UNIVERSITY OF CALIFORNIA
LICK OBSERVATORY TECHNICAL REPORTS
No. 58

THE HAMILTON SPECTROGRAPH USER'S MANUAL

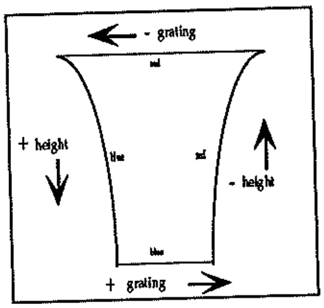
Anthony Misch

Santa Cruz, California
January, 1991

Useful Numbers

Translating the Spectrum

To move the spectrum with respect to the chip, use the following ratios to determine the numbers entered for "grating" and "height" at the Hamilton terminal:



<u>Grating 1.15 units pixel^{-1}</u>

Larger grating settings will move the spectrum to the right, revealing bluer wavelengths.

<u>Height 8.97 units pixel^{-1}</u>

Larger height settings will move the spectrum down, revealing redder orders.

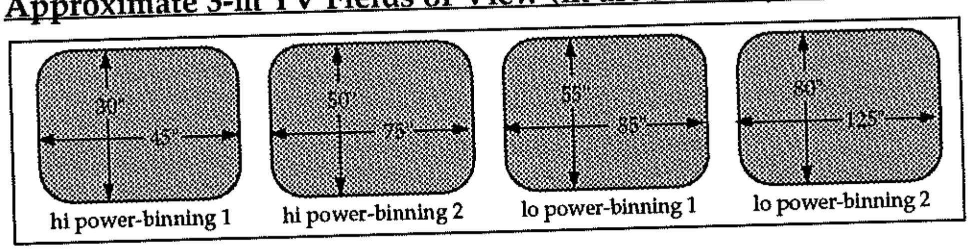
Plate Scale

3-meter	1.89 arc seconds mm^{-1}
CAT	9.45 arc seconds mm^{-1}

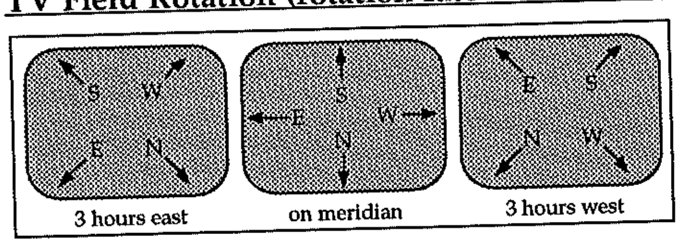
Slit Projection

slit on detector	330μ pixel^{-1} (15μ pixel)
slit on sky, 3-meter	530μ arc second^{-1}
slit on sky, CAT	106μ arc second^{-1}

Approximate 3-m TV Fields of View (in arc seconds; CAT users x 5)



TV Field Rotation (rotation rate = 15°/ hour of HA)



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PREFACE

In 1986 the power of coudé spectroscopy at the Shane 3-meter telescope was greatly enhanced by the addition of the Reverend Laurentine Hamilton High Resolution Echelle Spectrometer. It was conceived and designed by Steven S. Vogt, and made possible through a gift from Clara-Belle Hamilton. This manual is a guide to understanding and operating the instrument.

Ideally, manuals would be exhaustive without being too exhausting, but in reality they are woefully short on plot and rarely read from cover to cover. While the movie rights to the following are not attracting much attention, I do hope that it will be of use to both new and experienced users. One measure of its success will be how quickly it helps turn the former into the latter.

The main body of the text is in five sections. The first two sections are descriptive. Section one describes the spectrograph and its associated systems as a whole, section two details the principal components individually. The third section explains the operation of the Hamilton's several user interfaces. These first three sections may be skipped over and referred back to by those wishing to go directly to the hands-on material. The last two sections present step by step set-up and observing procedures, from arrival to closing down.

Following the body of the text is a checklist, covering much the same ground as the final two sections, but in abbreviated form. Next, "data sheets" give useful numbers for the spectrograph, the 3-meter and Coudé Auxilliary Telescope (CAT), and specifications for each of the detectors. They are followed by blaze and dispersion tables. Various appendices provide additional information. An overlay of the two CCDs used with the Hamilton accompanies the manual for use with the backcover illustration of the spectral format.

The CAT is a 24-inch fixed telescope fed by a siderostat located in a housing on the south side of the dome. It may be used with the Hamilton when the 3-meter is at cassegrain or prime focus. The spectrograph makes no distinction between the 3-meter and the CAT; however, operation of the latter is done without the benefit of a night assistant, and the data-taking operation is run from a separate computer room in the basement, on similar but not identical equipment. First-time CAT observers *must* be checked out on the telescope. Request assistance on your time application.

Most of the manual, though written with the 3-meter in mind, applies equally well when the Hamilton is used with the CAT. However, some differences exist. These are detailed in Appendix A.

The High-Resolution Retrofit uses a portion of the Hamilton optics, in combination with the coudé's 80-inch camera, to provide higher resolution, at the expense of wavelength coverage. It is the subject of a separate manual by Mary Beth Kaiser, to be published as a Lick Observatory Technical Report. It is therefore only briefly discussed here, in Appendix F.

The Hamilton user should be aware of two other sources of Hamilton lore in addition to the various references cited in the text and listed at the end of the manual. The *Hamilton Logbook* is an ongoing, user-written account of settings, suggestions, problems, and so forth. Its usefulness depends on contributions by observers. The *Hamilton Notebook* is a ringbound collection of memoranda, articles, and test information. Both are kept in the readout room.

If you have never used the Hamilton, it is required that you have one of the resident support scientists assist you the first day. Help is also available to returning users who may feel a bit rusty. Please request assistance on your time application.

Finally, a note on obsolescence. It is inevitable that a manual such as this will become dated as changes are made to the instrument and as new ideas emerge. Users are kept up-to-date with notices of important changes. These notices are posted, for a time, in the readout room and the downstairs computer room, and eventually end up in The *Hamilton Notebook.* If you wish to receive the memoranda at your home institution, send your mailing address or campus mail code to

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and I will include you on the distribution list. Corrections and/or suggestions for the manual are welcomed.

T.M. January, 1991

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Section 1

OVERVIEW

This section treats the instrument in a broad, descriptive fashion, beginning with a brief tour of the light path from slit to detector and a short discussion of its optical design and spectral format. Finally, it takes a look at how the Hamilton and its associated control systems are integrated. The "how to" of all the user-adjustable, user-controlled components is discussed in detail in sections 3 through 5.

Light Path

The spectrograph resides in two rooms in the basement of the 3-meter telescope: the slit room and adjoining camera room.

Starlight emerges from the 3-meter's hollow polar axle (or from the CAT portal) into the slit room, where it comes to a focus on the reflective jaws of the spectrograph's entrance slit. Just above the slit lies a remotely controlled, variable decker. The slit-jaws and decker are slightly tilted so that light not passing through to the spectrograph is reflected, off axis, to a flat mirror, and thence to a TV camera for acquisition and guiding.

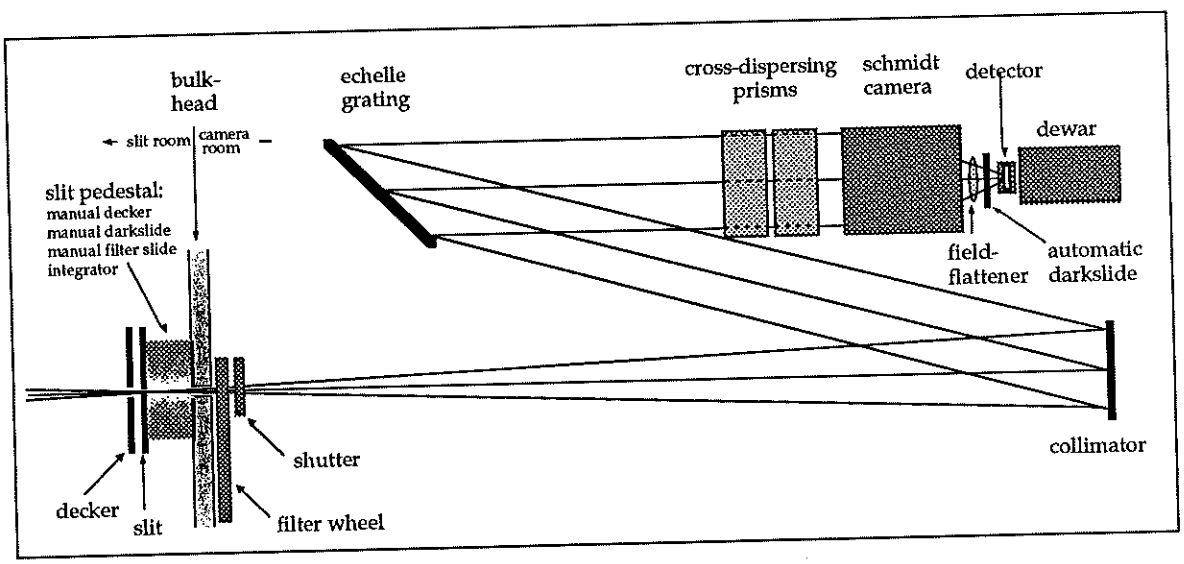

Fig. 1 Hamilton Light Path Not drawn to scale.

Mounted in the pedestal behind the slit are a manually controlled decker, dark slide, and filter slide. These predate the Hamilton and are usually left in their clear and open positions for Hamilton operation. A chopping mirror, also in the slit pedestal, can be used to pick off a small percentage of the light passing through the slit for metering by the coudé integrator.

Emerging from behind the slit pedestal, the now diverging beam enters the camera room, where it immediately encounters a twelve-position, computer-controlled, user-loadable filter wheel.

Attached to the filter wheel is an electronic shutter that automatically times the exposures.

Traversing the camera room, the beam is reflected from the Hamilton's off-axis collimating mirror to the echelle grating. From there the now dispersed light enters two large prisms where it is cross-dispersed before being focused by the Schmidt camera, consisting of a corrector plate, folding flat, spherical mirror, and field-flattening lens. Automated dark slides, for dewars 8 and 13, are located just after the camera and before the dewar. It is opened only during exposures so that at other times the camera room may be entered and lights turned on without disturbing the detector. Its timing and operation are automatic and invisible to the observer. Finally the beam passes through a window in the dewar and comes to a focus on the CCD.

Refer to the Data Sheets following the main body of the text for quantities pertaining to the spectrograph optics and detectors.

Design and Spectral Format[1]

The Hamilton spectrograph is optimized for high dispersion, broad spectral coverage, and good quantum efficiency. Its CCD detector takes advantage of the echelle format by simultaneously recording the multiple, parallel orders it produces.

The Hamilton's echelle grating is ruled for maximum efficiency at high blaze angles. Most of the light energy is concentrated in high (and highly dispersed) spectral orders. The orders, which overlap one another after being formed at the grating, are separated by cross-dispersing prisms. Some overlap occurs in the direction of dispersion, i.e., a feature appearing at one end of an order will also appear at the opposite end of an adjacent order. The "free

1. For a detailed account of the Hamilton's design, see Vogt, S.S. *The Lick Observatory Hamilton Echelle Spectrometer*, P.A.S.P. 99, 1214-1228, November 1987. A copy may be found in the Hamilton Notebook in the readout room.

spectral range" is the wavelength range of a given order not repeated in its adjacent orders. Overlap in the cross-dispersion direction is prevented by limiting the height of the slit with an adjustable decker. Numerical information on the spectral format is given in tables following the main body of the text.

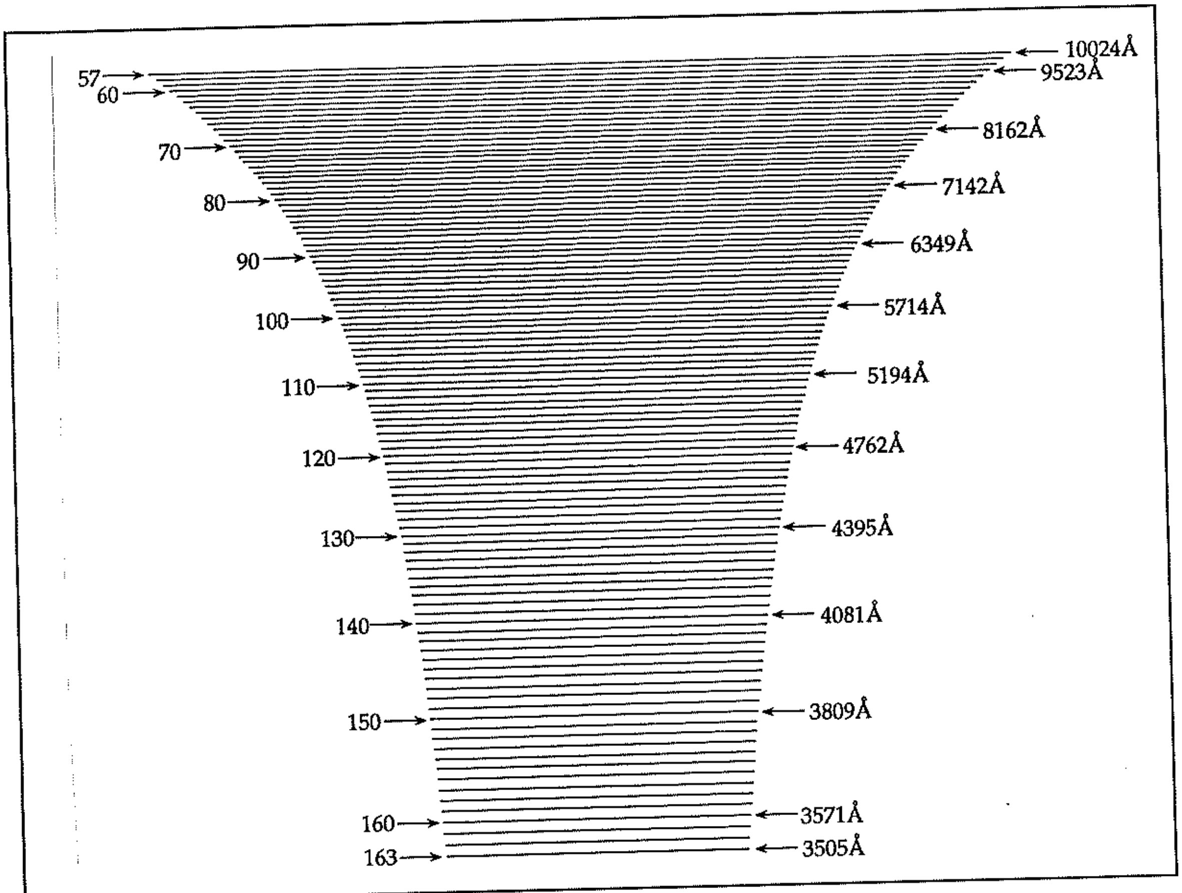

Fig. 2 Hamilton Spectral Format Scales are in mms., order numbers are given along the left side of the format, wavelengths on the right. Red is to the top and right. The horizontal extent of the lines represent the free spectral range. Note that dispersion and order separation increase towards the blue. (Reproduced from Vogt, PASP, November 1987.)

The wavelength range of the instrument is limited to about 1 micron at the red end by CCD performance and atmospheric blocking. CCD efficiency, transmission optics, and atmospheric blocking constrain the blue end at about 3500Å. However, while some photons are detected at the extreme blue end of the instrument's range, efficiency decreases rapidly at those wavelengths, making measurements difficult for all but the brightest, hottest targets.

See Appendix B for throughput curves.

As of this writing, one Ford Aerospace 2048 x 2048 CCD and two Texas Instrument's 800 x 800 CCDs are used with the Hamilton (see the Detecor Data Sheets). The former accomodates nearly the entire echelle format. The latter two are considerably smaller than the format but can be positioned anywhere within it. Changes along the direction of dispersion are accomplished with grating rotation, whereas perpendicular motions are made by moving the detector itself. Both motions are motorized and remotely controlled.

System Integration

Observing with the Hamilton requires the controllers for telescope, spectrograph, and CCD, and the Lick data-taking system, the TV acquisition and guiding system, and the VISTA image-processing programs. The integration of these parts has been engineered with great skill and appears virtually seamless to the user. Nevertheless it is useful to understand something of how it all fits together.

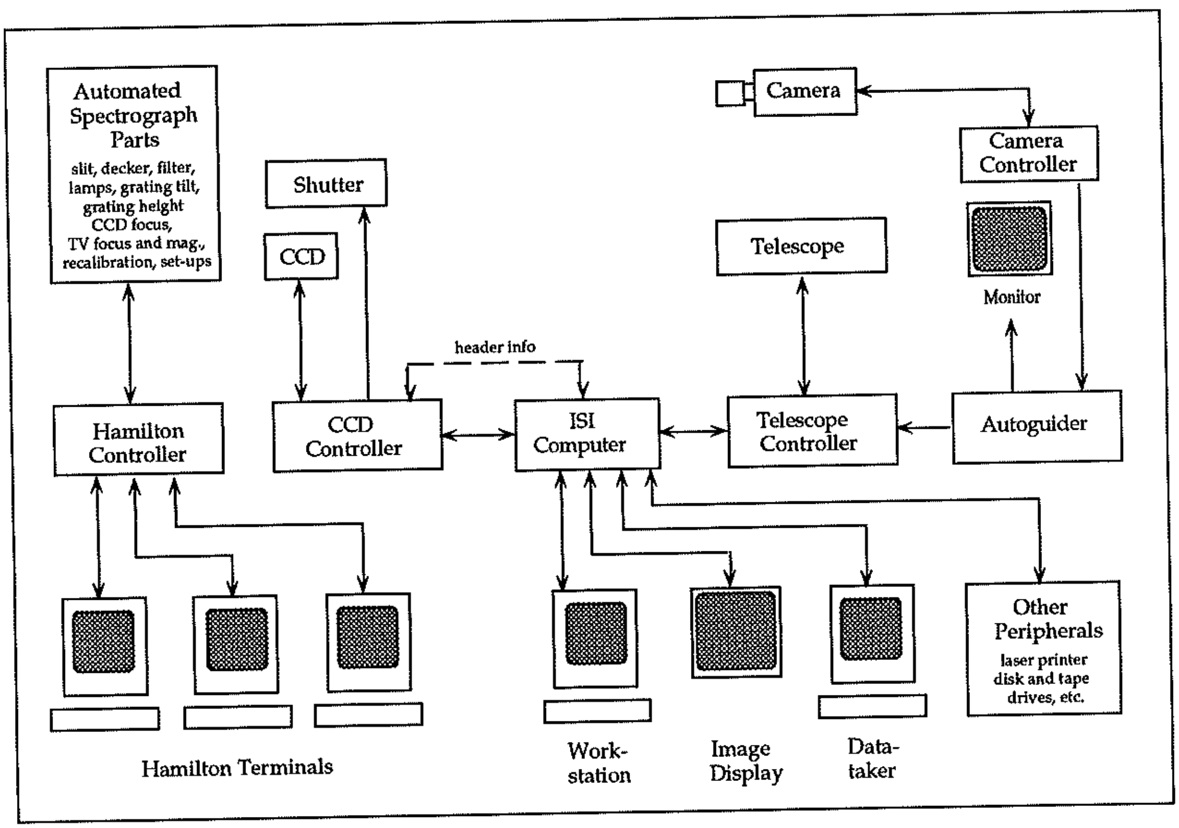

Fig. 3 System Integration

The observer interacts with the spectrograph itself through the Hamilton controller, which governs automated parameters such as slit width, decker size, CCD focus, and grating tilt. The controller is operated from one of several identical terminals located at different sites in the dome.

The user controls the observing process through the data-taking terminal supported by a Unix based computer from Integrated Solutions Incorporated (ISI), located upstairs in the readout room. Setting such parameters as exposure time, data storage, and CCD options is accomplished from this terminal, as is interactive control of the integration.

Actual control of the CCD is mediated by the CCD controller, which handles readout, temperature control, and so on. The user does not interact directly with the CCD controller but is linked to it via the data-taking system.

Data are examined using the VISTA image-processing programs running on the ISI's workstation in conjunction with a high-resolution image display. The ISI also supports a laser printer, storage devices, and other peripherals.

In addition to these systems, which deal more or less directly with the Hamilton, the TV acquisition and guiding systems and the telescope controller, or Telco, play parts in the observing process. The latter is not under the observer's control but is mentioned here because one of its peripheral functions is to provide information about the telescope's position for the autoguider and for the "header" attached to each observation.

Section 2

COMPONENT DESCRIPTIONS

This section contains individual descriptions of all the parts of the Hamilton and its associated systems that the observer is likely to encounter. The "how to" of all the user-adjustable, user-controlled components is discussed in detail in sections 3 through 5.

Slit Assembly

The spectrograph slit (located, of course, in the slit room) is surrounded by a confusing array of equipment, some of which is germane to the Hamilton and some of which, though not used, can get in the way and cause problems if not understood. Much of the Hamilton-related slit room equipment can be operated remotely, but a knowledge of its physical configuration is desirable.

The polished-steel slit-jaws move unilaterally, the west side being fixed. (This is important to remember, since moving the slit will thus change the positions of line centers in the final image.) Just above the slit rests a movable decker that can be positioned to limit the slit's vertical extent. Both slit and decker are remotely operated through the Hamilton controller.

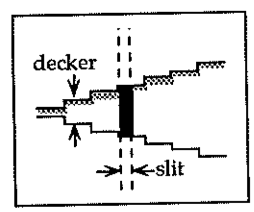

Fig. 4 Decker and Underlying Slit

The protruding pedestal on which the slit assembly is mounted contains three slides that, while not generally used with the Hamilton, can interfere with the light path if left in the wrong positions. The first is a dark slide that should be left open, since Hamilton exposures are electronically timed with a shutter in the camera room. It is slid in and out of the light path along two shafts connected by a plastic handle, located on the west side of the slit pedestal. The light path is clear when the handle is pulled all the way out. It may be locked in its open position.

The second is a manually operated decker, moved by means of a knob near the bottom of the slit. If one looks closely one can see a portion of its vernier scale peeking out from beneath the Hamilton's remotely controlled decker assembly. Most of the scale is, however, obscured and cannot be read with the assembly in place. The manual decker should be set at 45 for proper

Hamilton operation. Vignetting can occur if it has been left at either a higher or lower setting.

While I do not deem it necessary to check the manual decker's position as a matter of course (the Hamilton decker assembly must be removed to do so), it should be considered as an unlikely but possible cause in the event of unexplained light loss.

The third slide, located just below the decker, holds filters. Most filters can be installed in the more accessible, remotely controlled filter wheel (see below), so the slide is generally kept in its clear position. It is moved with a knurled-handled shaft, also located on the west side of the slit pedestal, just below the dark slide handle. It is clear when pushed all the way in.

An image rotator (or, more accurately, an image "derotator," since it compensates the natural rotation of the coudé field) is also available but its usefulness in the standard Hamilton mode is limited. Spatial resolution of extended sources is constrained by the need to separate orders to about 4 arc seconds, depending on one's requirements.

There may, however, be times when it is desirable to preserve spatial resolution along the slit.[2] In such cases, the image rotator will be necessary if the integration is long. The coudé field rotates through 15 degrees per hour.

The image rotator robs some light, depending on wavelength. Rotator throughput is about 90% around 9000Å, dipping steadily to a low of about 75% near 6000Å, climbing back to nearly 80% by 5000Å, and apparently leveling off. I have not measured it blueward of 4000Å.

On the rare occasion requiring offset guiding, the image rotator is a must. See "Offset Guiding" in Appendix C.

Filters

While order separating filters are not needed with the Hamilton, broad-band and neutral-density filters are often used for calibrations and with the acquisition/guiding TV (see the Calibrations section and Appendix E).

Four locations, including the TV, are provided along the light paths for the insertion of filters. Three of these accept the standard Lick filter holder. Standard holders accept a 50 x 50-mm filter(s) up to about 8 mm thick. Standard holders are also available for 38-mm diameter filters.

---

2. When spatial resolution is an important objective, an observer might consider a deckerless observation. To do so, a narrow-band interference filter is used to eliminate all but the order of greatest interest. The price is, of course, the loss of most of the wavelength coverage. Deckerless observations, without the restriction of a narrow-band filter, can be made with sources that show narrow emission lines and little or no continuum.

An automated filter wheel, operated from a Hamilton terminal, is installed just behind the slit bulkhead on the camera-room side. It provides slots for 11 standard Lick filter holders, plus a clear a position, and is the most versatile (and the only remotely controlled) of the filter locations. If you add or remove a filter from the wheel, it is imperative that you record the change on the Hamilton terminal, as the list of filter wheel contents is only as reliable as the people who use it. See the Installing Filters section.

In the slit room, attached to the post to the left of the pedestal, is a moveable arm holding a mount that accepts a single standard Lick filter holder. The arm can be swung into the light path about 6 inches above the slit.

When using this filter holder, it is a good idea to check its alignment when first swung into the beam. This can easily be done by turning on the polar quartz lamp (use the "lamp" option on the slit room Hamilton terminal) and checking that the shadow cast by the filter holder surrounds the slit symmetrically. If it does not, adjust the articulated arm.

A third filter position is located just behind the slit in the pedestal. It does not accept standard filter holders and is rarely used with the Hamilton, but it can provide a place for an odd-sized filter that cannot be otherwise accomodated. This position may be of particular use for mounting an undersized filter, since it is near the slit and the diverging beam is relatively small at this point.

Its long steel handle and knurled knob can be moved to several positions for selecting filters or a clear aperture. The contents of the slide are listed on a note, affixed to the bulkhead near the pedestal. These filters are rarely changed, but if you use one of them, it is wise to actually check the contents.

Removing the slide to check or load filters is a bit tricky and time-consuming and is not recommended unless absolutely necessary. In that case, ask a member of the crew for help if you have never attempted it before. If you are not using this filter position, the slide should be left in its clear position (handle all the way out).

The acquisiton/guiding TV usually has a mount for a standard Lick filter holder threaded to its lens. If it's not in place, it is probably not far away. It is a black anodized disk, knurled around its rim, with slot for the filter holder, and male threads that match the female ones on the end of the camera lens.

Empty holders, along with a selection of neutral-density and broad-band glass filters, are kept in two boxes in the slit room. One box contains filter holders, with and without filters in them. Note that some of the holders are labeled and should not have their contents changed. Unmounted filters are kept in labeled envelopes in the other box and must be mounted in empty holders for use. Please be sure that filters are returned to their proper envelopes or correctly labeled to avoid confusion.

Coudé filters are listed in Appendix E. Most of the broad-band filters in the coudé are from the Schott company. A catalogue of their filters, with transmission curves, is kept in the readout room.

Lamps

A variety of light sources are provided for focusing and calibration. In general, only two are required for use with the Hamilton. A hollow cathode thorium-argon line lamp serves for focusing and wavelength reference, and incandescent lamps provide continuum.

The most commonly used line lamp, called "Th-Ar upper" (menu selection 5) on the Hamilton terminal's lamp menu, is located above the slit on the bulkhead, along with a variety of other sources, also listed in the menu. The light is directed to the slit via a 45-degree flat mirror that is remotely controlled from the Hamilton terminal, sliding in front of the slit for line-lamp exposures and retracting when not in use. The slit is thus blocked to other sources of light when any of the line lamps are selected.

Two continuum sources are available; both are used for flat-fielding. The first, misleadingly labeled "dome quartz" on the lamp menu, and more properly known as "polar quartz," is located on a slide on the wall opposite the slit assembly, several feet from the slit, in front of the polar axle hole. Like the line lamps, it is remotely engaged by the Hamilton controller, sliding into the optical path when in use.

The second is a true dome quartz, consisting of a set of two lamps of the same type as the polar quartz, but mounted on the coudé ring at the top of the telescope, pointed upward toward the inside of the dome. They deliver less light to the slit than does the polar quartz, and require that the primary and tertiary mirror covers be open and the polar axle hole uncovered. However, by using the telescope's optics, they may more closely approximate the way a star illuminates the slit.

The latter are not run from the Hamilton terminal but from two pushbuttons, labeled "coudé lamps," on a panel in the rack just below the cassegrain spectrograph controls, to the left of the workstation. TUB power, which must be on to operate the lamps, is switched from a panel, located near the floor underneath the workstation table. They may be used singly or as a pair. If in doubt, ask a technician.

The line and the polar quartz lamps have "time-out" features that turn them off automatically after about a half hour of continuous use. The dome quartz does not.

Use of the lamps is discussed in the Calibrations section.

Acquisition/Guiding TV

The acquisition/guiding TV is mounted above and to the right of the slit. It is a cooled, low light-level, integrating CCD camera capable of detecting stars to about 17th or 18th visual magnitude at the 3-meter coudé. The reflective slit and decker surfaces are slightly tilted so that they can be seen by an off-axis flat mirror that directs the light to the camera. A filter mount that accepts standard Lick filter holders is usually threaded to the front of the lens.

The camera is mounted on an automated slide that permits low or high magnification. At low magnification the camera's full field is approximately 2 minutes of arc, and at high magnification it is about 1.25 minutes, at the 3-meter scale. CAT users have a five times larger field. Magnification and focus are adjusted via the Hamilton controller. See Fig. 12b.

A control panel for adjusting the camera's parameters (gain, integration time, etc.) is located in the readout room. The autoguider, which uses the TV's signal, is also controlled from the readout room. The telescope technicians are expert at operating the autoguider, so it is only touched on here and in a later section (see the Acquisition and Guiding section). Autoguiding is not, as of this writing, available for the CAT.

Coudé Integrator

The coudé integrator provides a means of monitoring the throughput at the slit. A reflective chopper in the slit pedestal diverts a small part (less than 10%) of the light passing through the slit to a photomultiplier. The integrator predates the Hamilton, being originally used as an exposure meter for photographic work. It is, however, sometimes used with the Hamilton. Its set-up and use are well described on pp. 14 and 15 of *Coudé Spectroscopy at Lick Observatory*, by David Soderblom, a copy of which may be found in the readout room and in the *Hamilton Notebook*.

Since that writing, however, the integrator signals and integrator shutter control (formerly only available in the slit room) have been patched to the readout room. Some additional set-up is required, so if you wish to use the integrator, inform a technician well in advance or, better yet, note it on your time application.

Terminals

Much of the Hamilton's operation is performed from three computer terminals in the readout room. The Hamilton terminal addresses the spectrograph itself through its own microprocessor; the data-taking terminal and workstation connect to the ISI computer and govern data-taking and analysis.

The CAT has its own, identical Hamilton terminal, but in place of the ISI is a Digital Equipment LSI 11/73 (soon to be replaced with a Sun Microsystems Sparkstation). Its software and peripherals differ slightly from those used with the 3-meter. These differences are detailed in Appendix A.

The **Hamilton terminal** allows the remote manipulation of virtually all the spectrograph's user-adjustable parts, and allows those parameters to be stored and recalled. Spectrograph configuration, filter selection, calibration sources, and some functions of the acquisition/guiding TV are controlled from the Hamilton terminal.

The spectrograph controller is a stand-alone system but does communicate with the data-taking system, providing information about the spectrograph settings for the header recorded with each observation.

The **data-taking terminal** runs a program that mediates the data-taking process. Through it the user sets integration parameters, controls the exposure and readout of the CCD, and directs the storage of data.

The **workstation** is a terminal capable of displaying multiple windows simultaneously. It is used primarily as a vehicle for the Lick image-processing and data-analysis program, VISTA.

The high-resolution **image display** screen, used for the display of CCD images, is mounted in the rack behind the workstation. VISTA allows the user to interact with the image. New images are automatically displayed as they are read off the chip, or stored images can be recalled for display using VISTA.

Using each of the terminals is fully described in the following section, "Interacting with the System."

Section 3

INTERACTING WITH THE SYSTEM

This section describes the operation of the three programs and their associated terminals that allow the observer to operate the spectrograph (Hamilton terminal), control the detector and the flow of data (Data-taking terminal), and handle those data (VISTA).

Hamilton Terminal

The observer interacts with the spectrograph controller via one of three identical Hamilton terminals found at three sites around the dome.

The **basement computer room terminal** is used in conjunction with the CAT. See Appendix A for a discussion of observing with the CAT.

The **slit room terminal** is found just inside the east door to the slit room. It is used mostly for testing but can prove handy to the observer. The slit room terminal is turned off when not in use, and should not be left illuminated while observing.

The **readout room terminal** is used when observing with the 3-meter. It is usually the rightmost of the three terminals on the long table in front of the racks.

The spectrograph control program is always running, so if a Hamilton screen is blank the terminal is probably off or dimmed. The power switch and dimmer knob are on the back of the terminal. If using these still does not produce a promising-looking screen, refresh it by pushing the "escape" key once or twice until a beep is heard, then type "control r." The screen should reappear. (This refresh sequence may also prove useful in the event that the screen becomes confused during normal use.)

The Hamilton controller interface is a menu-driven program. As illustrated in Fig. 5, the main menu options are displayed in the bottom third of the screen. The current status and most recent request for six of these options are displayed in the two rows of information above the menu. The status of a seventh, "TV control," is displayed at the upper left.

Selecting some of these options puts the cursor in the request row under the appropriate heading, where it awaits entry of a new setting from the keyboard. The change is then initiated by a carriage return and reflected in the status row when completed. Other menu selections invoke one or more sub-menus from which to choose.

The interface is usually friendly and mostly self-explanatory. The "escape" key will back you out of most situations. However, on rare and unhappy occasions the Hamilton program becomes so thoroughly traumatized that it is necessary to cycle power to the Hamilton controller. The condition is characterized by a garbled display that cannot be undone with a "control r." Controller power is cycled from the slit room. The controller is located in the rack below the slit room Hamilton terminal. If this becomes necessary, you will be glad that you have carefully written down all your hard-won settings, as they will be lost when the spectrograph recalibrates on powering up.

```
                HAMILTON SPECTROGRAPH CONTROLLER         readout rm.

TV POSITION     LOW POWER

             Grating   Height   Focus    Slit    Decker  Filter    Lamps
Present       494121   502300   49996   000640    s:2.5   none   No Lamps
Desired       494121   502300   49996   000640    s:2.5   none   No Lamps

______________________________ MAIN MENU ______________________________

ENTER OPTION:

          A: Auto Setups          C: CCD Focus        D: Decker
          R: Recalibrate          F: Filter           G: Grating
          C: Terminal Control     H: Height           S: Slit
                                  L: Lamps            V: TV Control

     CTRL/C stops all motions & restores to startup condition
```

Fig. 5 The Hamilton Terminal The main screen of the spectrograph controller, showing current status information above and menu selections below.

There are hardware limits on all the motors, as well as software limits that will refuse unreasonable requests. An explanation of each menu selection follows.

Grating Changes the tilt of the echelle grating.

Tilting the grating results in movement along the direction of dispersion. A move of 1.15 units will translate the spectrum 1 pixel (column-wise). Larger numbers will move the spectrum to the right, revealing shorter wavelengths.

See "Navigating the Format."

Height Changes the vertical position of the detector with respect to the echelle format.

Changing the height results in movement perpendicular to the direction of dispersion. A change of 8.97 units will move the spectrum one pixel (row-wise). Larger numbers will move the spectrum downward, revealing redder orders.

See "Navigating the Format."

CCD Focus Moves the detector along the optical axis, allowing it to pass through the spectrograph's focal plane.

A change of 4 units will move the chip about .001".

Note that focus is selected by typing `C` (for `CCD Focus`), not `F`, the latter having been used for the filter-wheel option.

See "Focusing the Spectrograph."

Slit Adjusts the width of the entrance slit.

The movement is unilateral; the west side is fixed. Units are given in microns; slit widths range from 0 to 2200 microns in one-micron increments.

The coudé plate scale is 1.89 arc seconds mm^{-1}, which translates to a slit projection of 529 microns arc $second^{-1}$ on the sky (CAT scale is 5 times smaller, or 9.45 arc seconds mm^{-1} and 106 microns arc $second^{-1}$).

The slit projects to the detector at 330 microns $pixel^{-1}$.

See "Selecting Slit and Decker."

Decker Adjusts the vertical extent of the entrance slit by moving a stepped mask over it.

The decker is required for most purposes because the stacking of an echelle's spectral orders necessitates limiting the height of each to prevent overlapping.

The first decker sub-menu offers three options: `single`, `dual`, or `none`. The single decker consists of one mask with numerous apertures; the dual decker does not exist; and the last choice, "none," moves the decker completely clear of the slit.

Selecting "single" invokes a second sub-menu offering a choice of apertures. These are measured in arc seconds at the 3-meter telescope scale (CAT users multiply by 5).

See "Selecting Slit and Decker."

<u>**Filter**</u> Rotates the twelve-position user filter wheel.

Selecting this option invokes a sub-menu that shows the current contents of the wheel (assuming changes have been faithfully recorded) and allows a filter to be selected. The advertised contents of the wheel are only as reliable as previous observers. Filters are not frequently changed, it is awkward to actually inspect the wheel, and, for the most part, filters are only used to improve the shapes of flat-field exposures. Nevertheless, *caveat observator* is the rule.

Filters must be changed from inside the camera room.

See "Installing Filters."

<u>**Lamps**</u> Selects one of several calibration sources.

Selecting this option brings up a sub-menu listing the available lamps. For most purposes only two are used with the Hamilton. These are selection eight `dome_quartz` (not to be confused with selection six `quartz`) and selection five `Th-Ar {up}` (not to be confused with selection four `Int_thor`).

The former consists of a bright incandescent lamp and ground glass diffuser that slide into position along the optical axis just below the telescope's polar axle opening. It is used primarily for flat-field illumination. Selecting `dome_quartz` automatically turns on and positions the lamp. Selecting `no lamps` (selection one) turns off the source and clears the light path.

`Th-Ar {up}` is a thorium-argon hollow cathode lamp located above and behind the slit on the slit room bulkhead.[3] Selecting this option turns on the lamp and inserts a diagonal mirror that directs its light to the slit. Selecting another lamp extinguishes the current selection before turning on the new one. `No lamps` withdraws the mirror and extinguishes the source. Hollow cathode lamps have limited lifetimes. Please turn off the lamp when not in use.

Both sources have a time-out feature that turns them off and stows them after about half an hour. This is useful if lamps are accidentally left burning but can also be a mystifying source of sudden light loss.

3. It is important that the lamp be replaced with the same Westinghouse type WL #32809 with a .313-inch cathode. An undersized cathode can cause line profile problems. New lamps must be carefully aligned to evenly fill the Hamilton collimator.

TV Control Permits focusing and changing magnification of the TV guiding/acquisition camera.

When selected, a sub-menu appears for these functions. "Position" moves the camera closer to or farther from the slit, for high and low power views. High power provides a full field of about 75 arc seconds (binning 2), and an unbinned field of about 45 arc seconds (binning 1). Low power sees about 125 arc seconds (binning 2), and about 85 arc seconds (binning 1). The actual fields of view may be slightly less due to the topography of the decker.

All dimensions are for the long (at meridian, East-West) direction on the TV screen. The screen's aspect ratio is about 1.5 to 1. All dimensions are given for the 3-meter plate scale--CAT fields are five times larger.

Changing the magnification from the Hamilton controller is independent of the magnification change that results when different binning levels are selected on the camera controller itself. The former actually moves the camera along a track, the latter is an electronic addition of pixels. Moving the camera requires refocusing.

See Fig. 12b.

Recalibrate Allows all spectrograph motors to be reset to their default positions, refreshing the controller's knowledge of their whereabouts.

The "recalibrate" sub-menu permits resetting any or all motors.

See "Recalibrating."

Auto Set-up Stores and recalls set-ups so that they need not be retyped each time the spectrograph is reconfigured.

This is particularly useful if you make observations at more than one setting, or if you wish to move quickly to calibration configurations.

Selecting "Auto Set-up" invokes a sub-menu with three options: "display/perform," "save present," and "delete." Each of these presents further options that allow you to view and initiate up to 200 settings, save and/or alter the present set-up, or delete existing set-ups.

Terminal Control Provides for baud rate selection for each of the Hamilton controller terminals (9600 default). The observer will probably have no occasion to use this option.

Data-taking Terminal

The **data-taking terminal** is usually found to the left of the Hamilton controller terminal in the readout room. To run the data-taking program, turn the terminal on, respond to the `login:` prompt with `user`, and, when the `ucscloc.user:` prompt appears, type `ham` (CAT users type `hamcat`). On rare occasions, the menu items get jumbled together on the screen. Typing "control a" usually remedies this.

```
Hamilton, dewar #8        TI 3-PHASE   800 R X 800 C     Galileo Galilei
                                                         CTL: Any Terminal
 OBSERVATION COMPLETED              Last image:  /scratch/scr.ccd tape  X
 SHUTTER CLOSED                          Remaining exposure:      0s =     0.
    ACTIVE SELECTION =  1                Elapsed   exposure:      1s =     0.
           ----------------------------------------------
 A.  Selection number:     1

 B.  Integ. time:        1 s =    0.02 m           R. START
 C.  Obs. Number:        1                         S. STOP
 D.  Window:                                       T. ABORT
     Size     (R C)    800   800                   U. PAUSE
     Origin   (R C)      0     0                   V. CHANGE INTEG
 E.  Binning  (R C)      1     1                   W. CHANGE SELECTION
 F.  Obs. type:     Normal slow                    X. COMMENTS
 G.  Recording:     Disk and Tape                  ?. HELP
 H.  Display:       TV          2
 I.  Object: Una Stella Nuova                      Z. SPECIAL
 J.  Selection summary                             +. Cursor display  -. CON
b Integ. time (seconds, 32767 max)= 1              *. Run C-shell
```

Fig. 6 The Data-taking Terminal The screen is divided into three sections. Current status and ID information are in the first two sections Beneath these are two columns of menu selections. In the left column are options for setting observation parameters; on the right are exposure control and other program functions.

The current Hamilton data-taking program is a descendant and close cousin of the original program described in Richard Stover's 1983 manual *CCD Data-taking at Lick Observatory*. Though fundamentally the same, the Hamilton version is briefly described here for ease of reference and to include the relevant updates. Stover's manual, particularly chapters 3 and 4, provides a more detailed description. A copy is in the *Hamilton Notebook* in the readout room. A brief description of each option follows:

A. <u>Selection number</u> 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. <u>Integration time</u> Sets the length of exposure in seconds.
The exposure is controlled with an electronic shutter near the slit. It is repeatable to within a few thousandths of a second. Minimum exposure time is one second.
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.
n.b. The total elapsed time of the exposure in seconds as shown on the data-taking terminal may differ from actual clock time by several percent, depending on the CCD controller in use.

C. <u>Observation number</u> 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"). A preexisting 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. <u>Window</u> Defines the portion of the CCD to be read out.
The window is specified by height (rows), width (columns), and origin. The origin is named from the upper left corner of the window. (For a quick, interactive way to define windows, see selection "+" below.)
Windowing the chip saves tape and, in some cases, readout time. Windowing is particularly useful when observing with the 2048 x 2048 chip, where readout time can be quite long. The amount of time saved depends on the *vertical* size and position of the window.
The CCDs' electronics require that readout begin with row zero, irrespective of the user-defined window. Thus, a window using half the total rows and originating at pixel (0,0) will read out in about half the time of a full chip, but the same window,

originating half way down the chip, will save no time. Limiting the horizontal dimension (columns) does not speed readout.

E. **Binning** Allows on-chip summing of adjacent pixels. The contribution of readout noise is decreased, but at the price of decreased sampling and increased interference from chip defects and cosmic rays; 1,1 is the unbinned setting and is most often used with the Hamilton. However, binning may be appropriate in rare instances, particularly low s/n observations (see Appendix C). Note that the Ford Aerospace 2048 x 2048 chip may not be binned horizontally.

F. **Observation type** Controls the automatic shutter. "Normal" allows the shutter to open and close and is used whenever the CCD is to be illuminated. "Dark" disables the shutter in the closed position. "Slow" reads out the chip at its normal rate. "Fast" nearly doubles the rate at the cost of about 20% increase in readout noise.

"Fast" should only be used for setting up; data-taking is normally done in the "Slow" mode.[4]

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 `/scr/scratch`, but will be overwritten by the next unrecorded observation. The scratch buffer can be saved to tape with the data-taker's "Z-2-D" option, or to a VISTA buffer using VISTA's "rd" command.

"Disk" refers to the logical unit called "data," or, when that unit is full, to the logical unit "vista." "Tape" may refer either to the

---

4. There exists another observation type which allows repeated exposures without the intervention of the observer. Called "steth" (it was developed for Steve Vogt's Hamilton adjunct, the "Stellar Stethoscope"), it appears as a third option under selection "F" only if one has run the "steth" data-taking program, instead of "ham." Choosing the "steth" observation type, with either "fast" or "slow," causes a new exposure to begin as soon as the previous one is read out. This will continue until an exposure is stopped (selection "S") or aborted (selection "T"). "Ham" and "steth" are otherwise the same.

If data are being recorded and the exposure is short, the time necessary to write to tape may cause them to begin backing up. Steth accomodates this, within the limits of available disk space, by creating a buffer containing completed frames not yet recorded. If recording under "steth," select only "tape" under the recording option (selection "G").

1600 bpi, 9-track, reel-to-reel tape drive, or to the Exabyte, 8-mm cassette drive.

More below at "Z-2" and in the Recording Data section.

H. Display Applies a new scaling constant to a raw image displayed on the high-resolution monitor causing the apparent brightness of the image to change (this selection will not act on old images redisplayed through VISTA; see the "L" and "Z" options of the VISTA's "TV" command in *The VISTA Manual*). The actual pixel values of the stored image are not affected.

This option may also be used to invoke a sub-menu from which other parameters of the image display are selected, notably "display window" and "video memory." The first limits the display to a subsection of the window defined in selection "D," the second determines the resolution of the display. The best choices for these parameters will depend on which size CCD you are using; consult the CCD data sheets.

I. Object Allows entry of a maximum 63-character label that will be attached to the image.

The label is independent of the comment lines (selection "X").

J. Selection summary Provides a listing of the contents of all ten preset selections (see option "A").

R. Start Initiates the exposure.

S. Stop Stops the exposure and reads out the chip. The shorter exposure time will be correctly recorded.

T. Abort Stops the exposure and discards the data.

U. Pause Pauses the exposure by stopping the clock and closing the shutter.

When "Pause" is invoked, the option becomes "Resume." Pressing "U" then resumes the observation.

V. Change integration Permits the integration time to be changed during an exposure.

The actual exposure times elapsed and remaining are displayed in the upper right part of the screen during an integration (see selection "B").

W. **Change selection** Permits the preset parameter selection to be changed during an exposure (see selections "A" and "J").

X. **Comments** Allows up to five lines of comments to be added to the current header or to all headers.

?. **Help** Invokes on line help.

Z. **Special** Invokes a five-option sub-menu, of which 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 used in preference to this one.
   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.
4. Tests
   A. Puts the chip in a continuous readout mode which can help clear the chip of residual charge (see Appendix C).

+. **Cursor display** Permits some interactive manipulation of the *last* image sent to the screen by the data-taker.

A cross is drawn on the image display and the trackball is awakened. The value of the current pixel is displayed and row and column plots may be drawn.

In addition to controlling cursor movement, the trackball has buttons for zooming and panning. The cursor may also be moved from the data-taking terminal or workstation keyboard using the "H, J, K," and "L" keys for left, down, up, and right, respectively. Jumps of 4 pixels per keystroke are the default. Typing "S" will slow this to 1 pixel, "F" will restore it to 4.

The plotting option of the "+" command uses its own graphics window on the workstation, independent of the one opened by VISTA's "itv" and "plot" commands.[5]

Drawing plots with "+" requires that the "plot" utility be running. The plot utility customarily shows up as a small window on top of the workstation's "plot" icon. If no graphics window is created when a plot is requested from the data-taking terminal, click on the "plot" icon and try again.

A new CCD window (see selection "D") may be graphically defined by drawing a box with the trackball. Upon returning to the main menu, the coordinates of the box will appear in the "window" line. Subsequent exposures will retain and display only this portion of the chip, until the values on the "window" line are again changed.

*. **Run C-shell** Is intended to place the user temporarily in a UNIX environment. However, a C-shell window may be opened on the workstation without interrupting the data-taking program.

VISTA

VISTA is a collection of programs developed by R Stover, T. Lauer, and D. Terndrup for manipulating and processing the images produced by Lick's CCDs. On the mountain it is generally run from the ISI workstation (or, in the case of the CAT, from the LSI's VT100 terminal). The workstation itself requires a bit of getting used to. An excellent introduction is given in Richard Stover's 1987 *The New Lick Data-taking System*, kept in the *Hamilton Notebook* in the readout room.

The workstation is the leftmost of the three terminals on the observer's table in the readout room. If it is turned off, turning it on will produce a large ISI logo over a `login:` prompt. Respond by typing `vista`. This should bring up a screen with various icons along the left-hand edge and a window labeled "Vista." VISTA news will appear in the window, followed by VISTA's `GO` prompt.

5. This option and VISTA's "itv" command are to some extent redundant, and the choice is largely a matter of taste. The plots produced by "itv" have better scales, and are preferred for most purposes. On the whole I find "itv" more useful for its numerous options and legible plots. However, "+" is very valuable for quickly and interactively defining a readout window.

VISTA is well documented. *The VISTA Manual* by Stover et al is available in hard copy in the readout room and on line, from within VISTA, by typing `help [option]`. *The VISTA Cookbook,* by R. Pogge, R. Goodrich, and S. Veilleux, is a collection of suggested routines and techniques for applying VISTA to the reduction of CCD images, including Hamilton echellograms. A copy is kept in the readout room.

VISTA particulars are thus not described here, save to mention that the command "itv" is indispensable to setting up the Hamilton. "Itv" activates a trackball that allows you to manipulate the image on the high-resolution display, and to examine it interactively by means of zooming, plotting, measuring, and so forth. If you are not already famillìar with "itv," read its description in *The VISTA Manual* before beginning your set-up.

A few of the data-taking program's functions may be run from VISTA. This permits them to be included in VISTA procedures so that some data-taking tasks can be accomplished as "batch" jobs. See VISTA's on-line help for "dtake." Help for writing procedures is also available on line and in *The VISTA Manual.*

VISTA also permits relatively sophisticated reductions, most notably, for Hamilton users, the creation of one-dimensional spectra from an echelle image. See "Examining Images with VISTA."

Making Hard Copies

Many of the processes described in the following pages produce images on the image display screen and/or plots on the workstation. Hard copies of either may be made.

Somewhere on the table, among the terminals, is a little beige box made by Mitsubishi. It produces a small, moderately good copy of whatever is on the image display screen. Use its "print" button. The "copy" button will make a copy of whatever was last printed, regardless of what is on the screen.

Though it is only capable of reproducing the image display screen, the Mitsubishi can print plots if they are sent to that screen using the "tv" option of VISTA's "plot" command (see *The VISTA Manual*).

Alternatively, a higher quality copy of an image can be made with the laser printer using VISTA's "lwimage" command, but it is slow. Making a hard copy in this way will usurp VISTA for about 30 seconds and then keep the laser printer busy for quite some time, depending on the image size (see on-line help for "lwimage").

Anything on the workstation screen, such as plots made with "itv," can be reproduced on the laser printer using the ISI's bit-mapped graphics capability. With the workstation's cursor in the gray area between windows, push the mouse's middle button and select "snapshot" from the pop-up menu. Use the resulting camera symbol and the left-hand button to define the area of the screen you wish to print . Then put the cursor on the "bmprint" icon and push the right-hand button. The "bmprint" window will appear, then collapse a few seconds later. The hard copy should be ready in relatively short order. (This utility knows nothing of the windows on the workstation and simply creates a hard copy of anything within the area you define.) See p. 13 of *The New Lick Data-taking System*, by Richard Stover, for details.

Finally, hard copies of plots can be made on the printer using the "hard" option of VISTA's "plot" command. This produces the most aesthetically satisfying plots in the shortest time, but requires that the original image first be placed in a buffer with the "rd" command. (The plot command, like many other VISTA commands which serve to process an image or spectrum, can only operate on buffers. See *The VISTA Manual.*)

Section 4

SET-UP PROCEDURES

The following step-by-step discussion of setting up the Hamilton and preparing for observations is addressed to the novice user, but assumes that she or he has at least scanned (or is willing to refer back to) the preceding parts of this manual. Experienced users may find this section (and the next) too elementary and will have their own tried-and-true routines, many of which will differ in their particulars from those outlined below. They may, however, wish to use the checklist, immediately following the main body of the text, which covers much the same ground in outline form.

Much of the system's set-up is performed in advance by the dome crew. The instrument, associated electronics, and computers will be configured according to your needs, as described in your time request. Some aspects of set-up are left to the observer. These are described below. Should you feel uncomfortable with any of them, don't hesitate to ask a member of the staff for help.

This section is organized so as to lead the observer from arrival through the various stages of set-up. It is divided into the following parts:

- **arrival**
- **camera room**
  - cooling the chip
  - opening the spectrograph
  - installing filters
- **slit room**
  - recalibration
  - focusing the TV
- **readout room**
  - checking the baseline
  - firing up the spectrograph
  - navigating the format
  - focusing the spectrograph

Arrival

Upon arriving, go first to the readout room. Check the last few entries in the *Hamilton Observer's Logbook*. (If it's not in evidence, try looking in the lower right-hand drawer of the desk to the right of the door.) This collection of notes from previous users can be a valuable source of the most up-to-date information on the instrument (please add your own comments at the end of your run). Also check the readout-room bulletin boards for recent notices.

If you plan to use any filters, this is a good time to check the current contents of the filter wheel. Selecting the "Filter" option on the Hamilton terminal invokes a list of currently installed filters. The filter you need may already be in place.

The Hamilton terminal is the far right of the three terminals arrayed along the observer's tables in front of the equipment racks. To invoke a listing of currently installed filters and their positions, type F from the main menu. Remember, however, that though filters are only rarely changed, the list is only as reliable as the persons who use it. You may check the contents of the wheel directly, following the same procedure as for loading filters.

If you change the contents of the wheel, be sure to record those changes, using the rename option in the filter sub-menu. A list of the filters kept in the coudé as of this writing is given in Appendix E. See "Installing Filters."

Camera Room

The camera room is the most restricted area of the dome for reasons of cleanliness and safety to the equipment. The following assumes that you have been in the camera room at least once with a qualified person who has shown you the lay of the land. If this is not the case, stop now and find such a person.

The Hamilton is highly automated, so that under normal circumstances the observer need only enter the camera room to open and close covers, refill the dewar, and install filters. Turning on the red light above the camera room door (master switch in the anteroom) will warn others not to enter. Try to keep your visits to the camera room to a minimum, and do not include it on the tour when showing friends around the telescope.

Before entering the camera room, put on one of the labcoats hanging near the entrance and clean your shoes with the floor-standing electric shoe brush located nearby (see memo, Appendix D).

<u>Cooling the Chip</u> While on the mountain, it is the duty of the astronomer to keep his or her CCD cooled. This is *very* important and should be performed religiously (or at least with secular devotion). A chip that is allowed to warm up will be severely affected, requiring extensive, time-consuming servicing to be resuscitated. The Hamilton dewars are large and have long hold times. Nevertheless, it is best to err on the side of

caution. Top it off at least twice in a 24-hour period. The Ford 2048 x 2048 chip has a smaller dewar and produces more heat than the TI 800 x 800 chips.

For low-light level work in particular, it is best to avoid visiting the camera room less than an hour or so before observing begins. Try to time your dewar feedings accordingly. Always make filling the dewar one of your first tasks when you arrive on the mountain. You can delegate the duty but not the responsibility.

A heater and feedback loop hold the chip at an optimum temperature, something above that of liquid nitrogen. The optimum temperature for a given CCD is found on the data sheet for that chip. Red LEDs on the CCD controller, kept in the tiled pit beneath the slit room, display the current temperature. A glance on your way to the camera room will tell you if the temperature is correct and help catch failures before any damage is done. If you are not happy with the temperature, notify a technician.

A thermos containing liquid nitrogen is found either in the small anteroom as you enter or on the wooden platform in the camera room, under the dewar itself. Should the thermos be running low, ask a telescope technician to replenish your supply. A funnel is usually lodged above and behind the dewar, along the I-beam. The fill-holes are on the side of the TI dewar and on the top of the Ford dewar, covered with a plastic cap. Use care inserting the funnel. Overflow at the fill-hole indicates that the dewar is full.

The dewar's vacuum is maintained by an ion pump whose power supply is a small gray box with a meter face, found on the wooden platform below the detector. Its pilot light has been disabled for use in the camera room. It is good practice to check that it is operating, particularly following a power failure, since even a momentary one will cause the pump to shut down. To do so, turn the multi-position switch fully left and watch for the meter to register. If the needle does not deflect, the unit is not pumping and needs to be reset. Make sure the toggle switch is on. Hold the reset button in until you hear the click of a relay. Repeat the meter test. If it still won't come on, alert a technician.

<u>Opening the Spectrograph</u> The spectrograph optics, housed in the camera room, must be opened before use (and closed after). Three covers must be manually opened to clear the Hamilton's light path. The collimator cover is hinged along its bottom edge and is simply swung down. The cross-dispersing prisms are protected by a sliding metal cover that must be slid completely out. (Be sure to remove it from the slide and set it aside. If left protruding from the slide in the "out" position it will vignette the beam.) The echelle cover is hinged along its bottom edge and is held by a suitcase-type latch on the top of the grating cell. Needless to say, special caution must be taken with all optics and with gratings most particularly. It is good practice to

make the grating the last thing opened when leaving the camera room and the first thing closed upon entering. All covers should be closed at the end of the night. (It is not necessary to close the covers during brief visits, but special care should always be exercised in the camera room.)

Installing Filters Normal Hamilton observations are done without filters, the cross-dispersers making order separation unnecessary. However, for calibrations--particularly for quartz-lamp-illuminated flat-fields--broad-band and neutral-density filters are often necessary to control the intensity across the Hamilton's broad bandpass. No perfect recipes for flat-fielding have been found, and requirements will vary with wavelength region. A Schott reference book, detailing the characteristics of all Schott filters, may be found in the readout room. Appendix E lists filters kept in the coudé.

A collection of user filters is kept in two wooden boxes in the slit room. Filters must be mounted in standard Lick filter holders for installation in the wheel. Sandwiches of from two to several filters can be mounted in a single holder, but should be slightly air-spaced. Small pieces of bond paper or thin stickers at the corners serve well. When combining filters, special attention should be paid to ensure that no grit is trapped between surfaces. Alternatively, filters may be combined by using both the filter wheel and the "swing in" filter holder above the slit. The latter is described in the Filters section.

Care should be taken in handling filters and returning them to their proper envelopes or holders. Confusion and ill feeling will result should filters stray or become mislabeled. Uncoated, broad-band filters may be cleaned with alcohol, lens tissue, and care. The first two are provided.

Filters are installed from inside the camera room in a twelve-position, automated filter wheel. The wheel housing is reached from the wooden platform just inside the camera room door. As seen from there, the filter currently in the light path is at the three o'clock position. To inspect this position, the electronic shutter, mounted to the wheel housing at this position, must be manually opened by means of a lever along its outer edge. Remember to close it when you're through.

A hinged door on the wheel housing, held closed by a sliding latch along its upper edge, provides access to the wheel at the six o'clock position. To move the wheel by hand, rotate the knurled knob protruding from the rear of the stepper motor on the upper left-hand corner of the wheel housing. Position one will not accept a filter and can thus be relied upon to be clear. Filter holders are simply slid in and out of the numbered slots.

Remember that the filter wheel must be recalibrated from a Hamilton terminal after being turned by hand, and that changes must be recorded.

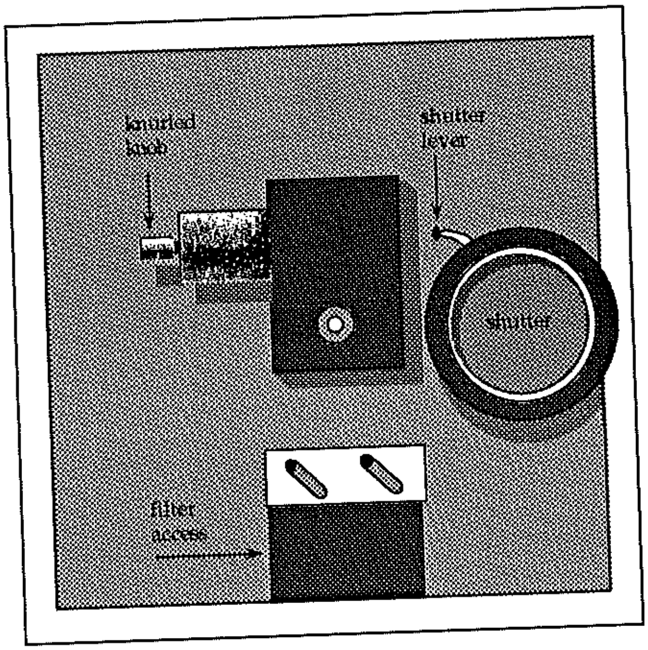

Fig. 7 Filter Wheel and Shutter The filter wheel housing is seen here as it appears from inside the camera room. The light path passes through the wheel and shutter at the three o'clock position. Filters are slid into place (or removed) through the door at six o'clock. The wheel is manually moved by turning the knurled knob on the stepper motor.

It is very important that you remember to recalibrate the wheel after manually moving it, and to record any filter changes. Both are accomplished from a Hamilton terminal.

Slit Room

Recalibrating It is good practice to recalibrate the various spectrograph motions at the beginning of your run. This can be accomplished from any Hamilton terminal. If performed from the slit room, you can observe some of the motions initiated by recalibrating. First check to see that the plexiglass slit cover has been removed. Bring the slit room terminal to life (it is in the rack to the left of the slit bulkhead) and, if necessary, type "control R" to refresh the screen. Select "Recalibrate" from the menu. A sub-menu will appear; choose "All." All spectrograph motions will seek their fiducials and recalibrate themselves, to the accompaniment of whirring, hissing, grinding, and buzzing. When finished, the terminal will display the default settings for all motions. This can be accomplished equally well, but without the sound-effects, from the Hamilton terminal in the readout room.

While in the slit room, it is wise to check that the behind-the-slit dark slide and filter slide are in their clear positions (see "Slit Assembly") and that nothing else is obstructing the light path in the neighborhood of the slit. Remove the square, black anodized polar axle cover, overhead on the sloping north wall opposite the slit.

At the other end of the slit room, around the corner from the bulkhead, a wall-mounted box fan can be turned on (exhausting the slit room) as an aid to seeing. Like many seeing-related practices, its usefulness is not entirely clearcut. Try it and see. Likewise, some observers feel that seeing is improved by keeping the slit room's east door open while the main dome fan is running.

Focusing the TV The acquisition/guiding TV must be focused on the slit-jaws. If you wish, you may leave the whole focusing operation to the telescope technician. The following is provided for those 3-meter observers who wish to do it themselves, and for CAT observers, who must.

Two camera positions provide high- and low-power fields. Both postions work; the choice is largely a matter of taste. The somewhat larger field at low power makes for easier acquisition, but the larger slit image at high power may be an aid to guiding. It is easiest to stick with your choice, once made, because the camera's focus and the apparent position of the slit on the monitor will change between high and low powers. Some flexibility in "magnification" can be had without moving the camera, by changing the TV's binning. The binning select switch is on the TV controller in the rack just below the screen. Scales are given on the Telescope Data Sheet following the main body of the text.

When in high power, the camera is slid fully forward (toward the slit) on its rail; in low power it is all the way back. The positions are selected using the "TV" option on the Hamilton menu. This may be done from the slit room Hamilton terminal, located in the rack at the east end of the slit room. Turn it on and type **v** for a menu of TV commands.

Focusing can be done from the slit room or readout room. The former is easiest, particularly if you are alone or if the evening sky is not available for illumination. The slit image can be seen on the monitor on top of the CAT control panel at the west end of the slit room. (Its video input should come from one of the connectors labeled "TV" on the patch panel to the right of the monitor. For the 3-meter, use the one coming from the readout room; for the CAT, use the one from the computer room. If no image appears on the monitor, consult a technician.) Hamilton controller functions can be run from the terminal in the rack at the east end of the slit room.

You should withdraw the decker in order to focus on the slit surface. Select "Decker" on the Hamilton terminal and, from the first sub-menu, select "None."

Carefully rotate the lens by hand to the approximate position for the power you've selected. The positions for high and low powers are marked on lens and barrel. (You may, of course, find that the previous observer has left it right where you want it, but it's nevertheless a good idea to check.)

Illuminating the slit can be tricky because the camera is extremely sensitive to varying light levels (a neutral-density filter on the camera can help). Proper illumination depends rather critically on the angle of incidence as well. However, once properly illuminated, you may focus on the slit itself, or, with a raking light, small scratches on the surfaces of the slit-jaws are revealed, which can be very sharply focused.

Fine focusing may be done manually or from the Hamilton terminal using the "TV" option. Note that the image of the slit appears to shift when the focus direction is reversed. This is due to eccentricity of the lens mount, so fiddling with the camera focus later on may change the apparent position of the slit on the screen.

Alternatively, the final focus may be done from the readout room, provided that the slit can be evenly illuminated at a low level. The evening sky can provide good illumination (a neutral-density filter on the camera may be required), but the dome and mirror covers must be open. Observers may open the telescope's mirror covers after having been checked out by a member of the staff. Only staff are permitted to open the dome.

Turn on the TV screen in the readout room, located several racks to the left of the workstation. Move the decker completely out of the way so that you see the unobstructed slit-jaws. Select the "TV" option on the Hamilton menu and focus (it is still easiest to have moved the lens to the approximate focus position by hand).

Readout Room

In the readout room three terminals are arrayed along the table in front of the racks. From right to left these are, customarily, the Hamilton controller terminal, the data-taking terminal, and the workstation. (Each is described in detail in section 3, "Interacting with the System.") All three are required for set-up and testing.

Checking the Baseline The baseline (not to be confused with the offset) is stored in the unilluminated, right-most column of the CCD. It is used to adjust the zero point of each row as it is read off the chip (see p. 120 in *The VISTA Manual*, or type **`help bl`** from within VISTA). When processing or analysing images, always apply the "bl" procedure first.

Though the baseline will usually have been set by a technician ahead of time, it is good practice to check it, at least the first day of your run. Start the data-taking program on the data-taking terminal (the middle one of the three observer's terminals in the readout room) by typing **`ham`** at the **`ucscloc.user`** prompt. Watch the messages as they scroll by. If certain problems are present or if the configuration is not correct, messages such as "can't talk to Hamilton spectrograph" or "no response from CCD" will appear. If all is in order, various unthreatening, if obscure, messages will scroll by. If the currently selected tape drive is off line when the program is run, it will complain to that effect. Don't worry, it will recognize the drive whenever it is brought on line.

Among the lines of computerese will appear a few of immediate interest to the observer, including a report on the baseline in "fast" and "slow" modes. If the data-taking program is already running when you arrive, you may wish to exit ("control Y") and begin again so that you can note the baseline.

A healthy baseline should be between 500 and 1500 in the mode you will be using for observing (most likely "slow"), and neither baseline should fall below 300. If it does, the program will suspend loading and prompt you to adjust the baseline. If this is the case, or if the baseline was acceptable to the computer but not to you, ask a technician to adjust it.

Alternatively, you can check the baseline after any exposure, as it is stored in the highest numbered (farthest right) column of every image. Use "itv" to examine the levels. A plot of the baseline column should not vary more than a few DN from top to bottom. If you are binning the CCD, the baseline will also be binned.

A baseline program also exists. Type `tvbl` from the data-taking terminal, and the baseline value will be displayed on the image display screen. However, never run the baseline program while the data-taking program is running. "Control C" exits the baseline program.

<u>Firing up the Spectrograph</u> At this point, all should be in readiness to test the system, but first, a note on readout rates. Two options for the speed at which the chip is read out are provided. "Fast" readout delivers the image in about half the time required by "slow," but readout speed is bought at the price of readout noise, and any data that are to be recorded, including calibration frames, should always be made with the readout set to "slow." However, for the many images that are made and discarded during the set-up process, "fast" is perfectly adequate and saves considerable time.

Slow readout of the full, unbinned 800 x 800 chip requires about 60 seconds; the 2048 x 2048 chip needs about 6 minutes. Windowing can also save time.

For the moment, the default settings on the Hamilton terminal will suffice. The data-taking terminal will require some input for the exposure. Set the integration time to 1 second, the window size to the full chip, the binning to "1 x 1," the observation type to "dark fast," the recording to "not recorded," and the display to "0." Push "r" to begin the exposure. Watch the status lines at the upper part of the screen; they will inform you of the progress of the exposure. When the status line declares "observation completed," the CCD image will appear on the display screen. (If it does not, check that the screen is turned on and that option "H," display level, is set to 0.) At this display level, an uncontaminated dark frame should appear as a fairly uniform blue square with some narrow vertical streaks representing bad columns. This first image may be contaminated with stray light from your visit to the camera room. Repeat the exposure if necessary.

To examine the image more quantitatively, turn to the workstation, where VISTA's "GO:" prompt should be awaiting you. Type `itv` (see *The VISTA Manual*). Alternatively, you could use the "+" selection on the data-taking terminal. In either case, a cross will be drawn on the image display screen. Use the trackball to move it around. As you do so, the row and column coordinates of the pixel currently under the cross and the intensity, in digital number (DN[6],) of that pixel, will be displayed at the bottom of the vista window (or near the center of the data-taking terminal). The chip is automatically given an offset of 64 DN. Readout noise will blur the levels plus/minus a few DN. If levels are much higher than this after a 1-second dark, the chip may have been recently overexposed.

Now try an exposure with some light in the system. At the Hamilton terminal, enter some ballpark figures for grating tilt, height, and focus. If you are in the dark regarding these numbers, refer to the observer's log for some reasonable--and reasonably recent--settings. Be sure that the observer whose log entry you are following was using the same dewar as you.

The dewars are taken on and off the spectrograph, and other changes are occasionally made that might affect spectrograph settings. We try to keep observers informed of such changes and to minimize their effects, but if you are using your own settings from a previous run, you may find that they no longer yield exactly the same wavelength coverage or focus. However, relative motions are very constant, so that offsets between settings are repeatable to within a pixel or so.

From the Hamilton terminal, adjust the spectrograph parameters: enter a small slit value (e.g., 100 microns); enter a decker of about 2.5 arc seconds; run the filter wheel to the "blank" position; invoke the "Lamp" menu and select the "dome quartz" (this is selection #8, not to be confused with #6).

In the data-taking program, change the observation type to "normal fast" (this reactivates the spectrograph shutter). Set the exposure time to 1 second

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6. The "digital number" or "DN" measures the intensity of a given pixel. Its correspondence to "counts"--that is, actual electrons in that pixel's well--is determined by a scaling constant, unique to each chip and its associated electronics. See the Detector Data Sheets following the main body of the text.

and start the integration. When the exposure is completed, turn off the quartz lamp.

The new CCD image will probably be a mess of confusing color. That something is there confirms that light is getting from the source lamp, through the instrument, onto the detector. Adjust the display scale by increasing the value of the "Display" option (selection "H") in the data-taking program until you can see parallel orders separated by darker, inter-order spaces (looking like a featureless version of the day sky spectrum illustrated in Fig. 8, below).

When working in the red, even a 1-second exposure through a small slit may be enough to saturate all or part of the chip. In this case the chip may have a strange appearance and orders may not be discernible at any display scale. Saturated pixels will have DNs of about 30,000. If this occurs, no great damage is done. The chip may show some residual charge for a few exposures. Use a filter to cut down the light.

If the new readout has the same quiet, uniform appearance as the previous dark frame, no light is getting to the chip. Consider what the problem might be. Is the lamp on? Is the exposure type "normal"? Are the spectrograph covers open? Is the CAT pick-off mirror, or some other slit room or behind-the-slit fixture, in the way? If you are still unable to get light through the system, call for help.

Navigating the Format (refer to Fig. 2, to the Tables of Orders following the main body of the text, and to the backcover illustration) The 2048 x 2048 detector embraces nearly the entire Hamilton format but will probably need to be moved to an optimum position for your program. The 800 x 800 detector is smaller than the format and must be moved with respect to it in order to select your desired spectral region(s). The following applies to either.

Movement along the direction of dispersion results when the grating is rotated; movement perpendicular to dispersion is accomplished by moving the detector up and down in the focal plane. These motions are initiated by selecting the "grating" and "height" options, respectively, in the Hamilton controller program.

There are two common methods for ascertaining your place in the format. They are not exclusive of each other and can be used together to find your precise location. You must have the chip at least within the echelle format to begin with, the closer to the center, the better. If you don't have settings that you think will get you in the ballpark, consult the *Hamilton Observer's Log* for a reasonable starting point.

1) Day sky The first technique uses the day sky to obtain a solar spectrum from which well-known features can be used as landmarks. Part of the CAT optics are generally used to supply daylight to the instrument. The 3-meter may also be used to provide day sky, but requires that the dome and mirror

covers be opened. Observers may open the telescope's mirror covers after having been checked out by a member of the staff. The dome is usually kept closed until midafternoon.

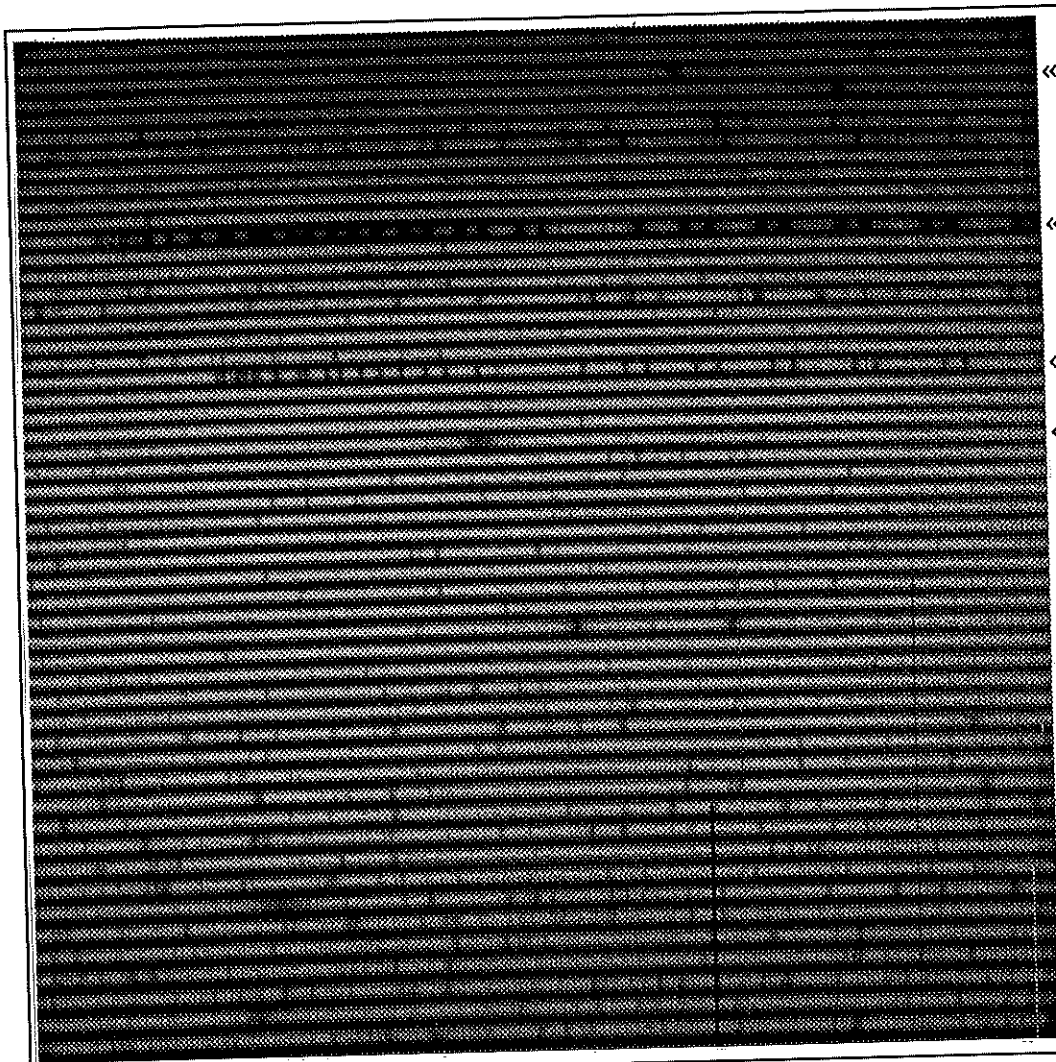


Fig. 8 The Day Sky Spectrum This image covers the region from about 8925Å in order 63 at the top of the chip, to about 4925Å in order 116 at the bottom. It is roughly centered left-right on the format.

Several prominent features are easily seen, including a member of the Ca IR triplet (8662), the atmospheric A and B bands (approx. 7600Å and 6900Å, respectively), Hα (6553Å), the sodium D lines (5890Å and 5896Å), and Mg (5184Å). (TI 800 x 800 CCD)

This method presupposes conditions under which either telescope may be opened (i.e., the same wind and humidity restrictions that would apply to nighttime observations). Given such conditions, the CAT optical path may be opened just far enough to illuminate the slit. It is not necessary to open the

CAT's siderostat housing, as the light reflected from its white roof is more than adequate. Four things must be done from inside the slit room, requiring a quick trip to the basement.

1. Open the shutter in the side of the dome by turning on the master power switch on the right side of the CAT control panel at the west end of the slit room and holding the spring-loaded toggle switch on the upper left side of that panel, labeled "SHUTTER," in the "up" position until its indicator light is green.

2. Open the CAT mirror cover by turning on the power switch on the small red box on the ledge to the right of the slit bulkhead, labeled "CAT MIRROR COVER," and hold the "open" button until the "open" indicator light comes on. (At times, particularly during cold weather, the CAT mirror cover may not wish to open all the way. For the purpose at hand, this is not important. However, be sure that it closes fully when you are through, as indicated by the "closed" light.)

3. Open the CAT portal cover by pulling down on, and turning, the red, T-shaped handle hanging from the ceiling directly above the slit.

4. Swing the CAT pick-off mirror into place. It is the black, rectangular box suspended by an arm from the large post to the left of the slit. Loosen the set screw that holds the collar to the post, swing in the mirror, tighten the screw, and open the mirror's hinged cover.

Reverse the procedure to close up. Be sure to stow the mirror, completely close all covers, and turn off the CAT power when you have finished.

Exposure time will vary depending on time of day, cloud cover, spectral region, and so forth, but with a slit width of several hundred microns exposures of 5-10 seconds should be adequate. Prominent features of the solar and telluric spectra, such as the oxygen bands, H-α, sodium-D, and H-β, are easily seen (see Fig. 8). They can be confirmed by plotting and comparing them to the National Solar Observatory's *Solar Flux Atlas*, a copy of which may be found in the readout room or the library.

2) Thorium-argon If conditions do not permit obtaining a daylight spectrum, if you wish to refine your position even further, or if you simply prefer line lamps to the sun, the many emission lines of the thorium-argon lamp

provide a thorough, if at first bewildering, map. Very accurate positioning will call for this technique in any case, as it provides a thorough sampling of wavelengths, free of doppler shifts.

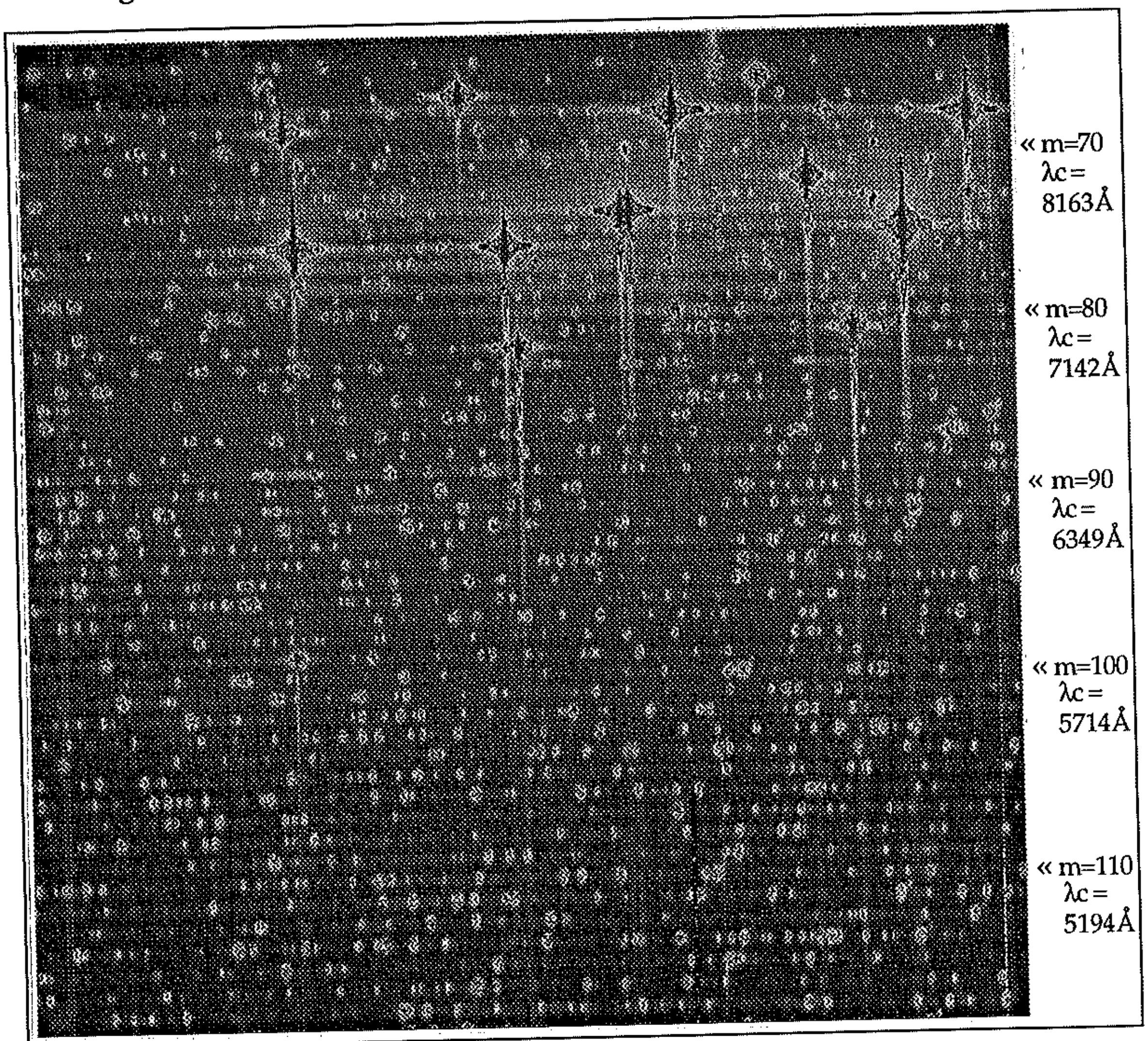


Fig. 9a The Thorium-Argon Spectrum, from about 8925Å (top) to 4925Å (bottom) The bright argon lines, redward of about 6900Å, are evident in the upper third of the image. The central wavelenghths are near the middle of the chip. Some order numbers and their central wavelengths are given at right. The wavelength region corresponds to the day sky spectrum illustrated in Fig. 8.

Turn the lamp on via the Hamilton terminal (use selection five, "Th-Ar {up}," not to be confused with selection four). Try an exposure of 1 to 3 seconds with a 100-micron slit. Please remember to turn the lamp off when you're through with the exposure.

Ascertaining the identity of the forest of lines that will appear is a bit daunting, especially if you are new to the game and vague about the region in the first place. A few observers prefer to first orient themselves using the far sparser Hg lamp (selection seven, "{AC1}Hg"), and then fine tune with Th-Ar. However, once you come to recognize them, there are numerous good landmarks in the Th-Ar spectrum (see Figs. 9A and 9B).

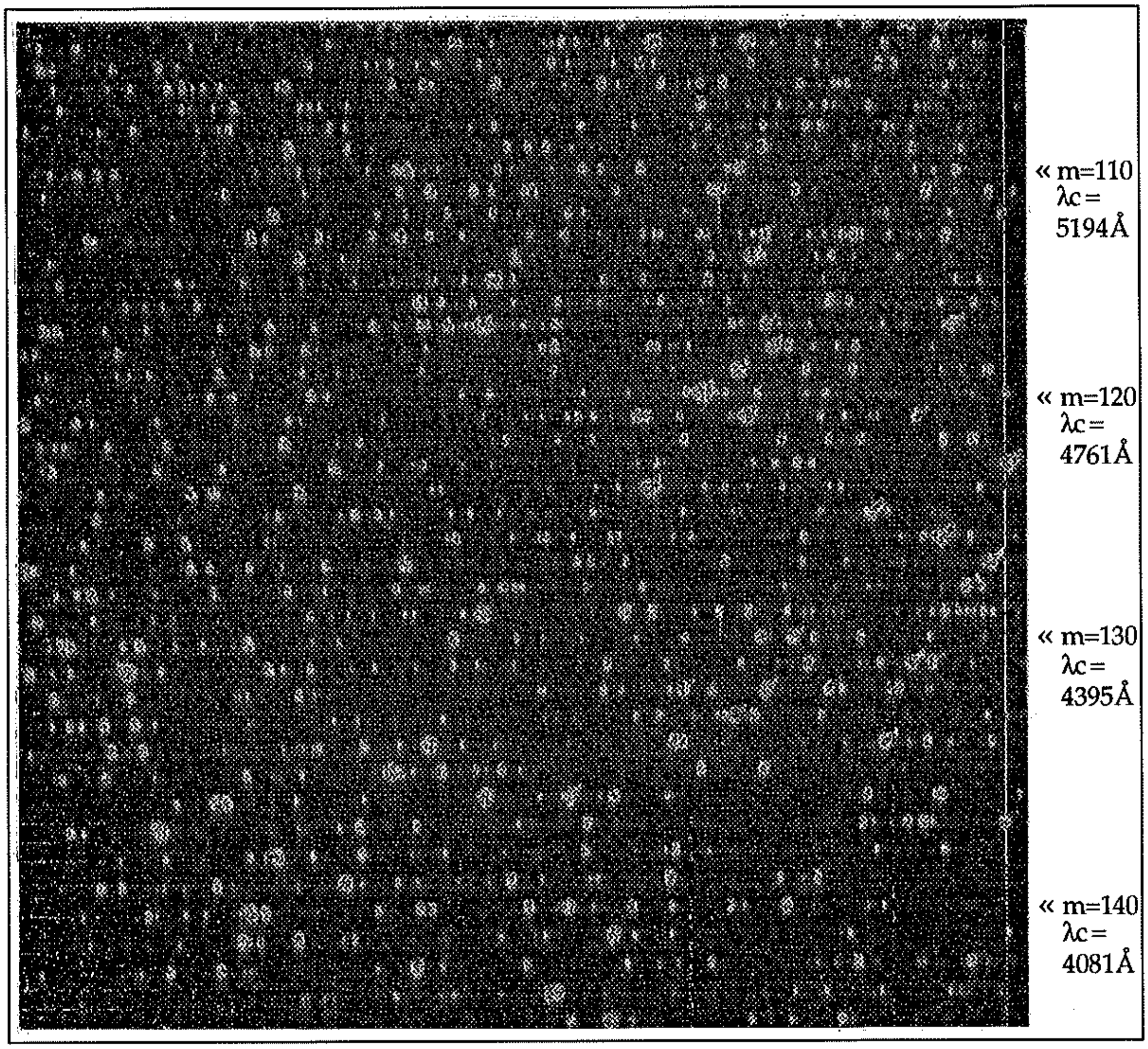


Fig. 9b The Thorium-Argon Spectrum, from about 5490Å (top) to 3990Å (bottom)
This portion of the spectral format lies beneath the region illustrated in Fig. 9a, with an overlap of about 13 orders. Central wavelengths are near middle. Some order numbers and their central wavelengths are given at right. (TI 800 x 800 CCD)

With some practice, you'll make friends with certain lines or groups of lines, and while you probably won't feel friendly towards them, the extremely bright argon lines which lie redward of about 6900Å, beginning in order 82, provide a good signpost at that end of the spectrum. Several thorium atlases are kept in the readout room, including one prepared by Gibor Basri, which, while not providing 100% coverage, is specific to the Hamilton and is arranged according to orders. If, despite these resources, you find yourself thoroughly flummoxed, adrift in a sea of thorium lines, contact one of the support scientists for assistance.

Once you have decided where you are, you will wish to offset to your region of interest, or perhaps nudge the chip a bit to optimize its position and avoid the coincidence of bad columns with interesting spectral features. Positions are reproducible to within about a pixel, from one move to another, so that settings for multiple regions can be determined at this time. Be sure to record your final settings. You may wish to use the Hamilton terminal's "Auto set-up" feature, particularly if you are working with more than one setting.

Fig. 10 illustrates the senses of motion of the spectrum with respect to chip. Motions are initiated by entering larger or smaller values for "grating" and "height" at the Hamilton terminal. Larger grating values move the spectrum to the right, revealing shorter wavelengths in the dispersion direction; larger height values move the spectrum downwards, revealing longer wavelength orders.

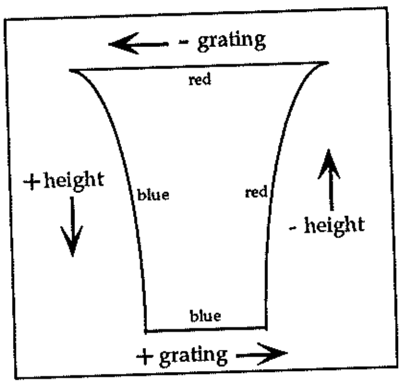


Fig 10 Motion of the Echelle Format Against the Chip See the Useful Numbers sheet for precise information on grating and height movements.

<u>Focusing the Spectrograph</u> Focusing is accomplished by means of a motorized, fine-motion stage that moves the detector through the spectrograph's focal plane. This movement is initiated by selecting the "CCD Focus" option on the Hamilton controller (remember: typing **c**, not **f**, invokes the focus option).

Every effort is made to keep the chips parallel to the focal plane. However, if you are using one of the smaller chips and plan to work in more than one position on the format, it is recommended that you check the focus at each setting.

The 800 x 800 CCDs have slightly undulating surfaces so that there is no one focus setting where all pixels lie precisely in the focal plane. The effect is small, and it (and other systematic errors) can be minimized by averaging focus values taken at several points around your area of interest.

As of this writing, the Ford 2048 x 2048 chip, unlike the smaller TI chips, is not thinned, and is, therefore, quite mechanically flat. Keep in mind, however, that optical aberations may influence the apparent focus, particularly over the large areas within the grasp of the Ford chip.

A series of thorium-argon exposures is made at different focus settings--try increments of 10 units, equivalent to about .0025". Line widths at each setting are measured, the position with the narrowest lines being the best focus. Use a slit width of about 100 microns; this projects to less than one third of a pixel. Depending on your spectral region, expose for about 1-5 seconds, or long enough to have numerous, reasonably strong lines to choose from.

Select one or more likely looking lines and draw quick plots of each (use itv's "box" and "row plot" options as described in *The VISTA Manual*), making sure that the lines are unblended and of suitable intensity (above about 500 DN but well below saturation). Once you have decided on a line or set of lines, stick with it throughout.

Four techniques are widely used for determining the best focus, two are graphical, two numerical. The choice is largely a matter of taste. If you are particularly finicky about your focus, or just plain prudent, you may wish to corroborate your results by using more than one method.

It is possible to confirm your line lamp focus using starlight. Sharp telluric lines, superimposed on the spectrum of a bright, rapidly rotating, early type star, work well. While not common practice, it's not a bad idea, particularly if your focus differs significantly from those used by other observers in the recent past. Check the *Hamilton Logbook* for recent settings.

1) Full width half maximum The full width at half maximum (fwhm) of an unblended line can be fairly accurately estimated from a plot of that line. Plots of single lines or groups of lines can be quickly drawn from "itv" using the "box" and "row plot" options (see *The VISTA Manual*).

A quick estimate of the fwhm can be made by plotting the line and finding its half power point. Count vertical segments and fractions of segments from the half power point on one side of the profile to the same point on the other. Fig. 11 illustrates this technique.

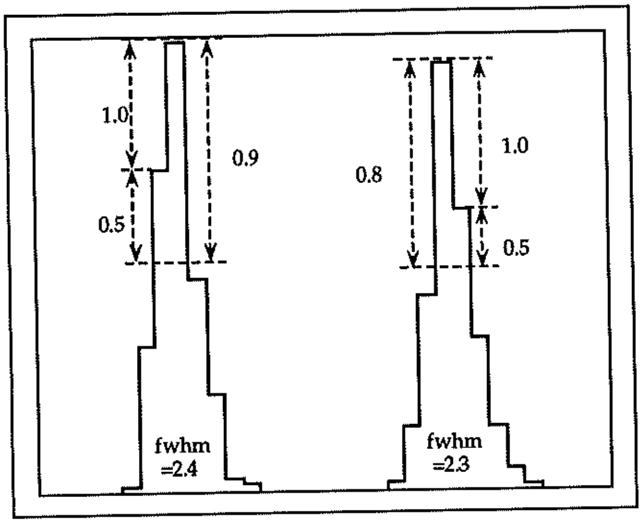


Fig.11 Estimating the Full Width Half Maximum Find the half power point of the line to be measured. Count vertical segments and fractions of vertical segments from the half power point on one side of the line to the half power point on the other side. The total segments counted represent the full width half maximum in pixels.

Width will vary somewhat from line to line, but you can aim for a best focus of about 2.5 pixels.

Note, however, that this approach is slightly flawed in that the apparent fwhm for a given line at a given focus depends to some extent on the coincidence between the line's peak and a pixel boundary. This dependence is strong for a line whose total energy falls within a single pixel, and weakens as broader lines are considered. Nevertheless, many observers use this technique, or use it in conjunction with one of the numerical methods,, because it allows them to see the shape of the line.

If you are only focusing within a limited region, a great deal of time can be saved by windowing the chip to include only those lines being examined.

2) Line separation You can choose a close pair or pairs of lines, plotting them as described for fwhm, and focus by maximizing the depth of the trough between them. Clearly this requires clean pairs of lines, appropriately spaced. It suffers from the same flaws, and enjoys the same advantage, as the fwhm method. Once lines are found, it is fast, easy, and graphic, and, according to its proponents, gives good results.

Two numerical methods are next described. The first, "itv/stellar statisitics," uses a routine developed by Steve Allen of UCSC for examining the shapes of direct images, but widely applied to examining Hamilton arc lines. It returns a "pseudo-sigma," based not on a gaussian fit but on the calculation of a line's moment. It is fast and easy to use, but is sensitive to changing background levels and asymmetries.

The second, "gaussian fit," is a recent addition in the form of a VISTA procedure written by Paul Butler of the University of Maryland. It requires some preparation, but is probably the most accurate technique, and the most automated. It lends itself well to examining a large sample of lines, which, in itself, further enhances its accuracy.

3) Itv/stellar statistics After taking a thorium-argon spectrum, run VISTA's "itv" program. A cross will be generated on the image. With the trackball, move the cross onto a line to be measured. Selecting the "stellar statistics" option by typing * will put the cross on the pixel containing the centroid of that line. A new screen will appear in the VISTA window, including row and column sigmas representing an index of the line's height and width. One then focuses by repeating the operation at different focus positions and minimizing the column sigma for each line being measured.

This and the other numerical approach have the disadvantage of not being graphical. It is good practice, therefore, to make plots of a few lines, as described for the first technique above, after establishing your focus position. The focus is limited by the instrumental profile to a full width at half maximum of about 2.5.

To ensure consistent results, observe the following precautions. The box size and background ("sky") level should be manually chosen. They are entered by typing + and responding to the prompts. "Box size" is selected to exclude any features but the one being examined (try 11 x 11). "Sky level" is the average intensity in the unilluminated neighborhood of the line. It is best to examine the background level and set it accordingly at the beginning of the focusing session. The value of sigma is quite sensitive to background level, so exposures should be of about equal brightness. Most importantly, do not change these quantities in midstream.

Sigma is also sensitive to blends and asymmetries. Choose clean lines and stick with them.

4) Gaussian fit The fitting program requires some initial care and set-up, but once done, it yields very accurate results. Its main drawback, like the previous numerical method, is that it is not graphical. Again, it is wise to plot a few lines at the final focus position to ensure good results.

The program requires the approximate positions of the emission lines to be examined. Positions within five pixels are quite accurate enough as the routine will seek the centroid. Line position information is recorded in a file called LINES.DAT, using UNIX's VI editor.

Take an exposure. Using "itv," find the approximate coordinates of the lines you wish to use, and note them. Open a C-shell window by clicking on the C-shell icon. You will want your line data file in VISTA's procedure directory, so go there by typing `cd /procedure`. Type `ls` to get to view the contents of the directory and make sure that no one else has left their copy of LINES.DAT or TH.DAT, the file created by the program to receive the results. If either is present, remove or rename them. Invoke the editor by typing `vi`

`LINES.DAT` (a vi reference guide is kept in the *Hamilton Notebook*). Enter the position information in the following format (the "-1" indicates end of file):

```
row   col
###   ###
###   ###
###   ###
###   ###
###   ###
-1
```

Save the file to the procedure diectory and return to VISTA.

The program operates on the image called /scratch/scr. The most recent unrecorded image ("none" selected under option "G. Recording" on the data-taking terminal) is always given this filename. Take an exposure at your first trial focus position ("CCD Focus," selection "C" on the Hamilton terminal).

The program is loaded into VISTA by typing **`rp foc`** followed by a carriage return, then invoked by typing **`go`** and another carriage return. The program will read the scratch file into buffer number one, then prompt you to enter the focus position. Once done, the program will return the gaussian sigma for each selected line in that image and the average for all lines in the image. The information is written to the screen and to a file called TH.DAT (in the procedure directory).

Move the chip to the next trial focus position and repeat the exposure. Type **`go`** again and the program will read the new image, prompt for the new focus position, and return the sigmas for the new setting. Repeat for as many focus positions as you wish. The results of each iteration of the procedure will be appended to TH.DAT. Choose the focus setting which yields the smallest average sigma.

When you've finished, please remove your LINES.DAT and TH.DAT files from the procedure directory by returning to the C-shell and typing **`rm LINES.DAT`** and **`rm TH.DAT`** to erase them, or copy them to your personal directory it you wish to save them. If you repeat your set-ups to within a few pixels from one run to the next, you can use the same LINES.DAT file again and again.

The program is in the form of a VISTA procedure, called "foc.pro." It and its subroutine "gfit" reside in the procedure directory, where they may be viewed if you wish to examine the code or read the programmer's comments.

Section 5

DATA-TAKING PROCEDURES

Like the preceding section, the following is aimed at the novice. Experienced observers may have their own techniques, differing from those suggested below. The section is divided into the following parts:

recording data
disk, 9-track tape, 8-mm cassette tape
archiving
selecting slit and decker
calibrations
flats
arcs
darks
acquisition and autoguiding
taking data
assessing data
closing down

Recording Data

The data-taking program offers four data-storage options: "disk," "tape," "both," or "not recorded." When you are playing for keeps, choose "both." Images are stored on tape in FITS format.

If you have not already done so, this is a good time to put your name and instrument in the header. Use the "Z-3" selection on the data-taking terminal.

The header attached to each recorded image contains many data pertaining to that observation, including all the current settings of the Hamilton controller, all the data-taking program parameters, telescope position information, comment lines, and CCD parameters such as temperature and voltage levels. The header may be examined using VISTA's "hedit" command. Hamilton logsheets are available from the telescope operator.

Disk The disk space allotted to image storage is divided into two logical units, the Data disk and the Vista disk. Raw images are written to the data disk and, when that device is full, to the vista disk. The disks will have been cleared by a technician before the beginning of each run. Typing **dir** or **dir vista** from the vista window on the workstation will produce listings of the data and vista disks, respectively. Adding **full** will produce an expanded listing. Typing **df** will invoke a listing of available disk space.

9-track Tape Data can be recorded on 9-track, reel-to-reel magnetic tapes at 1600 bpi. The observer must provide tapes. They can be bought at a fair price on the mountain, but supplies may be limited, so heavy tape users are advised to bring their own. One 2400-foot tape will hold twenty-five 800 x 800 or three 2048 x 2048 unbinned images.

Before mounting a tape, clean the tape heads with the alcohol (red squeeze bottle) and swabs provided. If you're not sure how, ask a technician. Mount the tape, bring it to the load point, and bring the unit on line. New tapes, or old tapes to be overwritten, must be initialized before they will acccept input. This is done via the "Z. special" option on the data-taking terminal. Select "2. tape" from the first sub-menu, choose "9-track" from the second, if it is not already selected. From the same menu, choose "A. Initialize a tape." If all is as it should be, the tape will do a brief dance as it initializes.

Caution: do not initialize a tape that still contains useful data, or they will be lost. If you wish to append images to a partially full tape, select option "C. Read and position to end of tape." This will run the tape to the end of the last file and prepare it to receive new data.

8-mm Cassette Tape Data can be stored at very high density on ordinary 8-mm video cassette tape using the Exabyte tape drive, located in the rack behind and to the left of the workstation. It is highly economical, particularly when using the large chip or saving numerous smaller images, but can only be read on compatible systems. About eleven hundred 800 x 800 or about one hundred seventy 2048 x 2048 unbinned images can be stored on a single cassette. Cassettes can be purchased on the mountain.

Turn on the Exabyte drive (switch at rear of unit) and press the only button on its front panel. When the door opens, load a cassette, close the door, and wait for the green light.

Select the "Z. special" option on the data-taking terminal. Select "2. tape" from the first sub-menu, and choose "Exabyte" from the second, if it is not already selected. While selecting the Exabyte informs the data-taking program that it is the active drive, VISTA must be given the "exabyte perm" command before it will recognize the Exabyte as the default tape drive. Type **help exabyte** for a full description of exabyte options.

Initialize or find the end of volume as for reel-to-reel tapes. Again, this is most easily done from the "tape" sub-menu on the data-taking terminal. Note that initialization takes several minutes with the Exabyte, as it must allocate space for directories during the process. Other procedures, such as searching for a file or finding the end of volume, are also slow with this drive. Writing images, however, takes about the same time with either tape unit.

Archiving A technician backs up data, at run's end, with the Exabyte. However, the number of backup tapes is not infinite, and eventually your data will be overwritten. Thus it is a good idea, upon returning home, to confirm that the tapes you made on the mountain can be read successfully.

If you are storing so many spectra on disk that you have filled the Data disk, are well into the Vista disk, and have more nights ahead, it may be wise to ask a telescope technician to back-up your data before the end of your run, clearing the disks for more mountains of knowledge.

Selecting Slit and Decker

Two important spectrograph parameters, slit width and decker, both controlled through the Hamilton terminal have not yet been discussed and must be decided upon before beginning calibrations.

Determining slit width is a tradeoff between throughput and resolution and depends on your program requirements and on the size of the seeing disk. The plate scale at the 3-meter's coudé focus is 1.89 arc seconds mm^{-1} so that the slit projects on the sky at a scale of about 530 microns arc $second^{-1}$. In the other direction, the slit projects onto the detector at about 320 microns $pixel^{-1}$. If you focused using the fwhm technique, you will have observed that the instrumental profile limits the best focus to between 2 and 3 pixels, so many observers choose slit widths in the range of 600 to 800 microns.

The decker limits the slit's vertical extent and therefore its vertical projection on both sky and detector. Available deckers are listed by their projected size, in arc seconds, on the sky (3-meter plate scale). While some observations or seeing conditions would benefit from as long a decker as possible, the size of the decker determines the orders' widths, and is thus limited to the largest decker which still prevents the orders from overlapping. The orders are more highly cross-dispersed (separated perpendicular to dispersion) in the blue than in the red, so that larger deckers may be used at shorter wavelengths. The best way to determine the appropriate decker is by experiment. Make an exposure using the quartz lamp. Try about 2.5 arc seconds to begin with. (This is the decker of choice of many observers. It is an intermediate size that appears to be free of significant overlap at all ordinary wavelengths.) Make a column plot with VISTA's "itv" command and examine it to ensure that the orders are well separated.

Overlapping is more subtle than it may at first appear. Light in the inter-order spaces may be present, even between well-separated orders, as some is due to scattered light not originating in the adjacent orders. To make a precise determination of the largest decker commensurate with well-separated orders in your wavelength region, you can compare column plots of quartz-illuminated images made with several different deckers. The inter-order light will cease to decrease when the orders are fully seperated.

Calibrations

As a rule, some or all of the following instrumental calibrations are made in conjunction with Hamilton observations. Flats are made with the continuum source for the purpose of recording and eventually dividing out differences in the detector's pixel-to-pixel response. Arcs or comparison spectra are usually made using the thorium-argon hollow cathode lamp, and are used for establishing the wavelength scale. Some observers also make dark exposures to have a record of the detector's dark current. Low s/n observations may require sky subtraction as well (see Appendix C). Finally, an exposure is made, using either a star or the continuum source, to serve as a model for mapping the exact locations of orders.

In general, calibrations should be performed with the spectrograph parameters set as they will be for observing, and should be repeated each time parameters are altered in the course of a night (e.g., changing regions). Remember that all recorded images should be made with the "slow" readout option.

It is a good idea to flush out the CCD by reading out at least one throw-away frame before beginning serious data-taking, particularly following possible exposure of the chip to stray light in the camera room or overexposure by a source lamp. Some chips are slower to recover from overexposure than others and may require some time to completely settle down. The only sure way to avoid this residual charge is not to expose the chip to bright light. Dewars #8 and #13 are equipped with automatic dark slides to prevent accidental contamination by stray light, but even an overexposure through the spectrograph can leave residual charge on the chip.

Some useful suggestions for Hamilton calibrations can be found in *The VISTA Cookbook*. The details of the calibrations will be decided by the dictates of each observing program. Their general form is described below:

<u>Flats</u> The changes, with wavelength, in the detector's response, combine with the quartz lamp's energy curve to make evenly illuminated flat-field exposures over the Hamilton's broad bandpass a problem for which no perfect solution (i.e., filter combination) has been found. On the whole, the

lamp is brighter and the CCD more sensitive in the red. Appendix E gives some suggestions for flat-fielding. It may be necessary to make multiple exposures and later to sum the images to improve the signal to noise at certain wavelengths. Alternatively, summing two exposures or sets of exposures with different filter combinations may provide the desired levels.

Two styles of flat-fielding are commonly used. The "longslit flat" is made with the decker slid completely out of the way so that the orders fully overlap. The undeckered slit projects to roughly 200 pixels, depending on your wavelength region. This causes considerable overlap of orders and, with it, mixing over a range of colors. The accuracy of the flat may therefore be compromised to the small extent that the pixels' response is wavelength-dependent over that range. A possible compromise might be an "intermediate" flat made with, say, a 15-arc second decker--large enough to fully illuminate the chip, yet small enough to restrict the blending of wavelengths.

The longslit technique provides even illumination, but has the disadvantage of obscuring fringing effects in the red that begin between 6000Å and 7000Å in deckered exposures.

Fringing appears to be an issue only with the the back-illuminated, thinned CCDs. The current, unthinned 2048 x 2048 chips appear not to suffer from it. They may, however, exhibit a Moray pattern when displayed, which is easily confused with fringing. (Thinned 2048 x 2048 chips are foreseen for the not too distant future.)

In any case, if fringing is an issue and if longslit flats are used, a deckered quartz must also be made to record fringing. See *The VISTA Cookbook* for an approach to the removal of red fringing.

Longslit flats are typically very bright and often must be controlled with a diffuser, or neutral-density or other filter(s).

Alternatively, one may chose to make deckered flats which serve both to remove fringing and pixel-to-pixel sensitivity variations. In this case, a decker somewhat larger than that used for observations must be chosen, so that the stellar spectrum falls completely within the broader flat-field orders.

The larger decker avoids the introduction of noise at the edges of the orders due to division by a flat with low s/n at its edges. It appears, however, that due to differences in how the polar quartz lamp and a star illuminate the spectrograph, quartz orders do not always coincide perfectly with stellar orders. This discrepancy seems greater in the blue. Be sure that your "wide-decker" flats are wide enough to account for this (or simply use a longslit flat).

A true "dome-quartz" (a lamp mounted on the end of the telescope and shining on the inside of the dome) has just been added. It is hoped that thus using the telescope optics for the flat-field lamp will more accurately mimic the way a star illuminates the spectrograph. Longer exposure are required.

The dome quartz is operated with two "dome flat" switches near the bottom of the rack to the left of the workstation. Two identical lamps are available and may be used singly or together. TUB power is required, but must be turned off when flats are completed. The switches for TUB power are located at floor level in the rack behind the workstation. To reach them, you must crawl under the table. If in doubt about the switches, consult a technician.

Echelle orders are somewhat curved along the direction of dispersion, so that they must be "tracked" for accurate reduction. Thus, irrespective of the style of flat-fielding you choose, one quartz-lamp exposure, using the same decker you will use for observations, should be made for each spectrograph setting. This exposure provides the template for that process (see "Examining Images with VISTA").

Some observers prefer making their templates with starlight, since the quartz orders may not be perfectly cospatial with stellar orders. An early type stellar spectrum makes a good template and assures a good match. You may find that your target star spectra themselves, if of sufficiently high signal to noise, can be used as their own template.

Once you've decided on the type of flats you'll use, turn on the flat-field lamp by selecting the "dome quartz" option from the "lamp" menu on the Hamilton terminal. Bring the appropriate filter(s), if any, into the light path (see Appendix E). Make a test exposure. Use VISTA's "itv" command to make a column plot through the center of the image; this will show you the intensity against wavelength and help you decide whether the filter selection and exposure time are suitable, and how many flats will be required to obtain adequate signal to noise. When you are satisfied with the quality of the flats, remember to change to "normal slow" and to tell the data-taker to record your images.

The intensity of the lamp drops off considerably in the first 5 minutes or so after being turned on. It dims as much as 40-50%, becoming quite stable after about 8 minutes. Warming up the lamp is recommended.

Remember not to overexpose the chip. Although the readout electronics will permit numbers up to 32K DN (less the baseline), this only reflects the limit of the A to D converter. A pixel's response, depending upon the chip, may become nonlinear well before that limit is reached. The brightest part of the exposure should not exceed the recommended maximum for that chip (see the Detector Data Sheets).

Arcs Comparison spectra are made with the same thorium-argon source (lamp selection "5") that was used for focusing. Use the same slit width and other parameters with which you will be observing (remember that the slit moves unilaterally, so that changing its width will displace line centers on the chip). The thorium-argon lamp requires no warm-up time, but takes a few seconds to slide into place. A wide slit may require a neutral-density filter.

When working in the red, the very bright argon lines already mentioned (beginning at about 6900Å in order 82) will invariably saturate, bleeding into adjacent orders and generally looking dreadful. They can be filtered, but with the attendant loss of information from useful lines in their neighborhood.

Darks Darks are made by selecting "Dark" as the "observation type" on the data-taking terminal, thus disabling the shutter. They are used to determine, and eventually subtract, dark current. Such current is very low in our chips, and darks are used mostly for faint spectra. Ideally, darks should be of the same duration as the exposures to which they will be applied. They can, however, be scaled. In this case, darks should be not less than five or six times shorter than one's longest observation (see Appendix C and *The VISTA Cookbook*, p. 23). If you make darks, remember to return to "Normal" for other data-gathering.

Acquisition and Guiding

A CCD TV camera mounted near the slit is used for acquisition and autoguiding. It provides an image of the slit's reflective surface or, as is usually the case with the Hamilton, the decker surface. While the TV image is available to the CAT observer for acquisition and manual guiding, no autoguider exists, at present, for that telescope.

The decker lies just above the slit and both are slightly tilted to accomodate the camera. As a result, there is some parallax between the two surfaces so that starlight falling on the decker will appear slightly offset from that part of the image falling on the slit-jaws. The effect created is a bit confusing at first but you'll quickly grow accustomed to it.

The TV is operated via the TV controller (in the readout room or CAT control room) and from any of the Hamilton terminals. The former provides control of integration time, gain, contrast, and binning. The latter allows the magnification and focus of the camera to be changed.

At coudé, the orientation of the field depends on the telescope's hour angle. The size of the TV field depends on one's choice of magnification and binning.

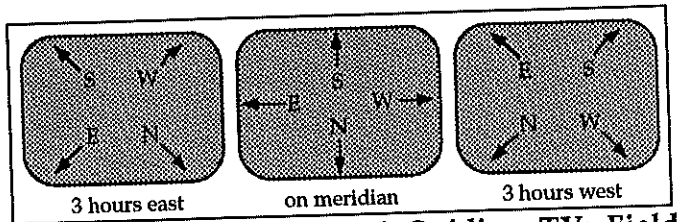


Fig. 12a Acquisition and Guiding TV: Field Rotation Rotation rate is 15° $hour^{-1}$ of HA.

With the 3-meter, the TV is capable of imaging stars to about the 19th magnitude. Hamilton targets are much brighter than this limit, and most are more than bright enough for direct guiding. Offset guiding is possible, but requires the use of the image rotator (see Appendix C for suggestions regarding faint object observations).

Bright stars may require a neutral-density filter to avoid saturating the camera. A mount, accepting standard Lick filter holders, can be threaded to the camera lens. It is usually found in place. Color filters may also prove useful for guiding on the appropriate part of an atmospherically refracted image.

The telescope technicians are experts with the autoguider and TV, and generally handle its operation. They will, if you wish, tutor you in its use.

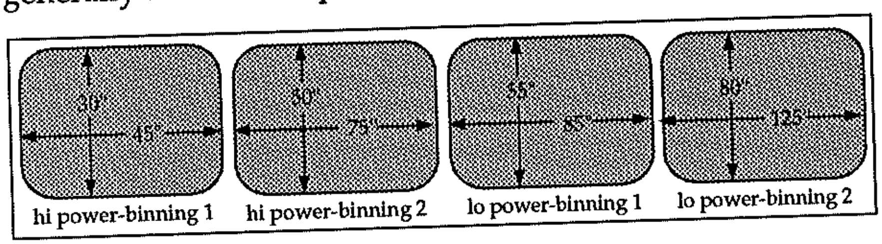


Fig. 12b Acquisition and Guiding TV: Approximate Scales (arc secs.) CAT users multiply by five.

Observing

The only parameter remaining to be determined before actually beginning observations is the integration time. Experience is the best guide here, but lacking that, a short test exposure can be made of the object if it is reasonably bright, or of a spectrally similar, brighter object if it is not.

For calculating the signal to noise per pixel, use the electron number rather than the digital number (DN). The numbers delivered by the datataker and used in VISTA are always the latter. (See data sheets for the conversion factor that applies to the chip you are using.) For the total signal to noise at any spectral location, sum across all the usable rows in the order.

Saturation of the stellar spectra is not usually an issue, but if you have an exceptionally bright target, remember that non-linearity of response begins well before the 32K A to D limit. See the appropriate CCD data sheet for the maximum recommended exposure.

Check the spectrograph parameters on the Hamilton terminal (lamps off, filters cleared, decker inserted, etc.), and the integration parameters on the data-taking terminal (readout normal slow, recording disk and tape, label, etc.). None of the former should be changed once an observation is begun; all of the latter, except the normal/dark option, may be changed during the observation, up to the time the readout begins. Remember, however, that to change the integration time once an observation has begun, you must invoke "V. Change Integration," not "B. Integration Time."

Once an integration is begun, it is prudent to keep an eye on the autoguider. Otherwise, under clear skies, the observation runs itself. If you are so inclined, it is possible to examine your last (or last night's) spectra in considerable depth as you observe. Your level of ambition and the choice of late night movie will guide you here. Some suggestions for extracting spectra, using mountain facilities, follow.

Examining Images with VISTA

The VISTA Manual is an indispensable guide to the following. A hard copy is kept in the readout room, and an on-line copy may be reached from within VISTA by typing **help** [command name].

Quick Look "Itv" has already been mentioned as a means of looking at images. It is very fast and easy to use but limited in that it can only plot one row or column at a time, and the plots it produces cannot be manipulated.

A variety of more sophisticated options exist. "Plot" and "mash" are briefly discussed here. Both these commands require that the image first be read into a buffer with the "rd" command. Reading the image does not affect the disk file but simply makes a copy of it in the desired buffer.

The flexible "plot" command includes a number of command-line options that permit adding rows or columns, scaling the x and y axes, overplotting, and so forth. "Itv" is useful for determining limits for the plot routine.

With "plot," an order or portion of an order can be compressed into a one-dimensional spectrum for plotting. "Mash," with its own set of options, also compresses orders, but does not plot them. Rather, it places them in a buffer whence they can be plotted or otherwise manipulated.

"Plot" and "mash" are quick and easy, but can only operate along rows or columns. Their accuracy is therefore limited by the intrinsic curvature of echelle orders. For observers who wish to perform a preliminary extraction that will produce spectra approaching those of a final reduction, the following is offered.

All Hamilton frames have a 64 DN pixel^{-1} offset (not to be confused with the baseline) automatically added to them. This can be seen in a short dark that has just been read out. The levels should be between about 60 and 70 DN pixel^{-1}, which is just that offset smeared by readout noise. Note, however, that the same image read into a buffer and redisplayed will hover near zero. This is because VISTA automatically subtracts the offset; the raw images, however, still include it.

Deeper Looks The reduction of Hamilton images is quite complex and will change with the nature of the data and the demands of the science. The following very simple routines are only intended for "first looks." They ignore many of the subtle (and some not so subtle) issues that must be addressed in a rigorous reduction.

Further suggestions can be found in *The VISTA Cookbook* and *Reduction of Hamilton Echelle Data at Lick Observatory* (PASP 100: 1572-1581, December 1988). The latter, and excerpts from the former, may be found in the *Hamilton Notebook*. While they depend on the batch processes "hamprep" and "hamreduce," which are not available on the mountain as of this writing, they nevertheless contain valuable general information.

Other observers have also devised techniques to meet particular requirements, such as precision radial velocities and critical line-profile analysis.

The low light-level regime is beginning to be more actively explored with the Hamilton, raising new observing and reduction issues. Some of these are discussed in Appendix C.

To flat-field an image, place the flat field-frame (or summed frames) in one buffer and the spectrum in another. Use the "divide" command with the "flat" option.

As has been noted, the Hamilton's broad bandpass causes flats to vary dramatically in intensity from red to blue across the chip. Filtering and summing improve the situation, but flats remain uneven at best. The "flat" option in the "divide" command causes the quotient to be rescaled by the mean intensity of the flat-field image. Dividing by an uneven flat and rescaling by a constant results in the loss of intensity information in the flat-fielded spectrum. Fluxing with a standard star or normalizing the continuum solve the problem, depending on your application, but are not discussed here (see *The VISTA Cookbook*).

The "spectroid" command (see *The Vista Manual*) is used to track curvature, subtract background, and mash the order. The output is a one-dimensional spectrum in a specified buffer.

Spectroid tracks the order spatially by continually finding the peak, perpendicular to dispersion, of a given order as it moves along that order. It seeks that peak from a user-provided starting point ("loc" in spectroid's command-line syntax) within a user-defined window ("spw").

Tracking a curved order is usually accomplished by first creating a model of the curvature for the purpose of guiding spectroid. The model may be derived from the quartz exposure made with the same size decker as was used for the star, or from an appropriate stellar spectrum. It must be examined to determine the starting row for the model. To do so, display the quartz frame and examine it with "itv." Draw a box around the order in question, at the left-hand edge of the image. Do a column plot, within the box, at one of the first columns and use it to find the center row of the order at that point ("loc").

A variant form of the spectroid command itself creates the model. By adding "nomash" and "tagalong" to the spectroid command line, a one-dimensional model of the curvature will be created which, when plotted, should be a smooth curve, with columns 0 to 799 along the x-axis and a few row numbers along the y-axis (wrongly labeled "intensity"). The curve should begin at column zero near the row number that was provided to "loc."

Examine the flat-fielded stellar frame, using "itv" as above. This time draw the box large enough to include the orders directly adjacent to your order of interest. Again do a column plot within the box. Based on this plot, decide how many rows you will include in the spectrum window ("spw") for mashing.

You also may choose to perform a background subtraction at this time. Background subtraction raises the issue of inter-order light in Hamilton spectra. That it is there is clear. Where it comes from is less so. It appears that some originates in the orders adjacent to the inter-order space in which it is seen, while there is also a more uniform, scattered component. This latter will, of course, be present within as well as between the orders.

To do background subtraction, select background windows ("bkw") in the inter-order spaces on either side of the spectral order, and decide how they should be disposed about the center.

Now apply spectroid to the image, plugging in the appropriate parameters for model and windows. Use "plot" to see the finished spectrum. Hard copies of plots and images may be made in any of several ways (see "Making Hard Copies").

Closing Down

At night's end, having completed any further calibrations, rewind and remove your tape from the tape drive (leaving tape mounted is hard on both tape and drive), and turn off the unit. For reel-to-reel tapes, simply take the unit off line and push rewind. The tape will return to its load point. Push rewind again, remove the tape, and turn off the drive. Exabyte tapes should be rewound from the data-taking terminal. Select "dismount" in the Z-2 menu. The door of the Exabyte drive will open when the tape is rewound. Remove the cassette and turn off the drive.

Log off the workstation by putting the cursor in the gray area between windows, holding the left-hand mouse button, selecting "log-out," and releasing the button. Turn it off. Leave the data-taking program by typing "control Y," log off by typing `lo` in response to the "ucscloc.user" prompt, and turn off the terminal. Turn off the Hamilton terminal (the program is left running). Turn off the image display monitor.

In the camera room, close the grating, collimator, and prism covers. Top off the dewar. Sweet dreams.

CHECKLIST

Hamilton with 3-meter[7]

Setting up

On arriving

- ❑ Check the *Hamilton Logbook*
- ❑ Check the contents of the filter wheel (if using filters)

From the camera room

- ❑ Check the CCD temperature in the pit on your way in
- ❑ *Fill the dewar*
- ❑ Check the ion pump
- ❑ Open the spectrograph covers
  - •Collimator
  - •Prisms
  - •Grating
- ❑ Install any filters (remember to record changes and recalibrate the filter wheel)

From the slit room

- ❑ Remove the slit cover
- ❑ Recalibrate the spectrograph (optional but recommended on first day)
- ❑ Check the light path for obstructions
- ❑ Remove the polar axle cover
- ❑ Turn on the box fan if desired
- ❑ Focus the acquisition/guiding TV (now or later, or leave it to a technician)

From the readout room

- ❑ Turn things on
  - •Workstation--log in with `vista`
  - •Data-taking terminal--log in with `user`, run `ham`
  - •Hamilton controller terminal
  - •Image display screen
- ❑ Check the baseline

---

7. The checklist applies, with minor changes, to the Hamilton/CAT combination. For "readout room" read "basement computer room," and substitute appropriate computer input (see Appendix A). CAT observers must also operate the telescope and be checked out to do so. Instructions for operating the CAT are not included in this manual.

- ❑ Check the spectrograph and detector
  - •Make a test dark exposure
  - •Make a test with light in system
- ❑ Position the chip to the desired region using day sky and/or Th-Ar
- ❑ Focus the spectrograph
- ❑ Repeat the last two steps for each setting (optional but recommended)

Observing

- ❑ Mount and initialize a tape
- ❑ Do calibrations
  - •Flats
  - •Arcs
  - •Darks
- ❑ Add a small gem to the vast teasure trove of human knowledge

Closing Down

From the readout room

- ❑ Complete any remaining calibrations
- ❑ Turn off the calibration lamps
- ❑ Dismount your 9-track or cassette tape and turn off the tape drive
- ❑ Leave the data-taking program with "control y," log off with `lo`
- ❑ Log off the workstation (cursor in gray area, left button on mouse)
- ❑ Turn off CRTs
  - •Workstation
  - •Data-taking terminal
  - •Hamilton controller terminal (program keeps running)
  - •Image display screen

From the slit room

- ❑ Cover the slit
- ❑ Turn off the box fan if necessary

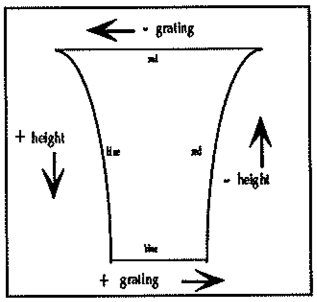
From the camera room

- ❑ Close the spectrograph
  - •Grating
  - •Prisms
  - •Collimator
- ❑ *Fill the dewar*

Useful Numbers

Translating the Spectrum

To move the spectrum with respect to the chip, use the following ratios to determine the numbers entered for "grating" and "height" at the Hamilton terminal:



Grating 1.15 units pixel^{-1}

Larger grating settings will move the spectrum to the right, revealing bluer wavelengths.

Height 8.97 units pixel^{-1}

Larger height settings will move the spectrum down, revealing redder orders.

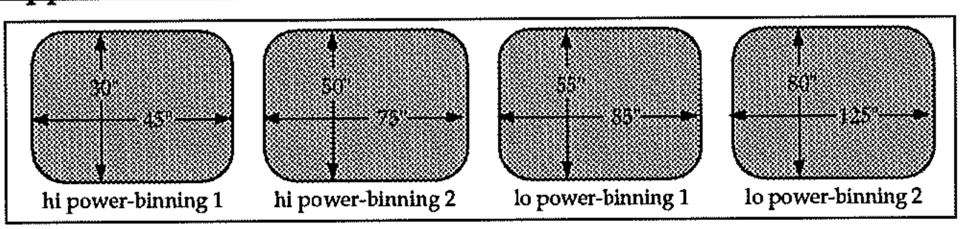
Plate Scale

3-meter	1.89 arc seconds mm^{-1}
CAT	9.45 arc seconds mm^{-1}

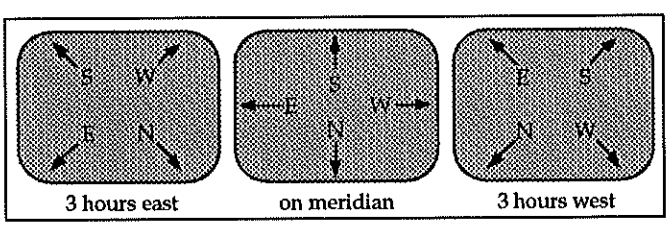
Slit Projection

slit on detector	330μ pixel^{-1} (15μ pixel)
slit on sky, 3-meter	530μ arc second^{-1}
slit on sky, CAT	106μ arc second^{-1}

Approximate 3-m TV Fields of View (in arc seconds; CAT users x 5)



TV Field Rotation (rotation rate = 15°/ hour of HA)



Telescope Limits

3-meter

wind steady to 40 mph/gusts to 45; x-wind 35/40; into wind 30/35

humidity limit humidity alarm or blowing fog (TT's discretion)

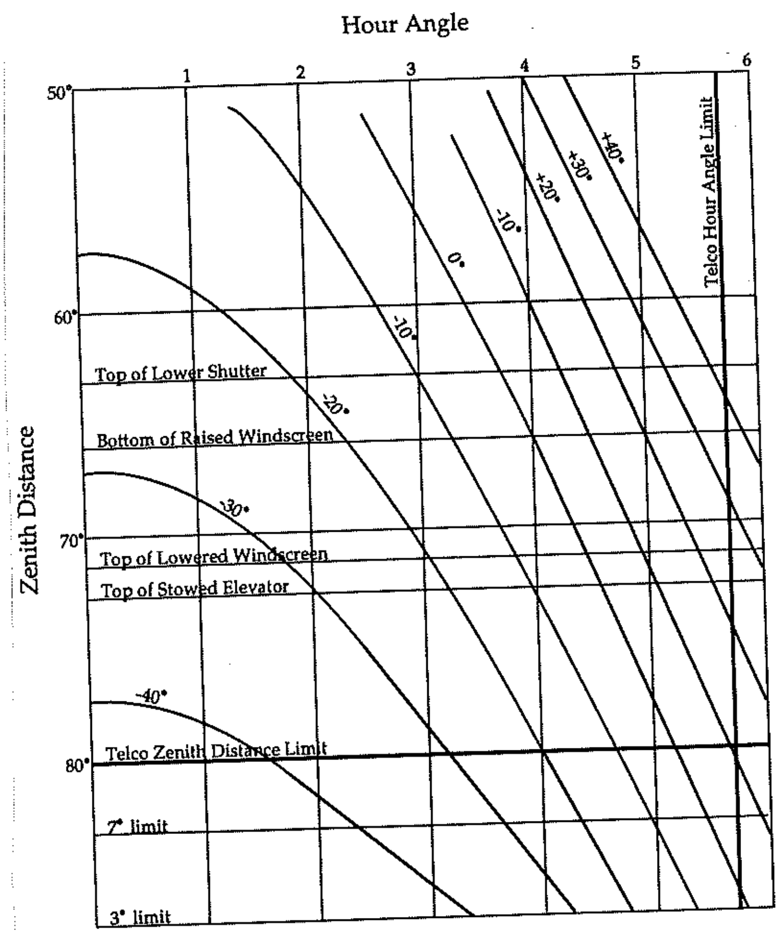


Fig 13 3-m Telescope Limits The hour angle limit of 5 hr. 40. min may be exceeded by the Director's permission.

Coudé Auxilliary Telescope

hour angle limit 5 hrs. 20 mins. (Limit may be exceeded with Director's permission. Vignetting by dome imposes practical limits, depending upon declination.)

declination limits north: +68° 30' (begin vignetting by dome on meridian)
south: -30° (begin underfilling primary)
-50° (primary 50% illuminated)

wind and humidity limits as per 3-meter

Spectrograph Data

Optics

Collimator	12-inch off-axis parabola stopped to 10-inches in normal use (8.1-inch beam at collimator)
Grating	echelle, 31.5 grooves mm^{-1}, blaze angle = 64.7°
Cross dispersers	two UBK7 prisms at 43.9°
Camera	508.3-mm f.l. folded Schmidt camera ($f_{1.7}$) and field flattener
Coatings	overcoated silver mirrors and anti-reflection coated transmissive optics
Magnification	-22 (slit to detector, dispersion direction)

Format

$Dispersion^{-1}$	5.51Å mm^{-1} @ 9840Å (m = 58) ... 1.68Å mm^{-1} @ 3000Å (m = 190)
Order separation	.22 mm @ 9840Å (m = 58) ... .51 mm @ 3000Å (m = 190)

Performance

Resolution ($\lambda/\Delta\lambda$)	approximately 48,000 (Note that $\lambda/\Delta\lambda$ is constant over the entire format.)
Instrumental profile	approximately 2.5 pixels fwhm (Note that due to optical aberrations there is some variation in line profiles with location in the format.)
Throughput	see throughput data, Appendix B

Detector Data

Note that Lick CCDs are identified by dewar number.

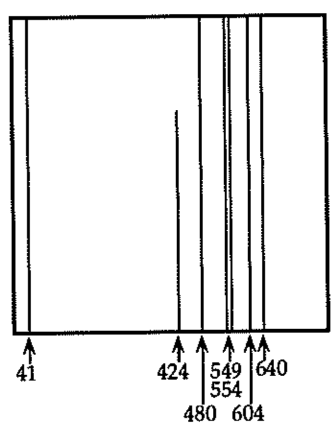
DEWAR #6

Specifications

Type	Texas Instruments 800 x 800, thinned, back-illuminated
Dimensions	12 mm x 12 mm
Pixel size	15µ

Characteristics

e^- : DN	2.5e^- DN^{-1}
linearity limit	18,000 DN
Readout noise	7e^- in slow readout, 10e^- in fast readout
Dark current	10-30 e^- $hr.^{-1}$ $pixel^{-1}$, depending on exposure history
Approx. readout time	whole chip, unbinned: 60-sec in slow, 30-sec in fast
Operating temp.	-125° C
Most notable bad cols.	Column 41 is hot and decays with time, others are blocked. Blockage in column 424 begins in row 240.



Notes

The chip in dewar #6 has more bad columns and less uniform response than its "twin" in dewar #8. The latter is natuarally preferred, but may not always be available to CAT observers as it is used with the UV Schmidt configuration of the cassegrain spectrograph.

Its quantum efficiency is roughly equivalent to Dewar #8 (see Appendix B).

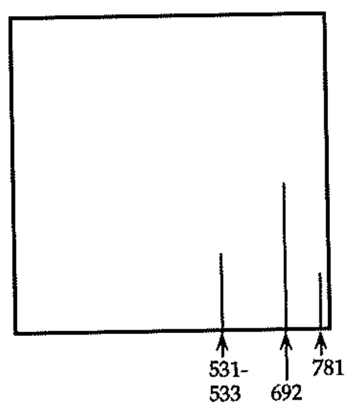
DEWAR #8

Specifications

Type	Texas Instruments 800 x 800, thinned, back illuminated
Dimensions	12 mm x 12 mm
Pixel size	15μ

Characteristics

e^-: DN	2.5e^- DN^{-1}
Linearity limit	18,000 DN
Readout noise	7e^- in slow readout, 10e^- in fast readout
Dark current	10-30 e^- $hr.^{-1}$ $pixel^{-1}$, depending on exposure history
Approx. readout time	whole chip unbinned: 60-sec in slow, 30-sec in fast
Operating temp.	-125° C
Most notable bad cols.	see diagram



Column 781 is hot, beginning in row 664; others are blocked. Blockage in columns 531-533 begins in row 240; blockage in column 692 begins in row 437.

Notes

This chip is preferred to the other TI CCD in dewar #6, but its availability for CAT users will depend on the cassegrain schedule, as it is used for the the UV Schmidt configuration of the cassegrain spectrograph.

The throughput of the Hamilton has been measured with this chip, and is given in Appendix B. Dewar #6 is roughly comparable, though perhaps somewhat slower in the blue. (Dewar #6 is cosmetically inferior and less uniform in response.) Dewar #13 is somewhat slower overall, most notably below about 4000Å.

DEWAR #13

Specifications

Type	Ford Aerospace 2048 x 2048, unthinned, front-illuminated, phosphor coated
Dimensions	approx. 30 mm x 30 mm
Pixel size	15μ

Characteristics

e^- : DN	3.5e^- DN^{-1}
Linearity limit	20,000 DN w/MPP on (>32,000 w/MPP off)
Readout noise	7e^- in slow readout, 10e^- in fast readout
Dark current	2-4e^- $hr.^{-1}$ $pixel^{-1}$ w/MPP on (Several-fold increase w/MPP off, see below.)
Approx. readout time	whole chip unbinned: approx. 6.2 mins. in slow, 3.1 mins. in fast
Operating temp.	-100° C
Most notable bad cols.	none

Notes

Do not use horizontal on-chip binning with this devicel; it creates charge transfer problems resulting in trailed images.

Dewar #13 may be run with the "Multi-Phased Pinout" option (MPP) on or off. The former gives the lowest dark current, but with a lower linearity limit (see above). Switch the MPP option via "Z-4" in the data-taking program.

For viewing the large area of the Ford chip on the image display screen, the "video memory size" can be reset through the display option on the data-taking terminal, selection "Z-1." 480 x 640 shows the entire chip at once, but bins 5 x 5. 1024 x 1024 bins 2 x 2 but shows only about 960 rows x 1435 cols. (though the whole chip may be seen by scrolling).

Quantum efficiency of the FA chip is somewhat lower than the TI devices. The recent addition of phosphor coatings has boosted the UV response to about 20%. Peak response (at between 6500 and 7000Å) is about 45%. Eventually these large chips will be thinned and are expected to rival the best of the TI chips in overall QE.

Table of Orders[8]

where m = order, λc = central or blaze wavelength, fsr = free spectral range, Δ = distance separating orders, h = distance from order 190 (3000Å), l = length of free spectral range, and d = dispersion

m	λc(Å)	fsr(Å)	Δ(mm)	Δ(arc")	h(mm)	l(mm)	d(Å/mm)
190	3007.3	15.8	0.518	14.272	0.000	9.40	1.68
189	3023.2	16.0	0.513	14.142	0.516	9.45	1.69
188	3039.2	16.2	0.509	14.011	1.027	9.50	1.70
187	3055.5	16.3	0.504	13.889	1.533	9.55	1.71
186	3071.9	16.5	0.500	13.763	2.036	9.61	1.72
185	3088.5	16.7	0.495	13.637	2.533	9.66	1.73
184	3105.3	16.9	0.491	13.514	3.026	9.71	1.74
183	3122.3	17.1	0.486	13.395	3.514	9.76	1.75
182	3139.4	17.2	0.482	13.274	3.999	9.82	1.76
181	3156.8	17.4	0.478	13.154	4.478	9.87	1.77
180	3174.3	17.6	0.473	13.038	4.954	9.93	1.78
179	3192.1	17.8	0.469	12.919	5.425	9.98	1.79
178	3210.0	18.0	0.465	12.803	5.892	10.04	1.80
177	3228.1	18.2	0.461	12.690	6.355	10.09	1.81
176	3246.5	18.4	0.457	12.576	6.814	10.15	1.82
175	3265.0	18.7	0.453	12.463	7.268	10.21	1.83
174	3283.8	18.9	0.448	12.352	7.719	10.27	1.84
173	3302.8	19.1	0.444	12.242	8.165	10.33	1.85
172	3322.0	19.3	0.440	12.131	8.608	10.39	1.86
171	3341.4	19.5	0.437	12.022	9.046	10.45	1.87
170	3361.0	19.8	0.433	11.915	9.481	10.51	1.88
169	3380.9	20.0	0.429	11.809	9.911	10.57	1.89
168	3401.1	20.2	0.425	11.702	10.338	10.64	1.90
167	3421.4	20.5	0.421	11.598	10.761	10.70	1.91
166	3442.0	20.7	0.417	11.496	11.180	10.76	1.93
165	3462.9	21.0	0.414	11.391	11.596	10.83	1.94
164	3484.0	21.2	0.410	11.288	12.008	10.89	1.95
163	3505.4	21.5	0.406	11.191	12.416	10.96	1.96
162	3527.0	21.8	0.403	11.089	12.820	11.03	1.97
161	3548.9	22.0	0.399	10.989	13.221	11.10	1.99
160	3571.1	22.3	0.395	10.892	13.618	11.17	2.00
159	3593.6	22.6	0.392	10.794	14.012	11.24	2.01
158	3616.3	22.9	0.388	10.697	14.402	11.31	2.02
157	3639.4	23.2	0.385	10.599	14.789	11.38	2.04
156	3662.7	23.5	0.381	10.505	15.172	11.45	2.05
155	3686.3	23.8	0.378	10.411	15.552	11.53	2.06
154	3710.2	24.1	0.375	10.318	15.928	11.60	2.08
153	3734.5	24.4	0.371	10.226	16.301	11.68	2.09
152	3759.1	24.7	0.368	10.133	16.671	11.75	2.10
151	3784.0	25.1	0.365	10.040	17.037	11.83	2.12
150	3809.2	25.4	0.361	9.953	17.400	11.91	2.13
149	3834.8	25.7	0.358	9.864	17.760	11.99	2.15
148	3860.7	26.1	0.355	9.774	18.116	12.07	2.16
147	3886.9	26.4	0.352	9.684	18.469	12.15	2.18

8. Updated 1990 by S. Allen from Vogt, S. S. *The Lick Observatory Hamilton Echelle Spectrometer*. PASP 99: 1214-1228, November 1987.

m	λc(Å)	fsr(Å)	Δ(mm)	Δ(arc")	h(mm)	l(mm)	d(Å/mm)
146	3913.5	26.8	0.349	9.600	18.819	12.24	2.19
145	3940.5	27.2	0.345	9.514	19.166	12.32	2.21
144	3967.9	27.6	0.342	9.425	19.510	12.41	2.22
143	3995.7	27.9	0.339	9.340	19.851	12.49	2.24
142	4023.8	28.3	0.336	9.256	20.188	12.58	2.25
141	4052.3	28.7	0.333	9.173	20.523	12.67	2.27
140	4081.3	29.2	0.330	9.090	20.855	12.76	2.28
139	4110.6	29.6	0.327	9.009	21.183	12.85	2.30
138	4140.4	30.0	0.324	8.926	21.509	12.95	2.32
137	4170.6	30.4	0.321	8.848	21.831	13.04	2.33
136	4201.3	30.9	0.318	8.766	22.151	13.14	2.35
135	4232.4	31.4	0.315	8.685	22.468	13.23	2.37
134	4264.0	31.8	0.313	8.608	22.782	13.33	2.39
133	4296.1	32.3	0.310	8.530	23.093	13.43	2.40
132	4328.6	32.8	0.307	8.451	23.401	13.54	2.42
131	4361.7	33.3	0.304	8.375	23.707	13.64	2.44
130	4395.2	33.8	0.301	8.301	24.010	13.74	2.46
129	4429.3	34.3	0.299	8.223	24.310	13.85	2.48
128	4463.9	34.9	0.296	8.151	24.607	13.96	2.50
127	4499.0	35.4	0.293	8.076	24.901	14.07	2.52
126	4534.7	36.0	0.291	8.002	25.193	14.18	2.54
125	4571.0	36.6	0.288	7.931	25.483	14.29	2.56
124	4607.9	37.2	0.285	7.858	25.769	14.41	2.58
123	4645.3	37.8	0.283	7.787	26.053	14.53	2.60
122	4683.4	38.4	0.280	7.717	26.335	14.64	2.62
121	4722.1	39.0	0.278	7.647	26.614	14.77	2.64
120	4761.5	39.7	0.275	7.579	26.890	14.89	2.66
119	4801.5	40.3	0.273	7.509	27.164	15.01	2.69
118	4842.2	41.0	0.270	7.440	27.435	15.14	2.71
117	4883.6	41.7	0.268	7.376	27.704	15.27	2.73
116	4925.7	42.5	0.265	7.309	27.971	15.40	2.76
115	4968.5	43.2	0.263	7.242	28.235	15.54	2.78
114	5012.1	44.0	0.261	7.178	28.497	15.67	2.81
113	5056.4	44.7	0.258	7.113	28.756	15.81	2.83
112	5101.6	45.5	0.256	7.049	29.013	15.95	2.86
111	5147.5	46.4	0.254	6.988	29.268	16.10	2.88
110	5194.3	47.2	0.252	6.927	29.521	16.24	2.91
109	5242.0	48.1	0.249	6.865	29.771	16.39	2.93
108	5290.5	49.0	0.247	6.803	30.019	16.54	2.96
107	5340.0	49.9	0.245	6.744	30.265	16.70	2.99
106	5390.4	50.9	0.243	6.686	30.509	16.86	3.02
105	5441.7	51.8	0.241	6.628	30.751	17.02	3.05
104	5494.0	52.8	0.239	6.571	30.990	17.18	3.07
103	5547.4	53.9	0.237	6.516	31.228	17.35	3.10
102	5601.7	54.9	0.235	6.460	31.464	17.52	3.14
101	5657.2	56.0	0.233	6.404	31.697	17.69	3.17
100	5713.8	57.1	0.231	6.352	31.929	17.87	3.20
99	5771.5	58.3	0.229	6.299	32.158	18.05	3.23
98	5830.4	59.5	0.227	6.247	32.386	18.23	3.26
97	5890.5	60.7	0.225	6.198	32.612	18.42	3.30
96	5951.9	62.0	0.223	6.149	32.836	18.61	3.33
95	6014.5	63.3	0.221	6.099	33.059	18.81	3.37
94	6078.5	64.7	0.220	6.052	33.279	19.01	3.40
93	6143.8	66.1	0.218	6.005	33.498	19.21	3.44
92	6210.6	67.5	0.216	5.962	33.715	19.42	3.48
91	6278.9	69.0	0.215	5.920	33.931	19.63	3.51
90	6348.6	70.5	0.213	5.876	34.145	19.85	3.55
89	6420.0	72.1	0.212	5.833	34.358	20.08	3.59
88	6492.9	73.8	0.210	5.797	34.569	20.30	3.63
87	6567.6	75.5	0.209	5.757	34.779	20.54	3.68
86	6643.9	77.3	0.208	5.719	34.987	20.78	3.72
85	6722.1	79.1	0.206	5.686	35.194	21.02	3.76

m	λc(Å)	fsr(Å)	Δ(mm)	Δ(arc")	h(mm)	l(mm)	d(Å/mm)
84	6802.1	81.0	0.205	5.651	35.400	21.27	3.81
83	6884.1	82.9	0.204	5.621	35.604	21.53	3.85
82	6968.0	85.0	0.203	5.593	35.808	21.79	3.90
81	7054.0	87.1	0.202	5.565	36.011	22.06	3.95
80	7142.2	89.3	0.201	5.535	36.212	22.33	4.00
79	7232.6	91.6	0.200	5.512	36.412	22.62	4.05
78	7325.4	93.9	0.199	5.492	36.612	22.91	4.10
77	7420.5	96.4	0.199	5.475	36.811	23.20	4.15
76	7518.1	98.9	0.198	5.461	37.010	23.51	4.21
75	7618.4	101.6	0.198	5.442	37.208	23.82	4.26
74	7721.3	104.3	0.197	5.431	37.405	24.14	4.32
73	7827.1	107.2	0.197	5.424	37.602	24.48	4.38
72	7935.8	110.2	0.197	5.420	37.799	24.82	4.44
71	8047.6	113.3	0.197	5.419	37.996	25.16	4.50
70	8162.5	116.6	0.197	5.420	38.193	25.52	4.57
69	8280.8	120.0	0.197	5.427	38.389	25.89	4.63
68	8402.6	123.6	0.197	5.439	38.587	26.27	4.70
67	8528.0	127.3	0.198	5.455	38.784	26.67	4.77
66	8657.2	131.2	0.199	5.475	38.983	27.07	4.85
65	8790.4	135.2	0.200	5.497	39.182	27.49	4.92
64	8927.8	139.5	0.201	5.530	39.382	27.92	5.00
63	9069.5	144.0	0.202	5.567	39.584	28.36	5.08
62	9215.8	148.6	0.204	5.609	39.786	28.82	5.16
61	9366.9	153.6	0.205	5.659	39.991	29.29	5.24
60	9523.0	158.7	0.208	5.716	40.197	29.78	5.33
59	9684.4	164.1	0.210	5.784	40.406	30.28	5.42
58	9851.3	169.9	0.213	5.859	40.617	30.80	5.51
57	10024.2	175.9	0.216	5.941	40.831	31.35	5.61

A: Observing with the Coudé Auxilliary Telescope

The Hamilton may be used, when the 3-meter is at cassegrain, with the 24-inch Coudé Auxilliary Telescope (CAT). The spectrograph makes no distinction between the two telescopes. Downstream from the slit, the differences between the two are invisible (both have the same focal ratio), and the characteristics of the instrument are the same for either. Much of the main body of this manual therefore applies to both. However, from the observer's standpoint, there are a variety of minor differences. The most important of these are addressed here. (See the Telescope Data Sheet for a comparison of the two telescopes.)

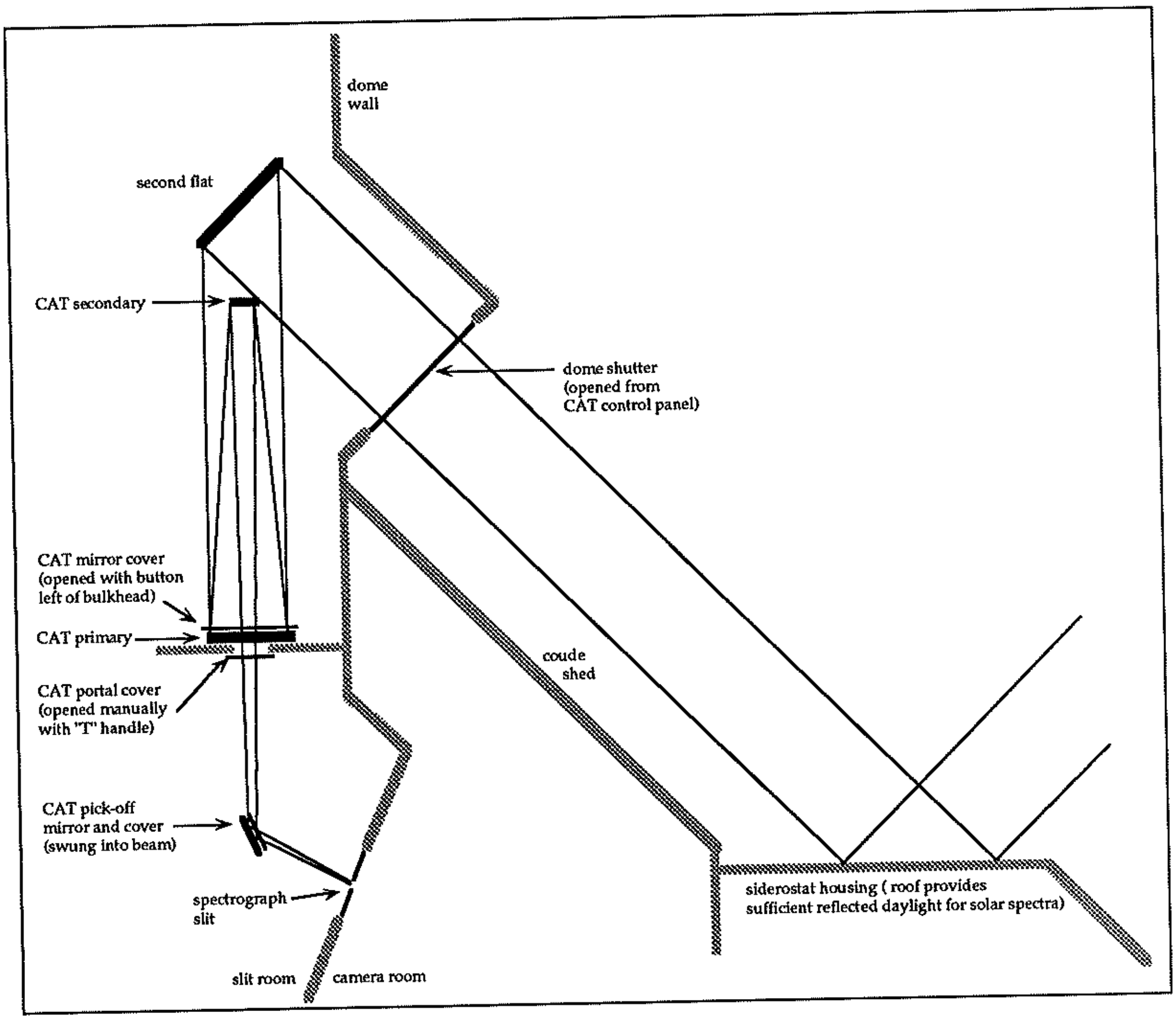


Fig. 14 The CAT Optical Path (without siderostat)

As of this writing, plans are afoot to install a SUN Microsystems SparkStation for use with the CAT. Much of the following material concerning the LSI 11/73 will be then rendered out of date. Until then, also note that the Ford 2048 x 2048 chip cannot be used with the CAT.

The CAT is a user-operated telescope, so quite apart from differences in spectrograph operation, the observer must know how to run the telescope. This is not covered in this manual. Observers must be checked out by one of the staff support scientists before using the CAT. If you are a first-time CAT user, or if you need a refresher, please request assistance on your time application.

The CAT is undersubscribed, but it is probably the busiest telescope on Mt. Hamilton after the 3-meter and 1-meter, so don't assume that it will be available at a moment's notice. Apply as you would for any other telescope.

Dewars #6 and #8 can be used with the CAT. As of this writing, however, dewar #8 (the usual Hamilton dewar) is often used during dark time with the UV Schmidt configuration of the 3-meter's cassegrain spectrograph. The 3-meter naturally takes precedence, so that dewar may not be available for some or all of your run. If #8 is a must, be sure to say so on your application.

When using the Hamilton with the CAT, you work from the basement computer room. A complete system for operating the spectrograph is available there. The Hamilton controller terminal is identical to the one in the readout room upstairs. An LSI 11/73 computer is used to run VISTA and the data-taking program. This smaller, slower computer imposes a few restrictions, particularly where VISTA is concerned. The data-taking program is very similar to the one upstairs, though noticeably slower, particularly when the computer is multi-tasking. Both programs are older implementations of their upstairs cousins. (CCD readout time is independent of the computer, but recording and display are slower with the LSI.) The peripherals are fewer and, on the whole, less sophisticated. All this said, there are no essential observing tasks that cannot be performed with the CAT's systems.

Log in on the LSI data-taker (middle terminal) as you would upstairs, with `user`; however, down here in the hold the data-taking program is called "hamcat." Apart from a few features not available on the LSI version, the data-taking program is the same as upstairs, and instructions from the main body of this manual apply.

VISTA is run on the RetroGraphics equiped VT-100 terminal on the left side of the observer's table. Log in with `vista`. While you won't find windows, a mouse, or a trackball, you will find all the fundamental VISTA routines needed to do preliminary examinations of your images. (Some of the more sophisticated image-processing routines, such as "spectroid," are not available on the LSI implementation.) The details of LSI VISTA can be learned from the old *VISTA Manual* by Richard Stover et al., kept in the basement computer room.

Note that to focus using the sigma technique you must type **itv2**--plain "itv" on the LSI is an older version without the necessary routines. The gaussian fitting procedure is not available on the LSI. See "Focusing the Spectrograph."

The cross on the image display screen is moved by the four keys "H,J,K, and L" for left, down, up, and right, respectively. Typing **S** will slow the cross' movement to 1 pixel per keystroke. Typing **F** restores the four to one default. You can zoom in on an image, but you must first define a box to zoom in on.

Plotting, moving and redisplaying images, and so forth, are noticeably slower. But take heart--think how long doing it by hand would require. (An advantage of the older LSI VISTA is the ability to perform many operations directly on disk files, without first transferring them to a buffer, as is required upstairs.)

The image display screen is above the VT-100. Its power switch is a bit hard to see and reach. It is on the lower left front corner, and is hidden behind part of the rack in which the unit sits. The monitor is not in a proper housing. Needless to say, don't reach into its exposed innards.

The only hard-copy device is a thermal printer, located in the rack below the image display. It makes moderately good copies of either the image display screen or the VT-100 screen. A small metal box with a toggle switch, usually found hanging around behind the VT-100, allows one to select between them.

The CAT's plate scale is a factor of five smaller than the 3-meter's (i.e., 9.45 arc seconds mm^{-1} for the CAT vs. 1.89 arc seconds mm^{-1} for the 3-meter). Consequently the slit and decker projections on the sky and the TV field of view (see Fig. 12b) differ by the same factor.

While the CAT uses the same TV system as the 3-meter for imaging the slit, it does not have an autoguider. The CAT is tricky to point and awkward to guide, particularly at large hour angles. This will be covered in your check-out. You may take some solace that, in these days of the ubiquitous autoguider, you are operating in the heroic tradition of hands-on astronomy. The solace will last about five minutes, but by that time you will have begun to master the CAT's quirky guiding.

B: System Throughput

The plots and tables in this appendix were drawn from observations I made in September 1989. They represent an approximate measure of the efficiency of the spectrograph and detector (TI 800 x 800 in dewar #8) with the 3-meter and CAT, respectively. Differences in the two measurements (made on separate nights) result from differences in seeing and transparency, plate scale, guiding, and the conditions of the telescopes' optical coatings.

The CAT's advantage can be accounted for in two ways: recently renewed coatings and a more favorable plate scale. The latter is a considerable advantage under average Mt. Hamilton seeing conditions. CAT observers can expect a comparison with the 3-meter substantially better than the 25:1 predicted by aperture alone. I measured a ratio of 17:1 at the time of these throughput tests, using the widest possible aperture; even more favorable ratios have been reported using normal slit sizes.

The quantum efficiencies of different chips will vary, particularly in the blue, but the two TI chips are roughly comparable, exhibiting QEs of about 65% in the red and 45% in the blue. A quantitative measure of the efficiency of the Ford 2048 x 2048 chip has not been made with the Hamilton, but its overall response is known to be lower than the TI chips. Lloyd Robinson reports QEs for the Ford chip of about 45% in the red, and 20% in the blue. (At present, the Ford chip is an unthinned, front-illuminated, phosphor coated device. When thinned chips become available, their efficiencies are expected to equal or surpass the thinned TI chips.)

These plots are intended to serve as broad guidelines for planning observations. Note, however, that the slit and decker used here were much larger than typically used with the Hamilton, and that the measurements were made on blaze.

A complete account of the observations and reductions may be found in the *Hamilton Notebook* in the readout room.

THROUGHPUT:TELESCOPE+SPECTROGRAPH+DETECTOR

FIRST NUMBER IN EACH COLUMN IS WAVELENGTH, SECOND IS % THROUGHPUT

3-METER						CAT					
9523	0.86	5890	5.69	4264	4.29	9523	0.86	5890	7.24	4264	6.35
9367	0.97	5830	5.71	4232	4.20	9367	0.95	5830	7.36	4232	6.27
9216	1.25	5771	5.71	4201	4.07	9216	1.30	5771	7.22	4201	6.10
9069	1.36	5714	5.72	4171	3.91	9069	1.35	5714	7.25	4171	5.86
8928	1.51	5657	5.79	4140	3.91	8928	1.51	5657	7.31	4140	5.94
8790	1.56	5602	5.78	4111	3.63	8790	1.64	5602	7.31	4111	5.45
8657	1.60	5547	5.76	4081	3.54	8657	1.68	5547	7.28	4081	5.44
8528	1.85	5494	5.71	4052	3.49	8528	1.90	5494	7.18	4052	5.31
8403	1.96	5442	5.72	4024	3.24	8403	2.00	5442	7.22	4024	4.94
8281	2.06	5390	5.77	3996	3.01	8281	2.15	5390	7.34	3996	4.58
8163	2.16	5340	5.74	3968	2.44	8163	2.20	5340	7.31	3968	3.87
8048	2.46	5291	5.73	3941	2.27	8048	2.55	5291	7.31	3941	4.01
7936	2.60	5242	5.82	3914	2.04	7936	2.73	5242	7.58	3914	3.52
7827	2.81	5194	5.83	3887	1.63	7827	2.96	5194	7.58	3887	2.93
7721	3.05	5148	5.78	3861	1.54	7721	3.22	5148	7.57	3861	2.74
7618	3.00	5102	5.77	3835	1.22	7618	3.15	5102	7.57	3835	2.22
7518	3.38	5056	5.74	3809	1.16	7518	3.65	5056	7.54	3809	2.06
7420	3.57	5012	5.63	3784	1.04	7420	3.87	5012	7.39	3784	1.85
7325	3.72	4969	5.58	3759	0.94	7325	4.07	4969	7.39	3759	1.65
7233	3.82	4926	5.42	3734	0.85	7233	4.29	4926	7.26	3734	1.52
7142	3.94	4884	5.35	3710	0.78	7142	4.34	4884	7.14	3710	1.37
7054	4.05	4842	5.34	3686	0.78	7054	4.52	4842	7.17	3686	1.45
6968	4.23	4801	5.24	3663	0.75	6968	4.77	4801	7.16	3663	1.41
6884	4.33	4761	5.19	3639	0.74	6884	4.90	4761	7.01	3639	1.41
6802	4.61	4722	5.17	3616	0.73	6802	5.27	4722	7.04	3616	1.46
6722	4.77	4683	5.04	3594	0.72	6722	5.47	4683	7.03	3594	1.44
6644	4.79	4645	4.82	3571	0.69	6644	5.71	4645	6.79	3571	1.44
6568	5.09	4608	4.81	3549	0.66	6568	5.97	4608	6.72	3549	1.40
6493	5.11	4571	4.72	3527	0.61	6493	6.03	4571	6.85	3527	1.33
6420	5.28	4535	4.84	3505	0.57	6420	6.29	4535	6.89	3505	1.31
6349	5.30	4499	4.85	3484	0.52	6349	6.40	4499	6.86	3484	1.23
6279	5.42	4464	4.73	3463	0.46	6279	6.64	4464	6.74	3463	1.13
6211	5.56	4429	4.45	3442		6211	6.86	4429	6.42	3442	1.01
6144	5.79	4396	4.50	3421	0.35	6144	7.04	4396	6.52	3421	8.85
6078	5.59	4362	4.47	3401	0.24	6078	7.13	4362	6.48	3401	7.59
6015	5.69	4329	4.30	3381	0.19	6015	7.17	4329	6.26	3381	5.35
5952	5.71	4296	4.33	3361	0.15	5952	7.16	4296	6.40	3361	4.34

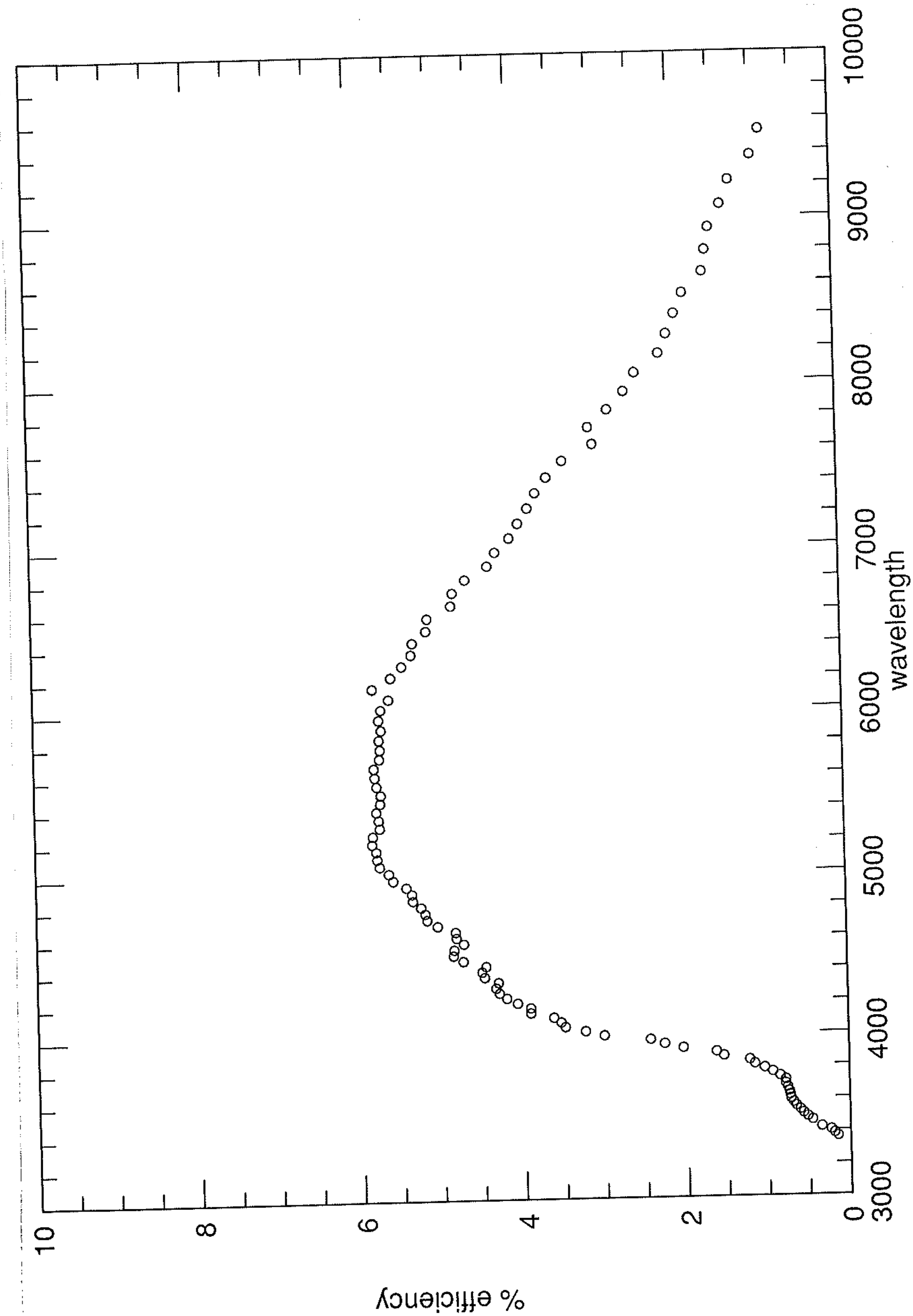


Fig. 15a Throughput: 3-m + Hamilton + Dewar #8

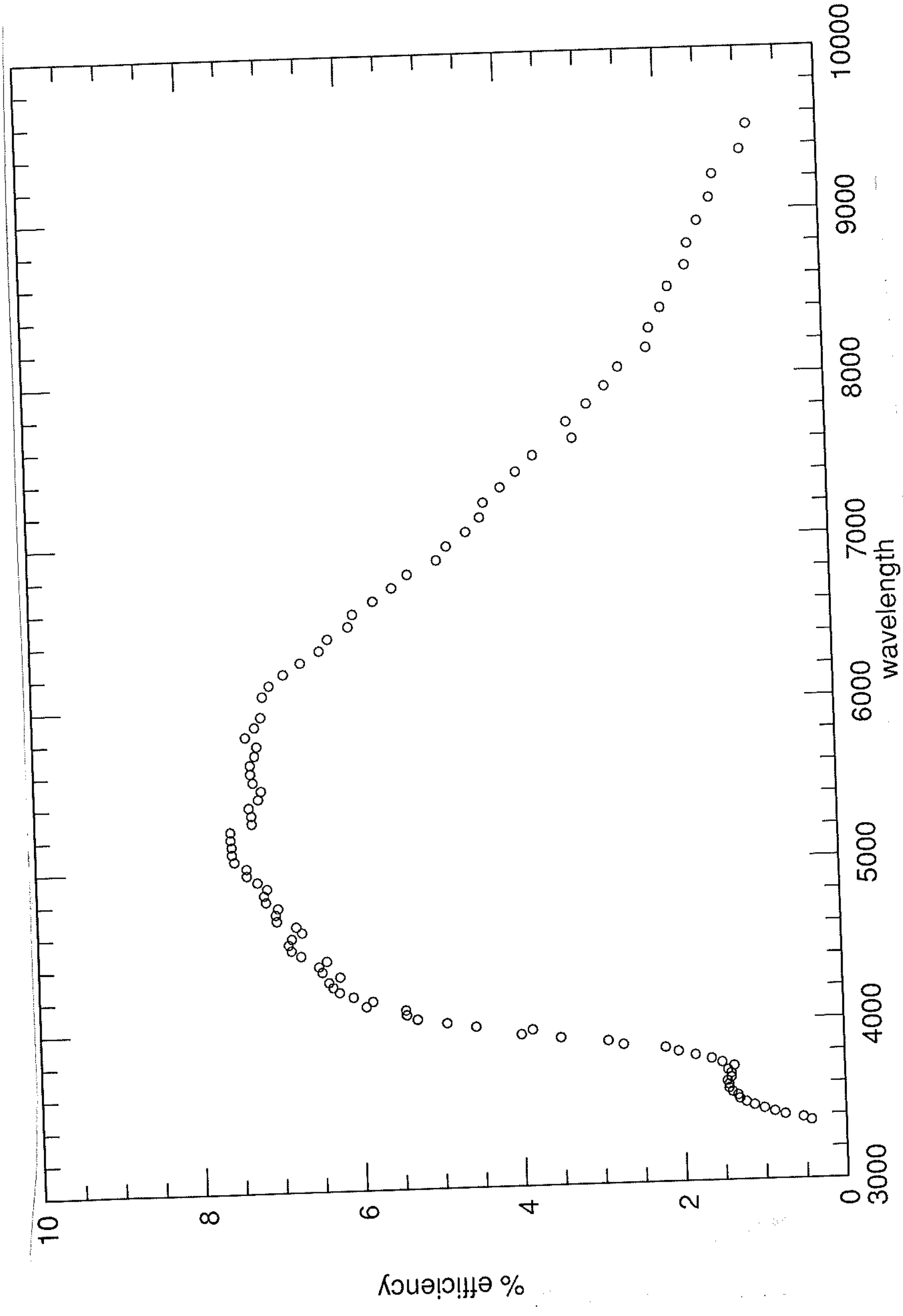


Fig. 15b Throughput: CAT + Hamilton + Dewar #8

C: Special Considerations for Low S/N Observations

As the Hamilton's limiting magnitude is approached, you must begin to consider contributions from sources that may be ignored for brighter targets. Observation and reduction techniques can address these issues. Many are discussed in greater depth in *The VISTA Cookbook,* a copy of which is kept in the readout room. A few suggestions follow. New ideas are welcomed.

Readout Noise Readout noise is independent of integration time and light level. At low exposure levels, it becomes a significant factor. Its contribution may be decreased with on-chip binning. This option (selection "E" in the data-taking program) sums groups of adjacent pixels. The resulting "composite" pixel will have the readout noise of a single pixel (see the Detector Data Sheets for a particular detector's characterisitc readout noise). Thus, 2 x 2 binning, for example, will decrease the total readout noise by a factor of four. The advantage of binning is bought at the price of decreased sampling and of multiplying the impact of defects by the binning factor (e.g., a cosmic ray in a single pixel will ruin four pixels when binning is 2 x 2).

Note that as of this writing dewar #13 cannot be binned horizontally.

Dark Current Dark current is proportional to integration time and dependent on temperature and on the recent exposure history of the chip. A chip that has had prolonged exposure to room or daylight may exhibit a slightly elevated dark current for hours or even days.

Dark calibrations may be made to establish the level of dark current for later subtraction (see the Detector Data Sheets for a particular detector's characterisitc dark current). Darks may be cautiously scaled to match longer exposures (see *The VISTA Cookbook,* p. 20), however, dark current in some pixels may not increase linearly with time.

Charge Transfer Efficiency Charge transfer efficiency is the measure of a CCD's ability to move electrons from one pixel to the next during readout. It varies from device to device and from place to place on a given chip. Like dark current, it is temperature dependent, but in the opposite sense, with efficiency decreasing at lower temperatures.

Poor transfer efficiency means that a substantial amount of a pixel's charge is left behind during readout. It is characterised by a slight smearing of spectral features in one direction along rows and one along columns. It can be seen as a trailing asymmetry in emission line profilies. In the case of our Hamilton chips, the trailing occurs to the right and downward, as seen on the image display screen.

At very low light levels, the charge not transferred can be a significant proportion of the total, compromising efficiency and resolution.

Residual Charge CCDs do not erase all traces of a previous exposure. While our chips have been adjusted to reduce residual charge as much as possible, it is nonetheless advisable, particularly in the low light-level regime, to avoid overexposing the chip for several hours prior to beginning observations.

On this account, it is best to make the necessary trips to the camera room in the early afternoon. If possible, calibration exposures should be made as long in advance of observations as is practical.

As an aid to clearing the chip of residual charge, it may be left in a continuous readout mode when not in use (selection "Z-4-A" in the data-taking program).

Sky At f_{36}, the background sky makes only a small contribution, but, for lengthy exposures of faint objects, it is significant, particularly at the wavelengths of natural and artificial sky lines, and when the moon is a factor.

Echelle geometry requires the use of a relatively narrow decker (see "Selecting Slit and Decker") to limit the vertical extent of the slit. It is thus nearly impossible to obtain a sky spectrum, uncontaminated by light from the target, simultaneously with the target spectrum. Independent sky observations are therefore necessary if sky subtraction is to be performed.

Fixed Pattern Very low-level patterns (2 to several electrons) appear on our images, probably due to 60-cycle interference.

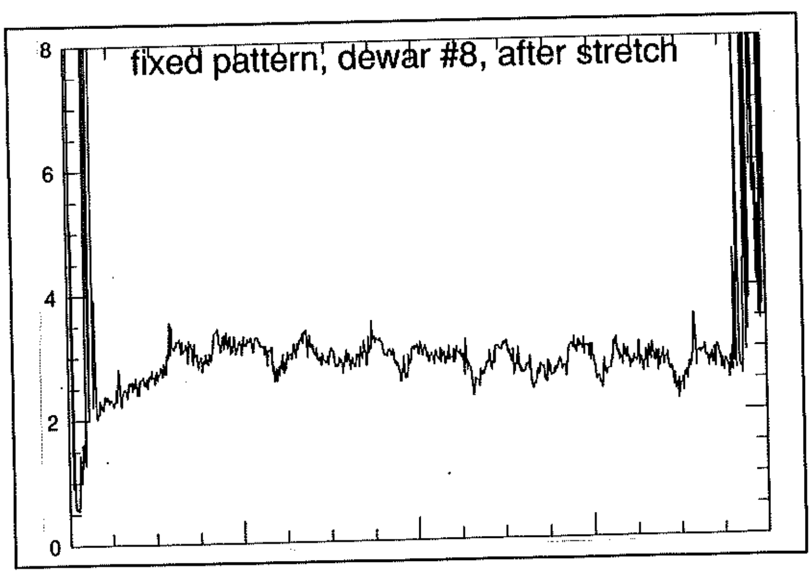


Fig. 16 Fixed Pattern after Extraction Column number is given along the x-axis, intensity in DN along the y-axis. The spikes at either end of the lot are due to hot columns on the chip. (1-sec. dark, dewar #8)

Fixed pattern may be extracted and removed along rows in the following manner. Make a 1-second dark on a quiet chip. Adjust for the baseline and mash all the rows in the image into a single row (VISTA commands "bl" and "mash"). Divide the resulting one-dimensional array by the number of rows mashed, and stretch the quotient back out to the size of the original two-dimesional image (VISTA commands "divide" and "stretch"). The new frame now contains a properly scaled map of the fixed pattern in the dispersion direction, and may be subtracted from your observations. See *The VISTA Cookbook*, p. 25.

Cosmic Rays The number of cosmic ray hits for a given exposure is proportional to the integration time. The strengths and shapes of the hits will vary. The thicker Ford 2048 x 2048 chip is more susceptible to cosmic ray hits than are the TI devices.

Cosmic ray hits may be largely accounted for by dividing the observation into two separate exposures and filtering the resulting frames. However, making two exposures will double the readout noise. VISTA's "zap," or "tvzap," functions may be used to remove hits interactively (see *The VISTA Cookbook*, p. 34).

A Good, Dark Basement While much black tape has been expended in and around the camera room, light leaks can still occur. The best insurance against wandering photons is a good, dark basement.

Stray light has been detected on very long integrations, but its source is not exactly known. It is wise to err on the side of caution, turning off all basement lights, including the red lights over the camera room door and in the pit (recall that red lights are fine for preserving the eyes' dark adaptation and for protecting blue sensitive photographic emulsions, but shine in a CCD's most sensitive wavelength region).

Offset Guiding Most objects within the Hamilton's grasp are bright enough for the autoguider to guide on directly. However, on the rare occasions that offset guiding is necessary (or if you are seeking resolution along the slit on a long observation), the image rotator must be used. Its purpose is to compensate the rotation of the coudé field. If you anticipate needing the image rotator, contact one of the suppport scientists in advance.

D: Director's Memo re Clean-Room Policy

October 7, 1988

TO: Shane 3-meter Telescope Coude Users

FROM: Robert P. Kraft, Director

SUBJECT: "Clean-room" Policy for the Camera Room

Considerable dust build-up has been observed in the heavily travelled areas of the coude camera room. In order to stay the flow of dust, we ask your cooperation in returning to the following clean-room practices:

1. Clean shoes with the electric shoe brush located just outside the camera room door.

2. Put on a labcoat before entering.

3. Observe "air-lock" procedure (i.e., wait for the outside door of the anteroom to close before opening the inner door).

E: Coudé Filter List and Flat-field Plots

The following filters are kept in the coudé as of this writing. They may be found in the user filter wheel, or in one of two wooden filter boxes in the slit room, either in standard Lick filter holders or in labeled envelopes. The characteristics of most are given in graphical and tabular form in *Optical Glass Filters*, published by Schott Glass Technologies Incorporated, a copy of which is kept in the readout room. Please take particular care to return filters to their proper envelopes, relabel filter holders if necessary, and always update the contents of the filter wheel on the Hamilton controller terminal following any changes.

All filters are 2-mm x 2 x 2-inches unless otherwise noted. Note that the numerical designation of neutral-density filters does not correspond to their transmittance. They are listed here from most to least transmitting. A trace for each neutral-density filter is given on p. 132 of *Optical Glass Filters.*

UG 1
UG 5
UG 5 (1-mm)
UG 11 (1-mm)

BG 3 (1-mm)
BG 12
BG 13
BG 14
BG 18
BG 24
BG 25
BG 38

GG 495 (1-mm)

OG 4
OG 550 (1-mm)
OG 515

RG 630
RG 695 (1-mm)

NG 11
NG 4 ? (1-mm)
NG 4
NG 9 ? (1-mm)
NG 3
NG 9
NG 10

KG 1
KG 2

KV 418 (3-mm)
KV 470 (3-mm)
KV 550 (3-mm)

Wr 88A (4-mm)

copper sulfate (1 x 2 x 0.5-in.)
detector trimmer (0.5-mm)
cyan dichroic
blue dichroic (1 x 2-in.)

As has been noted, no perfect solution to flat-fielding over the Hamilton's broad bandpass has been found, and probably none exists. Various recipes have, however, been devised which produce good results. Please record your good ones in the *Hamilton Logbook.*

One may chose to make a single filtered or unfiltered flat, perhaps repeating it several times to accumulate signal at some wavelengths; to make separate exposures through two or more filters, adding them later to even out the intensity; or to use several filters during a single exposure, pausing the integration while changing filters. A few examples of the latter two approaches are illustrated below.

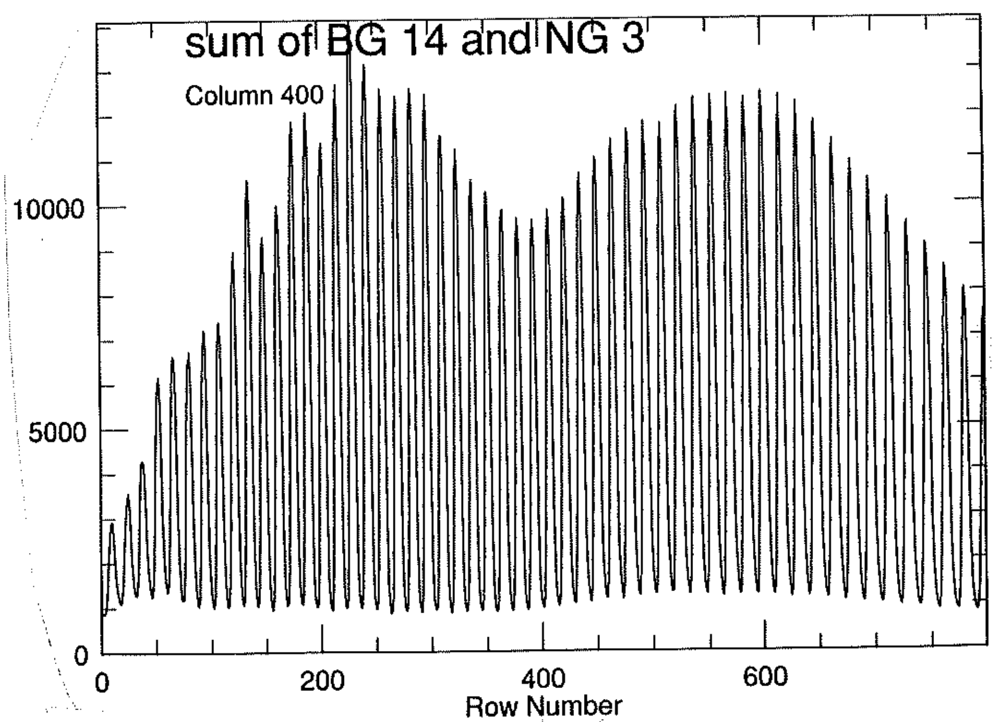


Fig. 17a BG 14 and NG 3 in ratio 1:3--coverage approx. 9500Å-5150Å (TI 800^2)

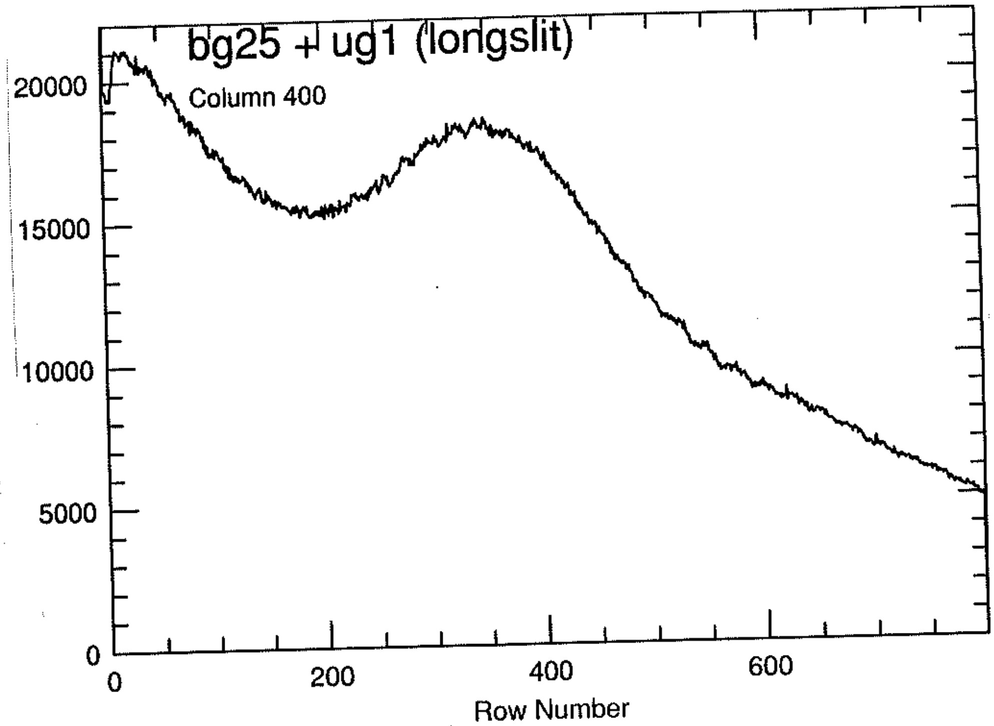


Fig. 17b BG 25 and UG 1 in ratio 1:8 --coverage approx. 4400Å-3550Å (TI 800^2)

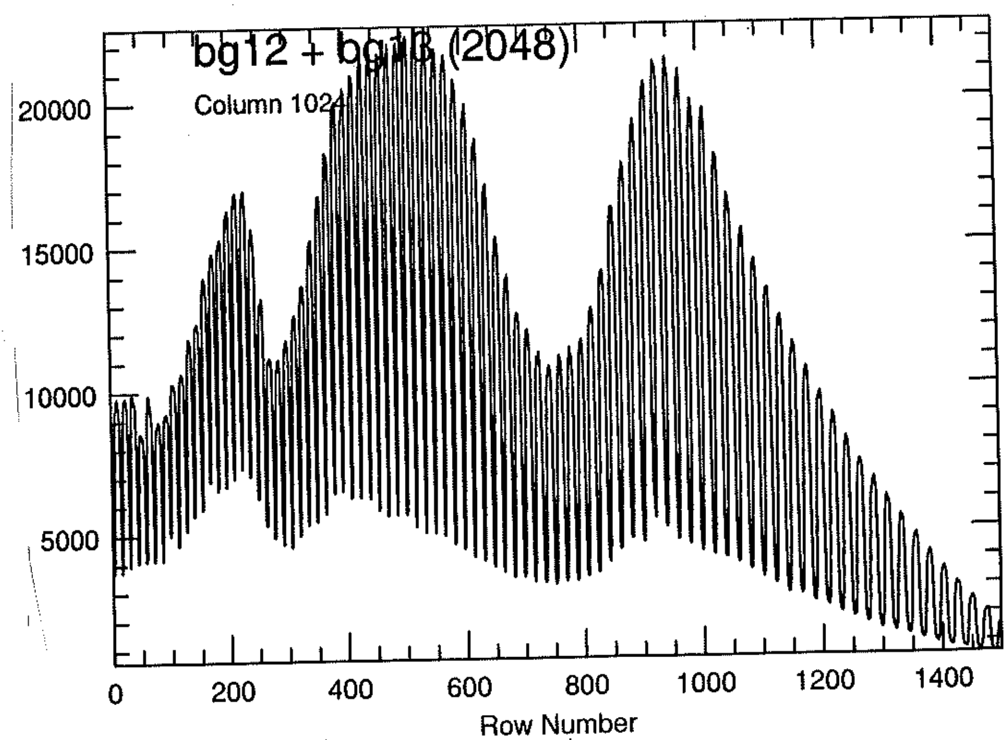


Fig. 17c BG 12 and BG 13 in ratio 11:1--coverage approx. 8900Å-3800Å (FA 2048^2)

F: The High-Resolution Retrofit

Developed by Mary Beth Kaiser and Harlan Epps (both then of UCLA), the High Resolution Retrofit uses the Hamilton's collimator and echelle grating but intercepts the beam before it reaches the cross-dispersing prisms. Two flat mirrors redirect the dispersed light to the 80-inch camera (used, in this case, without its Schmidt corrector), which focuses it onto a detector (dewar #3, as of this writing).

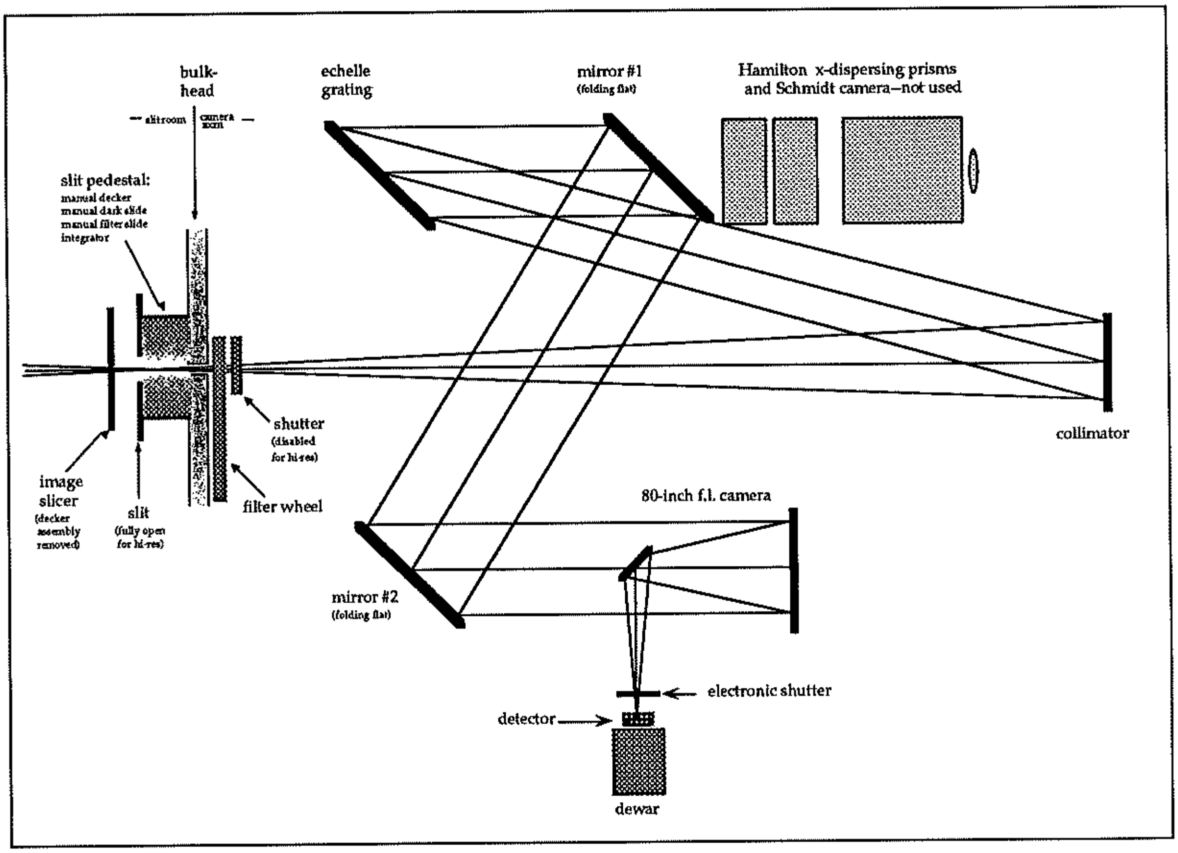


Fig. 18 The High Resolution Retrofit Note that dimensions and angles are not to scale.

In the absence of cross-dispersion, order separation is accomplished with a narrow-band interference filter placed near the slit. Since only one order is observed at a time, slit height need no longer be restricted, and the decker is removed. An image slicer may be installed to increase throughput.

The Retrofit provides increased resolution at the price of spectral coverage and throughput. A complete manual for the instrument is expected to appear. When it does, a copy will be kept in the readout room.

G: The Hamilton Format Program

A program which graphically shows the relationship of the 800 x 800 CCD to the Hamilton spectral format was written by Steve Allen to run on the workstation. It was intended to provide settings for given wavelength regions as an aid to navigating the format. However, it is not updated to account for changes in the spectrograph and is thus unreliable as a source of settings. Nevertheless, it contains other useful information, such as central wavelengths, dispersions, and order numbers, in a graphical form. The program also gives a nice, visual sense of chip and format, and is fun to use. Much of the same data are also available in tabular form; see the Table of Orders following the main body of the text.

With the mouse, click on the "Hamilton_format" icon. You will be prompted for a terminal type; enter **7** (for the ISI workstation). Push "return" when asked for the name of a wavelength list. Half the screen will fill with part of a new window. Put the cursor in the bar along the top of that window, hold the left button and move the mouse left. The window will expand to fill the whole screen. In it you will see the Hamilton format portrayed with red to the top and right, as it is seen on the image display screen.

With the cursor placed inside the format, a click on the left mouse button will give the following information with respect to the current cursor postion: wavelength at cursor position, order number, blaze wavelength of that order, dispersion, in angstroms mm^{-1}, vertical seperation of orders in millimeters, distance from the blue end (3000Å, m = 190) in millimeters, and the length of the current order in millimeters. These numbers are independent of changes to the chip and dewar.

The right and middle buttons of the mouse both draw the 800 x 800 TI CCD as a box projected, to scale, on the format. The box may be dragged around the format by holding either of these buttons and moving the mouse. When the button is released, numbers for height and tilt (grating rotation) will appear. These numbers are not only approximate, as the program warns upon entry, but are probably completely wrong. However, the projected chip permits fairly accurate estimates of total coverage in any part of the format.

To return to VISTA without stopping the format program, move the cursor to the bar at the top of the window, hold the center button, and select "back" from the pull-down window. To return to the program, simply click the right button with the cursor in the format program's window. To stop the program, click the right mouse button with the cursor on the tombstone at the upper left corner of the window.

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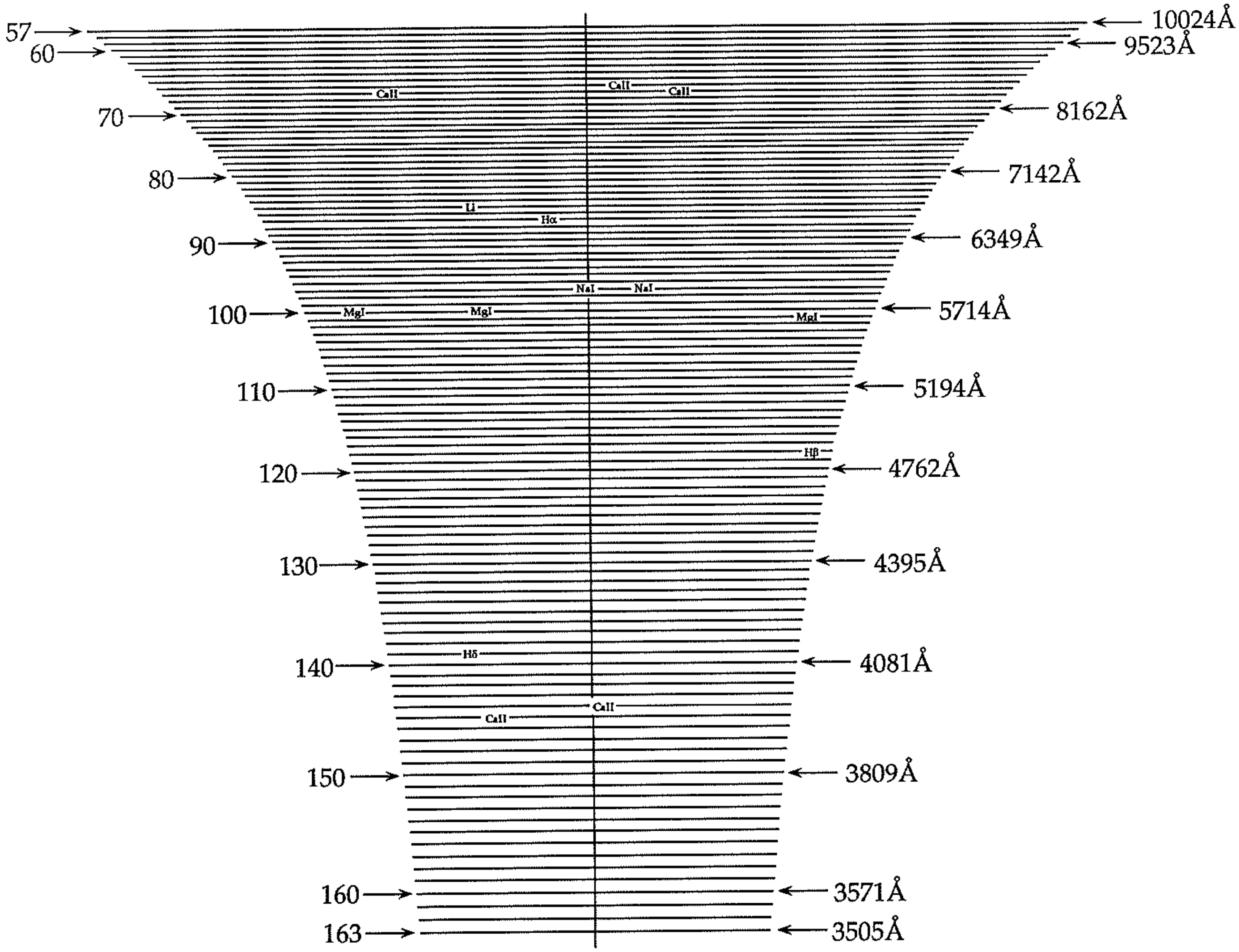
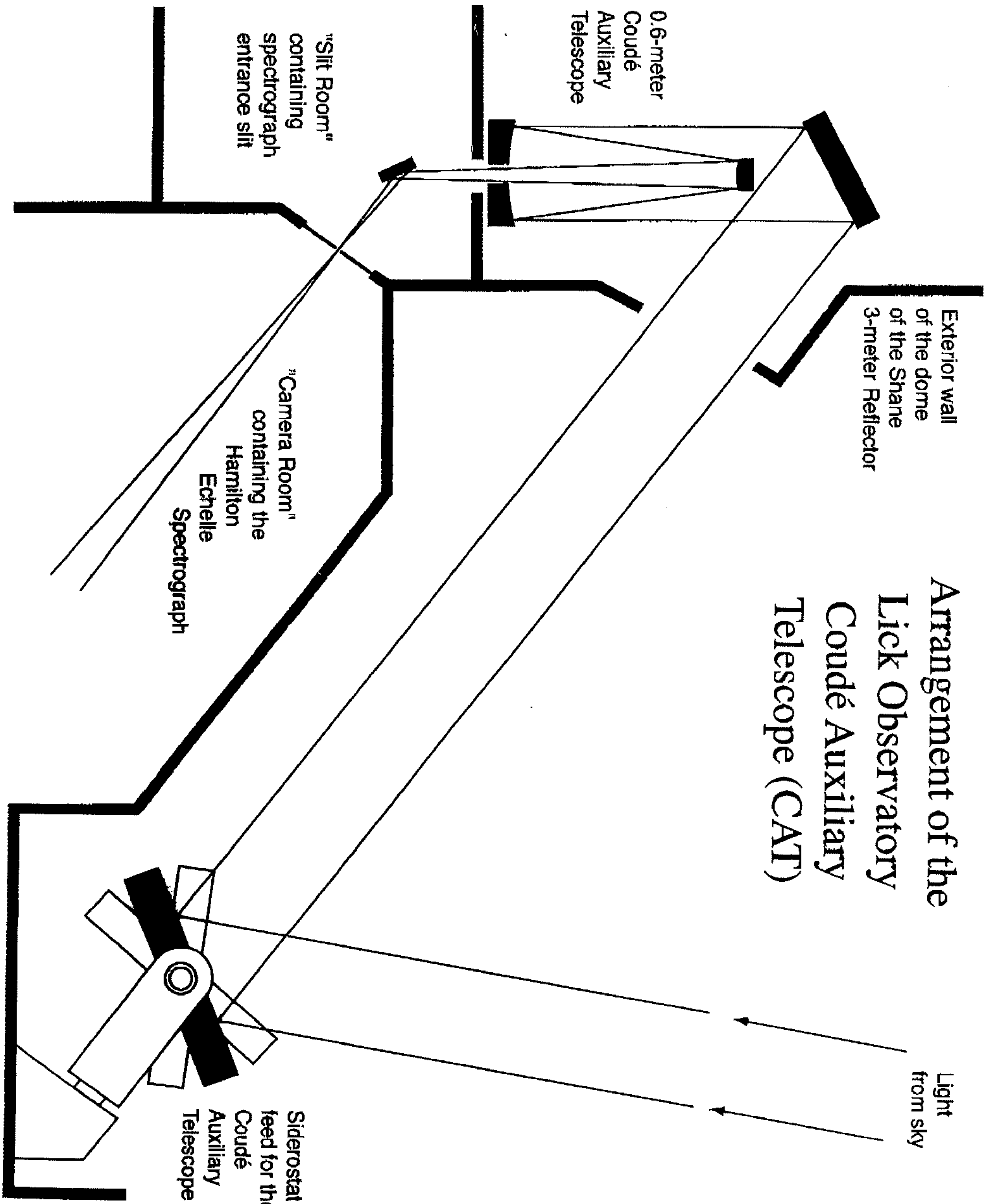
The Hamilton Spectral Format from 3500Å to 1000Å



The illustration is intended to be used with the overlay included with this manual. Order numbers are given on the left, central wavelengths on the right. Longer wavelengths are toward the right in each order.

Lengths and separations of orders are approximately to scale. An order's length represents its free spectral range. Note that the orders' intrinsic curvatures are not shown.

Some important features are shown at their primary positions. They may appear again, beyond the free spectral range, in an adjacent order.


Arrangement of the Lick Observatory Coudé Auxiliary Telescope (CAT)
0.6-meter Coudé Auxiliary Telescope
"Slit Room" containing spectrograph entrance slit
Exterior wall of the dome of the Shane 3-meter Reflector
"Camera Room" containing the Hamilton Echelle Spectrograph
Light from sky
Siderostat feed for the Coudé Auxiliary Telescope