field sources is not recommended. Many of the stars previously believed to have flat continua in the near IR do in fact show stellar absorption features which, at the resolution of IRSPEC, have depths of a few percent.

As discussed in section 2.3.2, the odd - even difference in the response of the array is corrected to first order by software. It may still be persistent at a low level even after flat fielding. If your observing program aims to measure spectra with high S/N, obtain science exposures with central wavelengths shifted by one or any other odd number of pixels.

The ultimate S/N that can be achieved is limited by the spatial noise of the array (see section 2.3.2). It cannot be improved by the accuracy with which flat field corrections are carried out nor by an increase of the total integration time. Whenever spatial noise is dominant, the faintest spectral features distinguishable are defined only by the uniformity of the array and the intensity of the background.

3.2.3 Saturation Measurements

In the J, H, and K bands, the maximum detector integration times possible depend largely on the brightness of the source. Note however that DITs larger than a minute suffer from an increased noise that arises from the internal background of the instrument (see Figure 2.2). In addition, 1/f noise may be present which further increases the read noise for long exposures. At wavelengths longer than $\lambda > 2.5$ μm, the detector saturates at small DITs. The maximal DITs are shown in in the following table:

Table 3.6: Detector Saturation

$\lambda(\mu m)$	DIT (sec)
3.0	5
3.5	1.5
4.0	0.5

3.3 Science Exposures

The **position angle** of the slit with respect to the sky is defined in the usual way: North = 0°, angle measured positive to East. The angle is set by specifying the rotator (*i.e.* adapter A) offset angle (command PRSET> RTOF, see section D.1). The **slit** is conventionally set to a width of 2 pixels corresponding to 560 μm, *i.e.* 4.″4. This ensures an adequate sampling in λ.

3.3.1 Observations in the Infrared

The near infrared wavelength region accessible to ground based observations may be divided into two regimes: the 1 - 2.5 μm wavelength region and the thermal infrared at longer wavelengths. The near IR is dominated by non-thermal emission by the polar aurora, OH and O_2 emission lines, and near IR nightglow. Vibrationally excited OH is produced in a reaction of Ozone with atomic hydrogen that takes place in a thin layer ($\approxeq$ 10 km) between the mesosphere and the ionosphere ($\approxeq$ 80 km height). The emission is highly variable on time scales of a few minutes. Pronounced diurnal intensity variations result from changes in the OH photodissociation rate which depends on the Doppler shift of the solar spectrum with respect to the predissociated OH absorption lines. Spectral variations result from changes in the rotational temperature of OH. Telluric O_2 emission in the IR is limited to wavelengths around $\approxeq$ 1.27 μm and $\approxeq$ 1.58 μm. It arises from electronically excited O_2 which is a photodissociation product of Ozone.

The wavelength windows accessible from ground based observations are determined by the atmospheric absorption lines of molecular species, mainly H_2O and CO_2. Figure C.1 contains the transmittance of the atmosphere between wavelengths of λ = 1 - 5 μm. The edges of the atmospheric windows are highly variable. The photometric atlas of the solar spetrum (Delbouille *et al.* 1981) can be consulted if a detailed knowledge of the atmospheric transmittance is required.

A proper flux calibration requires the observation of a standard star with the same instrument setting used for the science exposures. The star should be as hot as possible. For observations in bad atmospheric windows, chose a star as close as possible in air mass to the object in order to get an accurate flux calibration. *Do not forget to perform sky observations for the standard star as well!*

If the detector gets saturated, a memory of the previous image is present on the array. To clean the array, perform a number of Dummy read outs (*e.g.* 5 Dummy read outs with DITs of 1 sec). The number of Dummy read outs is specified in the **Exposure Parameters**

Form.

Changing from one photometric band to the other results in a motion of the source along the slit by a few arcsec. The displacement can be determined by the observation of a standard star at similar wavelengths.

As a major change compared to IRSPEC observations prior to the installation of the SBRC array, sky chopping and telescope beam switching have been removed from the observing menu. The detector is operated in DC mode, and FINALs up to several minutes on source are possible. Sky frames must thus be obtained explicitly. Sections 3.3.3 and 3.3.4 contain further information on sky observations.

The standard grating settings used for observations at the various wavelengths are:

Table 3.7: Standard Grating Settings.

Band	Grating number	Grating order
J	2	2
H	2	1
K	2	1
$> 3\mu m$	1	1

3.3.2 Pointing

The excellent pointing of the NTT of 1.3 arcsec RMS does not impose major problems for centering bright objects in the slit. Objects with visual magnitudes of $m_V \approx 15$ mag can easily be seen on the TV screen in a full moon night. Invisible IR sources may be centered by entering their position as an offset from a previously centered nearby star.

Objects with bright and point like IR emission may be 'peaked up'. In `PeakUp Mode`, the detector is read out continuously, the respective frames are displayed on the PPS screen, but no data are stored on the A900:

- Enter the `Exposure Parameters Form` (Table 3.5) and set DIT to 5 - 60 sec, depending on the expected strength of the signal. Select `sampling method` [1], i.e. triple correlated read out, to avoid the rapid flashing of the displayed DITs as it occurs in non destructive read out.
- Click [PeakUp Signal] from the menu bar displayed on NTI-LU39.
- Move the telescope to the 'sky' position and store a DIT as fixed pattern.
- Move the telescope to the 'source' and check the strength of the signal using the mouse driven arrow.
- Offset the telescope perpendicular to the slit, after every second DIT, until the intensity in the continuum or in the line is at maximum.

Note

The DIT cannot be changed when `PeakUp Mode` *is active. First abort the exposure (click* `Abort Exposure`*), then enter the* `Exposure Parameters Form` *and change the DIT. Although the form can be accessed and parameters specified at any time, the actual exposure time will not be altered as long as an exposure is active.*

3.3.3 Observations in the J, H, and K Bands

Analogous to chopping, cancellation of bright and variable sky emission is achieved through observations of a reference position close to the source. For compact sources, the sky observation may be obtained by observing the source at a different slit position. Total integration times per position are limited to $\approx$ 10 min during the night when the sky emission is stable in order to obtain a proper sky line subtraction. Before and after sunset and sunrise, significant variations in the sky emission may occur at time scales below 5 min.

Note

Poor cancellation of sky lines may arise from significant spectral and intensity variations of the emission lines at times shorter than the integration time. They may also result from movements of the grating after changing the grating position. The stability of the grating is checked through the DITs stored as fixed pattern frames during integration. Variations in the sky emission or grating instabilities show up as deviations from a uniform, noisy pattern.

3.3.4 Observations in the Thermal Infrared

Sky lines are no longer dominant at wavelengths longer than 2.5 μm because of the large background from thermal radiation from the atmosphere. As shown in Table 3.6, the detector saturates at small DITs. Shot noise of the thermal background photons dominate rather than read noise. Because of this, the sensitivity is severely decreased. Sources without an optical counterpart are therefore searched and centered at 2 μm where the S/N is in most cases higher. The stability of the thermal emission compared to the frequency of sky observations is the limiting factor that determines the sensitivity that can be achieved. Sky observations must be carried out at intervals of typically one minute.

The actually employed detector integration time is different from that specified in the `Exposure Parameters Form`. The correct DIT is displayed in the status display after the form is exited. It is also written into the header of the IHAP file stored on the NTI-A900. Because of the small DITs used in the thermal infrared, the actual integration time may differ significantly from the DIT specified.

3.4 Instrumental Performance

The resolving power R of IRSPEC at the various combinations of grating number and order are listed in Table 3.8. The filters listed in Table 3.8 are selected if the parameter `Auto Filter Selection` in the `IRSPEC Instrument Set Up Form` is set to `TRUE`. Note that the resolving power listed in Table 3.8 is given for a slit width corresponding to two pixels. Higher resolving powers are possible for narrower slit widths. A graphical representation of R as a function of wavelength is illustrated in Figure 3.1.

Table 3.8: IRSPEC Performance

Grating	λ-range μm	Order	Filter	Resolution[a]	Sensitivity (1σ noises) mag	10^{-22} W cm^{-2}
1	1.05 - 1.4	3	2	1500 - 2200	14.0	2.6
1	1.07 - 1.3	4	2	2300 - 3400	13.2	3.2
1	1.5 - 1.8	2	3	1400 - 1800	15.1	0.6
1	1.5 - 1.7	3	3	2400 - 3400	13.1	1.8
1	2.0 - 2.6	2	4	2000 - 3400	13.2	1.0
1	3.0 - 5.2	1	7	1400 - 3400	8.0[d]	33[d]
2	1.05 - 1.3	2	2	2200 - 3400	14.2	1.3
2	1.4- 2.0	1	3,8[b]	1300 - 2000	15.2	0.6
2	1.8 - 2.6	1	4,6[c]	1700 - 3400	14.0	0.5

[a] for a slit width of 560μm, corresponding to two pixels
[b] 1.41 - 1.52 μm: Filter 8; [c] 1.81 - 2.04 μm: Filter 6
[d] 3.6 μm, 0.5 sec

Table 3.8 contains preliminary results of sensitivity measurements at the centres of the standard photometric bands. The listed limiting magnitudes and fluxes per pixel correspond to 1σ noises derived from observations of a standard star using 60 sec of integration time on the star and 60 sec on the sky. If the long-slit capability of IRSPEC is not required, explicit sky observations are avoided by observing the source at two different slit positions. It is thus possible to gain a further factor of $\sqrt{2}$ in S/N.

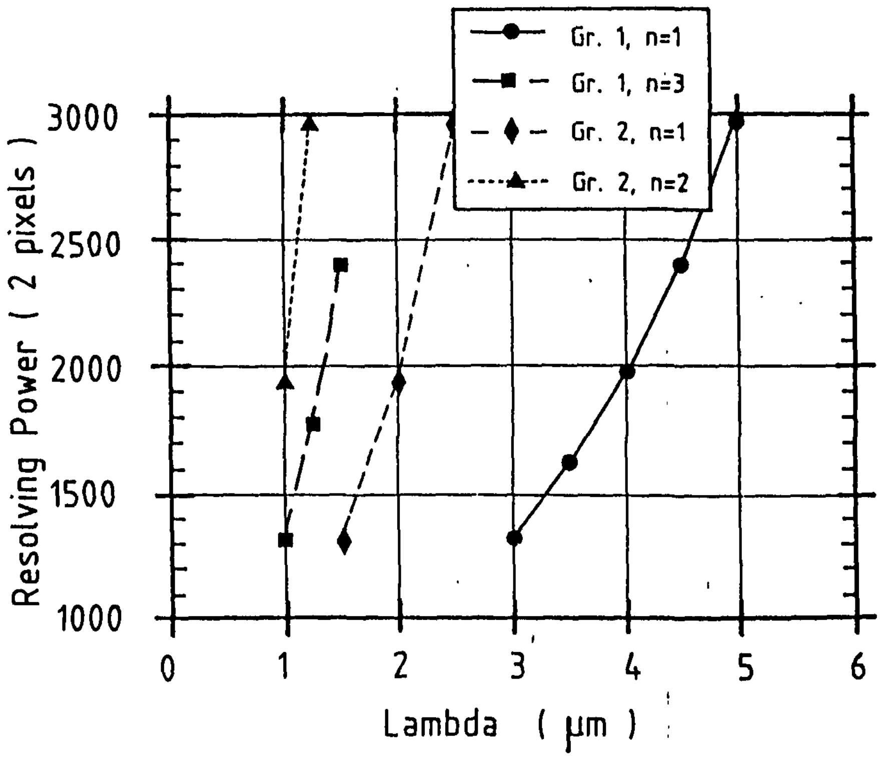


Figure 3.1: IRSPEC Resolving Power

The filters installed in position 1 - 8 of the filter wheel are described in the following Table 3.9. Type `RU,PF,FILTER` to display this table on the screen.

Table 3.9: Filter Transmission

Filter	Name	λ_{min}	λ_{max}
1	I	0.88	1.20 [a]
2	J	1.05	1.41
3	H	1.53	1.80
4	K	2.05	2.41
5	L1	1.05	10.0
6	L2	1.80	10.0
7	L3	3.05	10.0
8	BP	1.40	10.0

[a] Filter leaks at $\lambda > 2.5$ μm

3.5 ICTRL Command Summary

Parameters related to the setting of the instrument can be specified by typed commands as well. To use typed commands, call the program by typing ICTRL> followed by one of the following commands:

Table 3.10: ICTRL Command Explanation

Command	Description
DKCL	close Decker
DKER nn	move to decker number; 21=open 22=closed
DKOP	open Decker
EXIT	terminate ICTRL
FIAU*	filter automatic mode
FILT n	select filter number n
FINA A2	move filter no name (character ⋆ 2)
GRCW x	move grating to specified center wavelength
GREN nnnn	move grating to encoder value nnnn
GREX n	move grating exchange to grating 1 or 2
	Grating # 1: 300 lines/mm, for middle infrared
	Grating # 2: 600 lines/mm, for near infrared
GROR n	select grating order n
	Note: GROR does not move the grating until GRCW is issued
GRSP	move grating in pixel steps
INIT	initialize all controllers and functions
MOAL	move functions to parameters specified in form
SLEN nnnn	move slit to specified encoder position
SLIT nnn	move slit to specified slit width; nnn in microns
XPOF	enable ICTRL action
XPON	disable any ICTRL action (e.g. while integrating)

Chapter 4

Miscellaneous Comments and Advice

During Observations

- Always check the system messages displayed to verify that the desired commands are executed. Particularly towards the end of the night, commands are clicked inadvertently.
- Use vacuum center wavelengths when specifying central wavelengths*.
- Use `GRSP` ± `55` to move to the next segment in a continuous spectrum to get some pixel overlap.
- If `GRSP` is used in a continuous spectrum, make sure the actual wavelength is covered by the transmission of the current filter.
- Get at least two integrations with central wavelength differing by 1 pixel (`GRSP` ± `1`) to correct for remnants from the the odd - even effect in the detector response.
- Always update DIT when entering the `Exposure Parameters Form`. The DIT specified in the form differs from the exact DIT. The exact DIT appears in the form when entering it again. Accessing the form several times without re-setting DIT results in a series of measurements with increasingly smaller DITs.
- Make sure to measure source and standard star in the same filter.

Troubleshooting

- No emission visible: check that the combination of grating number, grating order, filter number is consistent with the central wavelength. Make sure the Decker is open.
- Integration does not start after clicking `Start Exposure` field. Check the message displayed on the NTI-LU54 terminal screen. New integrations cannot be started if the identifier is not set or if an exposure (`PeakUp`) is still active.

- The NTI-LU54 hangs: abort TH and SH from another terminal connected to the NTI A900. To do so, log on as `ESO` and type `OF,TH.54,ID` and `OF,SH.54,ID`.
- The NTI A900 is slow: remove all programs that take CPU time but are not necessary during your observing session. Logon as above and type `TWINON`.

Bibliography

[1] Moorwood, A.F.M., Biereichel, P., Finger, G., Lizon, J.-L., Meyer, M., Nees, W., and Paureau, J. 1986 *The Messenger* **44**, 19.

[2] Moorwood, A.F.M. 1987,*Infrared Astromony with Arrays*, eds. Wynn-Williams, C.G., and Becklin, E.E., 379.

[3] Moorwood, A.F.M., 1991 *The Messenger* **62**, 56.

[4] Moorwood, A.F.M., Moneti, A., and Gredel, R. 1991 *The Messenger* **63**, 77.

[5] M. J. McCaughrean, 1988, The Astronomical Application of Infrared Array Detectors, Ph. D. Thesis, University of Edinburgh.

[6] Biereichel, P. 1990 *IHAP Manual*

[7] Delbouille, L., Roland, G., Brault, J., and Testerman, L., 1981, *Photometric Atlas of the Solar Spectrum from 1,850 to 10,000* cm^{-1}

Appendix A

On-line Data Reduction

IHAP is available on line on the A900. The RAMTEK NTI-LU32 and the graphics terminal NTI-LU72 can be used to display 2-D images and 1-D traces.

A.1 IHAP Commands

A full description of available IHAP commands is given in Biereichel (1990).

Table A.1: IHAP Commands

Command	Description
`DLIST,# ,LONG`	`List the directory of file # n`
`WICOMMENT,#`	`List the extended directory block`
`DLIST,# n,# m`	`List files from # n to # m on the disk`
`KDISP,#`	`Display a 2-D image on the RAMTEK`
`XADD,#n,X1,XN`	`Average lines X1 - XN perpendicular to dispersion direction and create a new 1-D file`
`SADD,#n,S1,SN`	`Average lines S1 - SN in dispersion direction and create a new 1-D file`
`CUT,# n, l, h`	`set low and high cuts on Y axis`
`CTRA,BI`	`set histogramm display mode (default:point)`
`TRAN,# n`	`Display a 1-D spectrum on the graphics screen`
`PLOT`	`send a copy of the latest spectrum shown on the graphics screen to the plotter.`
`PFUN`	`Arithmetic operations on files` `PFUN, # a, # b,/ :  Divide file # a by file # b`

A.2 IRSPEC Batches

A few batches have been developed under IHAP to make on line data reduction easier.

Table A.2: IRSPEC Batches

Name	Description
K	Display 2-D images
KCHOP	Sky subtract images
TSPEC	Plot 1-D spectra

K: Display 2-D images

```
BATCH,K,,#
```

= Number of the image to be displayed

K determines the proper cut levels for an image, performs the IHAP commands `SCALE,#,X,8,Y,8` and `SAMP, #, X1, X62, Y1, Y58` and displays the image on the NTI-LU38 RAMTEK.

KCHOP: Sky subtract images

```
BATCH,KCHOP,,#,#
```

= Number of the images to subtract from each other

KCHOP performs the IHAP command `PFUN, #1, #2, -`. It performs `BATCH,K,,#` on the resulting image.

TSPEC: Plot 1-D spectra

```
BATCH,TSPEC,,n
```

n = number of lines to average

Do a KCHOP first. Move the cursor on the RAMTEK to the center row of rows to be averaged. TSPEC performs the IHAP command `SADD,#,S1,S2` where n = (S2 - S1) and displays the 1-D average on the NTI-LU72 graphics screen.

Appendix B

IRSPEC Wavelength Calibration

The most probable error in the IRSPEC wavelength calibration curve is a shift of the whole calibration curve. To determine the shift, proceed as follows:

- Set up the instrument as described in the beginning of section 3.1.2.
- Start Peak up mode by clicking the `PeakUp Signal` bar on NTI-LU39.
- Write down the grating encoder value that is printed in the Instrument Status Display.
- Type `GREN nnnn` to move the grating to encoder position nnnn which may differ from the displayed value by a few encoder units.
- Check the centering of the Ne line as the grating position is changed and repeat this until the line appears on pixel 31.5.
- Repeat this procedure for a few Neon lines to ensure the encoder offset is the same for the various grating positions.
- Type `RU,PF,GRATING,-u` to edit the `IRSPEC Grating Parameters` form. Enter the difference between the initial and final encoder values in the line
  `the number of encoder steps which are added (subtracted) to the calculated value, independently of the wavelength.`
  Note that this offset is in general different for grating #1 and grating #2.
- Perform a final integration to check the applied correction is correct.

If the encoder offset changes with λ, the IRSPEC master curve is obsolete. Establish a new curve with the aid of ESO staff. The procedure is as follows:

- Determine the encoder position for various wavelengths λ by observing lines in the Neon emission spectrum.
- Update the file `/IRSPEC/$IRCA1` and `/IRSPEC/$IRCA2`

- Enter the `Calibration menu` on NTI-LU39. Calculate the polynomial fit by clicking `Do Poly Fit`. Store the new parameters using `Store Parameters`. Plot the fit on the NTI-LU72 graphics screen with `Plot Poly Fit`.

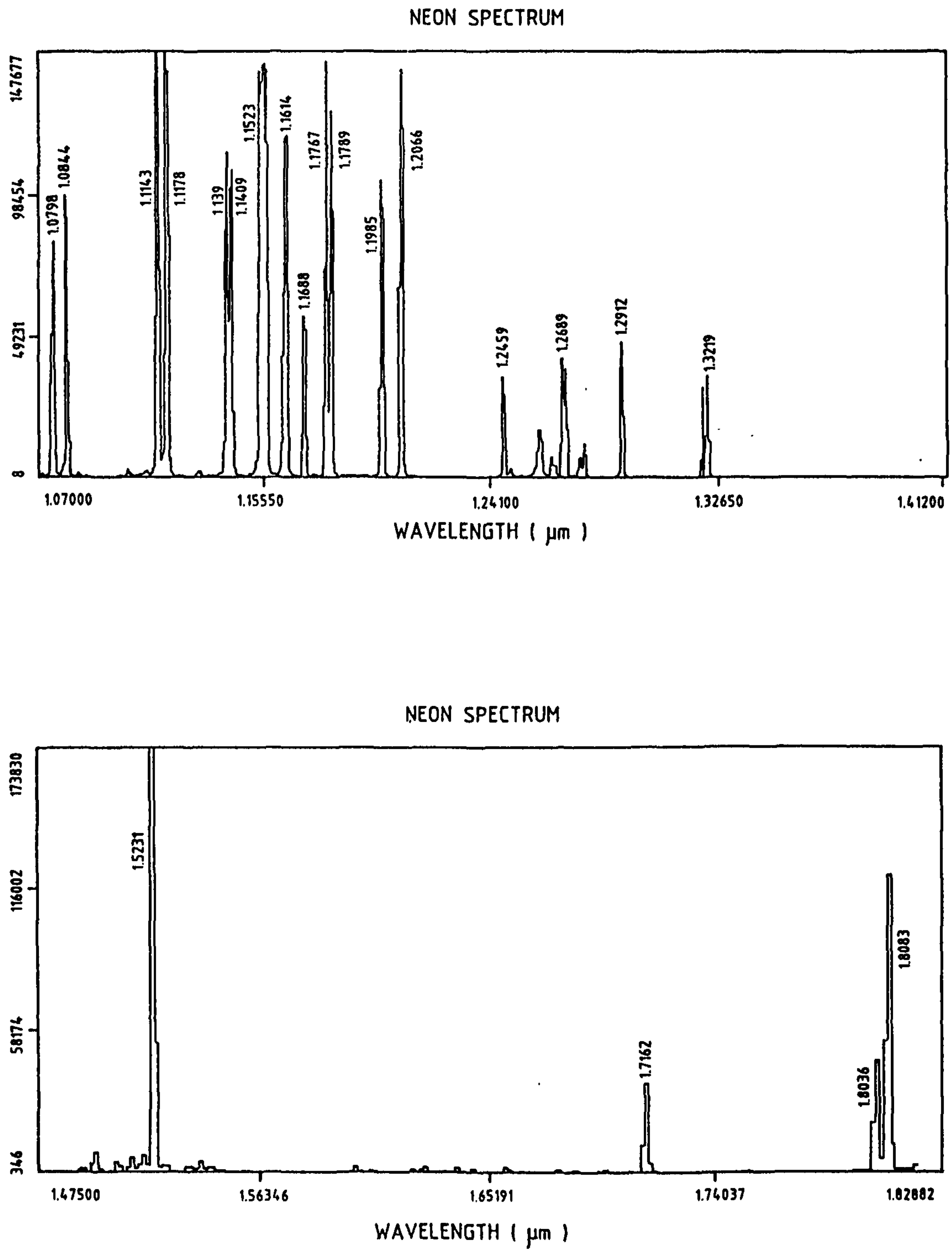


Figure B.1: Neon Spectrum from 1 - 1.8 μm

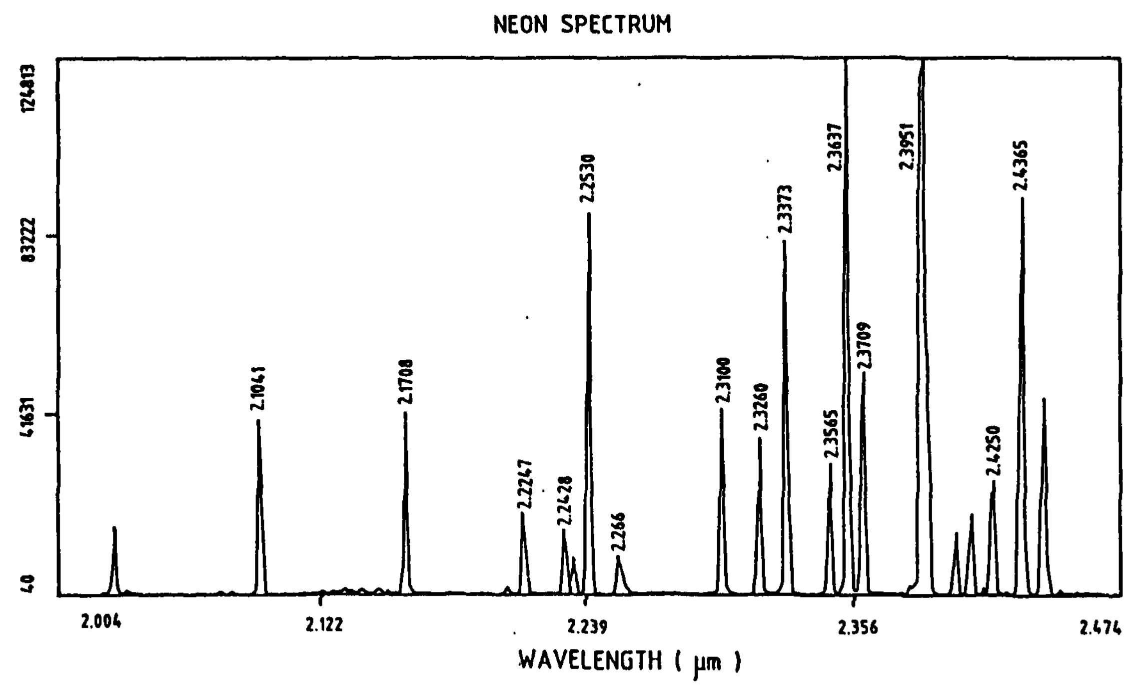
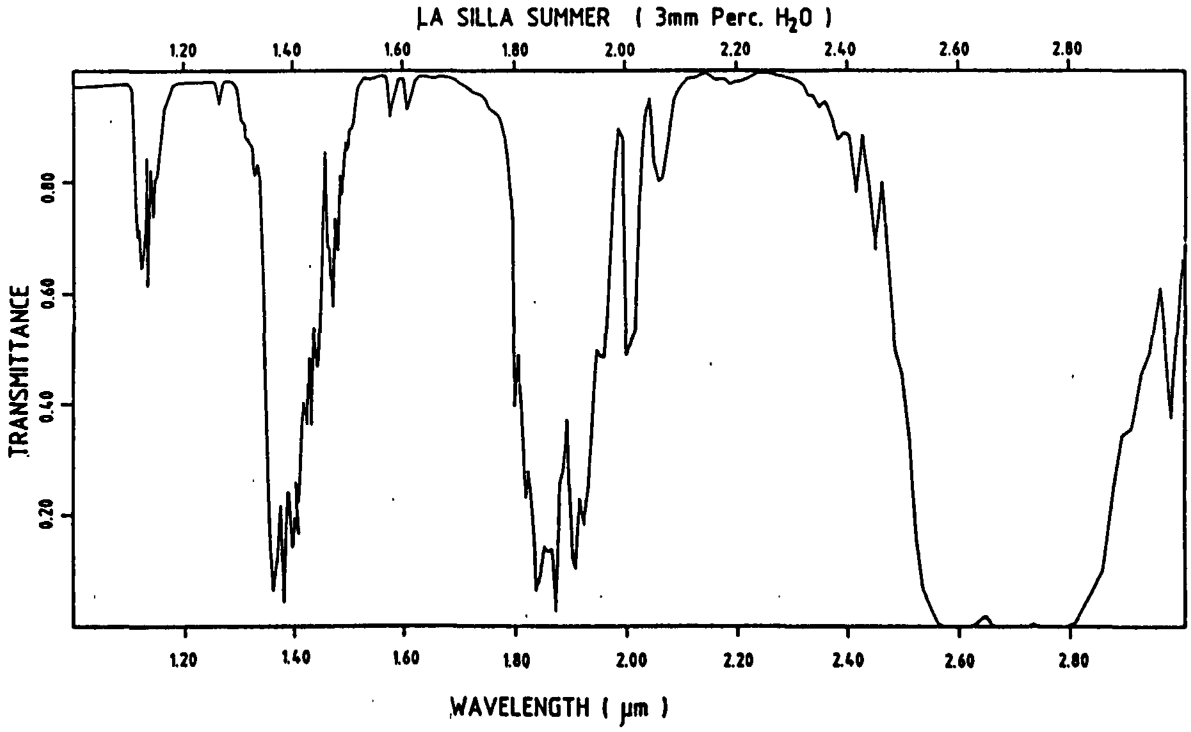


Figure B.2: Neon Spectrum from 2 - 2.5 μm

Appendix C

Atmospheric Transmission from 1 - 5 μm

The atmospheric transmission from 1 - 5 μm is shown in Figure C.1. Refer to the solar atlas of Delbouille *et al.* (1981) in cases where a detailed knowledge of the atmospheric transmission is required.



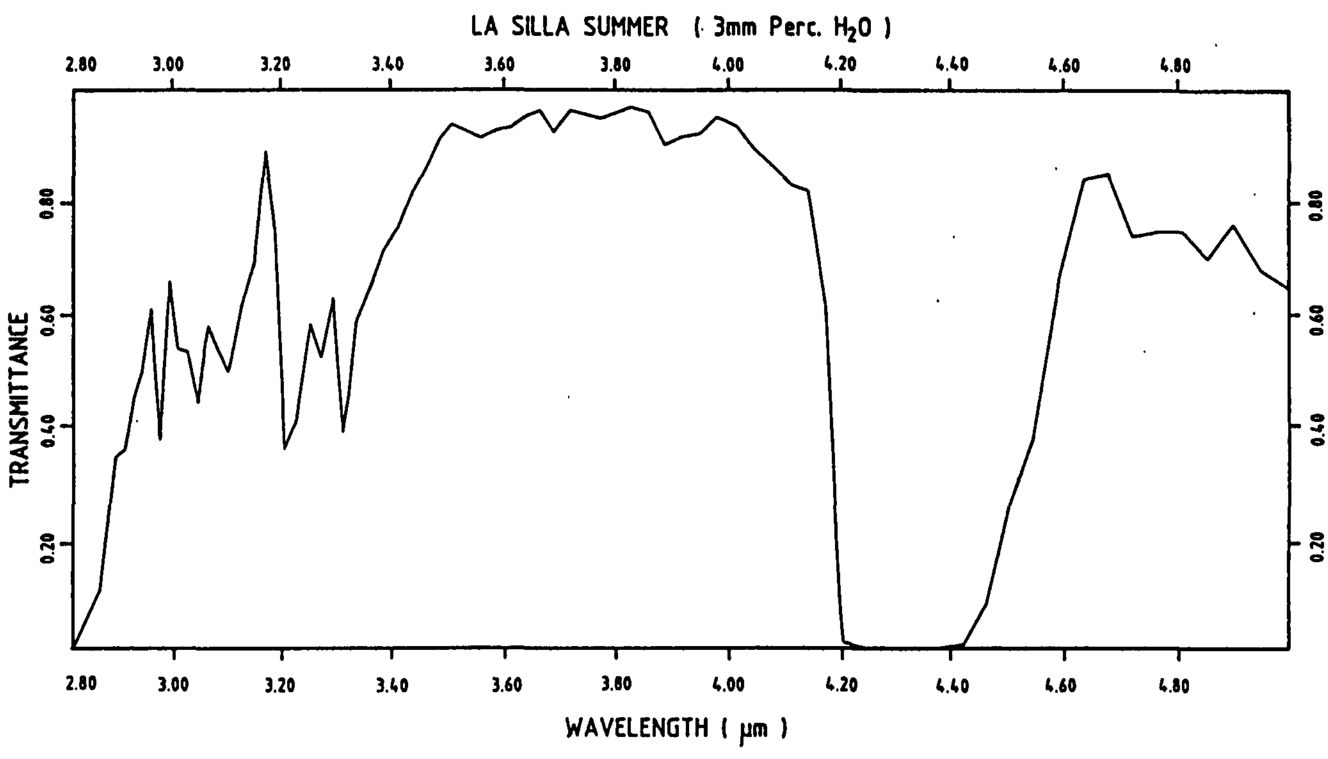


Figure C.1: Atmospheric Transmission from 1 - 5 μm

Appendix D

Programs on the NTT Computer

Among the various programs running on the NTT computer, three are of most interest for the observer with IRSPEC. They are `AGA LACM>`, which controls the calibration lamps of the NTT - Adapter A, `AGA AGCM>`, which controls the guide probes, the TV cameras etc., and `PRSET>`, which allows to preset the telescope to a given coordinate. A few commands are described in the following. They are called from the NTI-LU54 IRSPEC control console by typing the program name, including the > sign, followed by the command name.

Table D.1: NTT Programs and Commands

Command	Description
AGA LACM>	
CLON n	switch on calibration lamp n 1 = Krypton 2 = Neon 3 = Halogen
BBON	switch on the black body source
BBTM nnn	set blackbody to temperature nnn K nnn = 0 -- 600 ^{0}C
CSOP n	open Shutter in front of calibration lamp n
CLOF n	turn calibration lamp off
BBOF	turn black body source off
CSCL n	close shutter n
AGA AGCM>	
PRSET>	
RTOF nn	Specify rotator angle To set the position angle on the sky
PNEW RA,DE,EP	To set new telescope coordinates RA, DE at epoch EP
OFSA aa	To offset by aa arcsec from source coordinates
OFSD dd	To offset by dd arcsec from source coordinates
OFSG a d	To offset in RA and DE; keep auto guiding