THE REVISED GOLD CAMERA USER'S MANUAL

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Abstract

The Gold Camera is the CCD spectrometer on the Gold Spectrograph at the Kitt Peak 2.1-meter telescope. The system uses a Ford 3Kx1K CCD with 15 micron pixels. Using a set of thirteen reflective gratings, it provides resolutions ranging from 1-15 Angstroms and spectral coverage from about 3300Å to 1-micron. The maximum spatial coverage is 5.1 arc-minutes at a scale of 0.78 "/pixel.

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1 System Overview

The Gold Camera is the CCD spectrometer for long slit or stellar spectroscopy ($1 - 15\AA$ resolution) on the Gold spectrograph at the KPNO 2.1-meter telescope.

The camera itself is a semi-solid f/1.25, 190mm focal length three-component meniscus type. The slit demagnification factor is 4.3, producing a spatial scale of $\approx$0.78 arc-seconds/pixel on the chip. A description of the basic design ("E") by Wynne can be found in **MNRAS**, 157, 403,1972. Several modifications to this camera permit the use of a CCD. The last element of the camera has been replaced with a combination field flattener and dewar window. To optimize the performance at $3800\AA$, a new front meniscus lens was also constructed. This system has been designed to hold CCDs up to two inches square (with the capability to mount the chip off-center if only parts of the chip are good). The CCD is permanently mounted behind the camera (like the KPNO Cryogenic Camera and the CTIO Air Schmidt).

The CCD detector, labeled F3KC, was installed in the GoldCam in February 1992. It is a Ford chip with 3072 columns and 1024 rows. The pixel size is 15 microns making the physical length of the chip 45 millimeters. This is a good match for the spectrograph optics which were originally designed to feed a 40mm image tube. The chip is oriented such that the red end of the spectrum falls at low pixel numbers. Spatial scale on the chip is 0.78 arc-seconds/pixel. The entire five arc-minute slit length is usable with a slit demagnification of $\approx$4.3. Due to the camera design, the central 1.3 arc-minutes are unvignetted, but response falls off linearly to about 75% at either edge (25% vignetting). The plate scale of the 2.1-meter telescope is 12.7 arcsec/mm (79μ/arcsec). Figure 1 is an optical view of the spectrograph.

CCD data observations are taken with a SPARC 10-30 workstation called LAPIS. Lapis uses the IRAF Control Environment (ICE) for data acquisition, reduction and display of the data. Open Windows is the interface to the observer. The user also has access to several other functions, such as SNAPSHOT, MOSAIC, and WEATHER. Lapis has 5 GB of disk storage. In additional there are tape facilities for Exabyte, DAT, and nine-track.

Software exists within IRAF to reduce GOLDCAM data. Available documentation includes: *A User's Guide to Reducing Slit Spectra with IRAF* and *Guide to the Slit Reduction Task DOSLIT*. Other documents that will be found useful are *User's Guide to CCDRED* and Phil Massey's *A User's Guide to CCD Reductions With IRAF*. Although it is somewhat out of date the cookbook *Reduction of Longslit Spectroscopic Data Using IRAF* may be of some use. These manuals may be found in the IRAF Documentation Room downtown or can be viewed via *MOSAIC*..

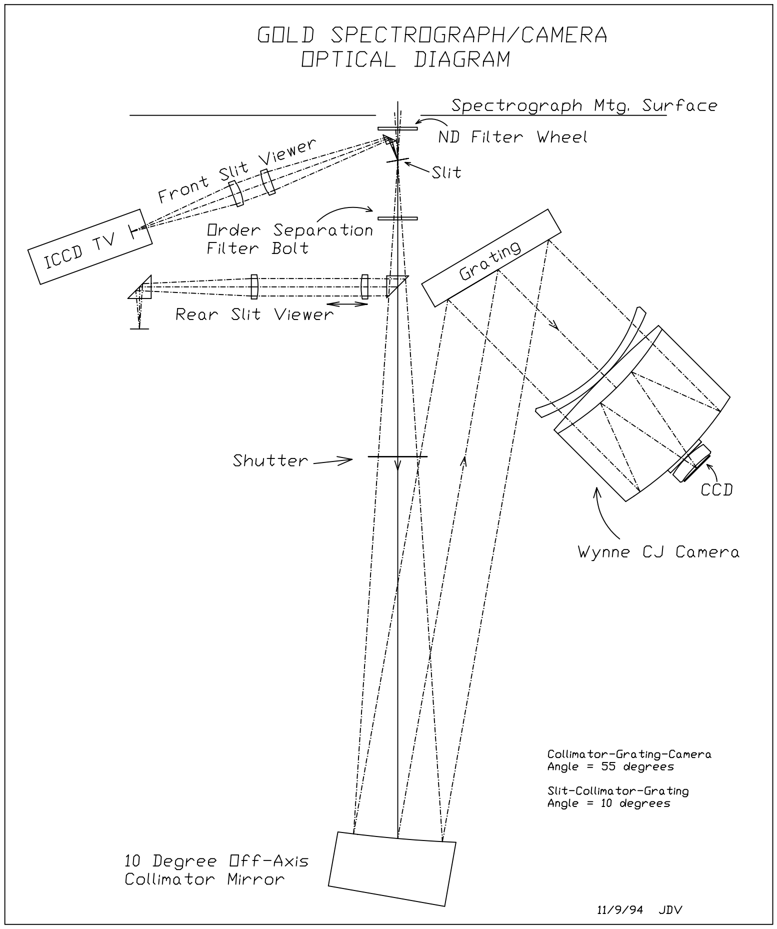

Figure 1: GCAM Spectrograph Optical Diagram

2 System Performance

Figure 2 shows the measured throughput for the system using the old Texas Instrument chip. The throughput with the Ford chip should be significantly better at all wavelengths, ($\approx 20 - 50\%$). The ordinate gives the fraction of photons striking the primary mirror that

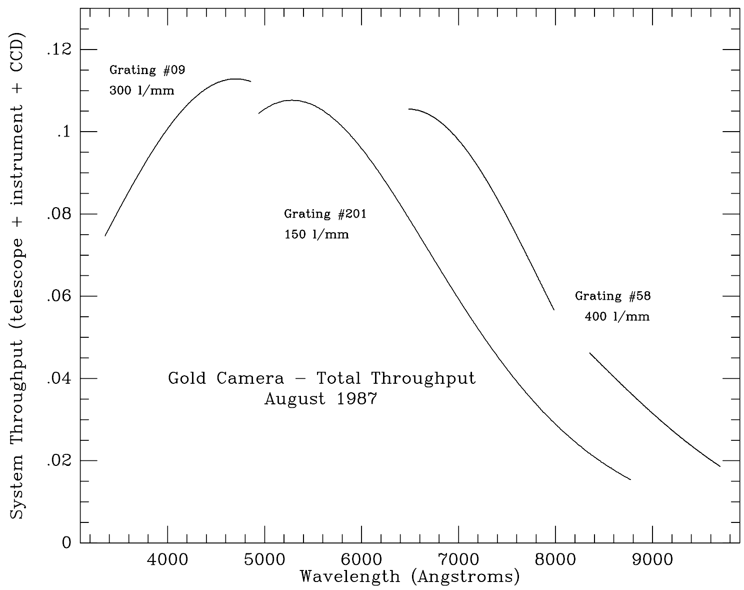

Figure 2: System Measured Throughput, TI-5

are detected by the CCD. These measurements were made with the old TI chip by observing Gunn & Oke standards through a very wide slit ($\geq$ 11”). The falloff in the UV is mostly due to transmission losses in the camera, while the loss of response towards 1 micron reflects the decreasing sensitivity of the TI CCD and the difference in blaze of the gratings used. A practical working wavelength limit is $\approx 9700\mathring{A}$.

Figure 3 shows the count rate expected at the zenith for a 10th magnitude star observed with several gratings using the old TI5 chip. Again, these refer to measurements taken with a very wide slit ($\geq$ 11”). Observed flux through a narrow slit will depend critically on seeing.

The expected count rate can be computed from the above curves and the number of photons per Angstrom per second incident on the 2.1-meter primary mirror. The equation below gives the number of photons/sec/Å, N_λ for a star of magnitude $m(\lambda)$ and an extinction loss of $A(\lambda)$ magnitudes for the 2.1-meter telescope. λ in Å.

$$N_\lambda = \frac{2.0 \times 10^{11}}{\lambda}\ 10^{-[(m(\lambda)+A(\lambda))/2.5]}$$

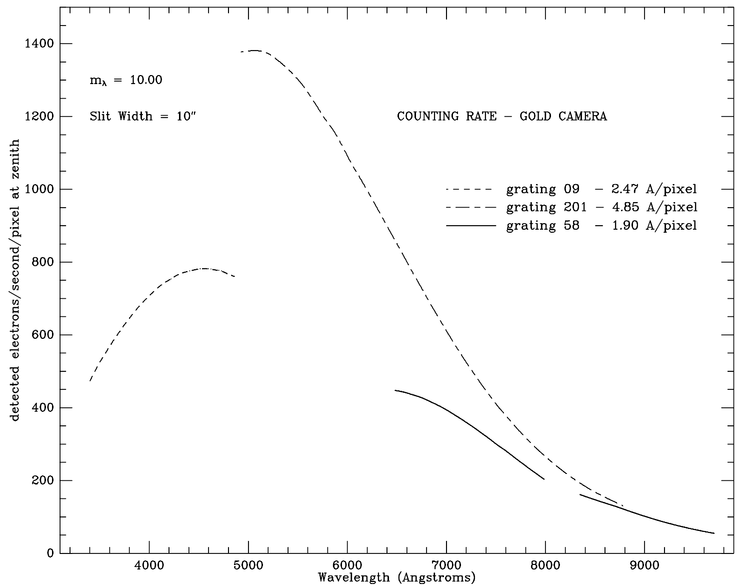

Figure 3: 10th Magnitude Star Count Rate with TI5

A star of $m(\lambda) = 15.0$ will illuminate the primary with $\approx$37 photons/second/Å at 4500$\AA$ at the zenith (extinction at 4500$\AA \approx 0.2$). For more discussion see the end of the paper by Massey, Strobel, Barnes, and Anderson **Ap.J.** 328 ,315,1988.

Finally, differential atmospheric refraction is non-negligible when observing in the UV with a narrow slit. For example, when working at an airmass of 2.0, there can be a displacement of 2 arcseconds between images at 4000$\AA$ and 8500$\AA$. The spectrograph slit can be rotated to the parallactic angle to reduce refractive effects, but there is non-negligible overhead in spectrograph rotation (done manually).

3 The Gold Spectrograph

Originally called the Image-Tube Spectrograph, this instrument has been the workhorse at the 2.1-meter telescope since it was built in the early 1970's. First used by Dr. Roger Lynds for his pioneering work on QSO's, it has been used with Carnegie image tubes in combination with photographic plates, in recent years with the IIDS and now with the Gold CCD Camera. The design is the classic off-axis collimator (4-inch point source beam diameter) feeding a 5x6-inch plane reflectance grating and a catadioptric camera that is an integral part the CCD dewar assembly. With the exceptions of the shutter and CCD, the entire spectrograph is manually operated.

3.1 Spectrograph Rotation, Auto-Guider and Telescope Limitations

The spectrograph can be rotated +/- 90 degrees from the default EW slit position. This must be done by hand while the telescope is at the zenith. The telescope operator is responsible for this operation to ensure that it is done in a safe manner and that the clamps are securely fastened. The position angle readout is in degrees using the classical definition (NS slit is zero degrees with increasing PA going from N towards E). Normally about ten minutes is required to change the position angle and rearrange the instrument cables during the night.

The telescope is equipped with an automatic guider capable of guiding on stars of magnitude

$$9 \leq V \leq 13.$$

Guide star coordinates are found using a special program, *gstar*, on the SUN workstation that searches on-disk AGK2/SAO catalogues or the ST Guide Star List on CD-ROM. The telescope operators will find guide stars and the observer need **not** pre-select guide stars. Full capabilities exist to electronically transfer object coordinates to the telescope control computer from outside the Observatory. Observers can email their coordinate lists to coords@noao.edu. See Appendix II. Contact Dave Summers (Internet: summers@noao.edu) for details.

The guider also contains a quartz lamp and HeNeA combination for calibration of spectra. The lamps and ND filter wheels are fully integrated into the TCS (Telescope Control System) software, using a graphical user interface (GUI).

3.2 The Slit, Deckers, and Acquisition TVs

The slit is 25mm long and the entire projected length falls on the CCD. A millimeter micrometer sets the slit width with typical widths varying from 75 to 250 microns at a scale of 79 microns per arcsecond. *Reading the micrometer can be tricky - note that the first 5 indicates 50 microns .* It is also **recommended to set the width going toward smaller numbers**, to avoid sticky-slit problems. A Philips ICCD TV camera views the central 3 arcminutes of the slit at all times off the tilted slit jaws. An integrating video memory, "leaky memory", permits integration of the video signal. Under good conditions, stellar objects of V $\approx$ 18.0 can be seen with several seconds of integration. Programs requiring acquisition of objects fainter than 18.5 should come prepared with offsets to ensure success. There is also a wide field TV ($\approx$5') available at an auxiliary port on the automatic guider.

The decker available for controlling the slit length are listed in Table 1. Scattered light may be an important consideration for some long slit problems. The decker will reduce the overall amount of light getting into the spectrograph. Also on the decker is a series of small holes for examining the spatial focus when high dispersion gratings are used.

3.3 Spectral Resolution and Slit Width

Figure 4 is a conservative estimate of the trend of resolution or FWHM (full-width at half-maximum) versus slit width for the instrument. The spatial scale is $\approx$**0.78 arcsecs/pixel.**

Decker-Gold Spectrograph		
No.	Length(mm)	arcsecs
1	8	101
2	12	152
3	18	229
4	24	305

Table 1: Available Decker Sizes

It should be pointed out that there is a general trend of slightly poorer focus as one goes from the center of the field to the edge.

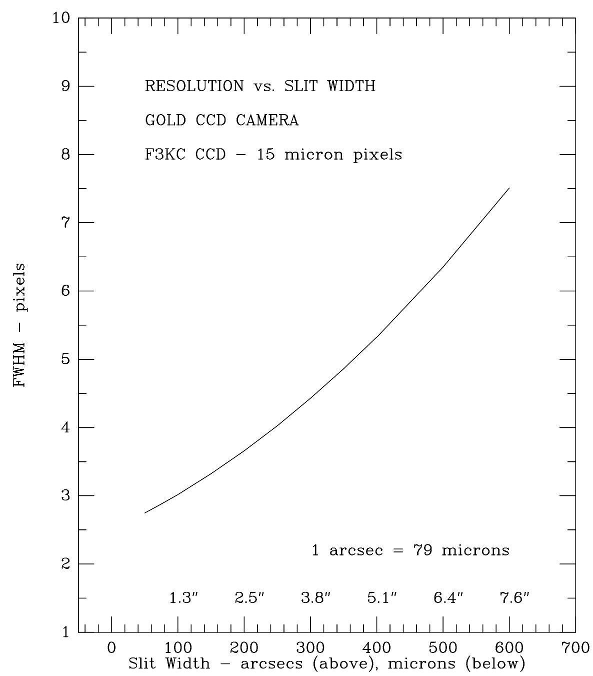

Figure 4: Resolution vs Slit Width

The procedure for slit width selection has been to try to match the projected slit width to the resolution of the detector with some consideration being given to the slit light losses. For spectrographs with significant collimator-to-camera angle ($\geq 15°$), such as the Gold spectrograph, the full expression for projected slit width should be used.

$$w = r(f_{cam}/f_{coll})W$$

Here w is the projected slit width, W the actual (physical) slit width, and r is the "grating anamorphic magnification". The factor r is a function of the grating tilt and collimator-camera angle, i.e.

$$r = cos(t + \phi/2)/cos(t - \phi/2)$$

where ϕ is the collimator-camera angle (55°) and t is the grating tilt. For the Wynne camera design, the camera-to-collimator focal ratio is ≈0.24 . At large grating inclinations the anamorphic demagnification factor becomes significant. In these cases the slit can be opened wider without degrading the resolution. See F. Schweizer's article **PASP** 91 , No. 539, 149, 1979 for more information.

Another factor, of lesser importance, for consideration at high grating inclinations is the grating fill factor, or that fraction of the light leaving the collimator that strikes the grating. As the grating tilt increases, a point is reached where the grating becomes overfilled and light is lost above and below the grating. This factor is also shown in Figure 5. Even at tilts as high as 5.00, the loss is only ≈9%.

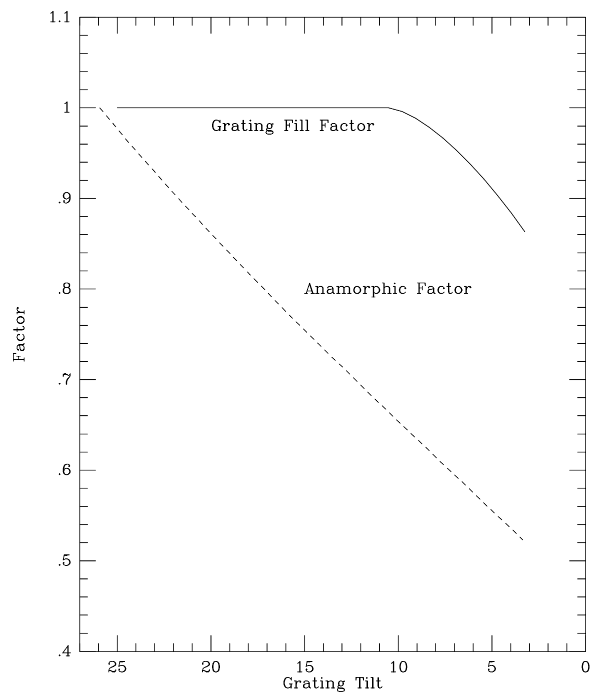

Figure 5: Anamorphic Magnification and Grating Fill Factors

3.4 Filters and the Shutter

Filters can be used in two places in the spectrograph:

- The upper filter wheel, located above the slit, contains neutral density filters (2.5, 5.0, 7.5 magnitudes of attenuation) and a clear position. If these filters are used for absolute or relative fluxes, they should be independently calibrated using standard stars. The filters are Inconel on a quartz substrate.

- The lower filter slide, located beneath the slit, contains the order separation filters. The filter dimensions are : 1.75 inches diameter and up to 8mm in thickness.

We have two interchangeable slides of order separating filters. Each of these slides has a positive lens in place for knife-edge focusing of the telescope with the rear slit viewing optics. Table 2 contains the current filter combinations available and a list of available filters.

Filter Bolts		
Position	Filter Bolt 1	Filter Bolt 2
1 (handle-end of bolt)	Knife-edge lens	Knife-edge lens
2	CuSO4 Crystal(8mm)	RG-610(2mm)
3	GG-420(2mm)	OG-550(2mm)
4	GG-495(2mm)	KG-3(2mm)
5 (Bolt out of light path)	Clear	Clear
Additional Filters		
Schott Glass	Schott Glass	Corning Glass
WG-1(WG-360)(2mm)	BG-1(1mm)	0-51(4mm)
WG-320(2mm)	BG-12(1mm)	3-75(2mm)
WG-345(2mm)	BG-38(1mm)	4-96(4mm)
GG-375(2mm)	BG-38(2mm)	
GG-385(2mm)	BG-39(2mm)	
GG-400(2mm)	OG-530(3mm)	
GG-420(3mm)	OG-570(2mm)	
GG-455(2mm)	RG-695(2mm)	
GG-475(2mm)		

Table 2: Order Separating Filters

Curves for the various Schott filters may be viewed on Internet by using the address http://www.noao.edu/kpno/filters.html. PLEASE NOTE THAT THE CRYSTAL COPPER SULFATE FILTER IS VERY SENSITIVE TO SUDDEN TEMPERATURE CHANGES AND SHOULD NEVER BE TAKEN FROM, SAY, THE COLD DOME INTO THE WARM CONTROL ROOM. The large difference in thermal expansion between the sulfate and the quartz cover plates can cause a shear fracture. Accordingly, the entire collection of order separation filters is kept in the old plate loading room in the dome. When you change bolts/filters please change the marking tape on the spectrograph so the filter positions are identified. Figure 6 is a transmission plot of the crystal CuSO4 filter.

The motorized shutter on the spectrograph is a modification of the original manually operated design and requires a noticeable time to open and close. The shortest exposure time possible with the mechanical shutter is 2 seconds (don't try 1 second - it leaves the shutter open requiring a manual reset). *minimum of 20 seconds is recommended if an absolute measurement of better than 1% is desired.*

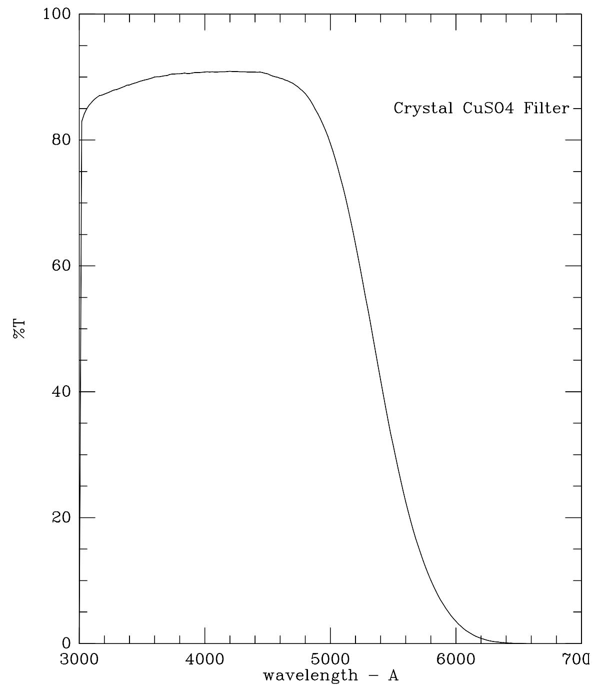

Figure 6: Transmission Plot of a Crystal CuSO4 Filter

3.5 Grating Data

Table 3 lists the gratings available. Gratings 32, 58, 35, 47, and 36 are often used in second order, while 56 has been used in both second and third orders. Grating no. 400 is silver coated for increased efficiency in the red. Efficiency curves for the gratings are reproduced in Figure 7. The 1200 line grating can not be used redward of about 8000Åbecause of mechanical limitations. Note that two copies exist of some rulings.

Since the CCD is sensitive over such a wide wavelength range, the use of order separating filters is imperative. Copper sulfate and a wide variety of Schott glasses are available.

The tilt of the different gratings are listed in the grating tilt Table 4. The tilt for zeroth order is 25.93 .

GRATING DATA - GOLD CAMERA+F3KC				
Grating	Lines/mm	Blaze λ (Å)	Å/pixel	Coverage (Å)*
201	150	5000	4.85	9700
250	158	3800	4.60	9200
400	158	6750	4.60	9200
09	300	4000	2.47	4940
32	300	6750	2.47	4940
58	400	8000	1.90	3800
240	500	5500	1.52	3040
26old	600	4000	1.24	2480
26new	600	4900	1.24	2480
35	600	6750	1.24	2480
56	600	11000	1.24	2480
47	831	8000	0.90	1800
36	1200	7500	0.62	1240
* 2000 usable pixels, First Order				

Table 3: Available Gratings

GRATING DATA - GOLD CAMERA					
Grating No.	201/250/400	09	32	58	240
Lines/mm	150/158/158	300	300	400	500
λ Blaze in Å	5000/3850/6750	4000	6750	8000	5500
dispersion Å/pixel - First Order	4.8/4.6/4.6	2.47	2.47	1.90	1.52
Wavelength Å	**Approximate Grating Tilt**				
3000		23.81	21.69(II)	20.33(II)	
3500		23.45	20.99(II)	19.39(II)	
4000	24.51	23.10	20.28(II)	18.45(II)	21.22
4500	24.34	22.75	19.57(II)	17.51(II)	20.63
5000	24.16	22.40	18.87(II)	16.56(II)	20.04
5500	23.99	22.05	22.05	20.80	19.45
6000	23.81	21.69	21.69	20.33	18.87
6500	23.63		21.34	19.86	18.28
7000	23.45		20.99	19.39	
7500	23.27		20.63	18.92	
8000	23.09		20.28	18.45	
8500			19.93	17.98	

GRATING - GOLD CAMERA					
Grating No.	26old/new	35	56	47	36
Lines/mm	600	600	600	831	1200
λ Blaze in Å	4000/4900	6750	11,000	8000	7500
dispersion Å/pixel - First Order	1.24	1.24	1.24	0.90	0.62
Wavelength Å	**Approximate Grating Tilt**				
3000	21.69	17.44(II)	13.20(III)	13.37(II)	6.83(II)
3500	20.97	16.02(II)	11.08(III)	11.28(II)	3.64(II)
4000	20.26	14.61(II)	8.96(III)	9.19(II)	
4500	19.55	13.20(II)	6.84(III)	7.09(II)	
5000	18.85	11.78(II)	11.78(II)	5.00(II)	
5500	18.14	18.14	10.37(II)	14.42	8.42
6000	17.44	17.44	8.96(II)	13.37	6.83
6500		16.73	7.55(II)	12.33	5.23
7000		16.02	6.14(II)	11.28	3.64
7500		15.32	4.72(II)	10.23	
8000		14.61	14.61	9.19	
8500		13.90	13.90	8.15	
( ) indicates grating order other than first					

Table 4: Grating Tilt Positions

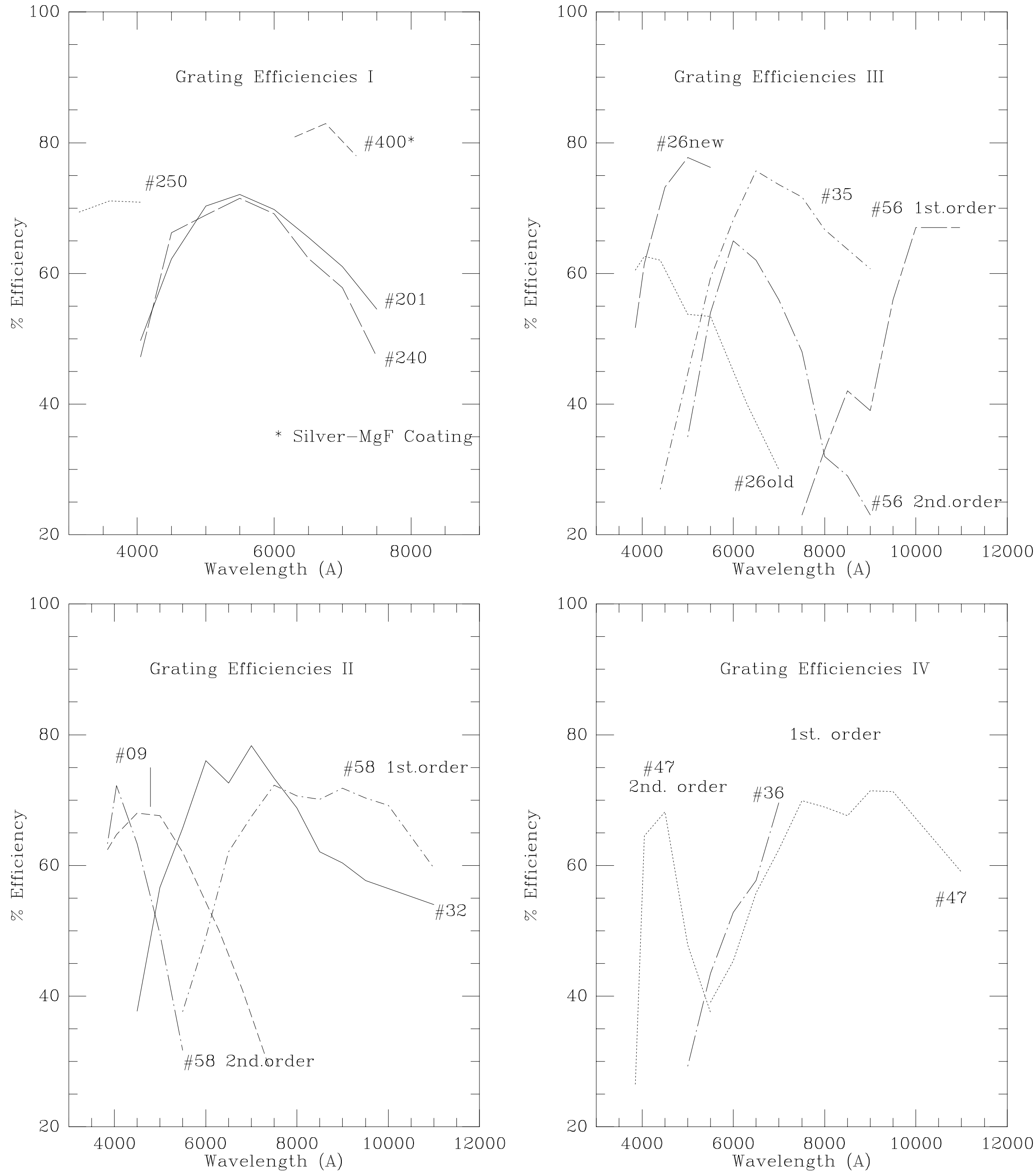

Figure 7: Grating Efficiencies

4 The CCD - Charge Coupled Device

4.1 Introduction

The current detector is a 3072x1024 pixel custom CCD (15μ pixels) fabricated through a joint program with Ford-Loral Aerospace, Steward Observatory and NOAO. The chip characteristics, as measured in the lab, include 8-9 electrons readout noise, 0.05% linearity at 80,000 electrons, and excellent CTE in both directions. The default gain is set at 2.8 electrons/ADU, DETPARS index 5, but one might consider setting it to 4.5 to cover the entire dynamic range of the chip. The chip, named F3KC and also referred to as GCAM, is thinned and AR coated. It must be UV flooded for improved sensitivity. However, it is less susceptible to losing its charge when warmed up. Although, it must be reflooded if it warms up.

Figure 8 shows the DQE of GoldCam CCD. For comparison purposes, the DQE of the old TI5 chip (no longer installed) is also shown. Additional information may be found in the CCD Characteristics Manual located in the telescope observing rooms.

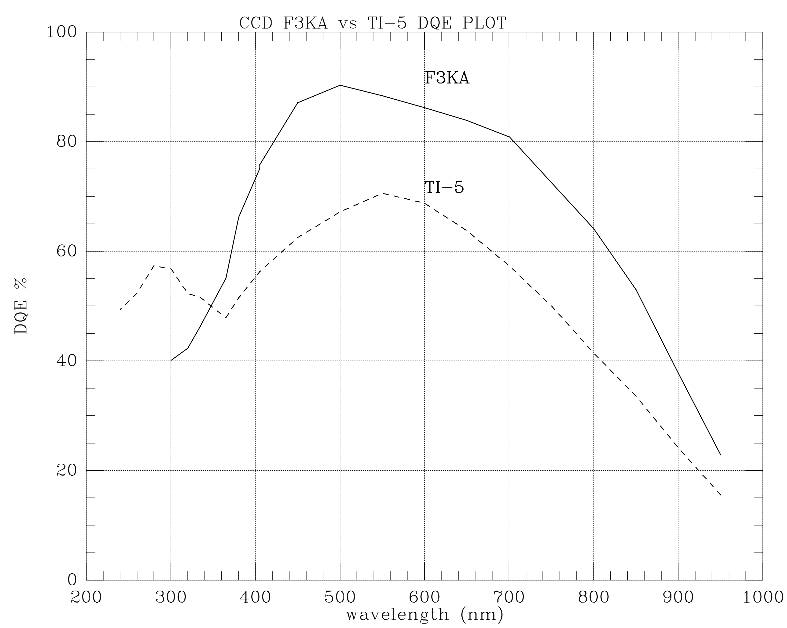

Figure 8: GCAM DQE

4.2 Resolution and Spectral Coverage

Due to "under thinning" , good resolution has not been achieved with the some recent Ford chips such as the GCAM device. The FWHM of arc lines seems to be limited to about 2.7 pixels.

Despite the fact that the chip is 45mm long, the usable spectral coverage is on the order of 36mm. The spectrograph optics cause appreciable vignetting near the edge of the field.

In terms of intensity, the illumination falls off fairly sharply in the first and last 200 pixels. In addition, inside of this the chip is not being illuminated by the entire beam, and the line shapes become irregular. Specifically (and this varies from grating to grating), below pixel 400 and above pixel 2600 the lines have shoulders. Depending on how critical the line shapes (and centroids) are to your program, you may want to trim the spectra accordingly. Also, one can't cover a wavelength range greater than a factor of two in first order and a factor of 1 1/2 in second order without order overlap. The wavelength range will depend on the order separation filters available in some cases.

4.3 Traps and Bad Columns

The chip has a number of cosmetic defects. It has hot columns at 603-604, 1143-1144, 1250-1251, and 1638-1639. It also has a number of bad traps between columns 250 and 300, but this falls in the vignetted area and is no real loss.

4.4 Dewar Rotation

With such a large spectral coverage, it is evident that the dispersion direction is not precisely along rows when the slit is projected along columns. This will vary from grating to grating depending on how well they are aligned in their cells. Distortion is also visible as the ends of the chip are considerably off-axis. In particular, the comparison lines and night sky lines are really curved, especially when using high angle gratings. The chip rotation will normally be adjusted on the first night.

4.5 Fringes

As with most thinned chips, interference fringes are evident in the red. The fringes have peak-to-peak amplitudes of 5% at 8000$\AA$ and 16% at 9000$\AA$. The fringe spacing is about 50$\AA$ at 9000. Internal projection flats (quartz) do a reasonable job of removing these fringes IF TAKEN AT THE POSITION OF THE OBJECT so as to minimize wavelength shift due to flexure. Figure 9 shows fringes from a setup with Grating 58.

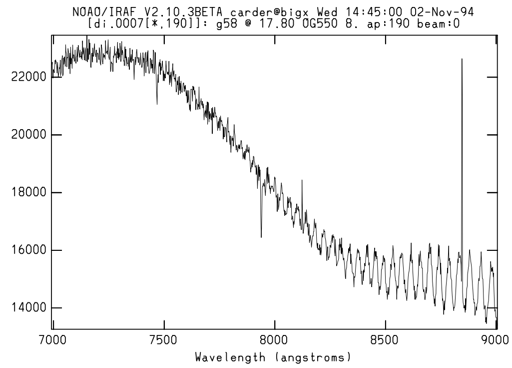

Figure 9: GCAM CCD Fringes

5 Setup and Observing Techniques

5.1 Bringing Up the Telescope Control System (TCS) Computer

TCS now uses a SUN terminal and X-windows based program for control of the telescope and guider. TCS resides on the computer "teal" and can be brought up from the "teal login:" prompt by logging in as *guest* with the proper password. X-windows can be started at the "teal guest-1>" prompt by typing *openwin*. This should bring up the full array of xtcs windows on the left side of the screen. Open the comparison window by double clicking with the left mouse button. Initially the neutral density filter wheel needs indexing. Do this from the comparison window by going to the set menu box. Then hold the left button, scroll down to index nd wheel and release. To adjust the comparison source brightness, go to the source intensity area, hold the middle mouse button and slide the cursor left/right to set the intensity. Zero intensity is full attenuation on the wheel. Full brightness is 100. To see the overall comparison source status, double click on the lower left status box. The status will appear in the lower part of the xtcs window.

5.2 Software Control - ICE and X-Windows

The ICE system and X-windows are covered in a separate manual labeled ICE. The ICE manual should be used with this manual when observing with the GoldCam.

5.3 Set-up Checklist

Observers are usually assisted with the setup of the instrument during the first afternoon and evening of a run. Below is a list to serve as a reminder of possible things to do:

1. Bring up the TCS computer and the comparison window (see above).

2. Log out of the ICE windows, do an *obsinit* at the UNIX level, log out and then back in.

3. Type *detpars* and reformat the detector to 1-3072 columns, and 130-330 rows.
4. Type *instrpars* and set dispaxis = 1.
5. Type *obspars* and set up wanted parameters.
6. Have an assistant install the grating and set the tilt. AVOID ALLOWING EXCESSIVE AMOUNTS OF LIGHT ON THE CHIP BY TURNING OUT THE SPOT LIGHTS AND DOME LIGHTS. Visiting observers are discouraged from changing gratings themselves.
7. Select/install the proper order blocking filter
8. Set the slit width to 50μ for initial focusing, select the decker, and check that the collimator is in the range 600-700.
9. On the telescope control computer (TCS), turn on the HeNeA lamp from the comparison window by clicking on HeNeA. This will position the guider optics for the HeNeA comparison source.
10. Using the TCS mouse, first index the ND attenuator (click on the menu box and select 'index nd wheel'). Then set to an initial value of 100 by holding the middle mouse button and sliding cursor in the intensity box until 100 is displayed.
11. From the CCD computer take a ten second test exposure with **comp**.
12. Inspect the ximtool window and adjust the parameters to suit the data.
13. Plot the spectrum using *implot filename* and determine if the correct wavelength is centered. Pay particular attention to the ends of the spectrum. The areas of high vignetting and poor images are below column 400 and above column 2500.
14. Adjust the neutral density and repeat if necessary.
15. Do a collimator focus run by starting at high numbers and move down in steps of 20. Past experience found best focus at 2.7-3.0 pixels, see below.
16. Return to the comparison lamp and check the spectral focus.
17. Adjust the rotation so that a spectral line runs exactly along columns, or if using the quartz lamp, along rows. See the section below on rotation adjustment.
18. Set the slit width for observing, the final grating tilt and on-chip binning (or format).

5.4 Focusing the Spectrograph and Telescope

Focusing the spectrograph is done by moving the collimator. Auto-collimation is at 500, and offsets from the nominal focus up to ± 100 units have been noticed for different gratings. Steps of 20 units starting at higher numbers are recommended for focusing. By moving the collimator, however, one will be operating slightly out of the auto-collimation position. The grating will then be illuminated in a slightly converging or diverging beam, rather than by parallel light. In this mode, the resolution will be degraded slightly, but the effect is probably not noticeable in this instrument where resolution is low to start with. (If focus offsets become large, say several hundred units, then refocusing the CCD behind the camera will be necessary.) With a $50 - 80\mu$ wide slit, one should be able to achieve a FWHM of $\approx 2.5 - 2.7$ pixels when in focus.

When using the higher dispersion gratings, say ≥ 831 l/mm, the line profiles may exhibit some asymmetry with FWHM being slightly greater than expected. This is normal for gratings used at high inclinations. See Section 5.5 for information on using gratings at higher dispersions.

The following steps can be used to focus:

1. Select the quartz lamp with the ND at 100
2. At the spectrograph, select the "holes" position with the decker control.
3. While looking into the post slit viewer, adjust the slit until the edges of the slit clear the round apertures.
4. Take an observation of the quartz at the highest collimator setting. Always adjust the collimator by increasing numbers 50 above the selected value then decreasing numbers to the value. This takes out the backlash.
5. Use **SPLOT** (ONEDSPEC) to plot several columns along the spectra, starting at about 500 and ending at 2500. At each plot use the command **a** to get the FWHM of one of the apertures.
6. Move the collimator down in increments of 20, until the FWHM of the apertures have minimized and begin increasing.
7. Select the collimator setting with the best FWHM readings across the chip from 500 to 2500.
8. Put in the HENEAR source, move the decker back to a normal decker setting, adjust the slit to 50μ, and check the spectral focus.
9. Adjust the decker to the observers position.

The telescope can be focused in this way also. Use the continuum of the star in place of the apertures. Try to duplicate the FWHM of the quartz.

5.5 Focusing Higher Dispersion Gratings

When higher dispersion gratings are used with the Gold Camera, users should be aware of a potentially troublesome "feature" of the system which becomes evident during the focusing procedure. The problem exhibits itself much as astigmatism does at a telescope focal plane. There are actually two positions of best collimator focus depending upon whether you are measuring in the spectral direction or in the spatial (along the slit) direction. When the spectrograph collimator is focused one must be sure to find the best compromise focus (spectral and spatial) or smallest "circle of confusion".

While not yet fully understood, the problem is connected with the extent of ellipticity of the collimated beam striking the grating. At high tilt angles, such as that required by high dispersion gratings, the beam produced by the collimator is more highly elliptical than that produced by gratings at smaller tilts. The spectrograph camera does not handle highly elliptical beams well and produces astigmatic-like images. The gratings most affected are those used at tilts of less than 14.00 units (see Table 4). Those particularly affected are numbers 36, 47, 56(orders 2 and 3) and number 35(2nd order). Note that tilt readout values run inversely with the angle, i.e. higher tilt angles occur at lower numbers.

To work around this problem, one needs to focus the collimator in the spectral direction and in the spatial direction. For spatial focusing, one uses the quartz lamp and a special set of holes on the decker plate. The FWHM of the height of the quartz spectrum is minimized using the collimator. The spectral focus is done in the traditional manner using spectrograph slit and the HeNeAr calibration lines. The compromise focus is reached by considering the collimator position for both methods.

For the highest dispersion configuration there is also a set of special oval masks that can be installed over the grating to apadize the beam into a more circular form. The spectral focusing is done with the mask in place, but most observers opt to remove it for the real observations.

5.6 Alignment of the Spectrum on the Chip

The camera-dewar assembly can be rotated, using two push-pull micrometers, to align the spectrum with the chip. For best sky subtraction, it is preferable to align the projected spectrograph slit along columns. Note that this does not guarantee that the dispersion will be perfectly aligned along rows (there is no grating rotational alignment adjustment). Any small dispersion misalignment can be taken out in the data reduction process. Since some gratings are slightly misaligned in their cells, this alignment should be checked after each grating change.

Check the alignment using the observation taken for the best focus above. Plot column 1000, then over-plot column 2000 using **implot**. If the spectra are not aligned one may have to adjust the dewar rotation. The HENEAR lamp should be used for alignment of spectral lines along columns.

5.7 Calibration Spectra

To reduce data taken with this instrument, the following are required:

1. Bias (zero) frames to determine the structure. The average or median of these frames will be subtracted from all other frames (darks, flats, and object frames).

2. Darks for long exposures. Multiple darks are essential to improve statistics and to be able to filter out radiation events.

3. Flat fields: dome flats are preferred over the internal quartz lamp for true long slit work because the dome flat field illuminates the slit much more evenly than does the quartz. However, the present dome spot is dead in the region $\leq 4000\AA$ and the internal quartz lamp is recommended for any work below $4000\AA$. Internal quartz flats are satisfactory for stellar observations where only a short section of the central slit is used. For long slit work, twilight sky frames are recommended.

4. Comparison source (HeNeAr) for wavelength calibration.

5. Standard stars for absolute flux calibration. Stars in the IRS list have data available at more wavelength points than do those in the IIDS list. The work of Massey, Strobel, Barnes, and Anderson **Ap.J.**, <u>328</u> ,315,1988) offers improved wavelength spacing, photometric accuracy, and a few new fainter stars than older lists. The following standard stars have flux data longward of 8000 Angstroms and are listed as they appear in the IRAF database onedstds$redcal.

The stars with extended wavelength coverage are noted in Table 5. † denotes extension to 1μ and $*$ denotes extension to $9000\AA$.

40erib*	g9937†	hd19445†	13633†	lds749b†
bd174708†	gd140†	hd84937†	1151234b†	ross627†
bd262606†	gd190†	he3	l74546a†	ross640†
feige24*	grw705824†	hz29	l93080*	sa29130†
g191b2b†	grw708247*	hz43†	l97030*	wolf1346†
g4718*	grw738031*	hz44†	lds235b	wolf485a*

Table 5: Flux Calibration Standard Stars

5.8 Flat Fielding - Dome Spot or Internal Quartz Lamp?

There are trade-offs that must be considered to answer this question. For working in the region $3500\mathring{A} \geq \lambda \geq 4100\mathring{A}$, the dome spot has poor reflectivity and the internal lamp is the preferred choice. Figure 10 shows the output of the internal quartz lamp.

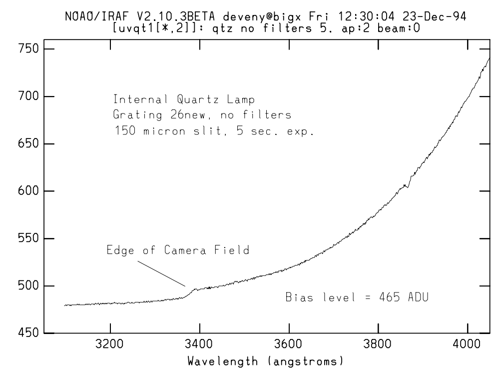

Figure 10: Internal Quartz Lamp in the UV

The internal quartz is much better color balanced over this limited region and will require less exposure time than the dome spot, although it still may be tens of minutes. Dome flats (using the high banks) are preferred for long slit work (not in the UV) due to a more uniform slit illumination. In the $8500\mathring{A}$ region, the high dome lamps also have a dip in response caused by the dichroic reflector on the back of the lamp. The low dome lamps (low banks) can be tried but generally have too low an output for most spectroscopic setups. The low banks reflectors have been aluminized to eliminate the dip at $8500\mathring{A}$.

For true long slit work (> 3 arc-minutes), the uniformity along the slit is better using the dome spot. For stellar objects requiring only a limited slit length, it will be more advantageous to use the internal lamp. The uniformity over the central part of the slit is nearly identical for the spot and internal lamp. It is, however, more convenient to use the internal lamp since the telescope does not have to be repositioned to the spot.

Another approach to the long slit problem is to do twilight sky exposures. Although these are uniform, they do change quickly in time and, one may encounter some problems with polarization in the twilight sky.

Bear in mind that the Gold Camera chip has 8-9 electrons noise and that, for 1% work, $10,000e^-$ *above bias* are required. On a per resolution element basis, this total charge is really spread over a ≈3x3 pixel area, or $\approx 1000e^-/pixel$ *above bias*. At low dispersion in the violet, the spectra will not be flat, and you may have to take several long exposures to attain at least 400 ADU above bias (gain=2.8 electrons/ADU) per resolution element.

5.9 Observing Hints

1. Request that your Instrument Assistant or Telescope Operator do a knife-edge telescope

focus at the start of your run. Also do a telescope focus run using just the TV and compare the focus values. After a telescope move of $15-20\,\mathrm{deg}$, refocus the telescope using the TV.

2. Cosmetically the F3KC chip is among the best CCDs we have. The area around 837,78 (in full format) is an area of depressed sensitivity and should be avoided.

3. To get a rough idea of your signal-to-noise, try the following. Do a row plot in the wavelength area of interest. Integrate the profile above bias with the "i" option in the cursor package. Multiply this by 2.8 electrons/ADU and by 3 pixels/resolution element (unbinned) to get the signal per resolution element. The square root of the signal ≈SNR/res. element .

4. If you require the best radial velocity precision, take a wavelength calibration exposure before and after each object exposure at the object position.

5. As mentioned earlier, the spectrograph shutter takes a noticeable time to open/close. The actual time the shutter is open is 100-250 milliseconds shorter than the advertised time. Exposure times of a minimum of 20 seconds are suggested if 1% or better timing accuracy is desired.

5.10 Spatial Directions on the Chip

With the Gold Camera, decreasing wavelength is always toward increasing column numbers (red is to the left). At a position angle of 90 deg (E-W slit), east is toward decreasing row numbers. At a position angle of 0 deg, north is toward decreasing row numbers. The Gold Camera has no facility allowing dispersion to run along columns.

5.11 System Flexure

Flexure tests have shown that the instrument is mechanically very stable. No shifts larger than a few tenths of a pixel were measured while moving the telescope from 4 hours east through the zenith to 4 hours west, and from -20 degrees to +70 degrees declination.

6 IRAF and Data Reduction: A PROVISO FOR USERS

The installation of Sun workstations running IRAF has proven a great addition to the Observatory's data collection and reduction capabilities on the mountaintop. We have seen a sharp increase in the number of observers who use the Suns to at least get started with the data reduction process. Many observing programs now have more than one observer on site with one person reducing the previous night's observations while the other observes. Two workstations or graphics terminals are available at most of the telescopes

Giving adequate support for reduction activity is becoming a difficult support problem. The mountaintop is not a fully supported IRAF site, and response to requests for help with the Suns or IRAF will depend on the availability of support personnel. We will certainly do our best to do what we can to assist you, but there will be times when no support will be available. We make the following suggestions to users:

• Minimum expected level of knowledge: Some previous computer experience, preferably with the UNIX operating system, including tape handling. Beginning level experience with IRAF is a plus. VMS is not used on Kitt Peak mountain.

• Learning IRAF and the optimum data reduction procedure is no small task. If you have not previously used IRAF, the mountaintop is not the best place to start learning unless you have made a fair effort to prepare in advance by reading the available "cookbooks" and talking with persons experienced with data reductions. Our resources do not allow for multi-hour "cold-start" teaching sessions with the uninitiated.

• The observer should know in advance what steps in the data reduction process he or she wishes to do. Your start-up person will help you with the Sun and get you going in IRAF, but the actual steps of the data reduction process are the responsibility of the observer. Many of our support people can offer advice depending on their level of experience.

• If you experience difficulties with IRAF and mountain support personnel are not able to answer your questions, call downtown IRAF support, Jeannette Barnes (8-381), or use the hotline (dial 9-323-4160). For less pressing questions/problems, use the IRAF Email service, i.e. "mail iraf@noao.edu". Jeannette Barnes is also willing to give introductory"tours" of IRAF/ICE downtown before your run, by pre-arrangement.

Your cooperation is appreciated.

7 How Do I Obtain a Copy of This Manual?

To obtain a copy of this manual via FTP use the following commands.

yourprmt%	ftp noao.edu	[login as anonymous with your name as password]
ftp>	cd kpno/manuals	[move to correct directory]
ftp>	ls -l	[check to see if the manual is there]
ftp>	binary	[set transfer for binary mode]
ftp>	get gcam.ps.Z	[transfers the file]
ftp>	quit	[exit from the ftp application]

Then back on your machine, you must uncompress the manual and print it out on a PostScript laserwriter. The UNIX commands below are appropriate for that operating system.

yourprmt%	uncompress gcam.ps.Z	[uncompresses file]
yourprmt%	lpr -Plw gcam.ps.Z	[substitute your laserwriter for lw]
	or	
yourprmt%	zcat gcam.ps.Z — lpr -Plw	

8 Appendix I: CCD Observing Software Summary

The following is a list of the most frequently used CCD commands. Refer to the **ICE Manual** by Phil Massey, et al. for more detailed information.

8.1 Observing Words

observe	Begin an exposure.
mores	Take n number of exposures of same type of previous one.
zeros	Take bias exposures, number is prompted for.
flats	Take flat exposures, number is prompted for.
comps	Take comparison exposures, number is prompted for.
darks	Take dark exposures, number is prompted for.
test	Take an exposure that overwrites previous test exposure.
ccdinfo	Displays CCD detector info, including gain and temp.
flpr	Flushes the process cache. Used after cntl c or any abort.
detpars	enter epar for the detector parameter set.
obspars	enter epar for the observing parameter set.
instrpars	enter epar for the instrument parameter set.
mkdir n	make a new directory with n name.
cd n	change to n directory.
implot n	Bring up plotting window for n image.
imexamine n	Bring up 'imexamine' for n image.
display n	Display n image in the ximtool window.
wfits n	Write an image n to tape or disk, fits format.
tele	Test the link to TCS computer for header information.
p	When typed during an exposure this will pause the exposure.
r	Resume a pause.
S	When typed following a p for pause, will stop an exposure.
A	When typed following a p for pause, will abort an exposure.

9 Appendix II: Target Coordinate Transfer

You may prepare a list of objects with their coordinates for use at the telescope prior to your arrival. Coordinate lists may be sent via email at least two weeks before your observing run to coords@noao.edu. Files should be ASCII text, no longer than 2000 lines. Larger files should be broken into smaller ones. Begin your file with your name, a cache name, telescope, and the dates of your observing run. Coordinates will be checked for format, loaded into the appropriate telescope computer, and acknowledged when all is ready for your arrival.

Each object in the file should be one line of text. The format for data entry is object name (which will be truncated to twelve characters by some telescope control computers), right ascension (starting in column 16 or greater, delimited by the first blank after column 15; hours, minutes, seconds), declination (degrees, minutes, seconds), and epoch. Each field should be separated by one or more spaces. Do not use tabs. The delimiter in the RA and Dec fields may be either spaces or colons. Note that the sign of declination must be adjacent to the declination degrees (i.e., -6 and -06 are allowed, but - 6 is not).

For example:

- alpha Lyr 18:36:21.70 +38:46:02.0 1983.0

Proper motion in right ascension and declination (arc seconds per year) may be added to entries after the epoch field as in the following example:

- HD 172167 18 36 21.7 +38 46 02 1983.0 +0.200 +0.285

More extensive instructions and options for the data format are available by emailing to coords@noao.edu with a request for complete documentation.