UNIVERSITY OF CALIFORNIA

LICK OBSERVATORY TECHNICAL REPORTS

No. 77

THE LICK INFRARED CAMERA USER'S MANUAL

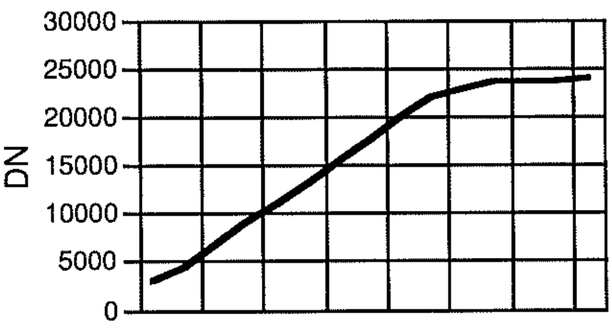
Santa Cruz, California

March, 1995

Array Characteristics

Characteristic	Approximate value
Array size	256 x 256
Pixel size	40 x 40 μ, 3-μ apart
Dark current	less then $2e^{-}$ sec^{-1}
Readnoise	approximately $50e^{-}$
Full well	$300{,}000e^{-}$
K-band QE	62% @ 77K
Cut-on wavelength	0.9 microns
Cut-off wavelength	2.5 microns
Gain	12 electrons DN^{-1}

Array Linearity (see also Appendix C)



Back Filter Wheel (traces in Appendix E)

Position or Filter Name	Bandpass or Central Wavelength (μ) at 77° K
K-band	1.98-2.39
J-band	1.10-1.44
Open	
OII	1.237 (within 1%)
FeII	1.644 (within 1%)
H2 S(1) 1-0	2.122 (within 1%)
Brackett g	2.166 (within 1%)
H2 S(1) 2-1	2.248 (within 1%)
CO	2.295 (within 3%)
K'	1.95-2.35
H-Band	1.50-1.82
Dark	between filters

Broadband Count Rates (3-meter)

Band	Magnitude	Approx. DN sec^{-1}
J	12.96	2300
H		2200
K	13.15	1650

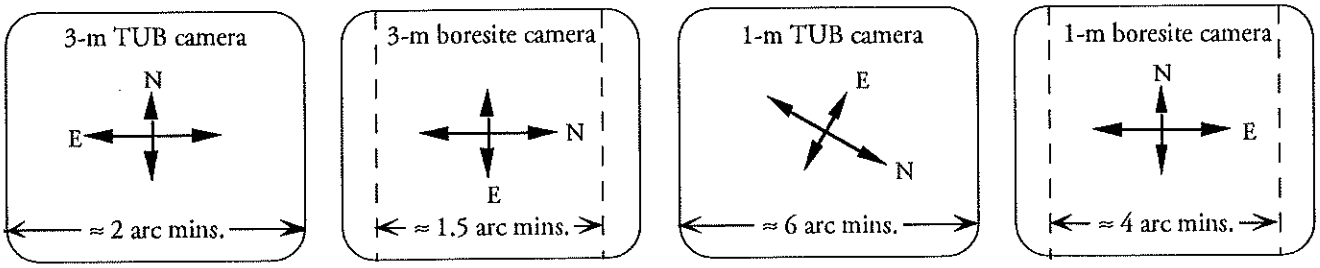
Sky Brightness (see also Appendix C)

outside air temp. (F)	camera field of view	approx. time to saturation
39°	narrow	165 secs.
39°	intermediate	70 secs.
39°	wide	20 secs.
55°	narrow	85 secs.
55°	intermediate	35 secs.
55°	wide	10 secs.

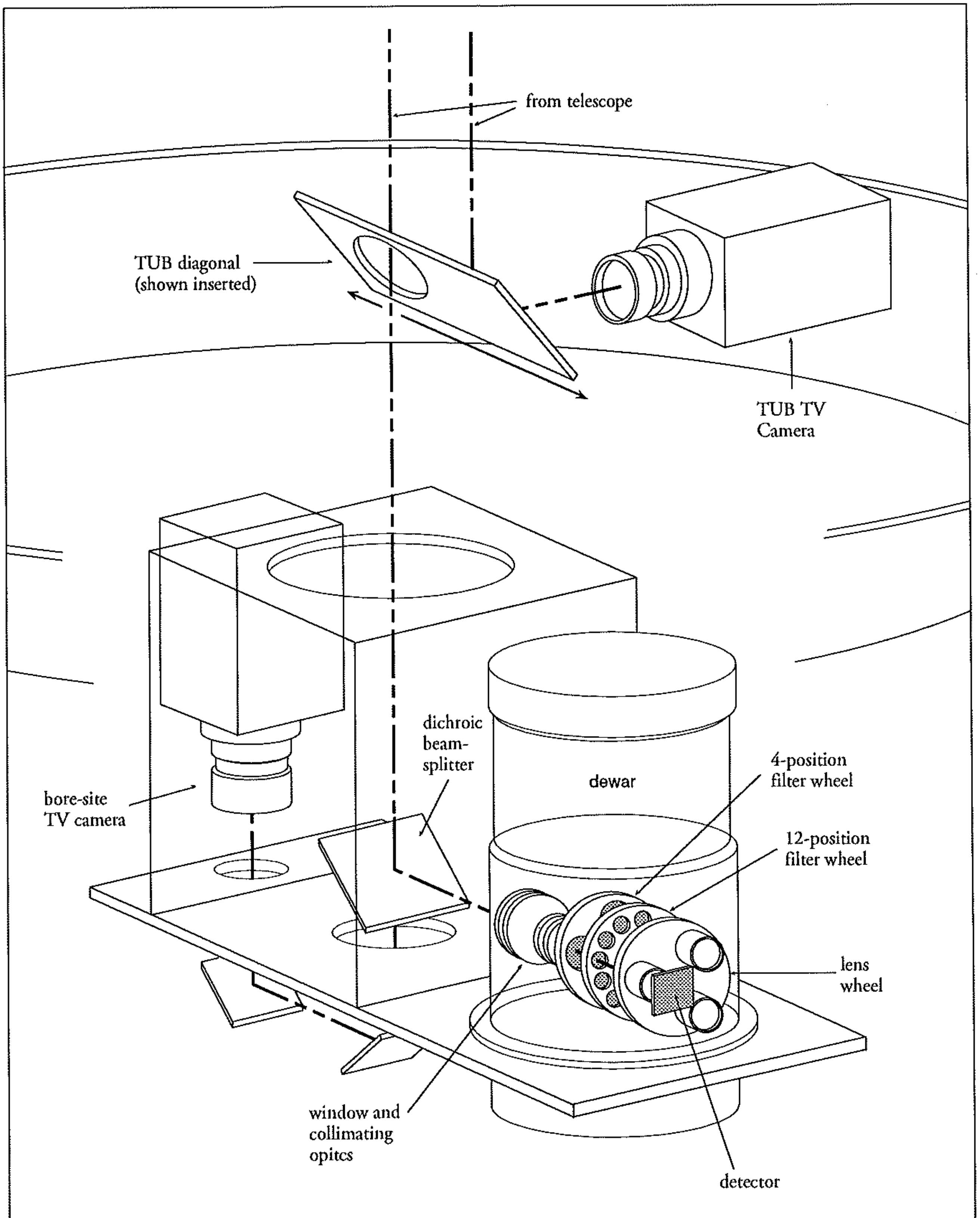
IR Camera Fields of View and Plate Scales (see also Figure 2. in text)

telescope	narrow field of view	intermediate field of view	wide field of view
3-meter	0.81 arc minutes 0.19 arc seconds $pixel^{-1}$	1.62 arc minutes 0.38 arc seconds $pixel^{-1}$	2.43 arc minutes 0.57 arc seconds $pixel^{-1}$
1-meter	2.43 arc minutes 0.57 arc seconds $pixel^{-1}$	4.86 arc minutes 1.14 arc seconds $pixel^{-1}$	7.29arc minutes 1.71 arc seconds $pixel^{-1}$

TV Fields of View and Directions (see also Section 2.7.4.)



THE LICK INFRARED CAMERA USER'S MANUAL



The Lick Infrared Camera (LIRC-II)

UNIVERSITY OF CALIFORNIA LICK OBSERVATORY

TECHNICAL REPORTS

No. 77

THE LICK INFRARED CAMERA USER'S MANUAL

Anthony Misch

Kirk Gilmore

Dave Rank

Santa Cruz, California

March, 1995

For copies of this manual, inquire with the
Lick Observatory Publications Office
publof@ucolick.org

CONTENTS

CONTENTS

CONTENTS

FIGURES

TABLES

First time LIRC-II observers must be checked out on the instrument by one of the resident astronomers. First time Nickel telescope users must also be checked out on the use of the telescope. Please ask for assistance on your time application.

1. DESCRIPTION

The Lick Infrared Camera, LIRC-II, is a facility instrument, developed at Lick Observatory; for use at the cassegrain foci of the 3- and 1-meter telescopes on Mt. Hamilton.[1] At its heart is a 256 x 256 pixel, NICMOS-3 array, from Rockwell International. The mercury-cadmium-telluride (HgCdTe) device is sensitive from 0.9μ to 2.5μ. The camera includes optics which may be remotely selected to provide narrow, intermediate, and wide fields of view. Observers may chose from a variety of cold filters, permanently mounted in two remotely controlled filter wheels.

Operation of the camera is, in large part, the same at the 3- and 1-meter telescopes, though plate scales and flux rates will, of course, differ. An observer at the 1-meter is required to operate systems such as the TV camera and autoguider, which, at the 3-meter, are generally handled by the telescope operator. This manual is for use at both telescopes. Instructions that pertain exclusively to one or the other are so noted. The camera's components and user interface are described in this section.

1.1. The Instrument

The frontispiece and back cover show a 3-D representation of the instrument's principal parts and optical path. The optical interface bolts to the telescope and supports the camera's other components. A dichroic beamsplitter reflects the infrared component of the telescope beam to the dewar, where it is filtered and reimaged on the array by the dewar's internal optics. The visual part of the telescope beam is transmitted by the beamsplitter and reflected by two

---

[1] The dewar may also be mounted on the 160-inch camera of the 3-m's coudé spectrograph, see Appendix G. While operation of the camera with the coudé spectrograph has many details in common with cassegrain imaging, the body of this manual treats only the latter.

plane mirrors to the bore-site guide camera. Also pictured are the diagonal mirror and guide camera located in the Telescope Utilization Bin (TUB). Either TV camera may be used for acquisition and guiding. Their relative merits are discussed in Section 2.7.

Figure 1. illustrates the dewar's internal optics. The telescope focal plane lies approximately 70-mm in front of the dewar window. Just behind the window, a three-element lens assembly collimates the beam. This is followed by independentally positioned 'front' and 'back' filter wheels with four and twelve positions, respectively. Their contents are listed in Table 1. Filter transmission curves are provided in Appendix E.

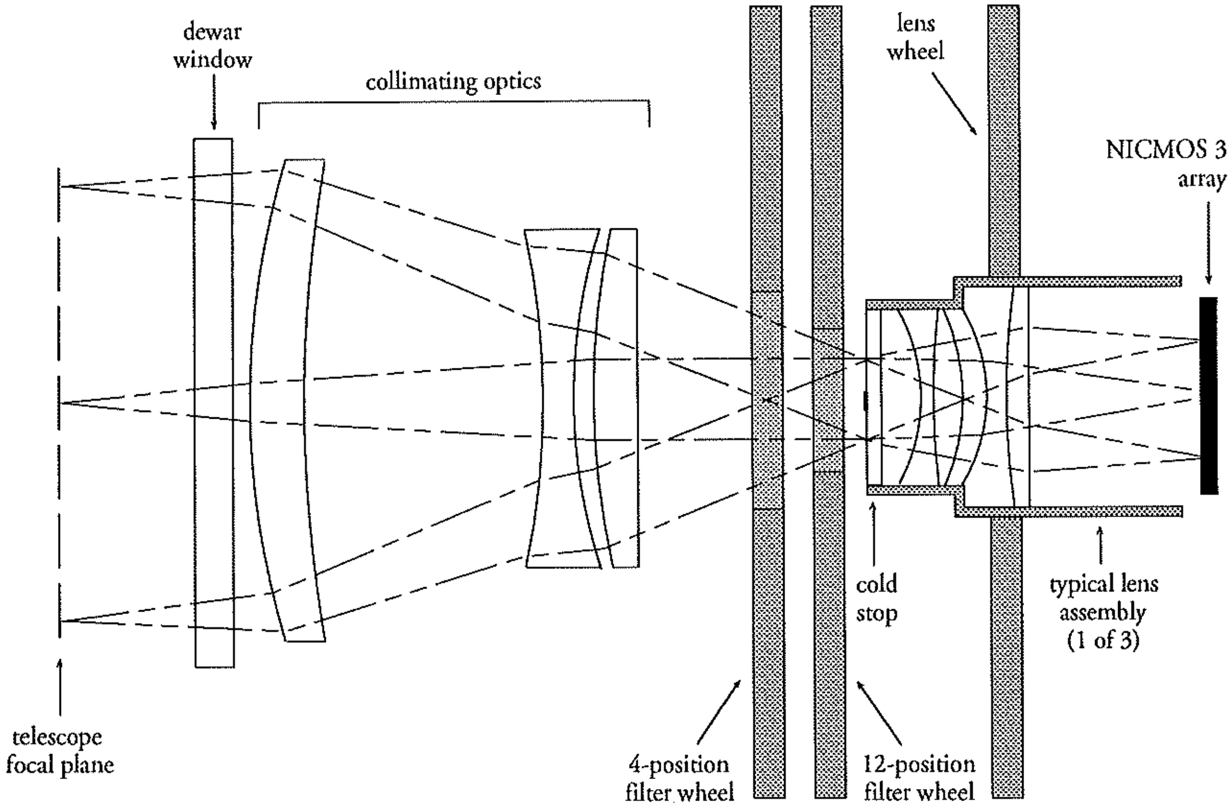


Figure 1. The dewar's internal optics

The 'lens wheel' carries three lens assemblies which reimage the focal plane on the detector at one of three plate scales (see Figure 2.). At the input end of each assembly, where the collimating optics have formed an image of the telescope's primary mirror, each is equipped with a cold stop to minimize background radiation from the telescope. The intermediate field of view also includes a cold central spot which blocks the shadow of the secondary mirror and is important when checking the camera's collimation (see Section 2.11.).

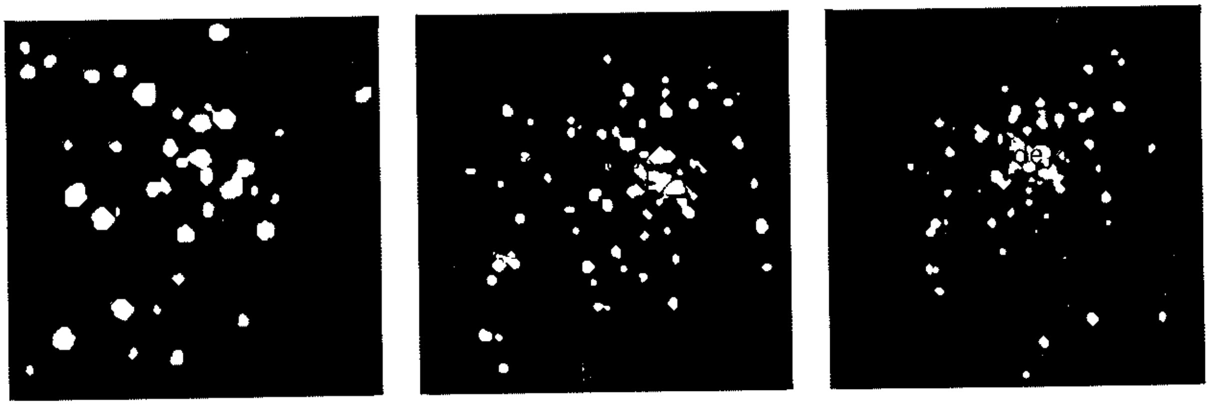
Back Filter Wheel

Position or Filter Name	Bandpass or Central Wavelength (μ) at 77° K
K-band	1.98-2.39
J-band	1.10-1.44
Open	
OII	1.237 (within 1%)
FeII	1.644 (within 1%)
H2 S(1) 1-0	2.122 (within 1%)
Brackett γ	2.166 (within 1%)
H2 S(1) 2-1	2.248 (within 1%)
CO	2.295 (within 3%)
K'	1.95-2.35
H-Band	1.50-1.82
Dark	between filters

Front Filter Wheel

Position or Filter Name	Bandpass or Central Wavelength (μ) at 77° K
Open	
ND 2	2% transmission
Fe I	1.56 (coudé spectrograph)
Open	
Dark	between filters

Table 1. Filter wheel contents (Filter transmission curves are given in Appendix E)



narrow
0.81 arc mins, 0.19 arc secs pixel^{-1}
(1-m: 2.43 arc mins, 0.57 arc secs pix^{-1})

intermediate
1.62 arc mins, 0.38 arc secs pixel^{-1}
(1-m: 4.86 arc mins, 1.14 arc secs pix^{-1})

wide
2.43 arc mins 0.57 arc secs pixel^{-1}
(1-m: 7.29 arc mins, 1.71 arc secs pix^{-1})

Figure 2. The camera's fields of view. The globular cluster M97 is shown, at the 3-meter scale, for each of the camera's fields of view. The corresponding 1-meter scales are given in parantheses. North is at bottom, East at left, on the data-taking system displays at both telescopes.

1.2. The User Interface

The observer opeartes the instrument from the telescope control room via the data-taking program, the motor control program, and the Lick TV camera controller. Figure 3. illustrates how the parts of LIRC-II and its associated systems fit together.

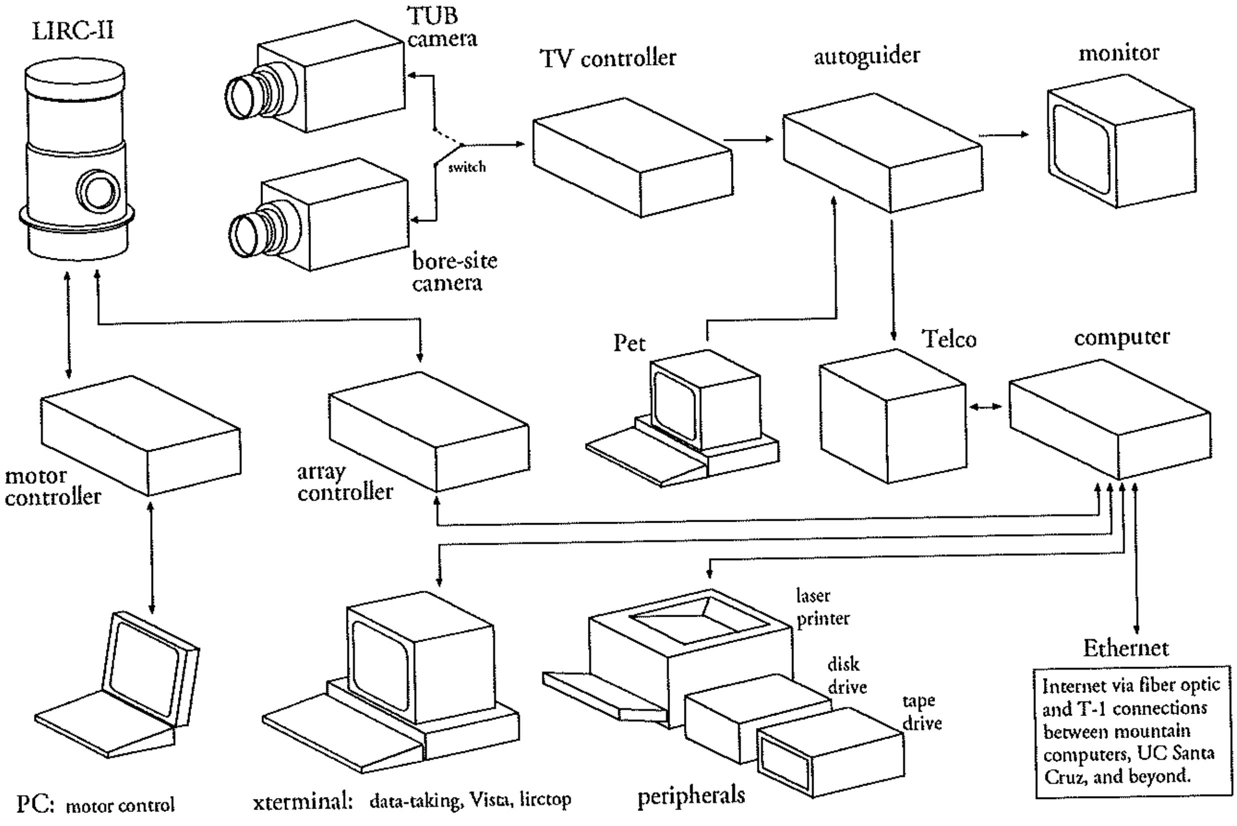


Figure 3. LIRC-II system integration

The LIRC-II data-taking system, based on Richard Stover's X-Windows program for Lick CCDs, and modified by Kirk Gilmore for use with the infrared camera, permits the user to input observing parameters, control integrations, provide information for the FITS header, initialize and position tapes, and perform tests on the array. The basic operation of the data-taking system, along with features unique to the LIRC-II version, are described in Sections 2.2. and 2.3. A detailed explanation of each data-taking command is given in Appendix A..

The motor control program, written by Pasquale Temi for a PC compatible computer, allows the user to select filters and field of view by positioning the dewar's internal filter wheels and lens turret. Operation of the motor control program is described in Section 2.4.

The bore-site and TUB guide cameras share the same standard Lick TV camera controller. Either can be used for acquisition and to provide the signal for the Lick autoguider, however, the two cameras differ in some important respects. Choosing the right TV camera is discussed in Section 2.7.

Some operations can be automated, or semi-automated, using Vista procedures. A number of procedures for calibrating, testing, and observing have been collected under the top-level calling procedure 'Lirctop' (see Section 2.6. and Appendix B).

Output devices for LIRC-II data include an X-Window terminal, high-capacity disk drive, 8-mm Exabyte tape drive, and a laser printer. Data are stored in standard FITS format. They may be sent, using FTP, to remote sites.

2. SETTING UP AND PREPARING TO OBSERVE

2.1. Upon Arriving

Initial setup is performed by the observatory staff. Starting computer programs, initializing the camera, and testing the detector are left to the observer. Upon arriving, confirm that the setup has been completed. Check that the dewar has adequate coolant and, in humid conditions, that the captive air cover has been installed (see below). Consult the Cassegrain Logbook at the 3-meter, or the User's Logbook at the 1-meter for notes by recent users. Check Lirctop's electronic log for the latest updates.

2.1.1. Filling the Dewar

At the 3-meter the dewar is filled by observatory staff, but at the 1-meter it is the observer's responsibility. The LIRC-II dewar is of the twin vessel type. Both vessels use liquid nitrogen. The outer vessel requires refilling every twelve hours; the inner vessel may be filled once a day. Bear in mind, however, that there may be spillage when working at large zenith distances, requiring more frequent refilling. <u>Note that the array may exhibit some instability in the first hour after filling.</u>

Both vessels are filled from the top of the dewar using a funnel with two 90-degree bends. Remove the tubes from the fill holes by unscrewing the knurled couplings, or, if they're frozen solid, carefully pull the hoses themselves out of the couplings. Gently insert the funnel into the inner vessel's fill hole, the one nearest the center of the dewar. The inner vessel generally requires very little nitrogen--minimize spillage by only pouring a small amount at a time into the funnel. The vessel is full when the coolant overflows the fill hole. Move the funnel to the outer vessel's fill hole and proceed in the same manner. The outer vessel will typically require 2 to 3 litres every 12 hours. Avoid spilling nitrogen onto the dewar--loss of vacuum due to a frozen o-ring could end your observing session and damage the camera.

<u>Always replace the rubber hoses</u>, they provide paths for the coolant to flow harmlessly to the floor when the telescope is moved to large hour angles. If they were removed at the couplings, simply screw them back into place. Turn the couplings several threads, but do not tighten. If the hoses were removed from the couplings, reinsert them after they have warmed up and become pliable.

2.1.2. The Captive Air Cover

Above about 70% relative humidity, the dewar's input window can fog over. A transparent captive air cover prevents fogging, with negligible light loss and image degradation. The cover is placed over the square, protruding collar of the input window, and its power supply plugged into an AC outlet on the telescope. Use of the captive air cover should be standard operating procedure during the damp winter months, and in all but the driest conditions throughout the year. Condensation on the window not only ruins images, but can permanently damage the window's coating. Use the captive air cover if humidity can be expected to reach 70% or higher anytime during the night.

Should condensation form, call a member of the staff, do not attempt to remove it yourself.

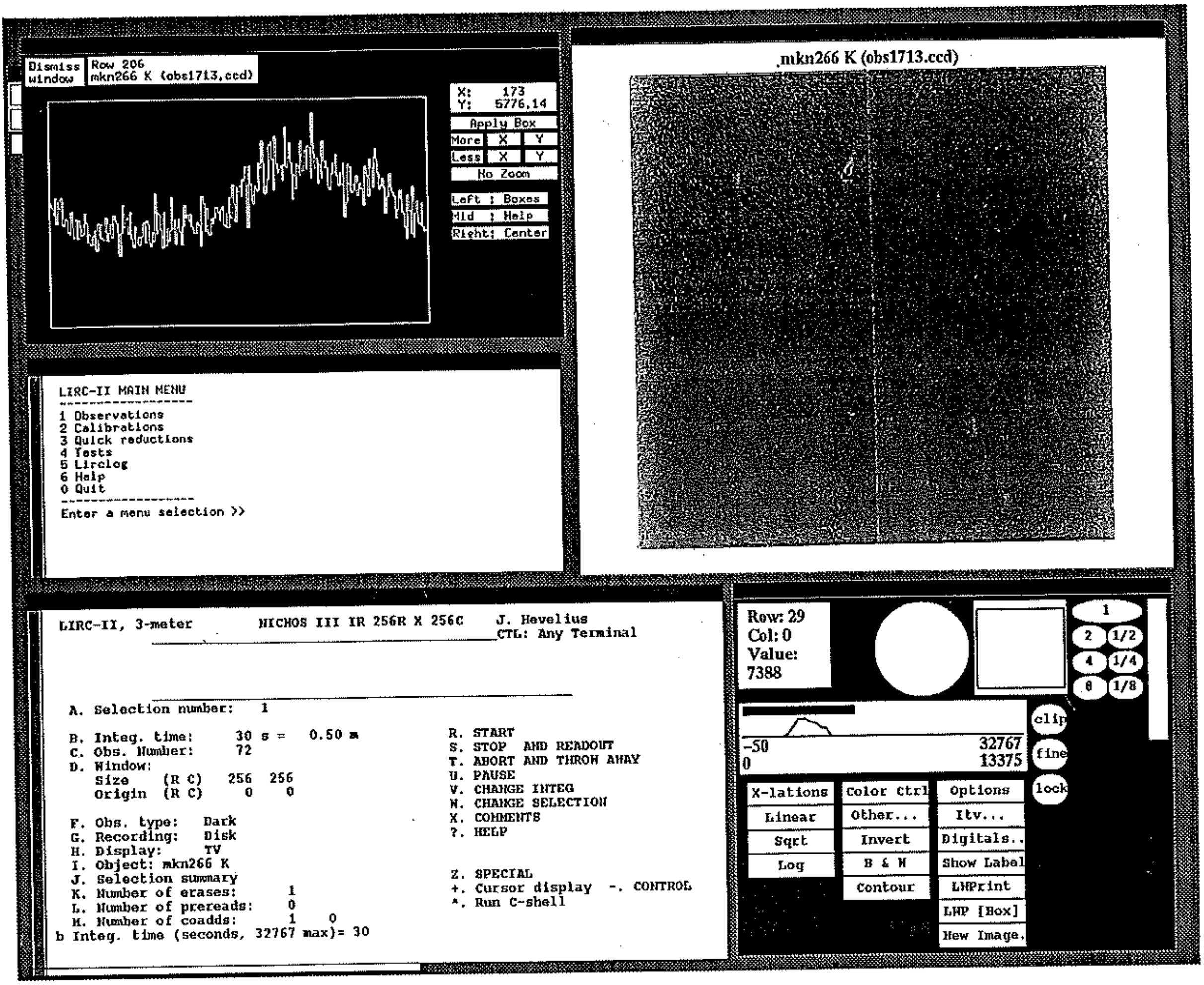
2.2. The Data-taking System

The LIRC-II data-taking program has much in common with the CCD data-taking program on which it is based, and will appear familiar to most Lick users. Here we only discuss those aspects of the data-taker which are unique to the LIRC-II version. A complete review of all data-taking commands is given in Appendix A..

Turn on the NCD terminal and log in as 'user' (the password is posted on the keyboard). Start the data-taking program from an 'xterm' window by typing 'lirc2', or use the pull-down menu. The data-taking program will automatically create three windows: an xterm window displaying the data-taking menu, an image window, and an image control window. Figure 4. shows the x-terminal screen with the image windows, and their parent data-taking window. (You may wish to conserve screen space by reducing the size of the font in the data-taking window. Put the cursor in the window, hold the control key and the right-hand mouse button simultaneously and select 'tiny' from the pull-down menu.)

The data-taking window presents a menu for setting observing parameters and controlling observations. The image window displays an image of the last completed observation, or can be used to redisplay a previous frame, stored on disk. The image control window provides options for a variety of measurements and manipulations of the image. Additional windows, including quick row and column plots and a variety of image statistics, may be spawned by the data-taker (see Appendix A).

Like the CCD data-taker, the LIRC-II version beeps when an exposure begins, when it ends, and when the readout is complete. This can become tiresome when making the many short integrations typical of near-infrared observing. The 'bell' may be turned off by typing 'XSET B 0' from an xterm window. Typing 'XSET B 1' turns it on again.



```
X:    173
Y:    5776,14
```

```
LIRC-II MAIN MENU
------------------
1 Observations
2 Calibrations
3 Quick reductions
4 Tests
5 Lirclog
6 Help
0 Quit
------------------
Enter a menu selection >>
```

```
LIRC-II, 3-meter        NICHOS III IR 256R X 256C    J. Hevelius
                                                     CTL: Any Terminal

 A. Selection number:   1

 B. Integ. time:      30 s =   0.50 m            R. START
 C. Obs. Number:      72                         S. STOP  AND READOUT
 D. Window:                                      T. ABORT AND THROW AWAY
    Size    (R C)   256  256                     U. PAUSE
    Origin  (R C)     0    0                     V. CHANGE INTEG
                                                 W. CHANGE SELECTION
 F. Obs. type:   Dark                            X. COMMENTS
 G. Recording:   Disk                            ?. HELP
 H. Display:     TV
 I. Object: mkn266 K
 J. Selection summary                            Z. SPECIAL
 K. Number of erases:        1                   +. Cursor display  -. CONTROL
 L. Number of prereads:      0                   *. Run C-shell
 M. Number of coadds:        1    0
b Integ. time (seconds, 32767 max)= 30
```

```
Row: 29
Col: 0
Value:
7388
```

Figure 4. The x-window terminal' An x-windows screen, showing the three basic windows of the data-taking program, a plot window, and a Vista window, running Lirctop.

2.3. Special LIRC-II Data-Taking Options

The three options 'Number of erases', 'Number of prereads', and 'Number of coadds' are unique to the LIRC-II version of the data-taker. Note, also, that there is no 'fast readout' option, and that in the absence of a shutter, the 'dark' option under 'observation type' has no effect. Dark exposures are accomplished by moving the filter wheels to their 'dark' positions (see Section 3.1.).

2.3.1. Number of Erases

'Number of erases' sets the number of times the array will be erased before the actual exposure is begun. We recommend two to three erases, depending on the brightness of the target, to insure that there is no residual charge from a previous exposure.

2.3.2. Number of Prereads

'Number of prereads' sets the number of optional zero-second darks (bias frames), used to reduce the effective readnoise in a single exposure. The bias frames are automatically added together, averaged, and held in a buffer until readout, at which time they are automatically subtracted from the target frame. Using prereads lengthens the duty cycle by adding about 3 seconds per preread, before the observation is begun. <u>'Number of prereads' is set to zero in most observing situations.</u>

2.3.3. Number of Coadds

Number of coadds' sets the number of frames to be coadded before being displayed and saved. Coaddition of several consecutive images is a common infrared observing practice. The data-taker's 'coadd' option automates the job by adding the requested number of frames in memory, before the final image is dispalyed and written to disk or tape. When using coadds, bear in mind that only the summed image is saved. Sources of error which might otherwise be recoverable, such as poor guiding or rapid changes in sky background level, will be blurred. To take individual, non-coadded images, set the number of coadds to one.

<u>Use of the coadd option affects the numbering of stored images</u>. Though the observation number increments each time a frame is taken, only the coadded frame is stored, taking as its number the number of the first frame in the coadded series. If, for example, an observation is begun with the observation number at 15, and the number of coadds set to 3, the data-taker will take three exposures--15,16, and 17--add them together, and write them to disk as 'd15.ccd'. If another image is made, frames 18, 19, and 20 will be summed and written as 'd18.ccd', and so on. Thus, gaps will appear in the numbering of disk images, reflecting the number of coadds making up a given image.

2.3.4. A/D Baseline (bias) Subtraction

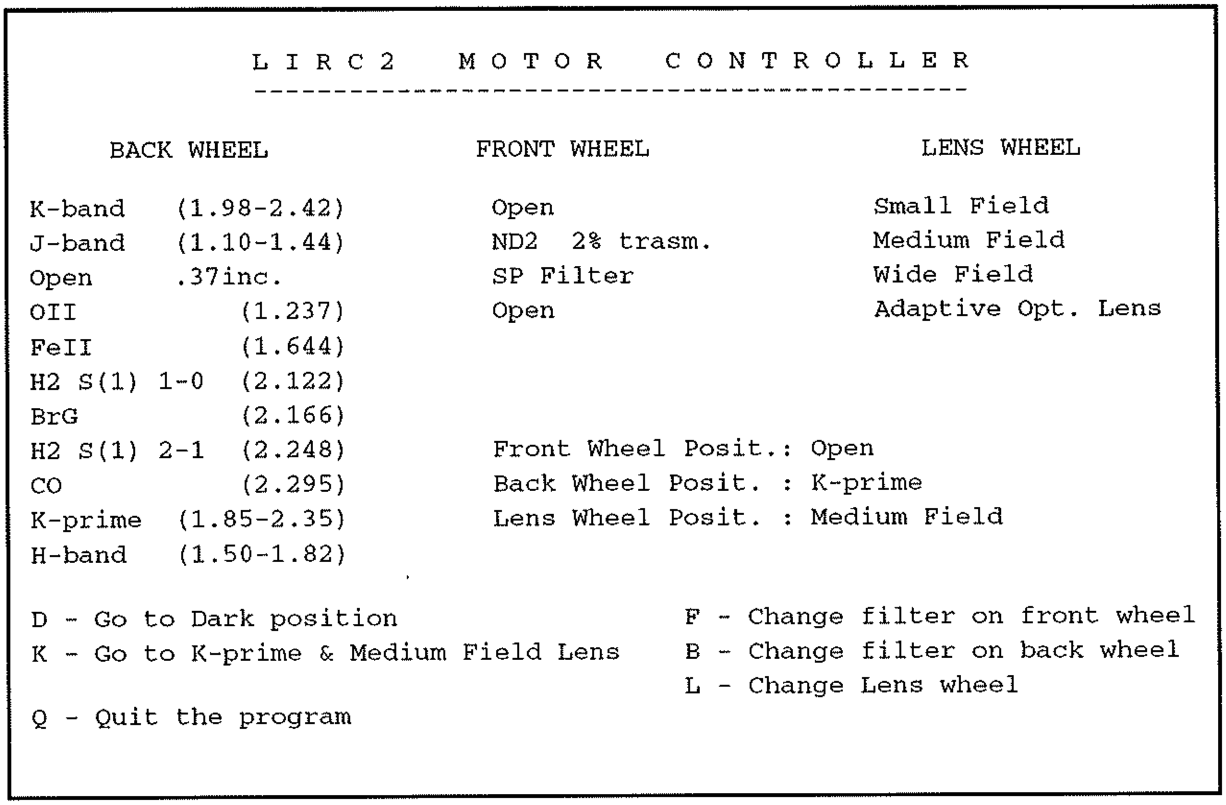
In the CCD version of the data-taking system, automatic subtraction of an array's baseline from raw images, is the default. The baseline is computed, subtracted, and stored as the highest number column in an image. <u>The LIRC-II version disables baseline subtraction by default.</u>. Baseline subtraction may be enabled from the data-taker by typing 'Z' and selecting option four.

<u>Keep in mind that when operating with the default condition of baseline subtraction disabled, the baseline counts will appear in raw images as approximately 2,000 additional DN that must be discounted when estimating flux levels.</u> The plots reproduced in this manual include the baseline.

2.4. The Motor Control Program

The motor control program allows the user to position LIRC-II's two internal filter wheels and to select from three possible fields of view by positioning the lens wheel.

Turn on the PC compatible computer and type 'lircmc' at the DOS prompt. On startup, the program checks its RS-232 connections with the motor controller; if a problem is detected an error message will appear. (If an error condition occurs, you can check the cable connections at the computer and at the motor controller, try cycling controller power, or call a staff member for help.) After successfully establishing communication with the controller, the program will ask if you wish the wheels to be sent to their 'home' positions. Typing 'yes' calibrates the positions of the three wheels. Doing so is recommended, especially following an error condition. The controller program's top level screen is illustrated in Figure 5a.

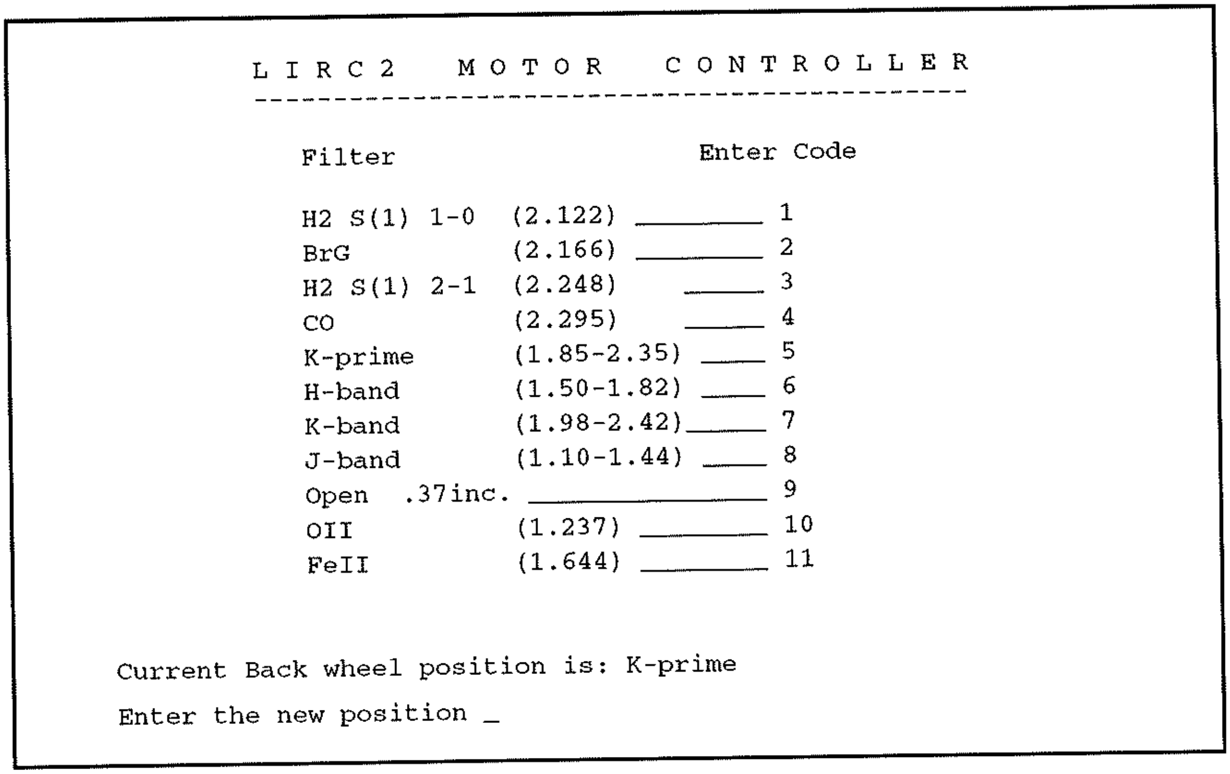


```
                 L I R C 2    M O T O R    C O N T R O L L E R
                 ---------------------------------------------

     BACK WHEEL                FRONT WHEEL                 LENS WHEEL

K-band    (1.98-2.42)          Open                    Small Field
J-band    (1.10-1.44)          ND2  2% trasm.          Medium Field
Open      .37inc.              SP Filter               Wide Field
OII           (1.237)          Open                    Adaptive Opt. Lens
FeII          (1.644)
H2 S(1) 1-0   (2.122)
BrG           (2.166)
H2 S(1) 2-1   (2.248)          Front Wheel Posit.: Open
CO            (2.295)          Back Wheel Posit. : K-prime
K-prime   (1.85-2.35)          Lens Wheel Posit. : Medium Field
H-band    (1.50-1.82)

D - Go to Dark position                     F - Change filter on front wheel
K - Go to K-prime & Medium Field Lens       B - Change filter on back wheel
                                            L - Change Lens wheel
Q - Quit the program
```

Figure 5a. Motor control program, top level menu.

The three columns list the contents of the wheels under their respective headings. Filters are not routinely changed, and users can be confident that the lists accurately reflect the contents. The currently selected position of each wheel is displayed at center right; commands are listed at the bottom of the screen.

Selecting 'H' will cause the positions of all three wheels to be reinitialized to their home positions. This is a useful recalibration procedure if there is any doubt as to their correct positions. To change the position of any wheel, type 'F', 'B', or 'L' (Front, Back, or Lens wheel) followed by a carriage return. This will invoke a screen like the one illustrated in Figure 5b, displaying the wheel's contents and a number corresponding to each position. From this screen's menu the observer selects the desired filter by entering the code number followed by a carriage return, initiating the movement and returning the program to the main menu. The program automatically removes backlash while repositioning the wheel.



```
            L I R C 2    M O T O R    C O N T R O L L E R
            ---------------------------------------------

               Filter                         Enter Code

               H2 S(1) 1-0   (2.122) ________   1
               BrG           (2.166) ________   2
               H2 S(1) 2-1   (2.248)    _____   3
               CO            (2.295)    _____   4
               K-prime       (1.85-2.35) ____   5
               H-band        (1.50-1.82) ____   6
               K-band        (1.98-2.42)_____   7
               J-band        (1.10-1.44) ____   8
               Open   .37inc. _______________   9
               OII           (1.237) ________   10
               FeII          (1.644) ________   11


   Current Back wheel position is: K-prime

   Enter the new position _
```

Figure 5b. Motor control program, second level menu, back filter wheel.

2.5. Recording Data

The data-taking system allows images to be recorded on disk, 8-mm tape, both, or neither. Most observers choose to record only to disk during the course of the night, thus improving the observing duty cycle slightly by saving the time needed to write each incoming image to tape. The data are then typically written to tape in the morning, and sometimes FTPed to a remote site, as well. Data quality casette tapes may be purchased on the mountain.

The data-taking system includes some tape commands (see Appendix A). Tapes may also be initialized, positioned for appending, and written using Vista's 'exabyte' and 'totape' commands.

The observatory archives all data taken with facility instruments on the 3- and 1-meter telescopes, including LIRC-II. Archival tapes are intended as a backup in the event of the accidental loss of data. They are not meant to substitute for the observer's backup. Archiving is customarily done at the end of each observing run. However, if the number of stored frames begins to task the available disk space, so that the disk must be cleared before the end of your run, you should notify a technician that an interim archival backup should be made. (The first indication that you're growing short of disk space is the message, from the data-taker, that the data disk is full and that it has begun writing to the vista disk.)

Observatory archiving has proven to be a worthwhile, but time consuming, process. This is particularly true for the very large number of images associated with infrared runs. Please make our job easier by deleting unnecessary frames before we archive, or informing the telescope technician if your data need not be saved, as, for example, calibration frames for a night during which no data were taken.

Some of LIRC-II's setup, such as focusing, is done with the data-taker operating in a continuous loop. This can generate a great many frames which, if inadvertantly recorded, rapidly swallow disk space. Be sure to turn recording off at such times.

2.6. **Lirctop** (see Appendix B for a guide to all Lirctop's functions)

Lirctop is a top-level, menu-driven program which calls a variety of Vista procedures for performing routine tasks such as making calibrations, taking repetitive exposures, dithering, mosaicing, and performing tests. Lirctop is largely self-explanatory and includes online help.

To run Lirctop, open a Vista window by selecting 'Vista' from the pull down menu which appears when pushing the left-hand mouse button with the cursor in the gray area between windows. A blue Vista window is created. (You may wish to conserve screen space by reducing the size of the font in the Vista window. Put the cursor in the window, hold the control key and the right-hand mouse button simultaneously and select 'tiny' from the pull-down menu.) Type 'rp lirctop' to load the program, type 'go' to run it. See Appendix B for a complete description of Lirctop.

2.7. Choosing a TV Camera

For acquisition and guiding, the observer may opt for either the standard cassegrain TUB TV camera or LIRC-II's boresite TV camera. Both share the same controller and are nominally the same type of camera. The boresite system is two to three magnitudes less sensitive, and has a somewhat narrower field of view than the TUB system. Nevertheless, we recommend using the boresite system whenever possible. The TV cameras are compared below.

2.7.1. The Boresite Camera

The boresite camera can reach stars of approximately 17th to 18th visual magnitude at the 3-meter, and 15th to 16th at the 1-meter, under the best conditions. Diffuse objects are more difficult. Moonlight can dramatically reduce the camera's ability to reach faint objects. Beyond these limits, it may be necessary to resort to the TUB camera, which, on a clear, dark night, can see objects at the limit of the old Palomar Sky Survey (about 19th magnitude) at the 1-meter. However, if the boresite is adequte to acquire a target, it is the preferred camera.

The boresite system does not require the introduction of a plane diagonal mirror, thus eliminating a significant source of thermal emission (see Section 2.7.3.) which is present when guiding with the TUB camera.

Observing is easier with the boresite camera. It receives its light from the visible portion of the telescope beam reflected from the dichroic beamsplitter (refer to frontispiece or back cover), and is therefore centered on the same patch of sky as the infrared array. This simplifies observing by eliminating the need to offset the TV camera or telescope to allow the target to reach the infrared array.

If you choose to use the boresite camera, especially if you are the first to use it following a run with TUB camera, or if you switch from one to the other, read Section 2.8.

2.7.2. The TUB Camera

Despite its disadvantages, the TUB camera may be necessary for acquiring faint sources. The 3- and 1-meter TUB cameras guide on patches of sky adjacent to the target. At both telescopes, a perforated diagonal mirror must be inserted to allow light from the target to pass through to the infrared camera. <u>This mirror represents a significant source of thermal emission</u> (see next section).

After acquiring a target with the TUB camera at the 1-meter, the telescope must be offset to allow light from the target to reach the detector. Offsets specific to LIRC-II are recorded in the Users' Log book. Use the most recent offsets recorded therein. Offsetting the telescope is described in the *Nickel Telescope User's Manual*, and is part of the regular training for 1-meter observers.

2.7.3. The TUB Diagonal Mirror

As noted above, an additional mirror is required to use the TUB camera at either telescope. The backside of this mirror faces LIRC-II and is seen by the infrared array as a source of thermal emission. At the 3-meter, the diagonal is in place when mirror position #3 is selected. At the 1-meter, the mirror is inserted by moving the switch behind the sliding door in the rack below the TV camera controller to the 'in' position.

Thermal emission from the diagonal mirror increases background ten to twenty percent at K-band, and affects flat-fielding in all bands. Thus, flats for images made when using the TUB camera must also be made with the diagonal mirror in place (mirror position 3 at the 3-meter; 'diagonal in' at the 1-meter).

If you do not plan to guide your exposures, you can acquire targets with the TUB camera and remove the diagonal after offsetting the telescope and before beginning the exposure. You must, however, remember to reinsert the diagonal for acquiring the next object, and remove it again for observing.

If observing with the boresite camera, be sure that the mirror is removed. Mirror position #4 withdraws the mirror at the 3-meter. At the 1-meter, move the TUB diagonal switch to the 'out' position.

2.7.4. TV Camera Fields

Figure 6. shows the fields of view and orientations for both TV cameras, at both telescopes, with the camera controller in binning mode 2. Note that while the TUB and boresite plate scales are comparable, vignetting narrows the boresite's field of view. Also note that with the TUB camera at the 1-meter, the cardinal directions are rotated 30°, due to TUB rotation. The directions on the array itself remain vertical and horizontal for all setups (see Figure 2).

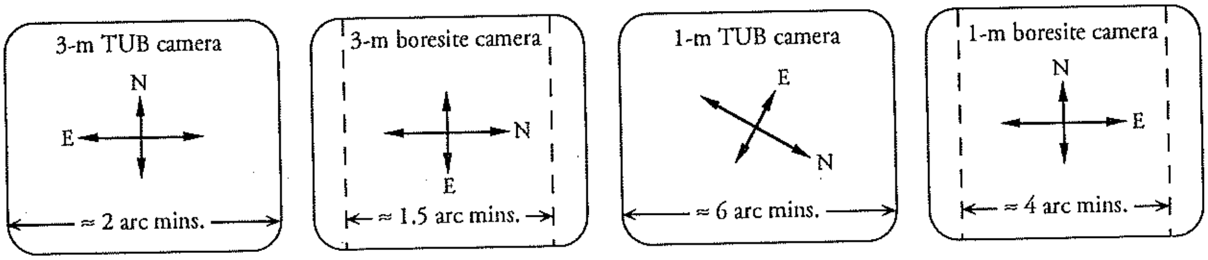


Figure 6. TV cameras' directions and fields of view (note slight vignetting in boresite fields)

The TUB camera will have been set in advance to its nominal focus position (7.6 at the 1-meter) by a technician, but may require slight adjustment (see 'folding flat mirrors' in the *Nickel Telescope User's Manual*).

The bore-site camera may need to be focused by the observer at the 1-meter, or, at the 3-meter, by the telescope operator at the observer's request. If, after the telescope has been focused on the infrared array, the bore-site image is not well-focused, correct it by rotating the focusing ring on the lens attached to the bore-site camera.

2.8. Changing TV Cameras

The 1-meter observer changes between the TUB and boresite cameras by changing the switch labeled 'TV Select' on the panel below the TV camera controller (the 'IR' position selects the boresite camera). However, the observer must be aware of two adjustments that must be made when cameras are switched: resetting the telescope coordinates and changing the guide matrix (at the 3-meter, the telescope operator will handle camera changes).

2.8.1. Resetting the Telescope

For instruments other than LIRC-II, the telescope coordinates at the 1-meter are set to bring objects into the field of the TUB camera. When changing to the boresite camera--or back to the TUB camera--the coordinates must be reset. This is most commonly required on the first night of a LIRC-II run, following an instrument change, but will also need to be done whenever cameras are switched. At the 1-meter, resetting the coordinates is the observer's job.

Choose a bright star near zenith. Run its coordinates through Setel, the position correction program (using Setel is part of the routine training for first time Nickel telescope users). Acquire the star with the camera for which the coordinates are currently set. This may not be obvious, so try both cameras, remembering to move the diagonal mirror to the 'in' position for the TUB camera. Center the star on the TV monitor.

Offset the telescope according to the most recently recorded LIRC-II offsets in the Users' Logbook. If you found the star with the TUB camera, offset the telescope in the direction that moves the star from TUB camera to detector. If you found it on the boresite camera, offset the telescope in the opposite direction. After the offset is complete, switch cameras and confirm that the star is now visible on the TV monitor. Recenter the star on the monitor using the camera you will use for observing. Rerun the coordinates through Setel. Reset the telescope coordinates to match Setel's corrected position by using the black buttons and the rate and direction switches, next to the right ascension and declination readouts. It will also be necessary to update the hour angle readout. Always use a star near zenith. Do not reset the coordinates to compensate for pointing errors at large hour angles. Check the newly calibrated coordinates by going to another bright star nearby.

Alternatively, you can try setting directly to the TV camera of your choice by using the finder telescope. Again, select a bright star near zenith and set the telescope according to Setel's corrected position. Find the most recent entry in the users' logbook illustrating the positions of stars for LIRC-II, with respect to the finder's reticle. Looking through the finder, move the star to the appropriate spot on the reticle. Confirm that the star is on the TV, then reset the coordinates as described above. Make a drawing in the logbook, even if it's the same as the one to which you referred, showing the position of the star on the reticle. Indicate which TV camera the star refers to, and that it was made for LIRC-II.

See the *Nickel Telescope User's Manual* for more instructions on offsetting the telescope, and resetting telescope coordinates.

2.8.2. Resetting the Guide Matrix

To account for the differences in orientation and scale of the TV fields for various instruments, the autoguider requires a rotation matrix--a set of numbers entered into Telco via the PET computer--appropriate to the current instrumental setup. The guide matrix for LIRC-II differs according to which TV camera is selected, and which telescope is being used. Telco automatically adopts a guide matrix appropriate to the TUB camera. The boresite camera, however, requires a unique matrix that must be entered manually.

At the 3-meter, the telescope operator is responsible for the guide matrix. At the 1-meter, the observer enters the boresite matrix by turning on the PET computer and inserting the floppy disk labeled 'LIRC-II Boresite Version' and pressing the shift and 'run' keys. To restore the TUB camera matrix, insert the customary floppy, and press the shift and 'run' keys.

Should the 1-meter's boresite matrix floppy disk be lost or unreadable, the matrix may be entered from the keyboard. At the PET's basic prompt, type the following:

```
MS% = 20
FF% = 0              (this sets the guider to cassegrain)
MS% = 18
TU% = 900            (this enters a TUB angle of 90 degrees)
MS% = 23
S1% = 1              (these set the guide matrix coefficients)
S2% = -1
S3% = -1
S4% = -1
SYS(40972)           (this sends the information to Telco)
```

2.9 Focusing the IR Camera

LIRC-II has no internal focus adjustment; focusing is instead accomplished by moving the telescope's secondary mirror with respect to the instrument. Nominal telescope focus is 060.00 at the 3-m, and 295 at the 1-m. These numbers are approximate and will depend on the field of view selected, as well as on temperature. Judging best focus may be done by eye or by using Vista's stellar statisitics capability as described below.

Choose a star of about tenth (3-meter) or eighth (1-meter) visual magnitude. Bear in mind that the peak DN of a star image will increase as it comes into focus--choose a star that will not saturate the detector when well-focused.

To focus by eye, take repeated, unrecorded exposures, incrementing the telescope focus slightly each time--about 1-2 units at the 3-meter or about 5 units at the 1-meter. Always moving the telescope focus in one direction to avoid backlash in the focus mechanism. The 'expose' command, in Lirctop's 'observing' submenu, may be used to automatically take multiple exposures (see Appendix B). Remember to turn 'recording' off in the data-taker, when taking frames which need not be saved.

A more quantitative, though not necessarily more accurate, approach uses the data-taking system's stellar statisitcs routines. Take a single exposure by typing 'r' from the the data-taking window, with the parameters set for an unrecorded exposure of an appropriate length. Choose 'Itv' from the image control window to create the Itv window. Choose 'pick stellar stat loc' from the Itv window, click on the star image, and choose 'do stats'. Yet another window will appear, with various statistics for the star (this is also a good way to measure the precise pixel location and the peak and approximate integrated DN of an object). From the Itv window, select 'add to focus file' and enter the telescope's focus position at the prompt. Change the focus as recommended above--remembering to move in the same direction to avoid backlash--and repeat the procedure on another image . After three iterations, a plot of image size vs. focus position will begin to be drawn in the statisitics window, along with a suggested focus. Expect more or less scatter of the data points as a function of seeing.

The size of the seeing disk may be directly measured by using the plotting capability in the data-taker's image display window (see Appendix A).

The various filters are very close to parfocal, but the three fields of view are not. Refocus after changing fields of view.

The focus should be routinely checked at least once during the night, and more often if the outside temperature has been changing.

2.10. Mapping the Array

Mapping the position of the array onto the TV image saves time and guesswork later on, and aids the accurate placement of targets on the best regions of the detector. The process differs slightly depending on whether the TUB or boresite camera is used. The former requires offsetting the telescope for each mapped point, the latter only requires moving the star with respect to the detector since the boresite camera sees the same field as the array.

After finding a bright star, set selection one in the data-taker for unrecorded exposures, of a length appropriate to the star, and use Lirctop's 'expose' option to take repeated exposures. Move the telescope so that the star is in one corner of the array.

If using the TUB camera, change to mirror position two (3-meter) or offset the telescope (1-meter) to bring the star back to the TV field. Mark its position on the TV screen with a grease pencil. Offset back to the IR camera, reposition the star to the opposite corner of the array, and repeat the process. If using the boresite camera, simply mark the star's position on the TV screen when it is positioned at one corner of the array, move the star to the opposite corner, and repeat.

2.11. Checking Collimation

Well-formed, unvignetted images depend on proper alignment of the IR camera. Collimation is generally very stable. The dewar's internal optics are fixed, and not subject to loss of alignment. Occasionally, however, small changes in the tip or tilt of the dichroic beamsplitter result in loss of collimation.

Collimation is easily checked by observing the out-of-focus image of a star. From the motor control program, select the intermediate field of view for the test. This is the only lens position suitable for testing collimation, as it alone has the central obscuration to which the incoming beam is aligned.

Select a relatively bright star--say 7th visual magnitude on the 3-meter, 5th on the 1-meter. Drive the telescope well out of focus, so that the star forms an image of the primary about one-third the size of the array. Center the image on the array. Integrate long enough to obtain a well exposed image, without saturating. You may wish to use the 'expose' command under Lirctop's 'observing' option to make continuous exposures while adjusting the size, position, and brightness of the image (see Appendix B), but remember to turn 'recording' off in the data-taker.

If the camera is properly collimated, the shadow of the secondary mirror, at the center of the image of the primary, will coincide with the central obscuration on the dewar's intermediate lens assembly. The resulting image will show only one central shadow, similar to the one on the right in Figure 7. If the camera is out of collimation, the two central spots will not coincide and the image will show two central shadows, something like the image on the left.

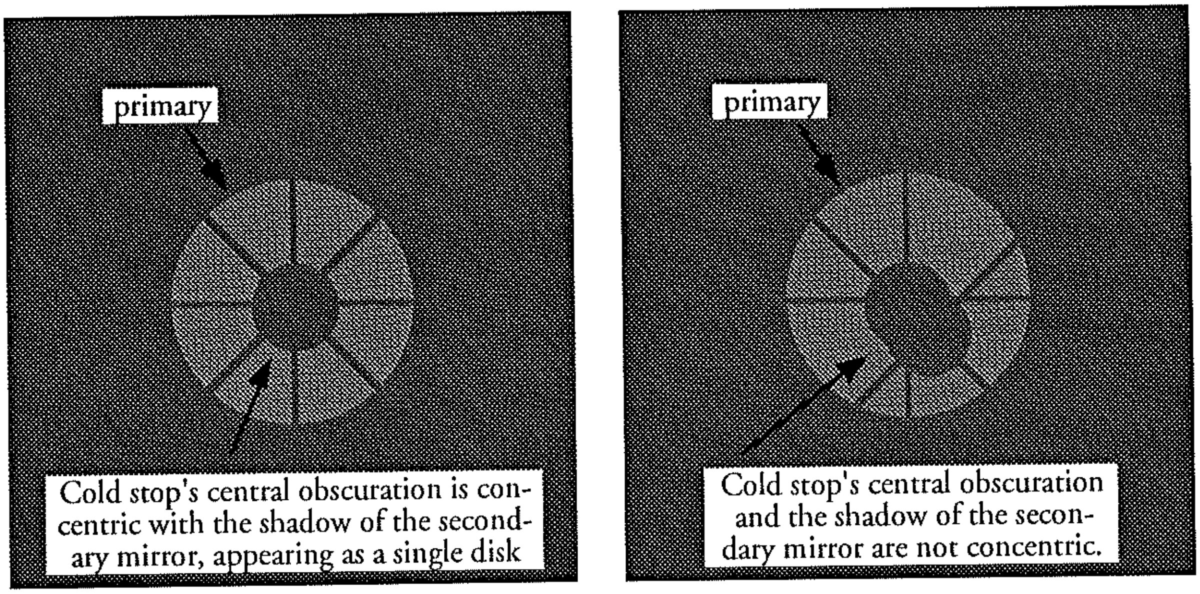


Figure 7. A well-collimated vs. a poorly-collimated image

If the camera is found to need collimating, call a member of the staff. Collimation is performed by manually tilting the dichroic beamsplitter while monitoring the defocused star image and is strictly a two-person operation, requiring one person at the computer, the other at the instrument. <u>The person adjusting the dichroic must be a telescope technician or support scientist.</u>

3. OBSERVING TECHNIQUES

Note that, due to controller electronics, actual exposures times are slightly longer than indicated by the data-taking system. Consult the users' logbook, the Lirctop log, or a support scientist, if you are not sure of the length of the delay.

A program's particular requirements will dictate the specifics of the observing strategy, but an observer will typically emerge from his or her observing run with some combination of source frames, sky frames, standard stars, darks, flats, and bias frames. See Section 4. for suggestions on reducing LIRC-II data.

Near-IR data can be gathered using methods similar to those used with CCDs, as long as the background is sky-dominated rather than thermally-dominated. However, IR techniques differ from the visual in some important respects:

- Exposures are generally sky background limited and relatively short. Observations usually consist of multiple exposures of the same target, which are later combined.
- Because of the strong sky contribution, sky subtraction is of fundamental importance. Sky frames are generally produced at the same rate as target frames, and near them in space and time.
- Near-infrared sky brightness can vary significantly on short time scales, requiring frequent sky frames.
- Dithering for sky subtraction and to remove bad pixels is a common practice.
- Observations are typically made without a shutter (LIRC-II has none), and sometimes without guiding.
- Twilight and/or night sky exposures are customarily used for flat-fielding, but must be coadded and appropriately filtered to create useful flat-field frames.
- Dark current and readnoise are significantly higher than with CCDs--approximately $2e^-$ pixel^{-1} second^{-1} and $50e^-$ respectively, for LIRC-II.
- Note that a minimum signal of about 1000 DN is required to ensure that the detector is not read-noise limited (ie. photon shot noise will be $(1000\text{ DN} * 12e^-/\text{DN})^{1/2}$ or about $110e^-$ rms of shotnoise in the signal vs. approximately $50e^-$ readnoise).

3.1. Darks

The dark current in the NICMOS-3 array is small (about 2 e^- pixel^{-1} sec^{-1}), but significant for some applications, and should be measured on a nightly basis so that it may be subtracted from the source and sky measurements. To reduce noise, a relatively large number of dark frames should be averaged together.

Darks are made by setting the filter and lens wheels to their dark positions, so that the array sees only the cold metal of the wheels. All three wheels can be set by selecting the 'dark' command in the motor control program.

Ideally, each dark frame should be of the same duration as the source and sky measurements to which it will be applied, but may be scaled with caution--remembering not to scale the bias. We suggest taking at least ten darks for each exposure time, and combining them with a median algorithm.

Darks can be taken in twilight or during the day, as long as the dome is closed and lights turned out. However, the dark current may change very slightly (<1%) during the course of a night. One can reduce this source of error by making two sets of dark frames, evening and morning, and applying them to the first and second halves of the night, respectively.

Lirctop (see Appendix B) includes a procedure, under the 'calibrations' option, for automatically taking multiple dark exposures. The procedure takes up to ten sets of dark frames without intervention. Each set can have a different integration time and a different number of exposures.

'Zero-second' darks, or bias frames, may be used as a separate bias measurement for baseline subtraction.

3.2. Flat-Fields

Flat-field calibration frames are necessary to remove pixel-to-pixel variations across the LIRC-II array. The ideal flat field is one which is illuminated in the same way as, and close in color to, the image to which it will be applied.

Using the evening and morning twilight sky to take flat-field frames makes efficient use of the available observing time, and generally provides the best flatness for data reduction. The telescope is opened to the twilight sky and a series of exposures made through each filter that will be used for observing. To permit the removal of stars from flat-field frames, move the telescope ten or more arcseconds between exposures. Lirctop (See Appendix B) includes a procedure, under its 'calibrations' option, which partly automates the taking of twilight flats.

The appropriate position of the TUB diagonal mirror while taking flats will depend on which TV camera you have chosen (see Sections 2.7.3. and 3.2.). If you anticipate using both TV cameras, complete sets of flats should be made at both mirror positions.

At K-band, the best flat field frame will be the difference of two twilight frames taken with the same integration time. Since the twighlight sky is changing, this removes thermal emission coming from the telescope, leaving the flat-field frame with only the far-field illumination.

However, it is not always possible to obtain twilight flats, or at least an adequate number of them. Twilight progresses rapidly, making them difficult to complete, especially if observing through several bandpasses or using both TV cameras. A series of relatively blank night-sky fields, slightly offset from one another, and later combined through a median filter or clipping algorithm to remove stars, provides a very good flat field.

If the source fields are relatively sparse, an average value of the sky, taken from several source frames, offset from one another, may *themselves* be used to create flat-field and sky-subtraction frames (Cowie, Gardner, Lilly, and McLean, 1990).

3.3. Standard Stars

Tables of photometric standard stars with their near IR magnitudes can be found in Appendix F. Sources for these standards are the *Kitt Peak National Observatory (KPNO) Infrared Observing Handbook* (1987); Elias et al. (1982); and Zuckerman and Becklin (1987).

Both the KPNO and Elias standards are bright enough to saturate the detector relatively quickly unless they are trailed on a short exposure. For rough estimates of count rates, see Appendix C. Do not defocus stars to prevent satuaration; doing so will cause the beam to be vignetted, and the star's brightness to be underestimated. Trailing bright stars along the array will decrease the flux per pixel without affecting the total flux.

Make several exposures of each standard, moving the source to different parts of the detector. Zenith distance corrections should be made in the standard fashion. Remeber, actual exposures times are slightly longer than indicated by the data-taking system. Consult the users' logbook, the Lirctop log, or a support scientist, if you are not sure of the length of the delay.

3.4. Sky Frames

Infrared photometric measurements usually require a nodding or chopping technique which results in half the observing time being spent on sky measurements. These sky frames not only measure the sky brightness, but, in some cases, may also be used for flat-fielding (see Section 3.2.).

The infrared sky, at wavelengths shorter than 2.0μ, is dominated by emission from the hydroxyl molecule OH. This emission is highly structured--spatially and spectrally--and exhibits intensity variations, in the worst case, of up to 50% on time scales of less than an hour (McCaughrean, 1988). Thus the sky brightness should be measured frequently, and should be recorded at the same bandpass as the source image to which it will be applied. Most observers choose to make skies at intervals of a few minutes.

It should be possible to find a reasonably blank patch of sky relatively near most sources. However, since there is a good chance of faint sources being present in any given piece of 'blank' sky, we recommend offsetting by a few arcseconds between sky measurements and then median filtering or averaging the images with a sigma clipping algorithm, in order to remove faint sources. In some cases, the source frames can themselves serve as sky frames, provided the field is sufficiently sparse.

Lirctop's 'Observing' option includes procedures for nodding and other telescope movements (see Appendix B).

3.5. Source Frames

Multiple exposures on a single source are the rule. Due to the brightness of the near-infrared sky, broad-band images quickly become background limited, and even observations made through narrow-band filters will become background limited within minutes. Moreover, the array's response becomes non-linear above about 20,000 DN (240,000 e^-). Thus, in the absence of a bright source, readnoise and the detector's linearity limit will combine to constrain the exposure to between about 1,000 and 15,000 DN, that is, well above the readnoise limit, and well below non-linearity.

Lirctop's 'Observing' option includes procedures for automating observations (see Appendix B).

3.6. Nodding, Dithering, and Mosaicing

Nodding refers to the technique of moving the telescope between the target and an adjacent position in the sky, making exposures at each position to create a matched set of source and sky frames. If the field is dense, or the target large compared to the size of the array, the nod may be relatively large. Sparse fields and small targets may only require small movements. In either case, the aim is to create a series of frames which can later be combined in such a way as to remove the sky contribution in the area of the target or targets.

Dithering is a more complex form of nodding. The telescope is moved several times, according to a pattern, and exposures are taken at each point in the pattern. Dithering typically consists of small moves which place the target at several positions on the array. Dithering can be used to make combined sky and target frames--provided the field is relatively sparse and the target small. A set of images created by dithering can later be combined to minimize the effects of bad pixels.

Mosaicing allows the imaging of regions of the sky larger than the array's field of view. The goal is to produce adjacent frames with enough overlap to allow them to be assembled into a single image. A variety of approaches are possible, but you must provide for later image registration, either by ensuring the presence of reference stars or by logging precise telescope positions. Sky-subtraction must also be taken into account, keeping in mind that the sky background varies temporally and spatially.

Lirctop's 'Observing' option includes procedures for nodding, dithering, and mosiacing (see Appendix B).

3.7. Guided vs. Unguided Exposures

The *Nickel Telescope User's Manual* includes a very complete discussion of the autoguider and its operation. At the 3-meter, operation of the autoguider is taken care of by the telescope operator.

However, the short exposures and frequent telescope moves that are typical for near infrared observations, prompt many observers to take at least some of their exposures unguided, relying on the telescope tracking to hold the image steady. Unguided exposures have the advantage of reducing the overhead required to reset the autoguider each time the telescope is moved, but can result in blurred or elongated images if the exposure is too long or the track rate not accurate. The best way to determine whether an observation can be safely made without guiding is to make a few unguided test exposures and carefully examine the shapes of the resulting images.

The nominal value for the 1-meter's right ascension track rate is -0.04. It is entered via the thumbwheel on the Telco panel. The track rate is adjusted according to input from the autoguider. It can be fine tuned by autoguiding for a few minutes on a star in the neighborhood of the target, prior ro beginnong a series of unguided exposures.

4. REDUCTION TECHNIQUES

4.1. A Suggested Reduction Sequence

The usual goal of the reduction process is the removal of dark current, cosmetic defects, pixel-to-pixel response variations, and sky contribution from individual images. Targets may be photometrically calibrated. Finally, individual images are combined. Most reduction strategies suggested by various 'experts' for the treatment of near-IR array data follow the same general theme as the one presented below.

- 1. **Dark Subtraction** A master dark frame is created by averaging a number of dark frames of a given exposure time. Dark frames may be scaled with caution, remembering not to scale the bias if it is present. The master dark frame is subtracted from all source and calibration frames with the same exposure time.

- 2. **Bias Subtraction** If baseline subtraction was disabled (default condition for LIRC-II), dark frames will have included the ADC bias, and it will be automatically removed in step one, above. Separate bias subtraction may be done, using a master bias frame made by averaging a series of 'zero' second darks. If baseline subtraction was enabled, the bias will have been removed from the raw frames at the time they were made.

- 3. **Removing Cosmetic Defects** Hot or dead pixels should now be removed from both sky and source frames. If allowed to remain, spurious counts in bad pixels may affect the flat-field renormalization. The customary procedure is to interpolate over bad pixels. A bad pixel map can be generated from a single suitable sky frame at the beginning of the data reduction.

- 4. **Flat-fielding** Flat field frames, be they twilight or night-sky frames, are averaged, using a median filtering or sigma clipping algorithm to remove any stars. It is assumed here that individual images, or sets of images, were offset from one another, so that the same star falls on different pixels in different frames. Each source frame is divided by the flat-field, and renormalized by multiplying by the mean of the flat-field frame.

- 6. **Sky Subtraction** Master sky frames are made for each observation by averaging and filtering its associated set of sky frames. The master frame is then subtracted from each source frame. Bear in mind that in many cases, source frames, taken at slightly different positions, can serve as one another's sky frames.

- 7. **Coaddition** The individual, reduced source frames are now combined, registering them as necessary, to create a final source frame with the best possible signal to noise. The use of a clipping algorithm here will eliminate cosmic ray events.

- **8. Flux Calibration** For absolute photometric work, the standard-star frames are reduced exactly like source frames. The data are then calibrated using the known standard star magnitudes and converting them to observed counts as in visual photometry.

4.2. Quick Looks

The foregoing reduction recipes are not suited for quick looks at new images while at the telescope. Simply subtracting a raw sky frame from a raw image frame of the same exposure time provides an adequate first look. Where the signal-to-noise in individual images is low, it may be necessary to coadd and average a series of sky-subtracted, co-aligned frames.

Lirctop provides a sky-subtraction procedure under its 'quick-reductions' option (see Appendix B).

4.3. Registering Images

A single image in its final form is usually the sum of a number of reduced source frames. Source frames are likely to be offset from one another due to small errors in telescope tracking, deliberate offsets, or mosaicing to cover regions of sky larger than the detector format. Images must be properly registered when being coadded or fitted into a mosaic.

One or more bright point sources, common to adjacent frames, serve well as registration marks. Frames without such reference points must be registered on the basis of telescope coordinates. It is therefore critical to have accurate records of the telescope's position for each offset. Note that the FITS header includes the telescope position at the time of the observation, so long as 'telco access' is enabled in the data-taker. While absolute positions recorded in this way are only as good as the pointing calibration of the telescope, relative positions within a limited field are quite accurate.

5. TROUBLESHOOTING

5.1. Acquiring Stars

- No stars on the TV: Their are a number of things which can cause this condition--or the appearance of it-- but barring symptoms which obviously point to electronic problems, an actual malfunction of the TV camera or controller is the least likely.

  Turn up the TV integration time to confirm that there really are no stars visible, and that the telescope is not simply looking at a relatively blank patch of sky. If you see even faint stars (you can make sure they're stars by moving the telescope a few arcseconds between TV integrations) the problem may have to do with pointing the telescope--see 'Cannot find targets', below.

  If, however, still no stars are visible, something may be blocking the lightpath. Are the mirror cover, rainscreen, and dome open? Is the telescope looking out the slit (at the 1-meter, check that the 'autodome' switch at the bottom of the Telco rack is on and that the 'dome in way' warning light is not lit). Have clouds or, heaven forbid, fog come in?

  Check the camera selection switch to make sure you're using the camera you think you're using. If it's the TUB camera, make sure that you're in mirror position #3 at the 3-meter, or that the TUB diagonal switch is in the 'in' position at the 1-meter. Check that the neutral density filter (red switch on the TV camera control panel at the 1-meter) is in the 'out' position.

  If you're using the boresite camera, make sure that the cover has been taken off the dichroic beamsplitter. Check that the TUB diagonal is out: mirror position #4 at the 3-meter, TUB diagonal switch is in the 'out' position at the 1-meter.

  Finally, the telescope or the TV cameras may be so out of focus that images are just not visible. Check that the telescope is at, or near, its nominal focus for LIRC-II (060.00 at the 3-meter, 295 at the 1-meter). At the 1-meter, if using the TUB camera, check that the folding flats, located in the TUB, are near their nominal position: 7.6 on the metric scale (see the *Nickel Telescope User's Manual* for an explanation of the folding flats and their adjustment).

- No stars on the IR array: If stars are also absent on the TV camera, first check the suggestions in the preceding troubleshooting entry. If stars appear on the TV camera but not on the IR array, either the light is being blocked downstream from their common path, or there are no stars in the IR camera's field, or the IR camera is malfunctioning. As long as the array appears to be reading out normally--customary uniformity, reasonable background and bias levels--an IR camera problem is the least likely.

Check that the filter and lens wheels are in their correct positions, and that none is in its 'dark' position. Try resetting them to their 'home' positions to reinitialize the encoders, then set them to the appropriate positions for your observation. Check that the dewar window cover has been removed and that the window is free from condensation. Make sure that the TUB diagonal mirror is in the proper position (at the 3-meter the mirror should be in position #3 for the TUB camera, and position #4 for the boresite camera; at the 1-meter, it should be 'in' for use with the TUB camera, and 'out' for use with the boresite camera). If using the TUB camera, check that the beamsplitter cover has been removed.

If using the TUB camera at the 1-meter, did you remember to offset the telescope? Are you sure that the offsets are accurate and that you moved the telescope in the correct sense? Is your integration time, or number of coadds, sufficient to reveal faint sources on the array? Look at the K-prime sky. Does the flux increase with integration time at about the expected rate (levels should reach the linearity threshold of about 20,000 DN in about 5 to 30 seconds in the intermediate field of view, depending on temperature and sky conditions)? Try moving to a very bright star, offset the telescope if using the TUB camera, and take an exposure.

A failure of the IR array itself would most likely be accompanied by obviously abnormal readouts. If this is observed, or, if after trying all of the above, you still see no star on the array, call a support scientist or technician for help.

- <u>Cannot find targets</u>: If no stars--targets or otherwise--are visible with the TV cameras, refer to 'No stars on TV' above. You can check this by increasing the TV integration time and by moving the telescope a few arcseconds between integrations to confirm the presence, or absence, of stars. Most fields will reveal at least one or two faint sources.

  If stars are visible on the TV, but you are unable to locate your target or recognize its field, the telescope may be incorrctly pointed. This can be due to poorly calibrated encoders or operator error. Before checking the encoder calibration, double check your coordinates and epoch. If you're at the 1-meter, are you using Setel, the precession and pointing correction program? Are you sure that your target is not too faint or diffuse for the TV camera you are using (the boresite camera has lower sensitivity than the TUB camera--see Section 2.7.1.). Are you sure that your finder chart corresponds to the TV? Check the directions on the TV camera by finding a star and moving the telescope slightly--remember that moving the telescope one direction causes the star to move in the opposite sense.

At the 1-meter, the telescope's coordinates may need resetting. This is especially true on the first night of a run following an instrument change, or if the last TV camera to be used was other than the one you're using. The TUB and boresite cameras look at slightly different positions in the sky, and require that the coordinate readouts be appropriately calibrated for their respective fields. Section 2.8.1. describes two methods for resetting the coordinates.

In the rare worst case, the telescope's position encoders may be completely lost, due to a power glitch or a Telco failure, and you will be unable even to find a bright star in the finder telescope. At the 1-meter, you may reset the telescope from first principles by following the instructions posted on the panel in the left-hand rack, labeled 'Nickel Telescope Fiducial'.

- Autoguider does not hold star: Check that the appropriate guide matrix has been entered for the TV camera you are using (see Section 2.8.2.). Check that Telco's track rate thumbwheel switches are not set at unreasonable values (nominal 1-meter values are -0.04 in right ascension, 0.0 in declination). Did you remember to turn on the 'guide enable' switch?

5.2. Data-taker and IR Camera Operation

- Data-taking system does not include the commands for erases, prereads, or coadds: You have accidentally loaded the CCD version of the data-taker. Exit the program (control-y), and start the LIRC-II version by typing 'lirc2'. If this fails to produce the IR version, try calling it directly by typing '/u/ccdev/isi/ircam/scr'.

- Array does not read out, or images are completely flat: This is propbably the result of a break in communication between the data-taker, array controlller, and the array, or may point to a problem with the controller or dewar electronics. Often, simply cycling power to the controller, as described below, will remedy the problem. If not, call a support scientist or technician.

  Exit the data-taker (control-y), and restart by typing 'lirc2'. Watch the window during program initialization. If you see the error message 'NO RESPONSE FROM CCD', exit the program at that point (control-c). Try cycling the power to the array controller. At the 1-meter, the controller is located on the telescope, above and to the west of the dewar. Its power switch is on the front panel. Turn it off, wait a few moments, and turn it back on. Try running the data-taker again. If the error message recurs, call a support scientist or technician.

- Data-taker does not recognize array: If the heading at the top of the data-taking window does not read ' NICMOS III IR 256R x 256C', the data-taking system, on startup, failed to establish communication with the array. Try cycling the power to the array controller as described in the previous troubleshooting entry. If this fails to fix the problem, call a technician or support scientist.

- Motor controller will not initialize: If an error message appears when starting up the motor control program, try cycling the power to the motor controller. At the 1-meter, it is located on the east arm of the telescope yoke. Run the program again. If the error persists, one of the RS232 connectors between the controller and the PC is probably loose. At the 1-meter, the cable runs from the back of the controller to a patch panel mounted on the large terminal box just east of the telescope's south support. The other end of the panel is located on the control room wall behind the equipment racks. From there, the cable runs to an in-line null-modem changer (its absence will cause an error message) and then to the PC. Check these connections or call a technician.

- Filter and lens wheels will not move: If the motor control program has successfully initialized, and you have determined that the filter and lens wheel motors, located beneath the dewar, are not responding, call a technician.

5.3. IR Images

- High background : K-band sky levels vary considerably; higher than average background may simply be due to sky brightness. However, other sources can contribute to elevated background levels. Check for clouds. Check that the diagonal mirror is removed if using the boresite camera. Check the camera collimation.

  At any wavelength, baseline counts can give the illusion of high background. Are you taking the baseline into account? Is the baseline set too high? Take a zero-second dark to confirm that the baseline is set near its nomnal level of about 2000 DN.

  Verify that the detector is operating properly by testing the thermal background (see Appendix D). If the test reveals significantly higher than average dark current, check that the array temperature is near its nominal value of -195; the temperature is displayed on the array controller, mounted on the telescope.

Note that K or K-prime skies can, at times, get high enough that, when using the wide field of view, saturation occurs in less than the minimum exposure time, precluding the use of that plate scale with those bandpasses.

- Low sensitivity: Confirm that you are using the correct filter. Recalibrate the filter wheels by sending them to their home positions and then resetting them.

  Check for clouds. Check for vignetting by the dome (at the 1-meter, the telescope is partially vignetted whenever it is within six degrees of zenith--look for a zenith warning light on Telco).

  Check that the dewar window is free from condensation. Is the captive air cover installed and its power supply plugged in? Condensation typically begins forming at the center of the window. It may appear as a uniform or blotchy circle of reduced sensitivity. If condensation is present, do not attempt to dry the window--call a staff member for help.

  Remember that the large sky contribution in the near infrared can make targets seem faint, or even invisible, on single frames before sky subtraction. A quick sky subtraction will allow a more accurate assessment of the camera's performance.

- Poorly formed or elongated images on the array: Star images with large or very asymetrical point-spread functions, can occur as a result of poor focus, inaccurate tracking or guiding, or misaligned optics. Poor seeing also enlarges and distorts images, while at the same time making it more difficult to focus and guide accurately. Condensation on the dewar window can also distort images, but is usually characterized by a global loss of sensitivity (see above).

  Recheck the focus. Both the size and symmetry of star images can be measured using the stellar statistics routines under 'itv' in the data-takers image control window (see Appendix A.).

  Elongated star images are usually indicative of inaccurate tracking or guiding. If you are using the autoguider, be sure that you have entered the appropriate guide matrix for the TV camera you are using, and that the autoguider's settings are appropriately adjusted (see the *Nickel Telescope User's Manual* for a thorough introduction to autoguiding).

  Whether or not you are autoguiding, a poor track rate can cause images to appear elongated. Check that the manually entered rates (thumbwheels on the Telco panel) are at there nominal settings of -0.04 in right ascension, 0.0 in declintaion. If wind is a factor, use the windscreen and avoid working into the wind, if possible. Poor collimation of the IR camera can cause distorted images. Check the collimation as described in Section 2.11.

- **Blotch at the center of the image**: This is almost certainly due to condensation on the dewar window. If condensation is seen, call a technician--do not attempt to dry the window yourself.

6. CHECKLIST AND REMINDERS

6.1. Observer's Checklist

● Applies to 3-m and 1-meter telescopes.

○ Applies to 1-meter telescope only.

In the afternoon

● Check that the instrument set up has been successfully completed. Check that the beamsplitter and dewar window covers have been removed. Check the Observers' Log Book for any recent notes pertaining to the instrument. In humid conditions, check that the dewar window's captive air cover has been installed.

○ FIll the dewar (Section 2.1.1.). Call the 3-meter at 5952 if the supply of nitrogen is running low. (At the 3-meter, the telescope operator will fill the dewar.) Check that the array temperature is near its nominal value of -195°.

● Turn on the x-terminal, log in as 'user' (the password is posted on the keyboard), and start the data-taking program by typing 'lirc2' (Section 2.2.).

● Open a Vista window on the workstation and start Lirctop by typing 'rp lirctop', a carriage return, then 'go' followed by another carriage return (Appendix B). Check Lirctop's electronic logbook for updates.

● Turn on the PC compatible computer and run the motor control program by typing 'lircmc' (Section 2.4.). Reinitialize the filter and lens wheels to their home positions.

● Test the performance of the array. This can be done by following the dark and noise tests described in Appendix D. Check the baseline.

● If you plan to record to tape in real time, load and initialize an exabyte tape now (Section 2.5.).

- Take at least ten dark frames for each exposure time you anticipate using for your targets. Be sure the lights are out in the dome. Take a set of bias frames as needed (Section 3.1.).

- Plan ahead for your twilight flats. When does twilight begin? Is everything ready? (Section 3.2.)

Before Dark

- Take twilight flats through the filter(s) and lens(es) you'll be using for observing (Section 3.2.). Be sure that the diagonal mirror is in the appropriate position.

- Check the humidity again. If it is 70% or higher, or if it appears to be rising, install the captive air cover (Section 2.1.2.).

- ○ If using the TUB camera, enter the telescope offsets in the PET computer (refer to the *Nickel Telescope User's Manual*).

- ○ If using the boresite camera, enter the boresite guide matrix in the PET computer (Section 2.8.2.).

At night

- Check the collimation of the IR camera (Section 2.11.).

- Focus the IR camera (Section 2.9.).

- Focus the TV camera if necessary (refer to the *Nickel Telescope User's Manual*).

- Map the chip to the TV screen (Section 2.10.).

- Refer to Section 3., *Observing Techniques.*

- Remember to check the position of the TUB diagonal.

● Check the focus occasionally, particularly if the temperature has been changing. Refocus if you have changed image scales (fields of view).

● In unstable weather, be alert for conditions that may exceed the telescope's wind and humidity limits (Appendix H), or cause fogging of the dewar window.

In the morning

● Record any information (eg. focus, offsets, etc.) that might be of use to other observers in the Observers' Log Book.

○ Call the 3-meter telescope (5952) before leaving, whether or not you have any problems to report. Report any problems--this is very important if they are to be dealt with in a timely way.

○ Check that the telescope and dome are properly stowed (refer to the the *Nickel Telescope User's Manual* and the 'Checklist for Closing' in *The CCD Spectrograph and Camera at the Nickel Telescope*).

● Install the captive air cover if you think the humidity might go up during the day--especially if rain is threatening.

○ Fill the dewar.

6.2. Reminders

- Actual exposures times are slightly longer than indicated by the data-taking system. Consult the observers' logbook, the Lirctop log, or a support scientist, if you are not sure of the length of the delay.

- Acquisition of faint objects, particularly under a bright sky, poses special problems for the TV cameras. We recommend coming prepared with a accurate offsets, expressed in arc seconds to bright stars near your targets. It is always recommended to prepare finding charts for all but the most self-evident targets.

- Detector non-linearity becomes significant at about 20,000 DN. We recommend limiting exposures to below 15,000 DN for best linearity.

- Baseline subtraction is disabled by default when the LIRC-II data-taking program is run. With subtraction disabled, the approximately 2,000 DN baseline will appear in raw images. Take this into account when estimating exposures and when scaling dark frames. Baseline subtraction may be reenabled under the data-taker's 'special' command.

- Sky brightness varies significantly in the infrared, as much as 50% in the course of a night, independent of cloud cover and moonlight. It is important to take frequent skies.

- Many IR standards saturate the array and, if chosen, must be trailed to reduce the flux per pixel. Defocusing stars to prevent saturation will cause vignetting and inaccurate flux measurements.

- Residual images from objects bright enough to saturate the detector may persist on subsequent frames. Increase the number of erases to at least three if any part of the array is being saturated.

- High humidity can cause the dewar window to fog. Prevent fogging by installing the captive air cover on the input window in even moderately humid conditions. Above 70% relative humidity the cover is mandatory.

- Unguided exposures may produce trailed or elongated images. Make a test exposure. Fine tune the tracking by autoguiding for a few minutes before beginning unguided exposures.

- The three fields of view are not precisely parfocal or concentric; check the focus and object position after changing fields of view. If moving to a narrower field of view, first center the object on the array.

- <u>Slight vignetting</u> in the corners of wide field images is normal.

- <u>Loss of coolant can occur at large Zenith distances:</u> liquid nitrogen spilling onto the dewar can freeze o-rings, resulting in a loss of vacuum, an aborted observing seession, or even damage to the array. If you anticipate working at very large zenith distances, try to fill the dewar well beforehand so that the vessels are not completely full when the telescope is tipped--you may, in fact, wish to only fill the inner vessel about half way, as it uses up very little nitrogen in any case, and this will help minimize spillage. Always reattach the fill-hole tubes after filling the dewar--these will help divert overflow away from the instrument.

- <u>The array may exhibit some instabiltiy</u> for as much as an hour after filling the dewar.

ACKNOWLEDGEMENTS

The authors would like to thank David Koo, David Harker, Pasquale Temi, Carol Gronwall, Gibor Basri, Darrell Severinsen, Evan Stateler, and Rem Stone for their help with the preparation of this manual, and Keith Baker, Jim Burrous, Wayne Earthman, and John Morey for their helpful comments. Finding charts for the UKIRT standard stars have been made available, under separate cover, courtesy of Stephane Courteau.

We would also like to thank the Rockwell Science Center for their generous donation of the HgCdTe array through NSF-PYI grant #AST-8858203.

REFERENCES

Elias J.H., Frogel.J.A., Matthews K., and Neugebauer K. A.stronJ., 87, p.1029, 1982.

Courteau, S., *A Compilation of the UKIRT Faint JHK Standards*, NOAO, 1995

Hayes D.S., IAU Symposium #111, eds. D.S. Hayes, L.E. Pasinetti, and A.G. Davies, 1985.

The Kitt Peak National Observatory (KPNO) Infrared Observing Handbook (1987).

Misch A., *The Hamilton Spectrograph User's Manual*, LOTR 58, 1991.

Stone R.P.S., *Nickel Telescope User's Manual*, LOTR 61, 1992.

Stone R.P.S. and Shields J., *The CCD Spectrograph and Camera at the Nickel Telescope*, LOTR 52, 1990

Zuckerman B. and Becklin E., Ap. J. Lett. 319, L99, 1987.

APPENDIX A: DATA-TAKING SYSTEM GUIDE

The Lick data-taking system developed by Richard Stover, has evolved over more than a decade. Its latest incarnation runs under X-Windows. The program was adapted for use with LIRC-II by Kirk Gilmore.

The data-taking program initially creates three windows: an xterm window displaying the data-taking menu, an image window, and an image control window. Some commands invoke submenus or additional windows. Following is a summary of the commands found in the LIRC-II version of the program.

A.1. Data-taking Menu

A. Selection number allows preselected parameters to be saved and recalled.
Changes made to the current parameters with options 'B' through 'I' are saved under the active selection number and can be recalled by selecting that number (see selection 'J'). Ten complete settings can be recorded.

B. Integration time sets the length of the exposure in seconds.
This option sets the exposure time in seconds. Note that changing this option *during* an exposure will not change the integration time. To do so, the 'Change integration' command (selection 'V') must be invoked. The actual exposure times elapsed and remaining are displayed in the upper right part of the screen during an integration.

C. Observation number numbers the current observation.
The observation number will be stored as part of the header. The observation number, preceded by the letter 'd' and with the extension '.ccd' appended, is the filename given that image on disk (e.g., observation number 3 will be labeled 'd3.ccd'). An existing file with the same name will be overwritten. The observation number only increments if an observation is recorded. Note that the displayed observation number represents the next image that will be recorded to disk, whereas the displayed tape number, if any, shows the last image recorded to tape.

D. Window defines the portion of the device to be read out.
The window is specified by height (rows), width (columns), and origin. The origin is counted from the upper left corner of the window. The LIRC-II window size is customarily kept at the full 256 x 256 pixels.

F. Observation type defines the observation as 'normal' or 'dark'
Note that in the absence of a shutter, there is no difference between normal and dark. LIRC-II darks are made by moving the filter and/or lens wheels to their 'dark' positions.

G. Recording selects the data storage medium.
Options are 'disk,' 'tape,' 'both,' or 'not recorded.' Note that when 'not recorded' is selected, the current image will be written to the scratch file /scratch/scr.ccd, but will be overwritten by the next unrecorded observation. 'Disk' refers to the disk directory /data, or, when that unit is full, to the /vista directory. 'Tape' refers to the Exabyte 8-mm cassette drive. To save time, most users write LIRC-II images only to disk during observations, and save them to tape at the end of the night.

H. Display chooses whether or not to display the next image on the terminal.

I. Object allows entry of a label that will be attached to the image.

J. Selection summary lists the ten preset selections (selection 'A').

K. Number of erases sets the number of erases before the exposure is begun.

L. Number of prereads sets the number of bias frames taken before the exposure is begun (see Section 2.3.2.).
The frames are automatically taken, stored, coadded, and averaged, then subtracted from the actual exposure during readout. Setting the number of prereads to zero disables the function.

M. Number of Coadds sets the number of target frames to be coadded before recording (see Section 2.3.3.).
The requested number of frames are added in the computer memory, before the final image is dispalyed and written to disk or tape. Only the summed image is saved. The saved image is given the observation number of the first image in the coadded series, so that when using coadds, observation numbers on disk will not be consecutive. To take individual, non-coadded images, set the number of coadds to one.

R. Start starts the exposure.

S. Stop stops the exposure, reads out the chip, and records the data. The user is prompted for confirmation.

T. Abort stops the exposure and discards the data. The user is prompted for confirmation.

V. Change integration changes the integration time during an exposure.
The actual exposure times elapsed and remaining are displayed in the upper right part of the screen during an integration (selection 'B').

W. Change selection changes the preset parameter selection during an exposure (selections 'A' and 'J').

X. Comments allows up to five lines of comments to be added to the current header or, if preceded with an asterisk, to all headers.

?. Help invokes on line help.

Z. Special invokes a five-option sub-menu, of which parts of options 2 and 3 are most commonly used and are further described here.

2. Tape

   A. Prepares a new tape for writing. Use this selection only with new or recycled tapes. Once initialized, any previous data on the tape will be lost.

   B. Rewinds a tape and then positions it to the end of last exisiting file (end of volume mark). Option 'C' is usually preferred.

   C. Reads the current tape position and then positions it to the end of the last existing file (end of volume mark).

   D. Writes the last image to tape.

3. Miscellaneous

   A. Accepts observer's name(s) for header.

   B. Accepts instrument description for header.

A.2. Image Display and Image Control Windows

The data-taking system creates an image window for displaying incoming raw images, and another for interactive control of the image window. The windows may be moved and sized as you would any x-window.

When the cursor is placed in the image window, the array coordinates and DN at the current cursor position are displayed in the upper left corner of the control window. For precise positioning, the cursor may be moved in the image window by using the arrow keys. The following commands are available when the cursor is in the image window.

To draw a row or column plot at the cursor positon: Place the cursor on the image at the desired row or column. Type 'r' or 'c', for a row or column plot. A blue plot window is spawned, displaying the plot. When the cursor is placed in the plot window, the values of X and Y are displayed in the upper right-hand corner of the plot window.

To limit the x-axis of a plot: Plots made as described above may be rescaled after they are drawn, by drawing a box on the plot itself, just large enough to contain the area of interest. Draw with the mouse while holding down the left-hand button, then click on 'apply box' in the upper right-hand corner of the plot window. Clicking on 'no zoom' restores the original plot. Alternatively, a box may be drawn on the image itself by typing 'b' with the cursor in the image window, and clicking and dragging to define the upper left and lower right corners of the box. Row and column plots made with the cursor inside the box will have only the extent of the box.

To draw rapid consecutive plots across the image: Hold down 'r' or 'c' while moving the cursor on the image. This provides a fast method for assessing the whole frame.

To see a magnified portion of the image, centered on the cursor: Activate the magnifying circle at the upper center of the image control window by placing the cursor on it and clicking the left-hand mouse button. Return the cursor to the image. A magnified view of the area around the cursor appears in the circle.

To recenter the image around the current cursor: Click the center mouse button with the cursor at the desired place on the image. This is useful as a first step to zooming in on a particular part of the image (see below).

Other options for manipulating and interacting with the image are available in the image control window, pictured in Figure 8. On-line help for image control functions may be invoked by placing the cursor on the command in question and clicking the middle mouse button. A few of the most commonly used functions are described below.

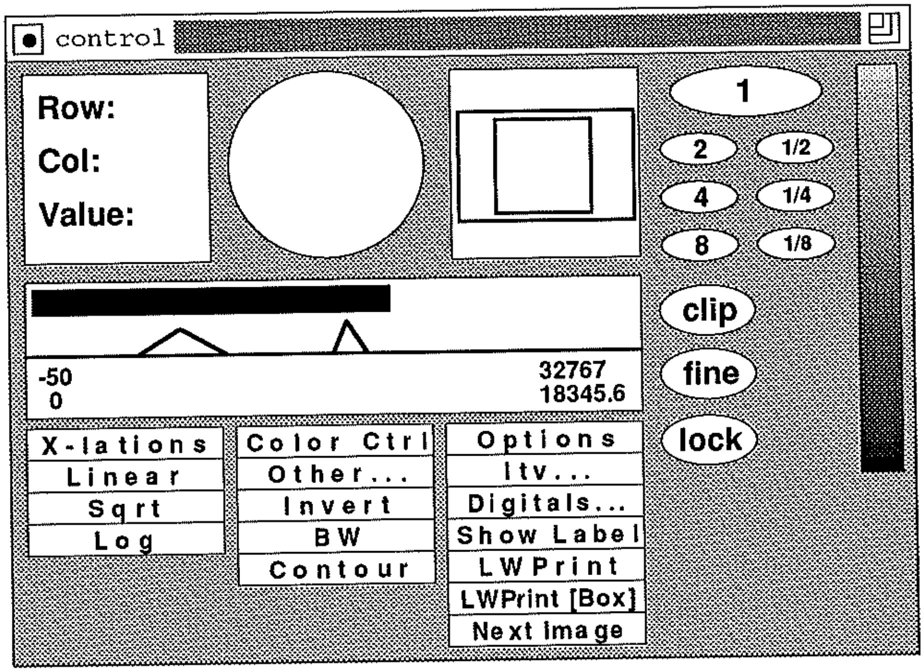


Figure 8. The image control window

<u>To enlarge or reduce the image</u>: With the left-hand mouse-button, click on the appropriate number, representing the magnification, in the upper-right portion of the window. The size and position of the image, with respect to the image display window, is graphically represented in the box at the upper right center of the control window. The green and black outlines represent the image and the display window, respectively.

<u>To pan</u>: Move the cursor to the box at the upper-right-center of the control window; the cursor will become a black dot. Place the dot on the representation of the image (green outline) at the point you wish to be at the center of the redrawn window. Click the left-hand mouse button. The image is redrawn in the display window at the new position.

<u>To expand or contract the range of the bitmap</u>: Move the cursor to the right-hand end of the solid blue, horizontal bar. When the cursor has changed to a left-slanting arrow, hold the left-hand mouse button and drag the bar right to expand the bitmap range, left to

contract it. The image will be redrawn using the new bitmap range. The longer the blue bar, the lower the contrast.

To change the zero-point of the bitmap: Move the cursor onto the solid blue, horizontal bar, hold the left-hand mouse button and slide the bar right or left.

To change the correspondence of the colormap to the bitmap: Move the cursor onto the vertical color bar on the right side of the control window. When the cursor has changed to a spray-can, hold the left-hand mouse button and drag the cursor up or down. The color map changes instantaneously. To apply an entirely different color map, invert the image, draw contour lines, or change to black and white, use the controls under the 'Color Ctrl' heading at the lower-left-center of the window.

To retain the current bitmap (ie. prevent autoscaling of new images): Click on the 'Lock' button.

To clip pixels lying beyond the range of the bitmap (ie. prevent wraparound): Click on the 'Clip' button.

To perform statisitics on portions of the image: Select 'Itv' under the 'Options' heading at the lower-right-center of the window. This will invoke another window with several options. The most commonly used is the 'Stellar Stats' command, which calculates and displays, in yet another window, a variety of useful information about the selected object. First click on 'Pick Stellar Stat Loc', move the cursor onto the image, and click on the object you wish to analyse, then click on 'Do Stats'.

To see numerical values over a portion of the image: Select 'Digitals' under the 'Options' heading at the lower-right-center of the window. Click on the region of the image for which you want imformation. A window appears, displaying a matrix of values for the pixels surrounding the selected region.

To display an image stored on disk: Select 'New Image' under the 'Options' heading at the lower-right-center of the window. Another window will appear with a directory of available images. Display the desired image by clicking once on its filename. By default, the last ten images written to the data disk are listed. You can change the directory and number of images listed by clicking on the appropriate boxes and replying to the prompts, and then clicking 'display new image list'.

APPENDIX B: LIRCTOP GUIDE

B.1. Introduction

Lirctop is a set of Vista procedures collected under a single, menu-driven calling program. It is designed to streamline common and repetitive tasks. It is capable of taking exposures, moving the telescope through small angles, automating calibrations, performiong simple reductions, and carrying out tests of the array. On-line help files describe each Lirctop command, and an electronic logbook contains the latest information about the IR camera, and will include updates and revisions to this manual.

Lirctop's functions are divided into six main categories: Observations, Calibrations, Tests, Quick Reductions, Lirclog, and Help. These invoke one or more submenus with a variety of choices, described below. The source code resides in a collection of subroutines in the directory /procedure/lirctop, and may be examined, though not altered or added to, by users. However, we welcome suggestions for the addition of new functions and improvements to exisiting ones. Report bugs to tony@ucolick.org.

Vista's--and therefore Lirctop's--interaction with the data-taking system is limited, and it has none with the LIRC-II motor controller. It can set the integration time, choose which preset selection to use, start an exposure, and make small telescope moves. With the exception of the 'Nod' function (see below), Lirctop always uses the parameters set in selection one of the data-taking system. Functions which prompt for integration times may change the integration time in selection one. Some functions move the telescope between target exposures. These will ask the user in advance if he or she wishes the procedure to pause before and after each exposure, to enable or disable the autoguider. (To resume a paused procedure, type 'continue', or simply 'c' as it is usually aliased in Vista.)

B.2.Starting Lirctop

To run Lirctop, open a Vista window by selecting 'Vista' from the pull down menu which appears when clicking the left-hand mouse button with the cursor in the gray area between windows. A light-blue Vista window is created. (You may wish to conserve screen space by reducing the size of the font in the Vista window. Put the cursor in the window, hold the control key and the right-hand mouse button simultaneously and select 'tiny' from the pull-down menu.) Type 'rp lirctop' to load the program, type 'go' to run it. The top-level menu will appear.

Some Lirctop selections spawn Vista image, image control, or plot windows, if they do not already exist. These are identical in appearance to the image and image control windows belonging to the data-taker, but are in the service of Vista and operate independently. They are necessary to take advantage of Vista's more complete image processing capabilities, such as sky subtraction and flat-field division. Their drawback is increased clutter and confusion as windows battle for territory on the screen. This may be made almost tolerable by shrinking windows when not in use, and by remembering how much worse it would be if you didn't have them at all.

Error trapping is weak in Lirctop, and incorrect input can crash the program, returning you to the Vista prompt. If this happens, simply type 'go' to start again.

B.3.Lirctop functions

B.3.1. Observations

Choosing the 'Observations' selection invokes a submenu with the four selections 'Expose', 'Nod', 'Dither', and 'Mosaic'. All make exposures; the latter three also move the telescope according to a pattern, making exposures at each point.

For the purposes of the program, the related operations of nodding, dithering, and mosaicing are separately defined as follows: nodding moves the telescope between two positions; dithering moves between two or more positions according to a pattern entered from the keyboard or stored in a file; mosaicing moves in a rectangular pattern for systematic mapping of large areas.

Selections which move the telescope include the option of pausing the procedure between moves to enable or disable the autoguider. If using the autoguider, you should reply 'yes' to this question, as moving the star off the guide reticle while guiding is enabled will cause errors in the track rate, resulting in poorer guiding.

Expose takes multiple exposures without moving the telescope.

The user is prompted for the number of exposures. The exposures are made using the parameters in selection one of the data-taker. Expose may be used as a continuous loop by entering an arbitrarily large number of exposures. This is particularly useful for focusing, checking collimation, and other operations requiring many short, repeated exposures. (Remeber to turn recording off in the data-taker, if images need not be saved.) There is, however, no graceful way to terminate the exposures before the requested number has been made, but it may be done gracelessly by typing 'control-c'. This will cause Lirctop to terminate completely. Simply type 'go' to restart the program.

Remember that with n coadds selected, each exposure is the sum of n frames. Remember also to turn off recording in the data-taker when appropriate.

<u>Nod</u> moves the telescope between a starting and an offset position, the requested number of times, takes the requested number of exposures at each position, and returns the telescope to the starting position when all the exposures have been completed.

Nod is useful for moving between target and sky positions. To help with recordkeeping, **<u>exposures at the starting position are all made with selection one in the data-taking system, while all those made at the offset position use selection two</u>**. For example, selection one and two could have identical parameters, except that the labels might read 'target' for selection one, and 'sky' for selection two.

The user is prompted for a single set of right ascension and declination offsets, in arc-seconds, which define the distance between the start and offset positions. Offsets are given in terms of telescope movement--remember that targets will appear to move in the opposite direction with respect to the array.

The user is prompted for the number of exposures at each position, the number of iterations of the sequence, and whether the program should pause before and after moves, to allow enabling or disabling of the autoguider.

Remember that with n coadds selected, each exposure is the sum of n frames.

<u>Dither</u> moves the telescope according to a predetermined pattern. The offsets can be entered from the keyboard, read from a user-created file, or from a 'canned' file.

In the first three cases below, the user is prompted for the number of exposures at each position, the number of iterations of the entire sequence, and whether the program should pause before and after moves, to allow enabling or disabling of the autoguider. The telescope always returns to its starting position on completion of the observations. Exposures are made according to the parameters in selection one of the data-taking system. Remember that with n coadds selected, each exposure is the sum of n frames.

<u>Read offsets from a file</u> This dithering option reads a series of telescope offsets from a user-created file, written and stored to disk using the 'Define a new dither pattern' selection, in the dithering submenu (see below). All dither files must reside in the /procedure/lirctop directory. To protect your own dither files from being accidentally

overwritten, save a copy in your personal directory. The user is prompted for a file name. If it is a valid file, the program will prompt the user for observing parameters before executing the observation.

Use a canned dither pattern This dithering option offers a choice of two ready-made patterns: a right triangle or rectangle. The user interactively defines a pattern's size and orientation. The program then prompts for observing parameters before executing the observation.

Canned dither patterns always move in a clockwise direction. Right triangles begin at the intersection of the base and leg; rectangles begin at the upper left corner.

Enter offsets from the keyboard This option allows a dither pattern to be entered at the keyboard. The user is prompted for input in terms of the number of points in the pattern, and the size of each move in arcseconds for both declination and right ascension. The program then prompts for observing parameters before executing the observation. This option is similar to 'Define a new dither pattern' below, but executes the pattern without necessarily storing it to a file. After execution, the user is asked whether he or she wishes to save the pattern.

Define a new dither pattern This selection permits the user to interactively define a dither pattern to be stored in a file. The user is prompted for an output file name, and then for input defining the pattern in terms of the number of points in the pattern, and the size of each move in arcseconds, for both declination and right ascension. The file is automatically saved in /procedure/lirctop, where it can be read by the dithering procedure. This function does not execute the pattern. To do so, the user must select dithering again, choose the 'Read offsets from a file' option, and enter the name of the newly created file.

Mosaic moves the telescope through a rectangular pattern. The aim of mosaicing is to systematically cover areas of the sky larger than the detector's field of view. A mosaicing pattern is defined interactively in terms the number of 'tiles' in the X and Y directions, and the extent of their overlap. After the pattern is defined, the user is prompted for the number of exposures at each position, the number of iterations of the entire sequence, and whether the program should pause before and after moves, to allow enabling or disabling of the autoguider. Exposures are made according to the parameters in selection one of the data-taking system.

All mosaics begin at the upper left-hand corner of the pattern. The observer may either point the telescope to the starting position, or answer 'yes' when queried whether to begin at the center. In the latter case, the observer points to the middle of the mosaic, and lets the program automatically move the telescope to the upper left-hand corner, before beginning exposures. Remember that with n coadds selected, each exposure is the sum of n frames.

B.3.2. Calibrations

Selecting 'Calibrations' invokes a submenu with the three selections 'Darks', 'Sky Flats', and 'Bias'. 'Darks' and 'Bias' are fully automated and may be left to run unattended. 'Sky Flats' requires the observer's attention to monitor and adjust exposure times, and to change filters as needed.

<u>Darks</u> allows the user to make unilluminated dark frames at exposure times equivalent to his or her target frames.

An unlimited number of frames, at a maximum of ten different exposure times, may be automatically made. The program prompts for the number of different exposure times, the times themselves, and the number of frames at each exposure time. Exposures are made according to the parameters in selection one of the data-taking system. Remember to set the filter and lens wheels to their 'dark' positons.

<u>Sky Flats</u> takes the requested number of exposures, while moving the telescope a small distance between each exposure.

The user is prompted for the integration time, and the size of the telescope offset, in arcseconds. We recommend a minimum of 10 arcseconds.

Bear in mind that twilight sky brightness changes rapidly, and that integration times must be adjusted accordingly. We suggest monitoring the flux of the incoming twilight sky frames, and keeping the integration time appropriately adjusted. You may change the integration time for the next frame, during the readout of the previous one, or you may choose to take only a few exposures each time you run 'sky flats', changing the integration time after each sequence.

Bias takes the requested number of zero-second dark frames for bias subtraction. Remember to set the filter and lens wheels to their 'dark' positons.

B.3.3. Tests

Selecting 'Tests' invokes a submenu with the two options, 'Dark and Noise Levels' and 'Array Stability'. These test the array's performance. (See also Appendix D, 'Testing the Array')

Dark and Noise Levels This procedure measures the array's dark current and readnoise. Note that in the course of running the test, a Vista image window, its associated control window, and a plot window will be created, if they do not already exist. This may take a half a minute or so. The procedure pauses between the dark and noise tests to allow the user to examine the results of the former. Type 'continue' (or simply 'c' as it is usually aliased in Vista) to resume. The test is fully described in Appendix D, Section D.1.

Array Stability This procedure checks the constancy of the system by taking a series of exposures with a uniform source of illumination, or a series of darks, and comparing the mean DN levels of the series, inside one or more user-defined boxes. It is fully described in Appendix D, Section D.2.

B.3.4. Quick Reductions

'Quick Reductions' provides a way to perform rudimentary reductions for quick looks at incoming data. Rigorous reductions are beyond Lirctop's scope (for suggestions regarding complete reduction strategies, see Section 4.). At present, this option includes only one quick reduction routine, 'Quick Sky Subtration'.

Quick Sky Subtraction This procedure performs a subtraction of two images, usually a source frame (or a sum of several source frames) and a sky frame.

B.4. Creating New Procedures

While Lirctop may not be changed or added to by users (though we welcome suggestions for additions and changes), new Vista procedures, independent of Lirctop, may be written in Vista's Fortran-like programming language.

Vista uses the vi editor for writing procedures. To create a new procedure, type 'pedit'. To edit an exisiting procedure, load it by typing 'rp [procedure name]' and then 'pedit'. To save procedures to disk, type 'wp [procedure name]'. This saves the latest version of the currently loaded procedure in the directory /procedure. (The procedure directory is periodically purged--save copies of your own procedures to your personal directory for safe keeping).

Writing procedures with Vista, like any other programming language, is best learned in the doing. General information on procedures and descriptions of commands are available through Vista's on-line help utility. From Vista, simply type 'help procedures' or help [command name].

APPENDIX C: INSTRUMENT CHARACTERISTICS

C.1. Detector Specifications;

Array size:	256x256
Pixel size:	40x40-μ with 3-μ between pixels
Dark Current:	less then 2e^{-} sec^{-1}
Readnoise:	approximately 50e^{-}
Full well:	300,000e^{-}
K-band QE:	62% @ 77K
Cut-on wavelength:	0.9um
Cut-off wavelength:	2.5um
Gain:	12 electrons DN^{-1}

C.2. Flux Information

C.2.1. Approximate Count Rates

Bandpass	Magnitude	DN sec^{-1}
J	12.96	2300
H		2200
K	13.15	1650

Table 2. Approximate exposure rates These numbers are based on 3-meter observations of the white dwarf standard GD 140. Narrow-band filters will be about 10% of the broad-band flux rates.

C.2.2. Approximate Sky Brightness

The Mt. Hamilton sky is approximately 13th to 14th magnitude per square arcsecond at K', and about one to two magnitudes fainter at J and H-bands. K and K' sky brightness, and consequently sky-limited exposures times, vary dramatically with local conditions, especially temperature. Table 3. gives approximate times to complete saturation of the array (about 23,000 DN) for two air temperatures at K'.

outside air temperature (F)	camera field of view	approximate time to saturation
39°	narrow	165 secs.
39°	intermediate	70 secs.
39°	wide	20 secs.
55°	narrow	85 secs.
55°	intermediate	35 secs.
55°	wide	10 secs.

Table 3. Times to saturation at K' These tests were made at the 1-meter under clear, dark skies, with the TUB diagonal mirror out. The same numbers should apply at the 3-meter.

C.3. Array Linearity

The array's linearity is plotted in Figure 9. The measurements were made by integrating a small photon flux for varying times from near zero to near saturation. Two different flux levels were used to correlate the relative slopes: about 50,000 $e^- \, sec^{-1}$ for the upper measurement, about 4,000 for the lower. The latter consists of four traces, each representing the response of one quadrant of the array.

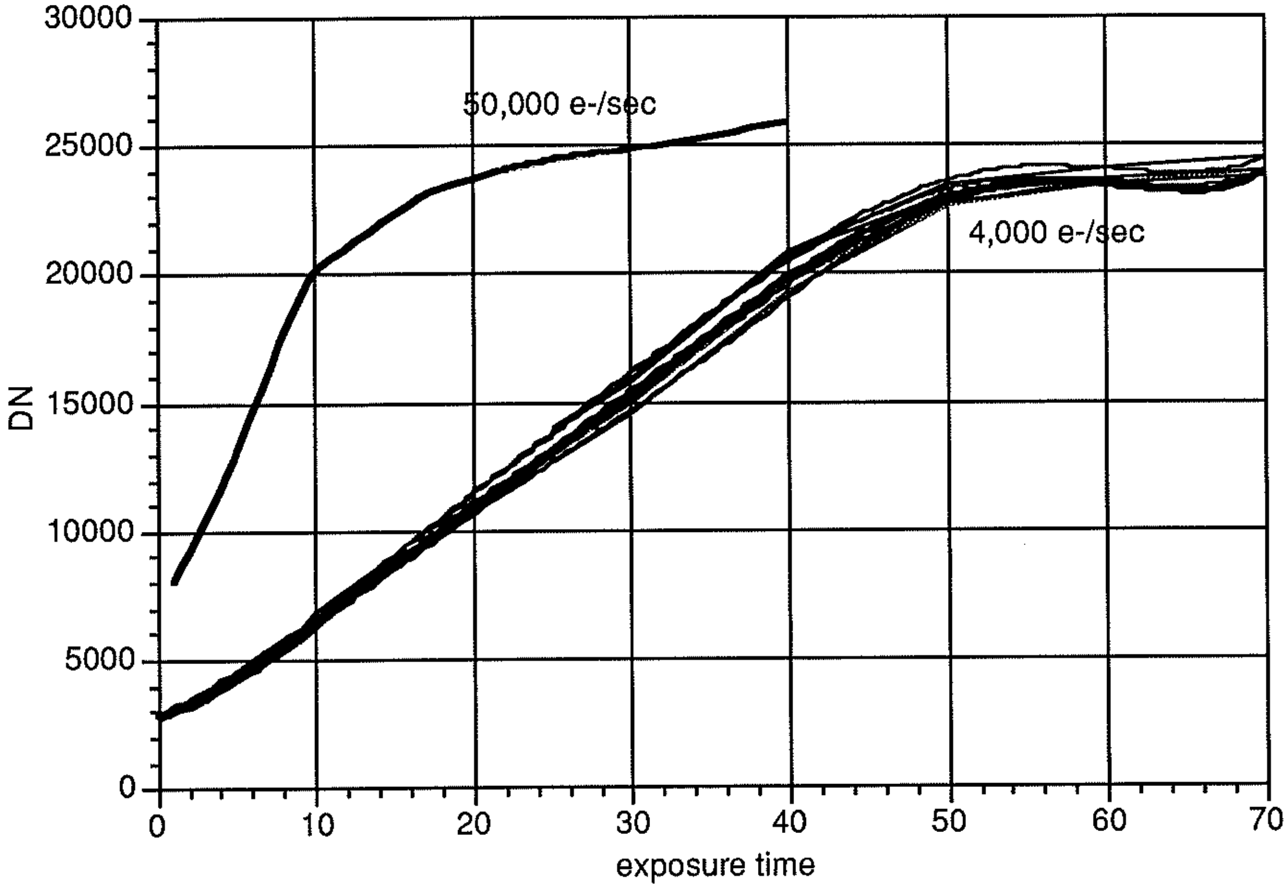


Figure 9 Array linearity

C.4. NICMOS 3 FPA Technical Description

The focal plane array (FPA) consists of a HgCdTe detector array hybridized to a silicon multiplexer using indium columns (bumps). The detector array converts the incoming infrared radiation into electrical charge and the multiplexer processes the charge. The two components are fabricated separately, resulting in the independent optimization of the performance of each device. Indium columns are evaporated on the detector and multiplexer array after each is fabricated. The two devices are then aligned and cold-welded together to form the hybrid focal plane array. The hybrid is illuminated through the substrate--in this case, sapphire.

The key component of the hybrid FPA is the readout multiplexer, which converts the integrated detector current into an output voltage and multiplexes the detectors into a serial data stream. The multiplexer was designed using 3-micron, single polysilicon, single metal, p-well CMOS design rules. The multipexer circuit consists of an array of MOSFET switches arranged so that each detector element is read out through a single unit cell repeated as a 128x128 array, connecting to each detector through an indium column. Four such arrays are mosaiced to form the NICMOS 3 256x256 detector.

The detector is biased to a voltage V_R - DetSub. In our case, this is a reverse bias level of 0.5 volts. After the detector is read, the reset switch is turned on, forcing the potential at the cathode of the detector to voltage VR. When this switch is then opened, the cathode of the detector is free to float in potential. Each detector has a depletion capacitance into which the photogenerated and leakage currents are integrated. As charge integrates, this potential discharges toward DETSUB. LIRC-II uses the reset gate for each pixel so that correlated double sampling can be used to reduce kTC noise. For correlated triple sampling and multiple readout of the same exposure, the reset gate is not used. This software-controllable feature is not yet an option in the LIRC-II camera system. Unfortunately, the process of resetting the detector bias is not uniform. This shows up as a non-uniform DC offset in the output signal. This is due to threshold variations caused by non-uniformity in the silicon MUX and processing variations. Because these non-uniformities are the result of materials variations, and not random electrical noise, they are repeatable from one readout of the array to the next and can therefore be removed by calibration.

The array uniformity is determined by the uniformity of the MUX and the detector material. Due to the way the MUX is laid out, there is a systematic odd/even offset built into the MUX. This offset is removed by most sampling schemes or by simple flat field calibration.

APPENDIX D: TESTING THE ARRAY

D.1. Dark and Noise Tests

Set all wheels to their dark positions by selecting the 'Dark' option in the motor control program. From the data-taking system, set the parameters for a zero-second exposure with three erases. If Lirctop is not running, start it as described in Appendix B. From Lirctop's main menu, select 'Tests', from the submenu, select 'Dark and Noise Levels'.

The script begins by taking, displaying, and plotting a one-second dark. If Vista's own image and control windows do not already exist, a few moments will be required for their creation. The dark-frame should appear in the image display window as a more or less uniform square composed of four quadrants, resembling Figure 10. Note the positions of the few blemishes.

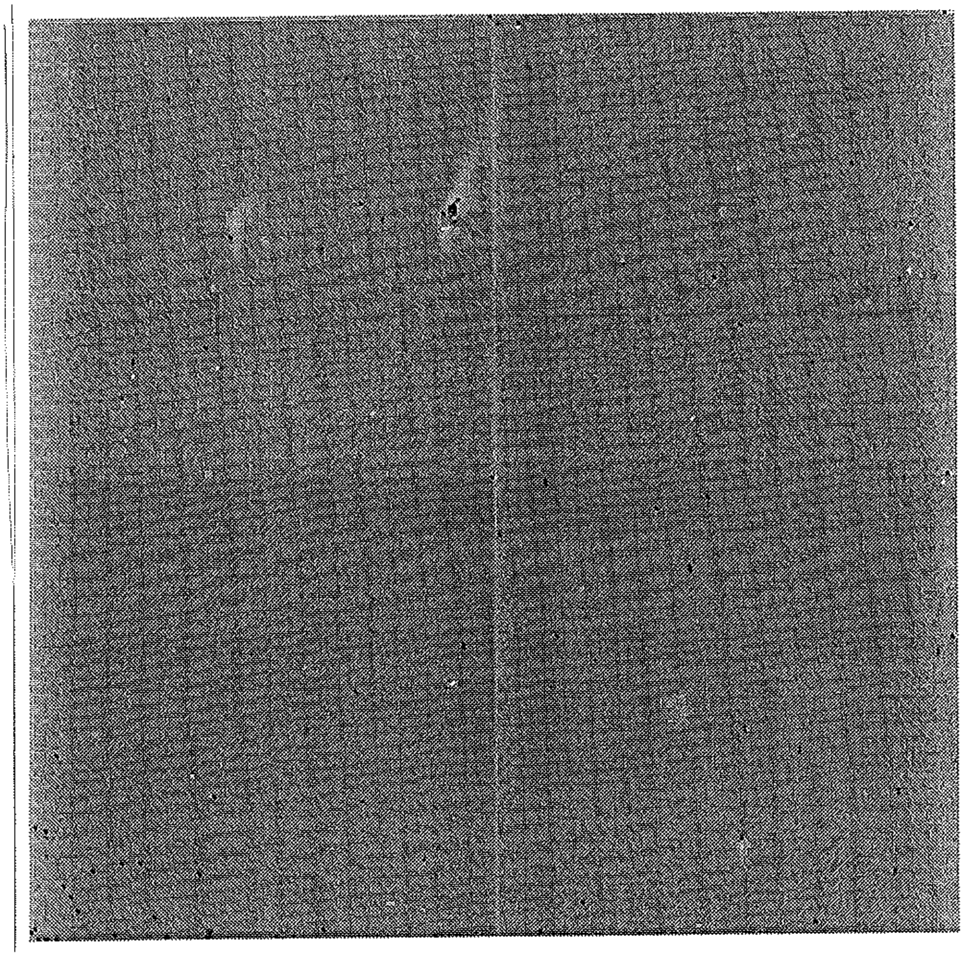
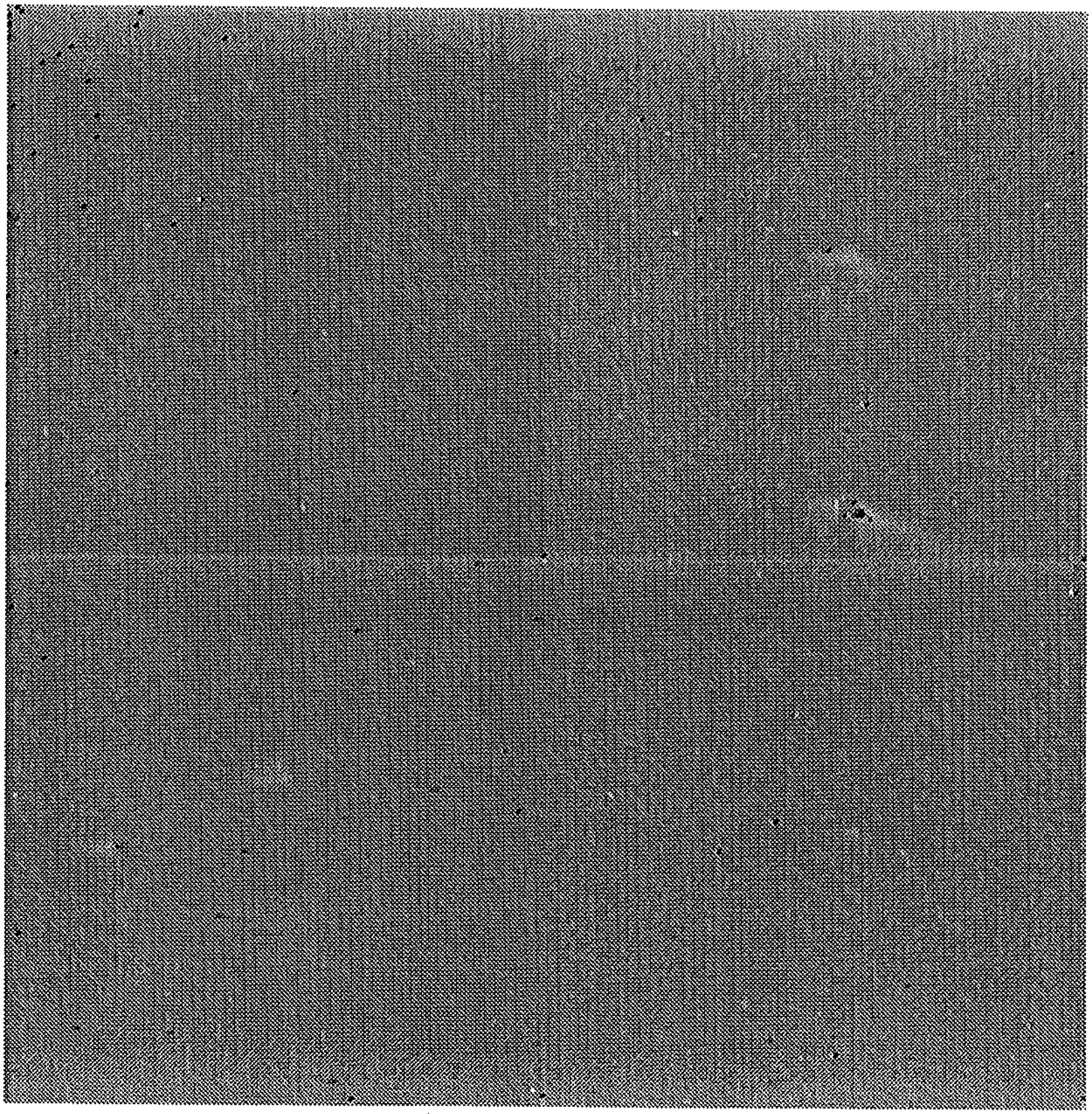


Figure 10. Typical dark frame



A black plot window will appear with a row plot which should look something like Figure 11. Values should vary about 100 DN peak to peak. The level should be in the neighborhood of 2,000 DN, representing the bias level. (Remember that if you've enabled baseline subtraction, the level should be much lower--about 100 DN--but the peak to peak variation should be the same.) If your image is markedly different, you may have a light leak or a baseline problem. Make sure that all wheels are in their 'Dark' positions. Have a technician check your baseline setting.

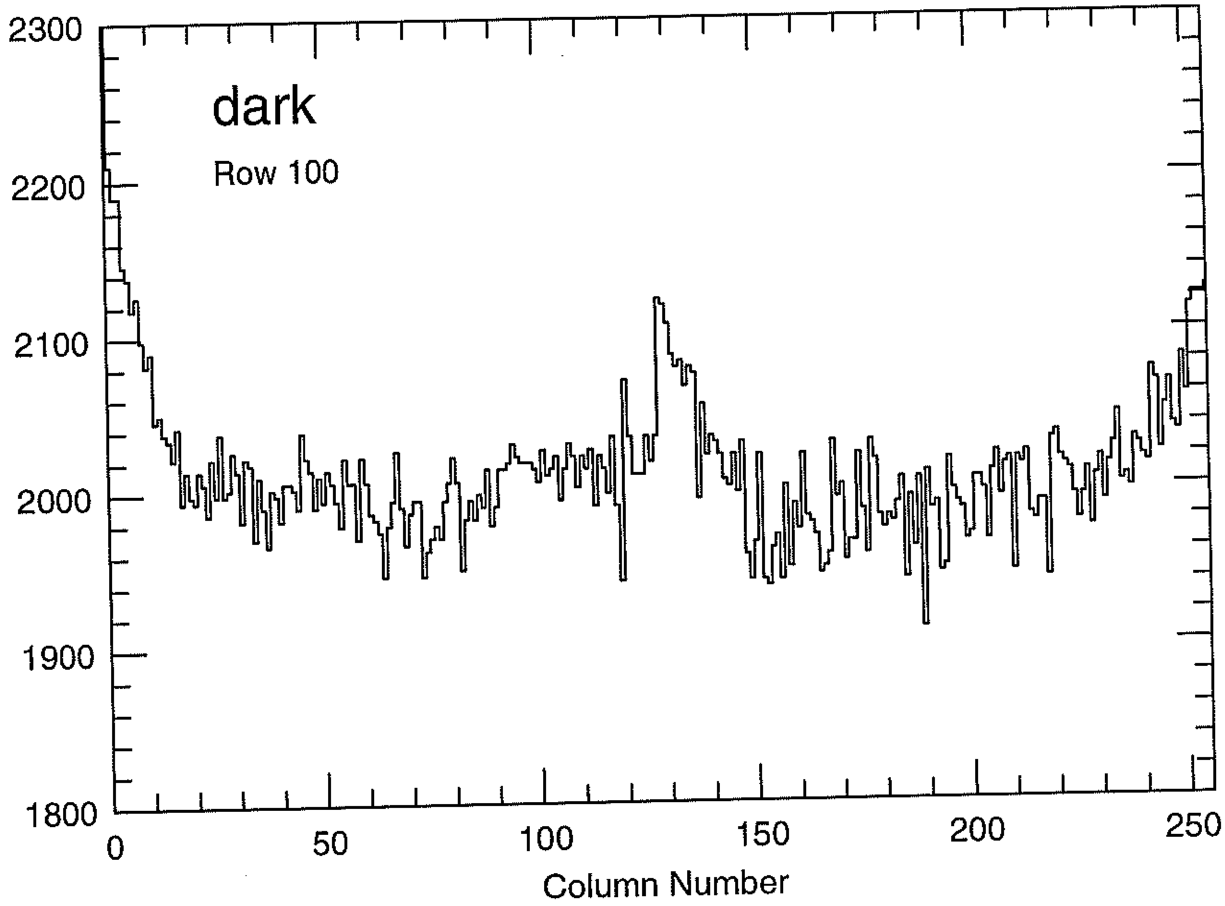


Figure 11. Row plot of typical dark frame

The procedure will have paused at this point to allow you to examine the image and plot. To resume, type 'continue' (or just 'c', as it is often aliased) in the Vista window. A second dark frame will be taken and subtracted from the first. The remainder is then displayed and plotted. The plot should resemble Figure 12., with levels of about 30 DN peak to peak. This number, divided by six and multiplied by $12e^{-}DN^{-1}$, will yield the approximate read-noise level in terms of $e^{-}pixel^{-1}$.

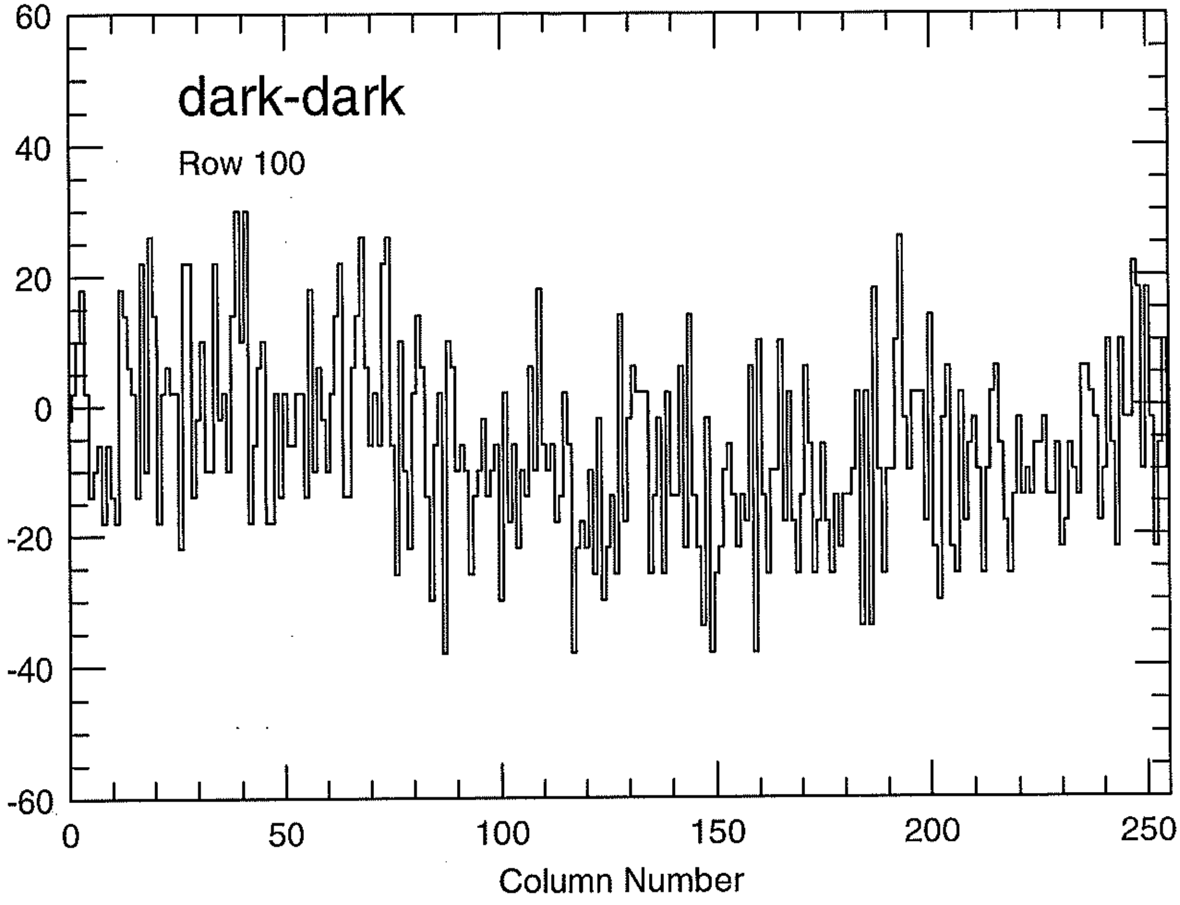


Figure 12. Row plot of dark minus dark

D.2. Stability

The constancy of the systems response can be measured by examining flux levels in repeated exposures, or the stability of the baseline can be checked by looking at a series of darks. Such tests measure the stability of the array and its associated electronics, including exposure timing.

If it's not already running, open a Vista window and start Lirctop as described in Appendix B. From the main menu, select 'Tests', from the submenu select 'Stability'. This procedure automates the stability test by taking the requested number of exposures, calculating the mean DN within one or more user-defined boxes, and finally plotting mean DN against exposure number.

The response test is only as accurate as the illumination is constant. A good, stable thermal source, over periods of time during which the dome temperature does not change significantly, is the backside of the TUB diagonal mirror or the inside of the primary mirror cover.

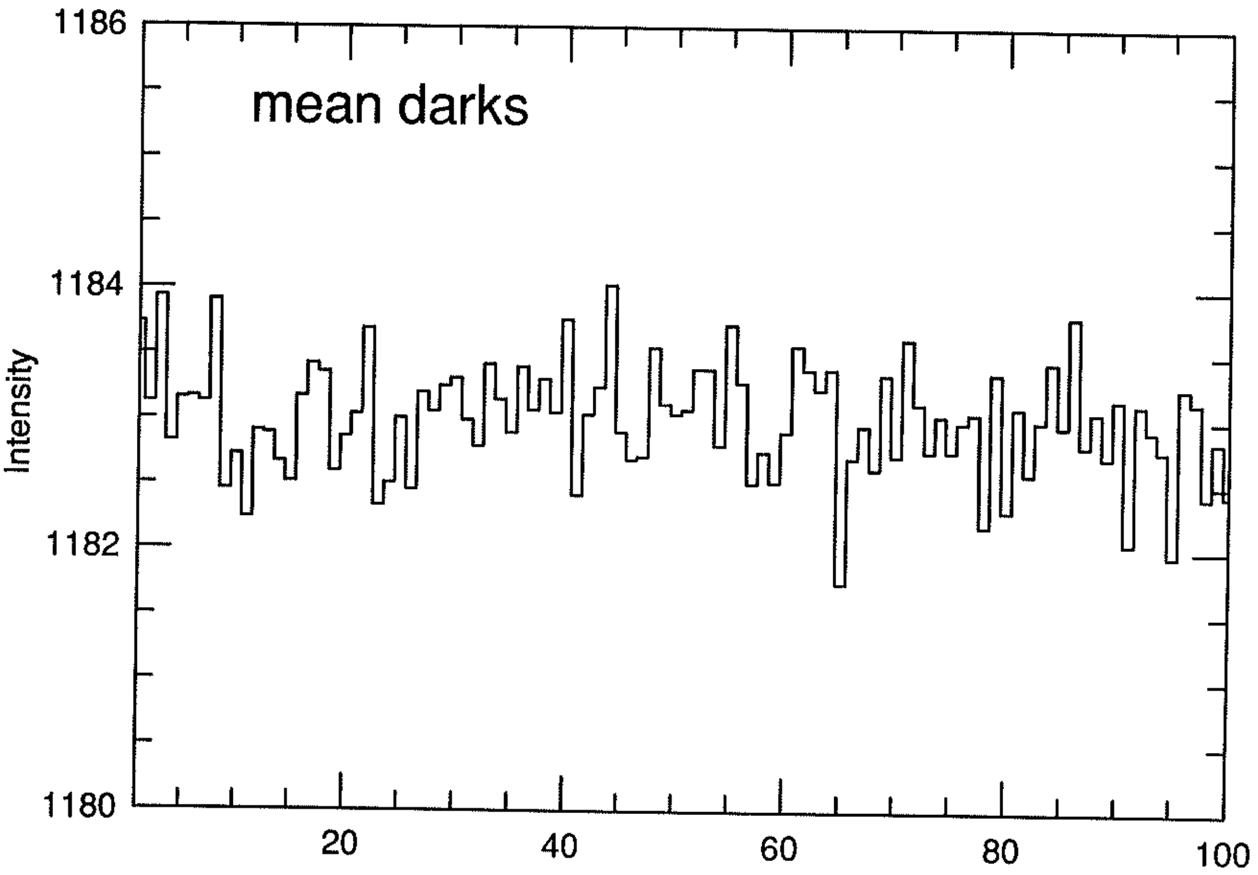


Figure 13. Plot of baseline stability The mean of one hundred, 1-second dark exposures, plotted against exposure number. The y-axis is the mean DN measured in a 56x56 pixel box, centered on the array.

D.3. Sky Test

This check must be performed after dark. From the motor control program, select the K' filter and the intermediate field of view. Take an exposure of the evening sky, long enough to bring the average pixel to about 15,000 DN, and make a rowplot. It should resemble Figure 14.

The appropriate exposure time will depend strongly on air temperature and other local conditions, varying by as much as a factor of three or four between summer and winter. The 45-

second exposure shown in Figure 14 was made with the intermediate field of view, at 39° Farenheit, under a clear, moonless sky. The same exposure level is reached in about half the time at 55°. See the 'Times to Saturation' table in Appendix C, Section C.2.2.

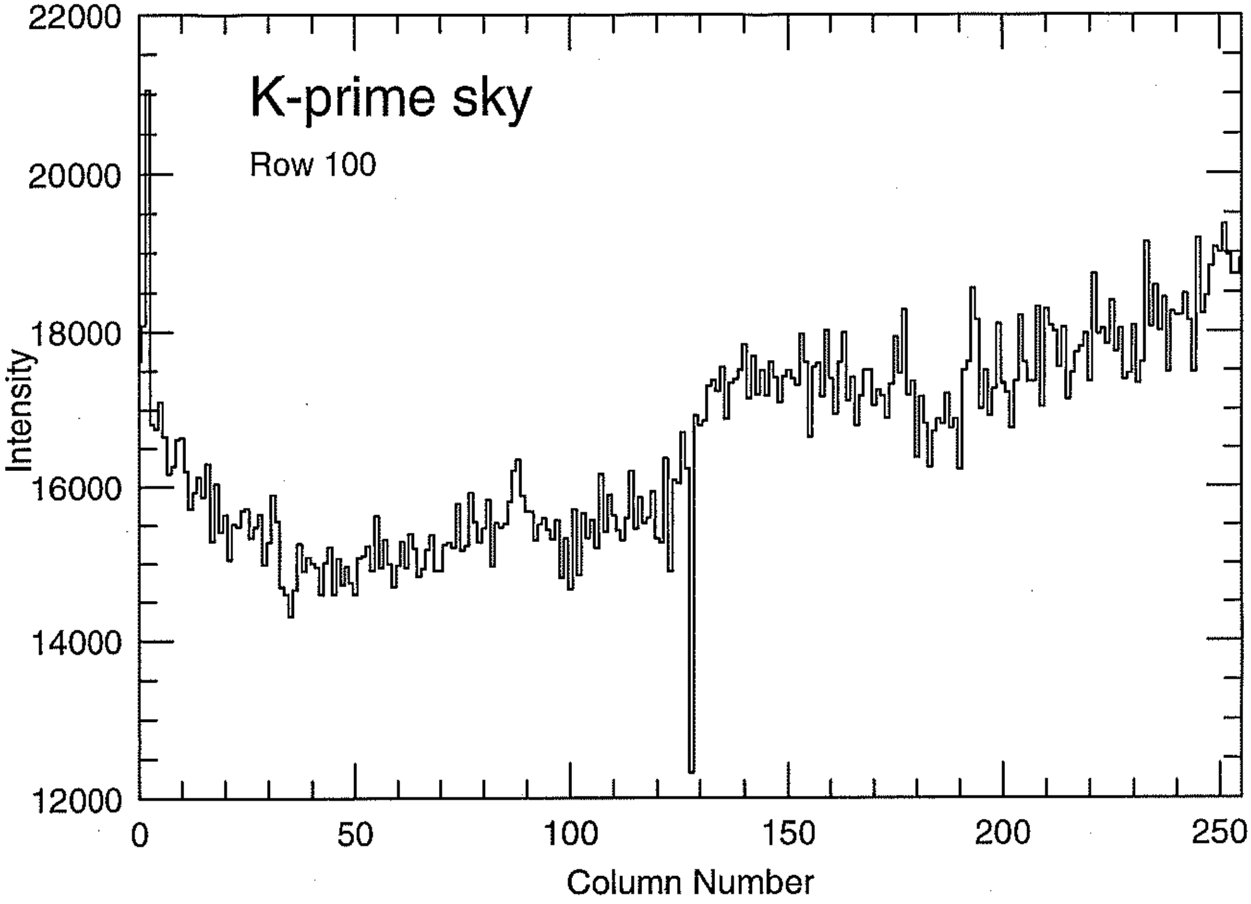


Figure 14. Row plot of the K' sky. This 45-second exposure was made with the intermediate field of view, at 39° F, under a clear, moonless sky. Local conditions, especially temperature, can cause K' sky brightness to vary several fold.

APPENDIX E: FILTER TRANSMISSION CURVES

Transmission curves in this appendix:

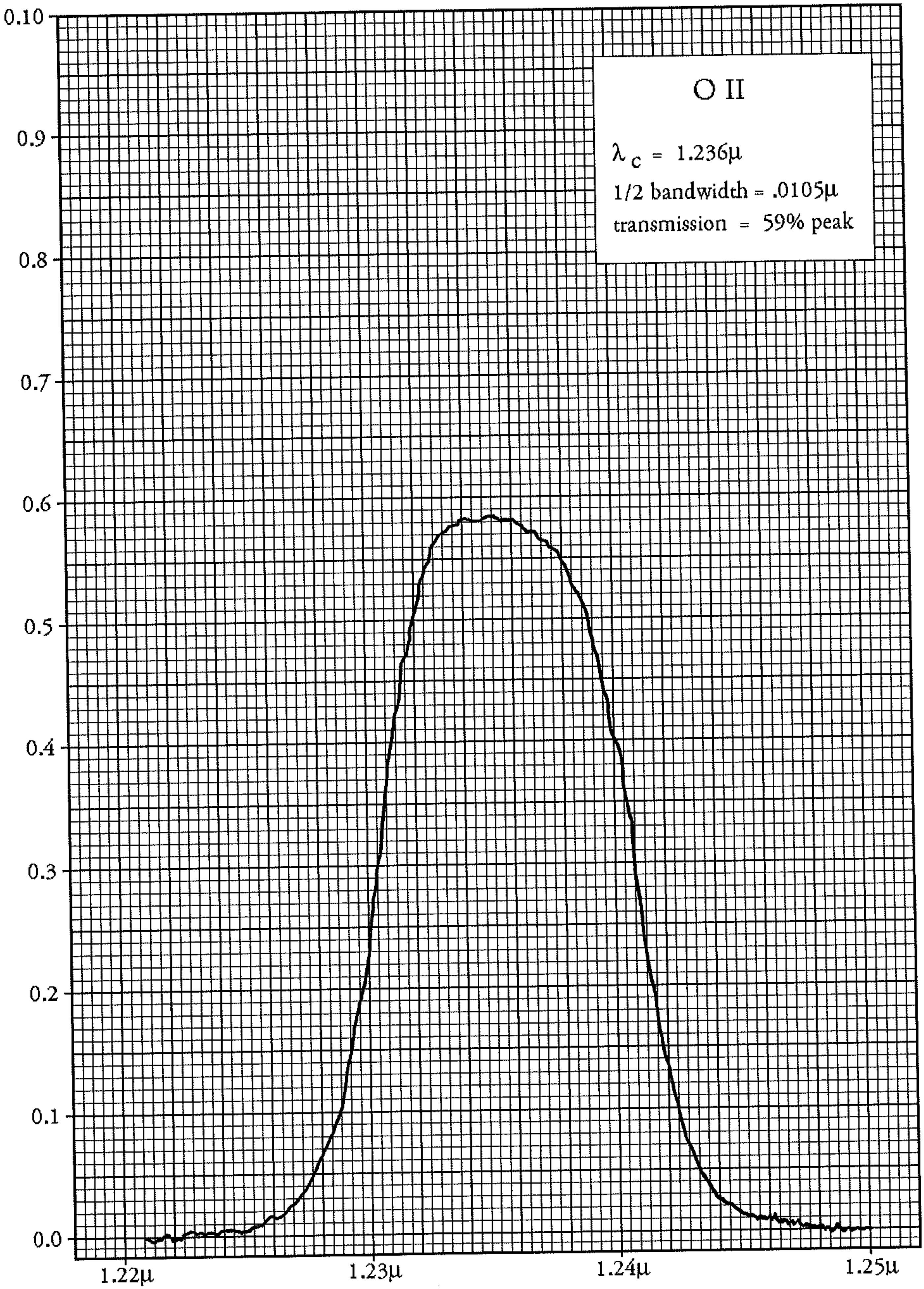


Figure 15. O II filter transmission curve.

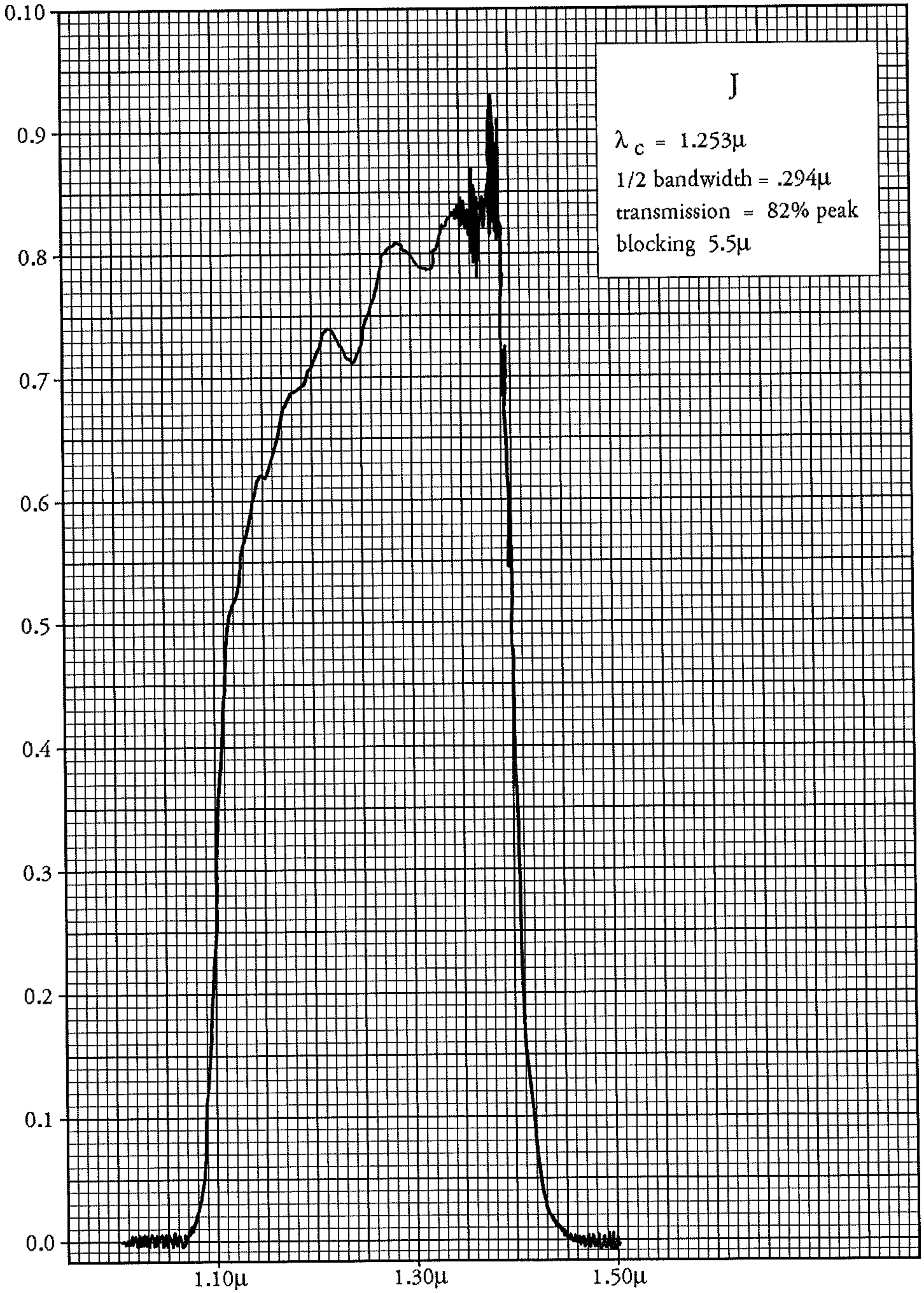


Figure 16. J-Band filter transmission curve.

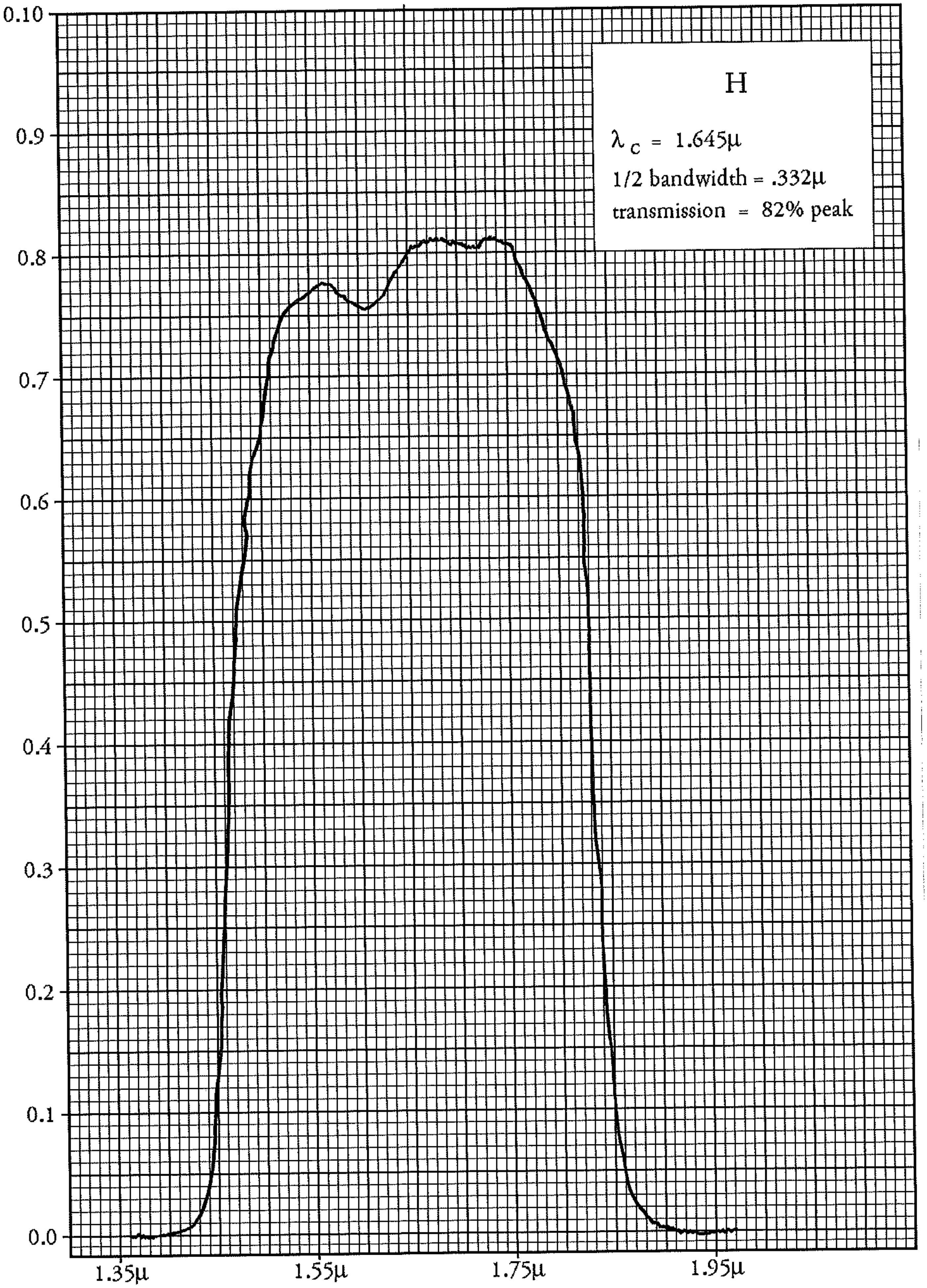


Figure 17. H-band filter transmission curve.

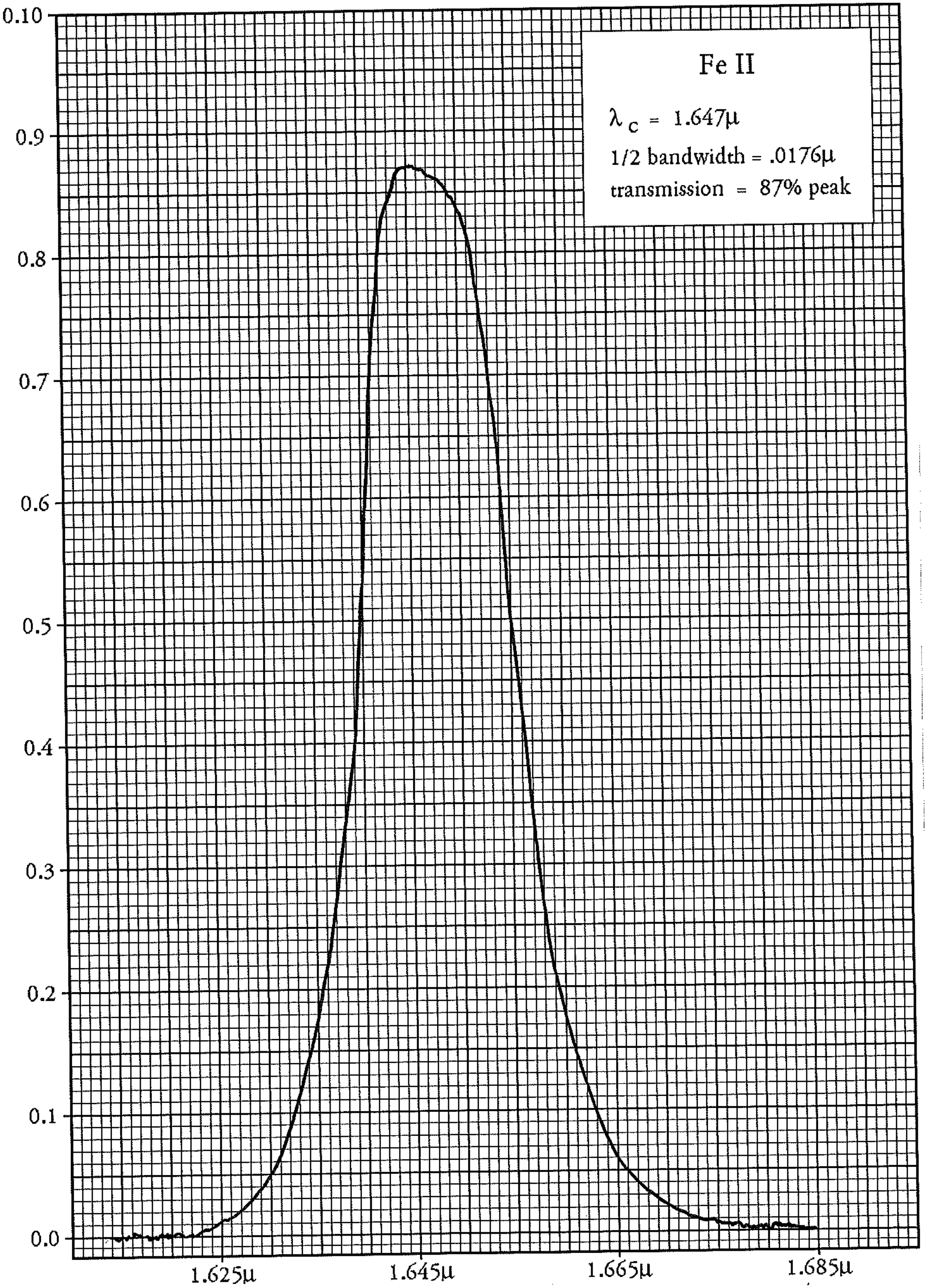


Figure 18. Fe II filter transmission curve.

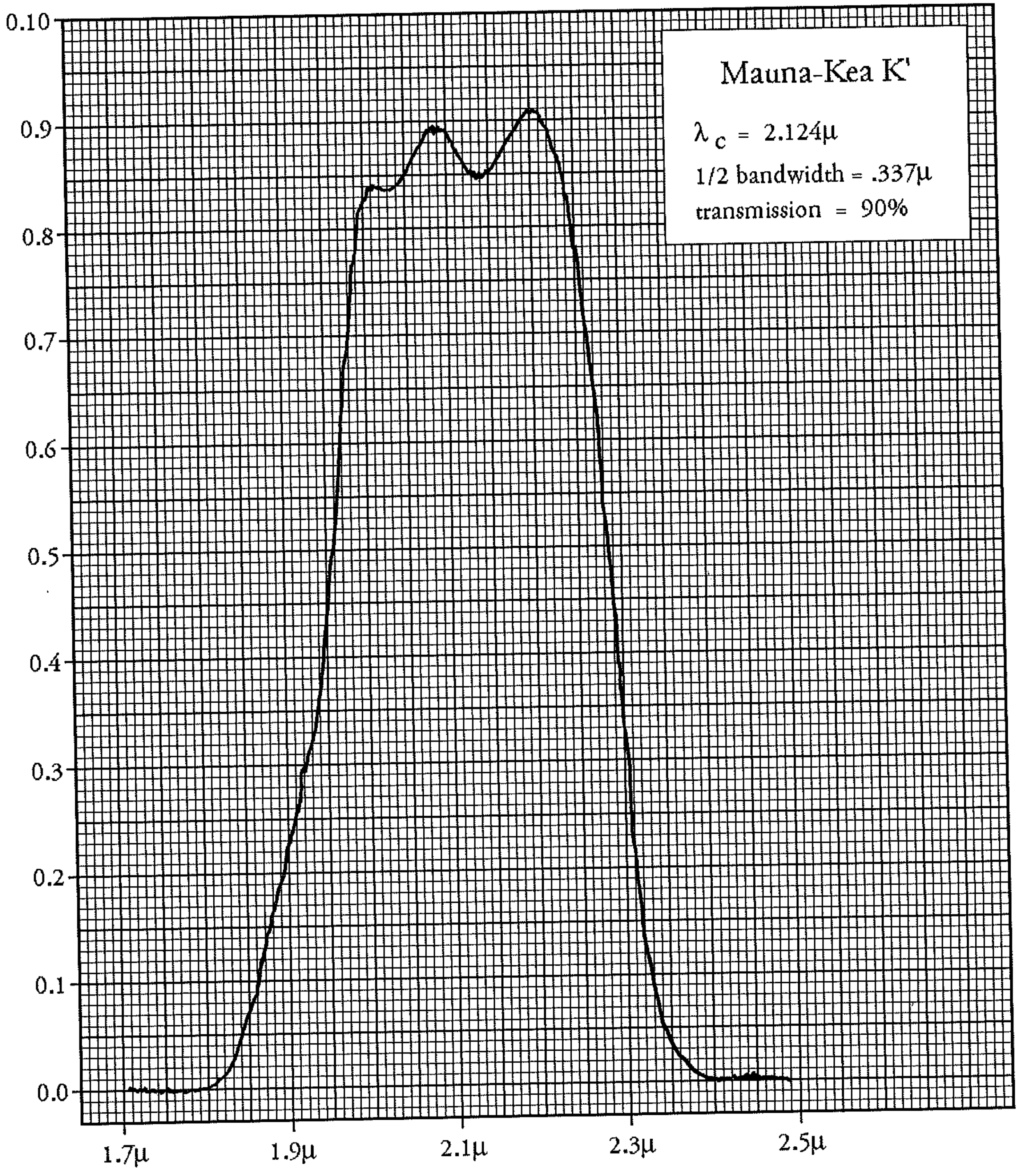


Figure 19. K' filter transmission curve.

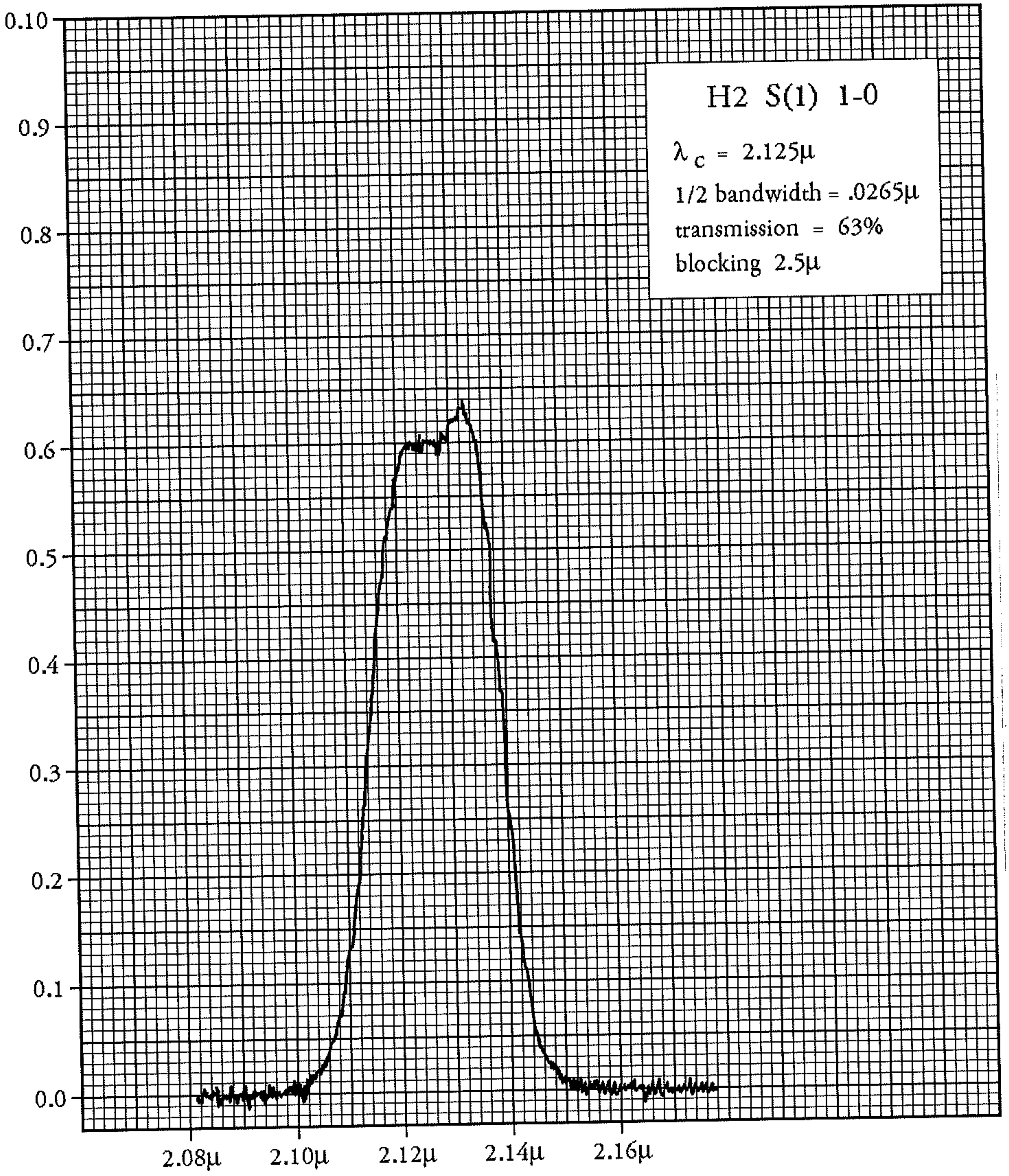


Figure 20. H2 S(1) 1-0 filter transmission curve.

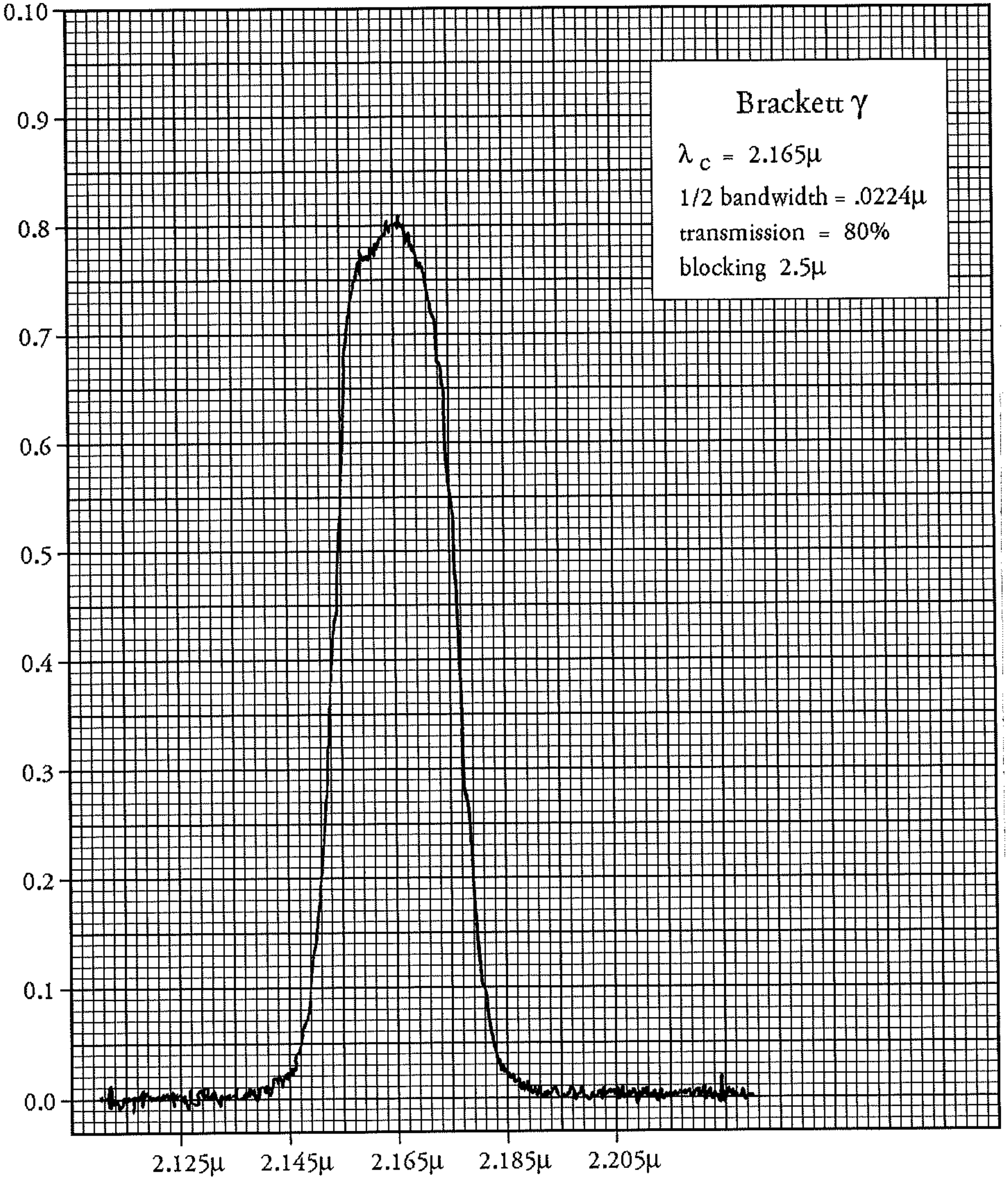


Figure 21. Bracket γ filter transmission curve.

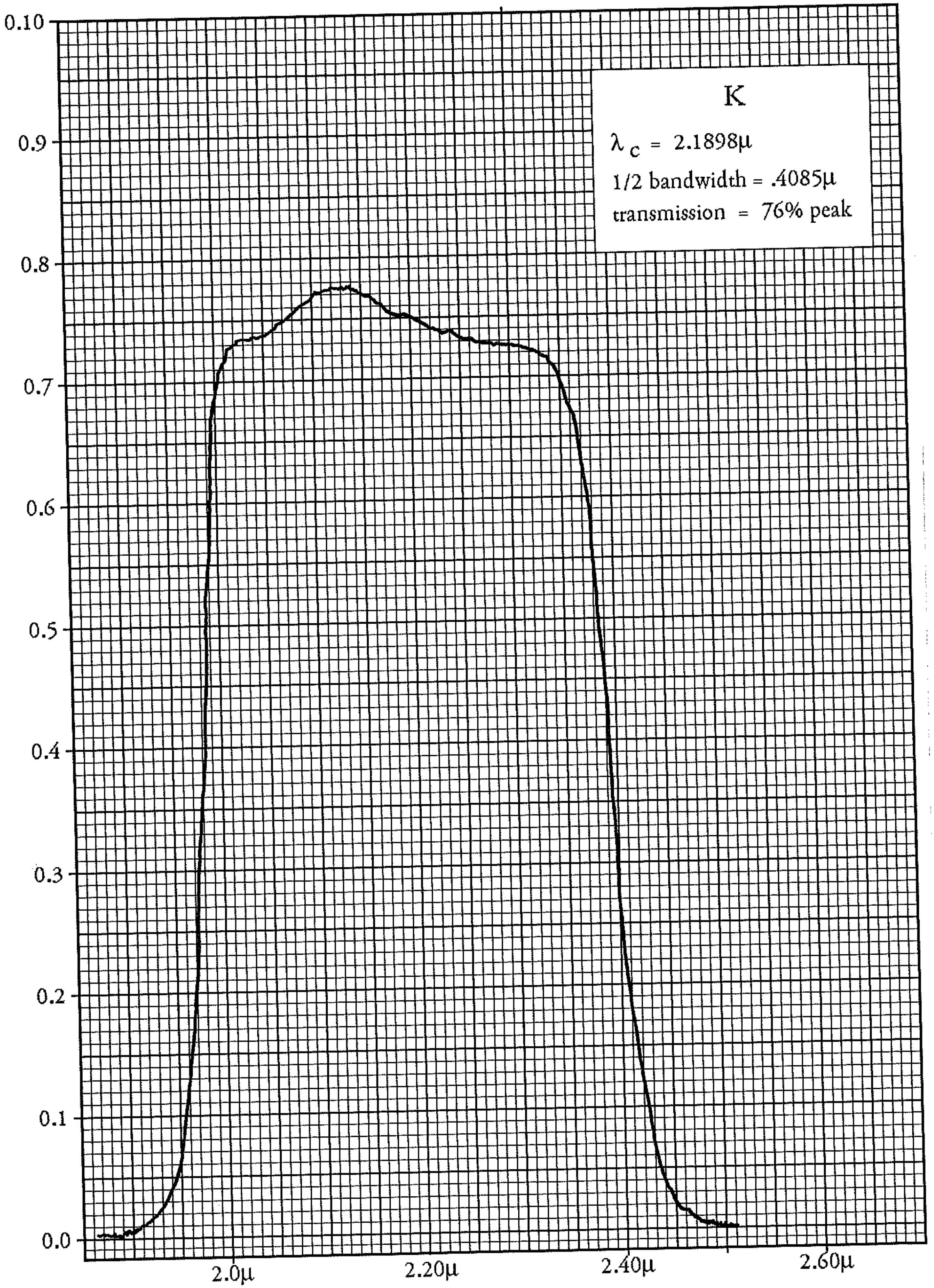


Figure 22. K-band filter transmission curve.

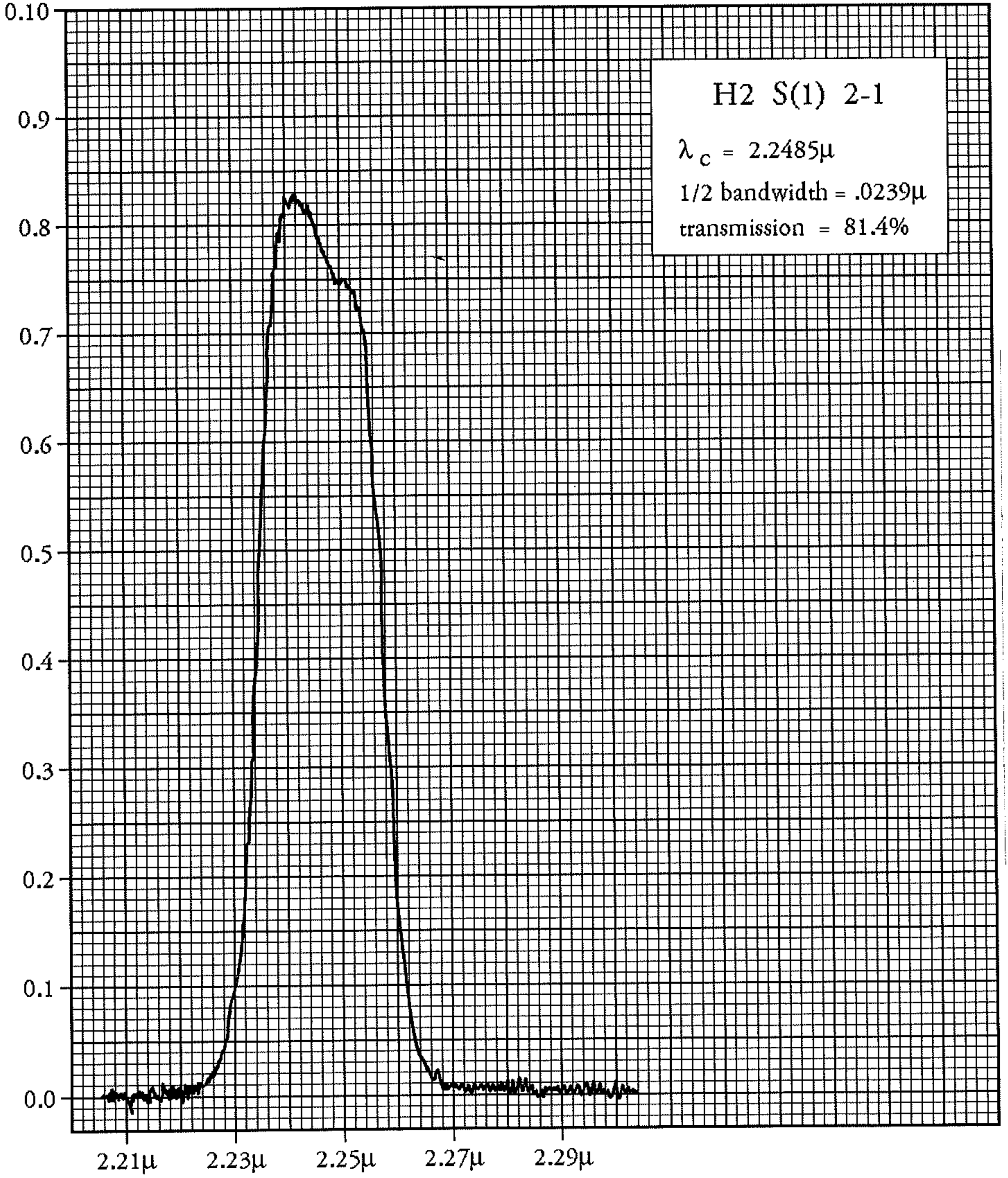


Figure 23. H2 S(1) 2-1 filter transmission curve.

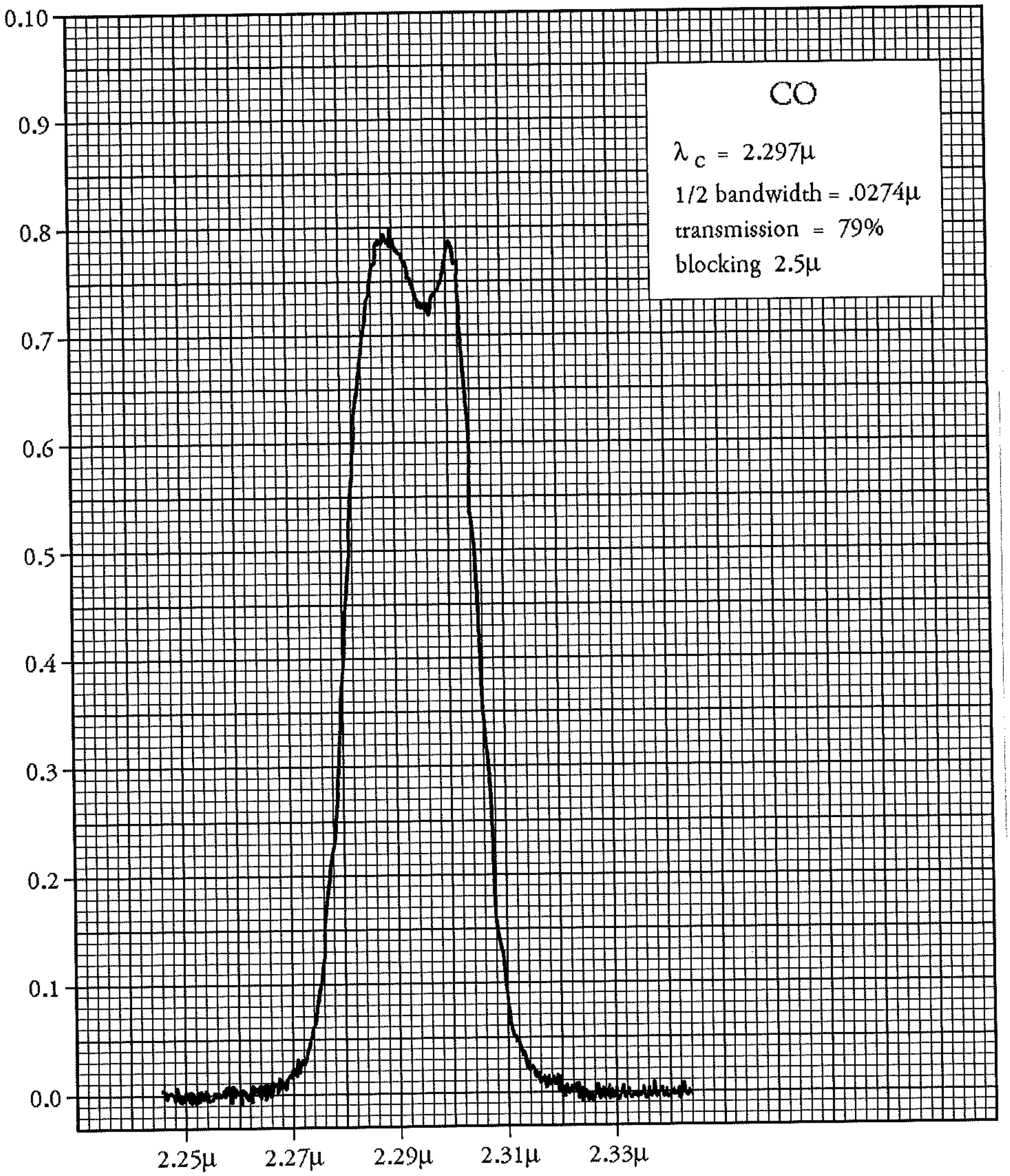


Figure 24. CO filter transmission curve.

APPENDIX F: TABLES OF IR STANDARD STARS

F.1. Table 4. White dwarf standards

STAR	α 1950	δ 1950	INSTRUMENT	V	J	H	K
GD 9	$0^h 58^m 29^s.6$	-4° 27' 22"	IRTF	15.31	15.77		15.98
GD 52	$3^h 48^m 47^s.9$	33° 58' 33"	IRTF	15.15	15.44		15.54
LB 1497	$3^h 49^m 11^s.5$	24° 46' 55"	IRTF	16.59	17.15		17.14
HZ 4	$3^h 52^m 38^s.4$	9° 38' 36"	IRTF	14.54	14.76		15.00
LB 277	$4^h 06^m 36^s.9$	17° 00' 04"	IRTF	15.13	15.66		15.71
V411 Tau	$4^h 15^m 51^s.8$	27° 10' 33"	IRTF	14.95	15.14		15.20
			NOAO Camera		15.12		15.16
VA 292 (VR 7)	$4^h 21^m 03^s.6$	16° 14' 23"		14.28	14.75		14.86
VA 490 (VR 16)	$4^h 25^m 46^s.5$	16° 51' 39"		13.99	14.64		14.85
VA 673 (HZ 9)	$4^h 29^m 29^s.8$	17° 38' 45"		13.88	10.78		9.89
VA 722 (HZ 7)	$4^h 30^m 56^s.9$	12° 36' 28"		14.23	14.70		14.90
LP 475-242	$4^h 37^m 34^s.6$	13° 53' 03"	IRTF	14.86	15.20		15.39
HZ 14	$4^h 38^m 15^s.8$	10° 45' 03"	IRTF	13.86	14.46		14.68
GD 74	$6^h 25^m 32^s.0$	41° 32' 47"	IRTF	14.99	15.39		15.65
GD 77	$6^h 37^m 26^s.5$	47° 47' 10"	IRTF	14.80	15.02		15.22
GD 84	$7^h 14^m 23^s.3$	45° 53' 20"	IRTF-RC2	15.33	15.05		14.97
			IRTF-Primo		15.09		
			UKIRT-UKT9		15.21	15.11	15.16
			Palomar-200"		15.16	15.18	15.22
LP550-292	$10^h 26^m 35^s.3$	2° 21' 19"	IRTF-RC2	14.2	14.36		14.44
			IRTF-Primo		14.37		14.51
			UKIRT-UKT9		14.53	14.56	14.57
			Palomar-200"		14.43	14.59	14.52
GD 140	$11^h 34^m 27^s.6$	30° 04' 35"	IRTF-RC2	12.38	12.98		13.17
			IRTF-Primo		12.90		13.13
			UKIRT-UKT9		12.96		13.14
GD 153	$12^h 54^m 35^s.1$	22° 18' 08"	IRTF-RC2	13.42	14.04		14.29
			UKIRT-UKT9		14.04		14.31
EG 141	$20^h 39^m 41^s.9$	-20° 15' 21"	IRTF-RC2	12.34	12.90		13.02
			UKIRT-UKT9		12.78		12.96

F.2. Table 5. UKIRT faint standards: K 7.9 to 14.9

Finding charts for the UKIRT faint standards have been provided courtesy of Stephane Courteau.[5] Bound copies are kept in the 3- and 1-meter control rooms, <u>for use at the telescope only</u>, and are not for copying or distribution.

No	Name	α 1950	δ 1950	K	J-K	H-K	ref.
1	G158-100	00 31 22.7	-12 24 29	12.967	0.462	0.081	2
2	SA92-342	00 52 36.0	00 26 58	10.466	0.247	0.038	1
3	F 11	01 01 46.6	03 57 34	12.822	-0.222	-0.097	1, 2
4	SA93-317	01 52 03.7	00 28 20	10.264	0.292	0.040	1
5	F 16	01 52 04.7	-07 00 47	12.342	-0.007	-0.002	1, 2
6	F 22	02 27 39.2	05 02 34	13.374	-0.135	-0.069	1, 2
7	SA94-242	02 54 47.2	00 06 39	10.940	0.165	0.037	1
8	SA94-251	02 55 12.9	00 04 04	8.313	0.766	0.129	1
9	SA94-702	02 55 38.8	00 58 54	8.266	0.884	0.158	1
10	GD 50	03 46 17.4	-01 07 38	14.919	-0.170	-0.049	2
11	SA96-83	04 50 25.4	-00 19 34	11.278	0.076	0.016	1
12	GD 71	05 49 34.8	15 52 37	13.898	-0.217	-0.091	1
13	SA97-249	05 54 33.8	00 00 53	10.135	0.382	0.047	1
14	Rubin 149	07 21 41.2	-00 27 10	14.261	-0.153	-0.079	2
15	M67-I-48	08 48 21.9	11 55 02	12.360	0.418	0.060	3
16	M67-IV-8	08 48 31.0	12 00 36	12.631	0.340	0.038	3
17	M67-IV-27	08 48 35.4	12 03 26	12.270	0.411	0.073	3
18	SA100-280	08 51 02.1	-00 25 14	10.522	0.292	0.031	1
19	G162-66	10 31 14.5	-11 26 08	13.796	-0.231	-0.142	1, 2
20	G163-50	11 05 27.6	-04 53 04	13.473	-0.120	-0.069	1, 2
23	M3-193	13 39 25.7	28 44 59	12.374	0.623	0.072	4
24	SA106-1024	14 37 33.3	00 14 36	10.753	0.151	0.019	1
25	SA107-1006	15 35 59.9	00 24 03	9.756	0.475	0.070	1

Table 5. continued

No	Name	α 1950	δ 1950	K	J-K	H-K	ref.
26	SA108-475	16 34 26.3	-00 28 39	7.972	0.858	0.155	1
27	M13-A14	16 38 54.2	36 26 56	13.123	0.371	0.058	4
28	SA109-71	17 41 32.5	-00 23 44	10.597	0.148	0.047	1
35	G21-15	18 24 44.5	04 01 17	11.757	0.474	0.089	2
29	G93-48	21 49 53.0	02 09 16	13.346	-0.171	-0.075	1, 2
30	SA114-750	22 39 11.3	00 56 55	12.015	-0.092	-0.036	1
31	GD 246	23 09 50.4	10 30 46	14.039	-0.241	-0.120	1, 2
32	F 108	23 13 38.2	-02 06 58	13.664	-0.205	-0.088	1, 2

References:

1. Landolt 1983 A.J. 88, 439

2. Turnshek et al 1990 A.J. 99, 1243

3. Eggen and Sandage Ap.J. 140,130

4. Private communication

5. Courteau, S., *A Compilation of the UKIRT Faint JHK Standards*, NOAO, 1995

F.3. Table 6. KPNO Standards: K 4.2 to 7.8

star	R.A. 1950	Dec.	J	H	K	L	q
HD 225023	$00^{h}00^{m}11.8^{s}$	+35°32'14"	7.065	6.985	6.960	-	b
G158-27	00 04 12.	-07 47 54	8.305	7.755	7.430	-	b
HD 1160	00 13 23.1	+03 58 24	7.055	7.045	7.040	7.025	a
HD 2811	00 28 53.0	-43 52 58	7.170	7.090	7.065	7.040	a+
HD 3029	00 31 02.3	+20 09 30	7.250	7.120	7.090	-	b
Gℓ 105.5	02 38 07.6	+00 58 57	7.240	6.635	6.525	6.460	a
HD 18881	03 00 20.5	+38 12 53	7.125	7.130	7.140	-	c
HD 19904	03 08 49.1	-39 14 24	6.720	6.660	6.640	6.620	a+
G77-31	03 10 40.5	+04 35 12	8.740	8.160	7.840	7.550	b
HD 22686	03 36 18.7	+02 36 07	7.195	7.190	7.185	7.195	a
HD 38921	05 45 41.0	-38 14 51	7.570	7.550	7.535	7.525	a+
HD 40335	05 55 37.6	+01 51 09	6.540	6.470	6.450	6.415	a
HD 44612	06 21 09.7	+43 34 35	7.060	7.035	7.040	-	c
BD+0°1694	06 52 07.3	+00 00 52	5.640	4.810	4.585	4.415	a+
Gℓ 299	08 09 11.	+08 59 42	8.380	7.915	7.640	7.360	a+
HD 75223	08 45 29.8	-39 36 54	7.325	7.295	7.280	7.260	a+
HD 77281	08 59 05.4	-01 16 45	7.105	7.050	7.030	6.995	a+
Gℓ 347a	09 26 25.	-07 08 30	8.410	7.860	7.630	7.425	b
HD 84800	09 45 35.9	+43 53 56	7.560	7.530	7.530	-	c
Gℓ 390	10 22 44.	-09 58 36	6.870	6.250	6.045	5.880	a
Gℓ 406	10 54 06	+07 19 12	7.060	6.440	6.080	5.730	b
HD 101452	11 37 45.1	-38 52 09	7.005	6.885	6.845	6.810	a+
HD 105601	12 06 56.1	+38 54 39	6.810	6.715	6.685	-	c
HD 106965	12 15 24.0	+01 51 10	7.375	7.335	7.315	7.295	a+
HD 129653	14 40 38.2	+36 58 07	6.980	6.940	6.920	-	b
HD 129655	14 41 11.0	-02 17 38	6.815	6.720	6.690	6.665	a
HD 130163	14 44 36.2	-39 43 04	6.855	6.845	6.835	6.810	a+
BD+3°2954	14 52 23.2	+03 11 33	5.840	4.995	4.805	4.650	b
HD 136754	15 19 24.3	+24 31 19	7.150	7.130	7.135	-	b
BD+2°2957	15 22 29.0	+01 41 06	5.200	4.425	4.245	4.095	b
S-R 3	16 23 07.7	-24 27 26	7.705	6.965	6.520	-	c
Oph S1	16 23 32.8	-24 16 44	8.800	7.270	6.330	5.770	c
HD 161743	17 45 31.8	-38 06 11	7.620	7.620	7.615	7.605	a+
HD 161903	17 45 43.3	-01 47 34	7.170	7.055	7.020	6.985	a
HD 162208	17 46 20.7	+39 59 40	7.215	7.145	7.110	-	b
Gℓ 748	19 09 38.	+02 48 36	7.075	6.545	6.305	-	c
Gℓ 811.1	20 54 04.	-10 37 36	7.755	7.150	6.930	6.740	c
HD 201941	21 10 13.6	+02 26 12	6.700	6.640	6.625	6.610	a
HD 203856	21 21 37.1	+39 48 12	6.925	6.880	6.860	-	b
HD 205772	21 35 33.6	-41 16 26	7.765	7.685	7.655	7.635	a+

HR#	name	R.A. 1950	Dec.	Sp T	V	J	H	K	L	L'	M	N	Q
0117	12 Cet	00:27:29.2	-04:14:00	M0III	5.71	2.77f	2.03f	1.87f					
0134		00:30:10.4	28:00:16	K0III	6.30	4.60f	4.15f	4.07f					
0337	β And	01:06:55.5	35:21:22	M0IIIa	2.06	-0.92	-1.73	-1.87	-2.01	-2.02s	-1.76s	-2.04t	-2.09t
0531	χ Cet	01:47:07.6	-10:55:59	F3III	4.67		3.90j	3.89j		3.84s	3.84s		
0617	α Ari	02:04:20.9	23:13:35	K2IIIa	2.00	0.08c		-0.66c	-0.72c			-0.80r	-0.85r
0696	10 Per	02:21:43.1	56:23:04	B2Iae	6.25	5.59e	5.50e	5.44e	5.35e	5.32s	5.30s		
0718	ξ^2 Cet	02:25:29.8	08:14:13	B9III	4.28	4.37e	4.38e	4.39e	4.42e	4.41s	4.37s		
1017	α Per	03:20:44.4	49:41:06	F5Ib	1.79	0.85c		0.54c	0.50c				
1140	16 Tau	03:41:49.5	24:08:01	B7IV	5.46	5.52j	5.50j	5.51j		5.64s	5.64s		
1165	η Tau	03:44:30.4	23:57:08	B7IIIe	2.87	2.93c	2.93c	2.94c	2.92c		2.92c		
1457	α Tau	04:33:02.9	16:24:37	K5III	0.85	-1.86	-2.64	-2.80	-2.98	-2.93s	-2.77	-3.03t	-3.09t
1552	π^4 Ori	04:48:32.4	05:31:16	B2III	3.69	4.04e	4.10e	4.14e	4.17e	4.17x	4.32s		
1641	η Aur	05:03:00.2	41:10:08	B3V	3.17		3.65j	3.68	3.70j	3.74s	3.76s		
1713	β Ori	05:12:08.0	-08:15:29	B8Iae	0.12	0.20c		0.18c	0.19c	0.08s	0.08s		
1708	α Aur	05:12:59.5	45:56:58	G5IIIe	0.08	-1.34	-1.73	-1.81	-1.87	-1.87s	-1.80s	-1.94t	-1.93t
1948	ζ Ori	05:38:14.1	-01:58:03	O9.5Ib	2.05	2.21k	2.28j	2.31j	2.30j		2.29k		
2061	α Ori	05:52:27.8	07:23:58	M1-2Ia	0.50				-4.48		-4.24	-5.13	-5.70
2491	α CMa	06:42:56.7	-16:38:46	A1Vm	-1.46	-1.30j	-1.32j	-1.32j	-1.35k	-1.37s	-1.38s	-1.42t	-1.36t
2560	15 Lyn	06:52:57.2	58:29:27	G5III	4.35		2.37	2.31	2.27	2.24s	2.38s		
2890	α Gem	07:31:24.6	31:59:59	A2Vm	1.58	1.53c		1.51c	1.53c				
2943	α CMi	07:36:41.1	05:21:16	F5IV-V	0.38	-0.44	-0.57	-0.65	-0.66j		-0.66	-0.76t	-0.73t
2990	β Gem	07:42:15.6	28:08:55	K0IIIb	1.14	-0.51c	-0.99j	-1.11c	-1.15j	-1.19s	-1.09s	-1.24t	-1.21t
3188	ζ Mon	08:06:04.9	-02:50:13	G2 Ib	4.34		2.39	2.32	2.22j	2.20s	2.30s		
3748	α Hya	09:25:07.7	-08:26:26	K3III	1.98							-1.44r	-1.49r
3888	υ UMa	09:47:27.1	59:16:30	F2IV	3.80	3.14e	3.02e	2.99e	2.97	2.93s	2.93s		
3903	υ^1 Hya	09:49:04.3	-14:36:40	G7III	4.12	2.61j	2.12j	2.04j			2.01k		
3982	α Leo	10:05:42.6	12:12:44	B7V	1.35	1.53c		1.60c	1.62c				
4069	μ UMa	10:19:21.5	41:45:06	M0III	3.05	0.12j	-0.68	-0.82	-0.94	-1.00v	-0.64v	-1.03t	-1.08t
4295	β UMa	10:58:50.3	56:39:03	A1V	2.37							2.33t	2.23t
4534	β Leo	11:46:29.6	14:51:02	A3V	2.14							1.84t	1.83t
4550	CF UMa	11:50:06.2	38:04:39	G8Vp	6.45	4.87e	4.46e	4.39e	4.34e	4.35s	4.41s		
4554	γ UMa	11:51:12.9	53:58:22	A0Ve	2.44							2.32t	2.47t
4689	η Vir	12:17:20.8	-00:23:21	A2IV	3.89	3.79e	3.78e	3.77e	3.76e	3.78s	3.77s		
4828	ρ Vir	12:39:21.2	10:30:39	A0V	4.88		4.69j	4.68j		4.69s	4.68s		
4935		13:01:05.1	-20:18:55	F7V	5.58	4.60j	4.28j	4.26j					

F.4. Table 7. IRTF standards

HR#	name	R.A. 1950	Dec.	Sp T	V	J	H	K	L	L'	M	N	Q
4983	β Com	13:09:32.5	28:07:52	G0V	4.26	3.19	2.92	2.88	2.87	2.87s	2.87s		
5054	ζ UMa	13:21:55.4	55:11:09	A1Vp	2.27							2.24t	2.28t
5107	ζ Vir	13:32:08.6	-00:20:28	A3V	3.37		3.08j	3.06j		3.06s	3.11s		
5191	η UMa	13:45:34.3	49:33:44	B3V	1.86		2.32j	2.37j	2.35j				
5340	α Boo	14:13:22.8	19:26:31	K1III	-0.04	-2.21	-2.90	-2.99	-3.10	-3.08s	-2.92s	-3.17t	-3.13t
5447	σ Boo	14:32:30.2	29:57:41	F2V	4.46	3.68e	3.51e	3.49e	3.44e	3.48s	3.46s		
5685	β Lib	15:14:18.7	-09:11:59	B8V	2.61	2.76j	2.79j	2.80j	2.84k	2.85s	2.87s		
5793	α CrB	15:32:34.1	26:52:54	A0V	2.23							2.19t	2.04t
6084	σ Sco	16:18:08.7	-25:28:29	B2III	2.89	2.49k	2.44k	2.42k	2.42k	2.41s	2.41s		
6092	τ Her	16:18:14.1	46:25:53	B5IV	3.89	4.20e	4.27e	4.30e		4.35s	4.37s		
6136		16:26:00.9	00:46:32	K4IIIp	5.39	2.83e	2.16e	2.02e	1.87e				
6134	α Sco	16:26:20.2	-26:19:22	M1.5Ib	0.96				-4.17j		-3.84	-4.54	-4.70
6147	φ Oph	16:28:16.4	-16:30:19	G8IIIa	4.28	2.76	2.32	2.26	2.18j	2.20s	2.27s		
6406	α Her	17:12:22.0	14:26:45	M5Ib	3.48	-2.29	-3.14	-3.37	-3.71	-3.70s	-3.45s	-3.94t	-4.17t
6603	β Oph	17:41:00.0	04:35:12	K2III	2.77	0.90c	0.40c	0.21c	0.15c				
6705	γ Dra	17:55:26.5	51:29:37	K5III	2.23							-1.50r	-1.56r
6707	ν Her	17:56:35.3	30:11:32	F2II	4.41	3.45e	3.25e	3.21e	3.15	3.17s	3.16s		
7001	α Lyr	18:35:14.7	38:44:09	A0Va	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7120	ν^2 Sgr	18:52:05.8	-22:44:08	K3II	4.99	2.73j	2.10j	2.02j	1.91j		2.11k		
7525	γ Aql	19:43:52.9	10:29:24	K3II	2.72	0.32k	-0.38k	-0.55k			-0.62k	-0.78t	-0.82t
7615	η Cyg	19:54:25.7	34:56:58	K0III	3.89	2.16e	1.70e	1.63e	1.52e	1.54s	1.65s		
7924	α Cyg	20:39:43.5	45:06:03	A2Iae	1.25	0.98c	0.93c	0.87c	0.80c		0.80c		
7949	ε Cyg	20:44:11.2	33:46:55	K0III	2.46	0.75c	0.27c	0.09c	0.02c				
8028	ν Cyg	20:55:18.4	40:58:26	A1Vn	3.94					3.79s	3.76s		
8143	σ Cyg	21:15:26.9	39:11:03	B9Iab	4.23	3.87e	3.83e	3.80e	3.71e	3.72s	3.68s		
8167	ι Cap	21:19:27.9	-17:02:55	G8III	4.28	2.84k	2.38k	2.24j		2.18s	2.25s		
8316	μ Cep	21:41:58.5	58:33:00	M2Iae	4.08				-2.24j	-2.27v	-2.15v	-3.84t	-4.59t
8541	4 Lac	22:22:29.0	49:13:20	B9Iab	4.57	4.30e	4.27e	4.25e	4.23e	4.21s	4.22s		
8551	35 Peg	22:25:19.6	04:26:39	K0III	4.79	2.91e	2.37e	2.30e	2.22e	2.21s	2.31s		
8728	α PsA	22:54:53.5	-29:53:16	A3V	1.16	1.04k	1.03k	1.00k	1.00k	0.96s	0.94s		
8775	β Peg	23:01:20.8	27:48:40	M2.5II	2.42	-1.19	-2.05	-2.22	-2.39	-2.38s	-2.19s	-2.64t	-2.61t
8781	α Peg	23:02:16.1	14:56:09	B9V	2.49	2.50c	2.51c	2.52c	2.53c		2.53c		
8808		23:05:44.7	63:21:46	B3V	6.26					6.41s	6.44s		
8905	υ Peg	23:22:52.8	23:07:43	F8III	4.40		3.07j	3.00j		2.97s	2.97s		

Table 7. continued

F.5. Table 8. α Lyrae flux density

	λ	ν	f_λ W m^{-2} μm^{-1}	f_ν W m^{-2} Hz^{-1}
V	0.5556	5.4×10^{14}	3.44×10^{-8}	3.54×10^{-23}
J	1.25	2.4×10^{14}	3.07×10^{-9}	1.60×10^{-23}
H	1.65	1.8×10^{14}	1.12×10^{-9}	1.02×10^{-23}
K	2.20	1.4×10^{14}	4.07×10^{-10}	6.57×10^{-24}
L	3.45	8.7×10^{13}	7.30×10^{-11}	2.90×10^{-24}
L'	3.80	7.9×10^{13}	5.24×10^{-11}	2.52×10^{-24}
M	4.80	6.3×10^{13}	2.12×10^{-11}	1.63×10^{-24}
	7.8	3.8×10^{13}	3.22×10^{-12}	6.53×10^{-25}
	8.7	3.5×10^{13}	2.10×10^{-12}	5.30×10^{-25}
	9.8	3.1×10^{13}	1.32×10^{-12}	4.23×10^{-25}
N	10.1	3.0×10^{13}	1.17×10^{-12}	3.98×10^{-25}
	10.3	2.9×10^{13}	1.09×10^{-12}	3.85×10^{-25}
	11.6	2.6×10^{13}	6.81×10^{-13}	3.05×10^{-25}
	12.5	2.4×10^{13}	5.07×10^{-13}	2.64×10^{-25}
Q	20.0	1.5×10^{13}	7.80×10^{-14}	1.04×10^{-25}

Notes:

(1) The estimated uncertainties are 3% at JHKLL', 6% at M, 3% at N, and 5% at Q.

(2) The flux density for 0.5556 μm is from Hayes (1985).

(3) The "reference wavelengths" (i.e., monochromatic wavelengths) of the IRTF N and Q filters are 10.1 and 20.0 μm for standard stars (see section C).

(4) f_λ is given in MKS units for consistency. This unit is widely used outside of the US and it is a better unit for posterity.

APPENDIX G: COUDÉ SPECTROSCOPY WITH LIRC-II

The LIRC-II dewar, including its internal optics (refer to Figure 1.), but without the optical interface, has been used experimentally with the coudé spectrograph's 160-inch camera. The spectrograph may be used with either the 3-meter or the Coudé Auxilliary Telescope (CAT). As of this writing, the LIRC-II/coudé combination is not considered a user instrument. Persons contemplating a proposal to use this instrument should first contact Gibor Basri (UCB), Kirk Gilmore (UCSC), or Tony Misch (Mt. Hamilton).

The following numbers, courtesy of Gibor Basri, represent early tests with the system. More--and more precise--evaluations are expected to follow.

LIRC-II lens	λ_C (microns)	Coverage (microns)	Dispersion (Angstroms pixel^{-1})	Dispersion (km sec^{-1} pixel^{-1})
narrow	1.1260	32	0.125	3.33
narrow	1.2814	32	0.126	2.95
narrow	1.5655	28	0.110	2.11
narrow	1.5883	28	0.108	2.04
intermediate	1.1255	64	0.25	6.66
intermediate	1.5883	54	0.216	4.08
wide	1.5833	83	0.324	6.12

Table 9. Coudé configuration: Wavelength coverage and dispersion

λ_C (microns)	Count rate (DN pixel^{-1} sec^{-1})	Filter	Transmission	Magnitude (IRTF manual)
1.5648	120	H	60%	H = -2.9
1.5648	110	Fe I	??	H = -2.9
1.322	130	J	50%	J = -2.21

Table 10. Coudé configuration: Approximate throughput

APPENDIX H: TELESCOPE LIMITS

B.1. 3-Meter

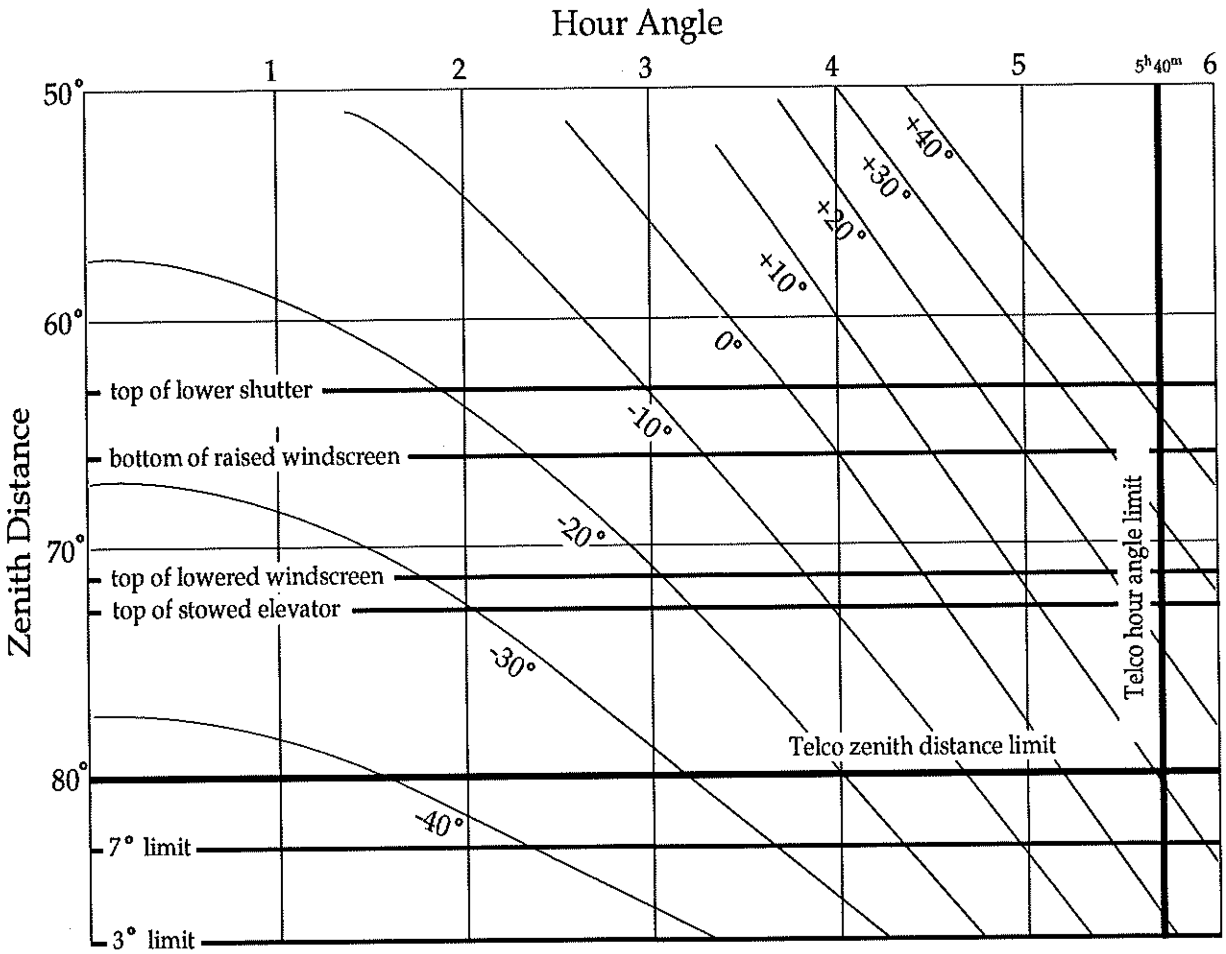


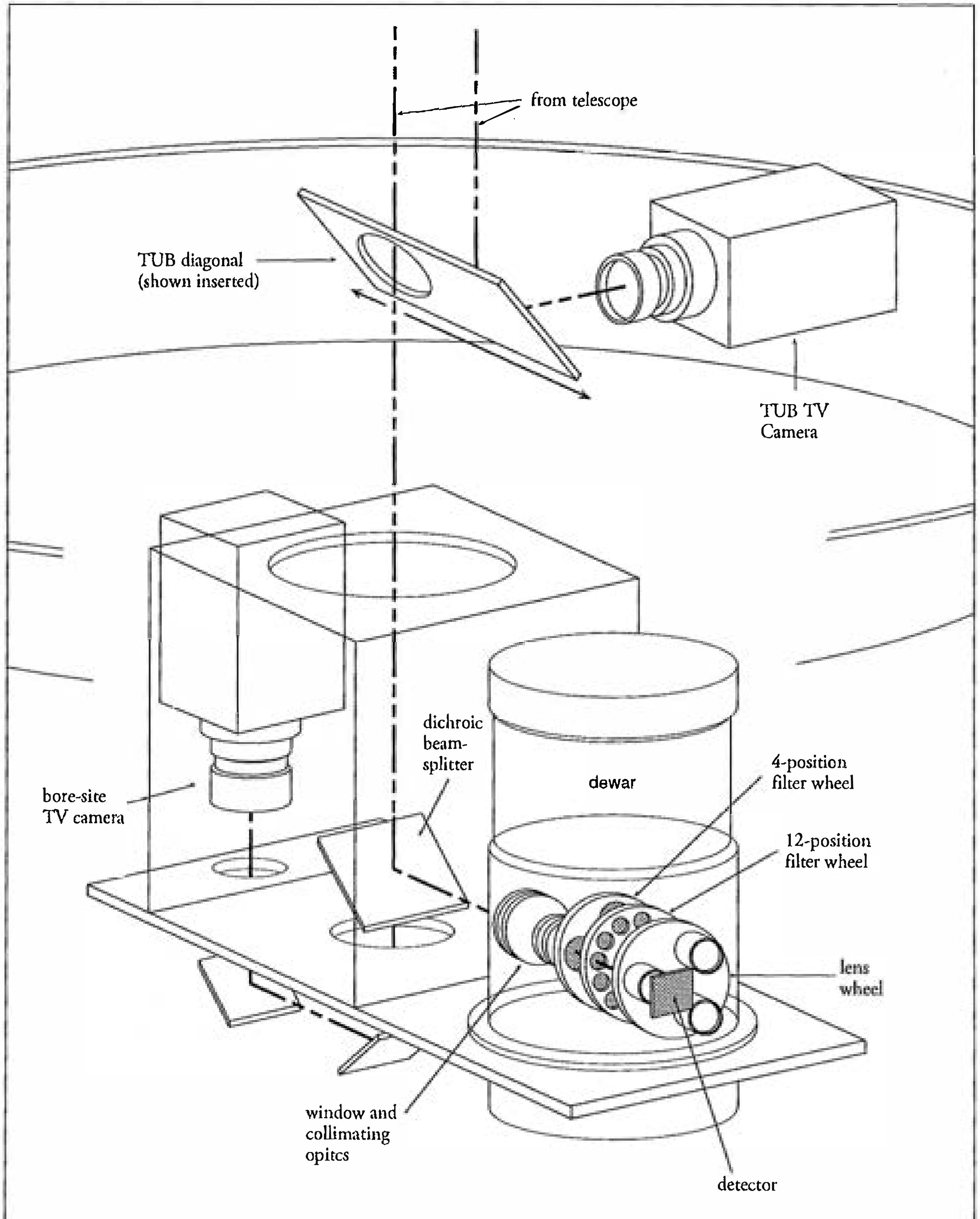
Figure 25. 3-meter pointing limits The hour angle limit of 5-hrs. 40-mins. may be exceeded with advance permission from the Director. Note that observing below the top of the lower shutter will require several minutes for the telescope operator to make the necessary adjustments.

<u>Humidity limit</u>	Sounded by the automatic dew sensor, at temperatures above freezing. 95% at temperatures below freezing, or at the telescope operator's discretion at any temperature.
<u>Wind limits</u>	30-mph average or gusting to 35-mph when observing into the wind. 35- or 40-mph cross-wind. 40- or 45-mph downwind.

B.2. 1-Meter

Pointing limits	±5-hrs. 30-mins. hour angle +58.5° and -19.5° declination.
Humidity limit	Sounded by the automatic dew sensor, at temperatures above freezing. 95% at temperatures below freezing, or whenever fog is visible.
Wind limit	50-mph.

INDEX



The Lick Infrared Camera (LIRC-II)