THE MARS MANUAL

(The Multi-Aperture Red Spectometer)

Kitt Peak National Observatory

National Optical Astronomy Observatory

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Observing Programs That May Benefit From MARS

- Programs that need low-to-moderate dispersion spectra in the red
- Programs requiring high throughput
- Programs requiring a high density of multislits
- Programs that need superior sky-subtraction using the nod-and-shuffle observing mode

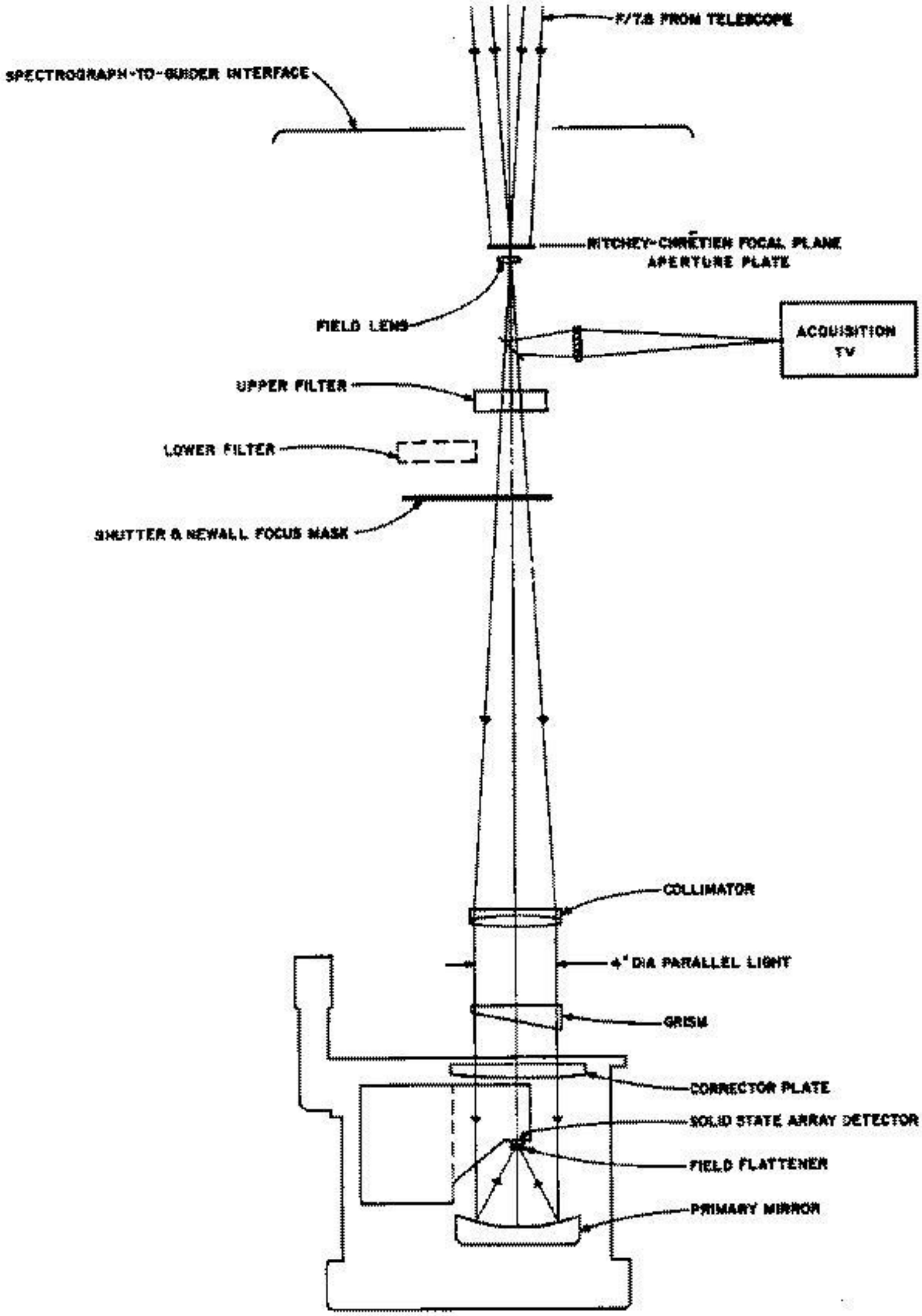
System Overview

The MARS instrument is a reincarnation of the old Cryogenic Camera, but now upgraded with the following:

- a new high resisitivity p-channel CCD with no fringing
- a newly overcoated-Ag Schmidt primary mirror
- a new chip mount for the CCD with smaller cross-section
- a new field flattener lens
- a new volume-phase holographic grism (450 g/mm)

The instrument is designed to obtain low-to medium-resolution (8-30 Angstroms) spectra of faint objects using a high throughput spectrograph and CCD detector. Spectra (S/N~8-10 per resolution element) of objects of magnitude R~21 can be obtained in ~45 minutes of integration under good observing conditions. The system consists of the 4-Meter R.C. Spectrograph (see Figure 1) with the main MARS assembly mounted in place of the normal collimator mirror housing. The straight-through design employs a lens collimator and a "grism" (transmission grating replicated on a prism) preceding the camera. The camera consists of an evacuated f/1 classical Schmidt with a thick LBNL (Lawrence-Berkeley National Labs) 1980x800 pixel CCD (15x15 microns) at the focus. This chip is sensitive over the 3400-10,500A spectral region and has a readout noise of ~8 electrons rms. Since this is a thick device, there is no fringing. The quantum efficiency of the chip peaks at ~92% at 8000-9000A. The overall system efficiency, including the atmosphere, telescope, and instrument peaks in the ~40% region with the new VG8050-450 grism (see Figure 2). The normal slit of the spectrograph is replaced by an aperture plate assembly giving a coverage of 5-arcminutes. The system can be operated in two different modes: long-slit or multi-object. For long-slit observations, a collection of metal aperture plate slits of various widths is available. For multi-object work a user-designed slitlet mask is used.

1.2. Optical Diagram - R.C. Spectrograph & Cryogenic Camera



MARS optical diagram

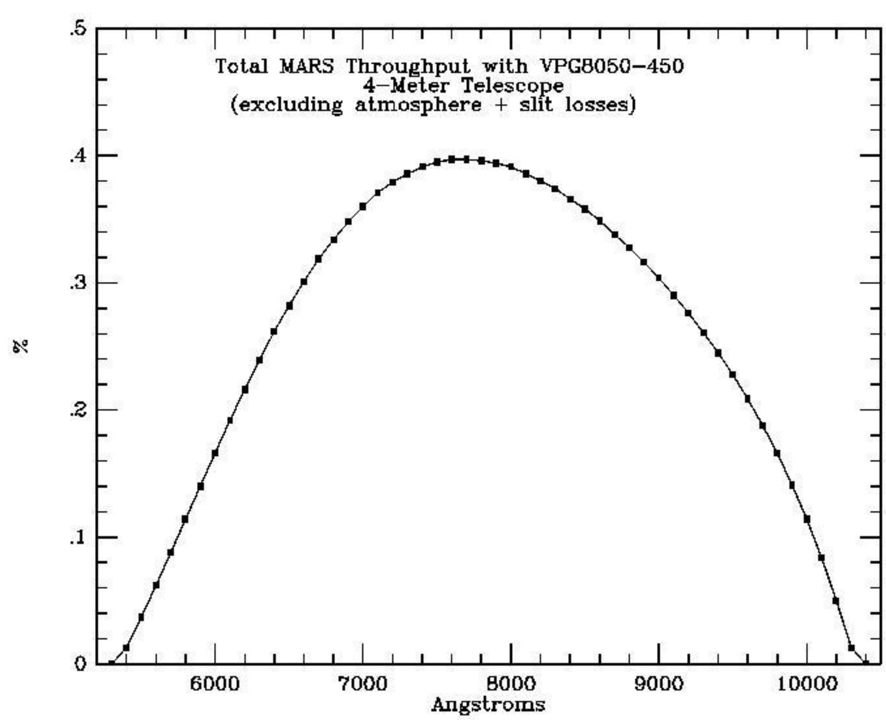
Multi-slit masks are individual masks fabricated for each target field. They require substantial effort to prepare, since good astrometric prositions are required for each object. To maximize the number of objects that can be observed without overlapping their spectra, an ancient UNIX-Fortran77 program, MSLIT, designs the mask pattern*. With this observing mode coupled with the nod-and-shuffle technique, one can observe up to 30 objects simultaneously. Refer to the manual "*Multi-Slits at Kitt Peak*" which is available from the [KPNO documents website](#) for details on design and construction. Please note that the multi-slit design software is being significantly updated with an anticipated release date of summer 2002

* Soon to be upgraded.

Exposure Time Calculator

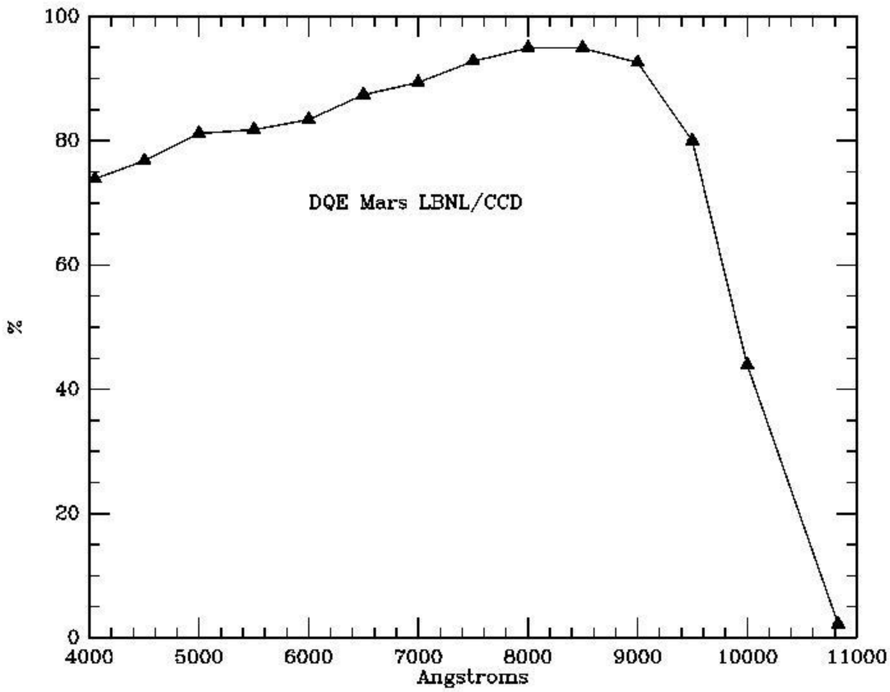
- [Click here to link to Exposure Time Calculator](#)

Total System Throughput - The Optimum Case



Caption *UNDER CONSTRUCTION*

DQE Curve for the MARS/LBNL CCD



Measured DQE values

```
From dey@noao.edu Mon Feb 18 13:03:26 2002
Date: Fri, 15 Feb 2002 17:54:44 -0700 (MST)
From: Arjun Dey <dey@noao.edu>
To: deveny@noao.edu
Subject: DQE curve for current Cryocam CCD

CCD ID:cry02  Date:1111111  Pixel:15.0um
 Gain:1.70 e-/dn  Bias:1480 dn

Wavelength      %QE

    4050      73.9
    4500      76.8
    5000      81.2
    5500      81.8
    6000      83.4
    6500      87.4
    7000      89.4
    7500      92.8
    8000      94.9
    8500      94.9
    9000      92.6
    9500      80.0
   10000      43.9
   10830      2.2
```

Instrument Observing Configurations

Three observing modes are currently supported:

- A long-slit configuration using metal aperture plate slits.
- A multi-object mode employing observer designed multislit masks (see "*Multislits at Kitt Peak*" for mask design parameters).
- An imaging mode can be used by removing the grism and slit-mask. See below for more information.

Any of these modes can optionally use the "nod-and-shuffle" technique for accurate sky-subtraction. See the section below for more details on using this technique.

Standard Long Slit Masks

Mask #	Width- Arcsecs	Width-mm	Length-arcmins	Length-mm
1	1.0	.150	4.5	41
2	1.7	.255	4.7	43
3	2.5	.375	4.4	40
4	2.5 spare	.375		
5	3.2	.480	4.4	40
6	3.17 spare	.479		
7	3.7	.555	4.2	38

Offset Slit Aperture Plates

This set of slits are laterally offset from the normal on-axis position and shift the central wavelength up to + - 500-600 Angstroms from the normal grism centers. Slit lengths vary, so consult with your Instrument Assistant if the length is critical to your program. Nearly all of these slits are at least 4.4 arc-minutes in length.

List of Offset Slits for MARS

Mask #	Width " /Shift	~A Shift *	Offset mm	Mask #	Width " /Shift	~A Shift *	Offset mm
8-B	1.4" Blue	-520	15	8-R	1.7" Red	260	7.5
9-B	1.7 Blue	-260	7.5	9-R	1.7 Red	520	15
10-B	1.7 Blue	-520	15	10-R	2.5 Red	260	7.5
11-B	2.5 Blue	-260	7.5	11-R	2.5 Red	380	111
12-B	2.5 Blue	-520	15	12-R	2.5 Red	520	15
13-B	3.2 Blue	-260	7.5	13-R	3.2 Red	260	7.5
14-B	3.2 Blue	-520	15	14-R	3.2 Red	380	11
15-B	10.2 Blue	-520	15	15-R	3.2 Red	520	15
16-B	10.8 Blue	-520	15	16-R	2.5 Red	700	22.6
17-B	11.1 Blue	-520	15				
18-B	21.0 Blue	-520	15				

* For 300 l/mm grisms. Other grisms shift proportionally.

Other Setup Aperture Plate Masks

--- SETUP MASKS ---
#19 Lynds Test line of holes, 32 holes, 380 micron diam.
#20 Knife-edge Hole 1.95mm diameter
#21 Knife-edge Hole 2.05mm diameter
--- TEST MASKS ---
#22 Test Centroid 6 holes
#23 Garth No.I alternating double hole pattern
#24 Garth No.II another double hole pattern
#25 Fowler Test X-pattern centered at 45 deg., 200 micron holes
--- MISCELLANEOUS MASKS ---
#26 1 hole, 2.5" diam. centered
#27 2 holes, 2.5" diam. (star/sky)
#28 2.5" slit with 2" center occultation
#29 2.5" slit with 4" center occultati

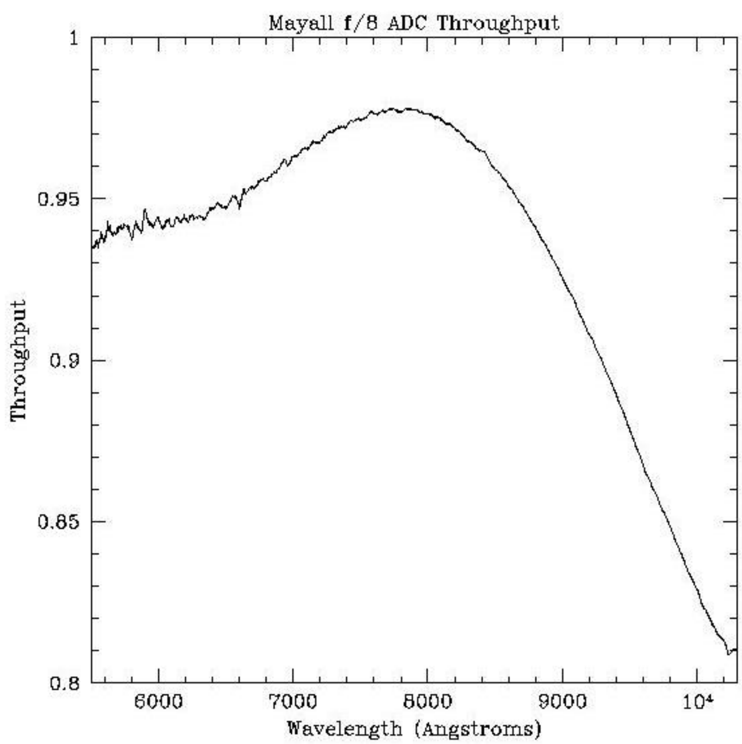
Imaging Mode

This observing mode is still in a somewhat experimental status. The setup involves removing the grism and slitmask from the instrument. Note that the physical slitmask must be removed but the slitmask assembly (decker), which carries the field lens, must remain in the beam (i.e. the decker must be "IN") . The FOV in this mode is a circle of diameter 5.2 arcminutes. The instrument has two filter bolt slides (an upper and a lower) which can hold up to four filters each plus an open position. There are actually four interchangeable physical bolts for each slide. One of the l*ower* bolts has been modified so that two slots will hold 4x4-inch filters. There is also a set of Bessel BVRI filters (3.875x3.875 inches, lower bolt) dedicated to MARS use. Adapters for using 2x2-inch filters exist but the FOV will be reduced.

The Optical System

Atmospheric Dispersion Compensation - The ADC or Risley Prisms

A set of Risley Prisms is available for atmospheric dispersion correction at the RC focus of the 4-meter telescope. This ADC covers a field slightly larger than MARS field (~5 arcminutes) and is automatically controlled by the telescope control system. One inconvenience caused by the Risleys is difficulty of locating guide stars. The Telescope Operator must be aware that suitable guide stars must fall inside the annular area just outside the instrument FOV but inside the field of the prisms. Choosing a guide star in or too close to the MARS FOV will result in vignetting the instrument field. The ADC is used at the option of the observer and may not be suitable for all types of observations.



A plot of the ADC throughput in the 5500-10,000A spectral region.

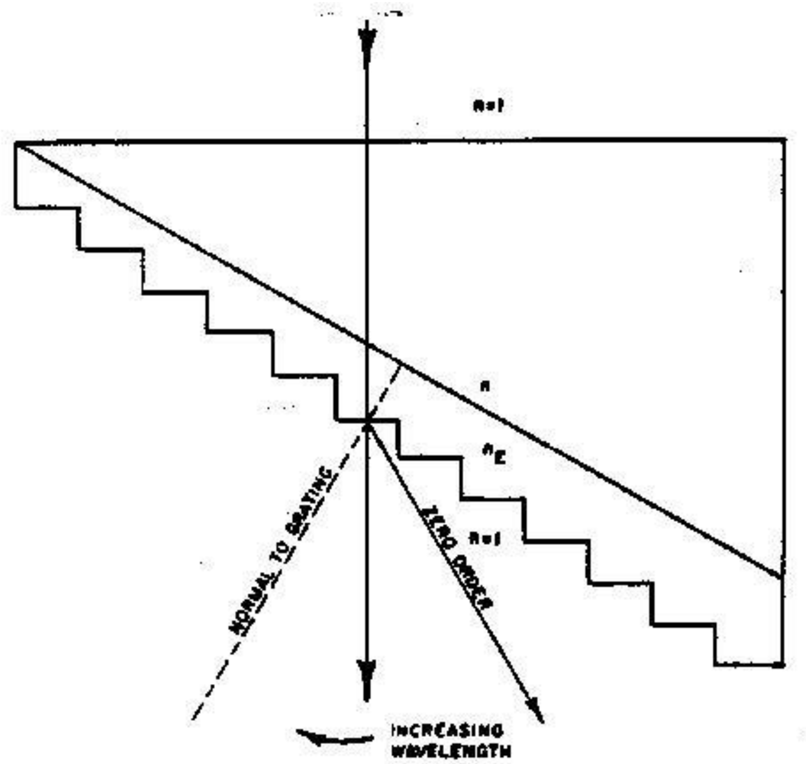
The Collimator Lens

The collimator optics consist of a re-imaging field lens, located just beneath the aperture plate near the focal plane of the telescope, and a collimating doublet. The field lens is a simple plano-convex lens that images the pupil of the telescope onto the collimating doublet and also reduces vignetting when the full 50mm spectrograph aperture is used.The plano-side of the lens goes upward (skyward).

The doublet collimating lens is a classical crown-flint cemented lens with the achromatic range centered at a wavelength of 0.63 microns. The clear aperture of the lens is 4.2 inches, and the effective focal length is 31.5inches. The flint element faces the incoming beam. Both the field lens and collimator are anti-reflection coated. The flint element is not a good UV transmitter and contributes to the poor throughput below 4000A.

The Grism Dispersive Element

The dispersive element consists of a transmission grating replicated on the hypotenuse exit face of a right angle prism. The grism follows the collimator and was chosen for this application because of its high efficiency. The purpose of the grism is to obtain dispersion without deviation at the center of the spectral range. The instrument performs as a direct-vision spectrograph with the ``zero" order of the grism falling outside the field of view of the detector. The grism is fixed and there is no provision for adjusting the central wavelength by tilting the assembly. Adjustments of a few hundred Angstroms are possible by using offset slits as described in an earlier section of this manual.
This instrument uses two types of grisms, a "conventional" grism, shown below, and a new volume-phase holographic grism (see NOAO Newsletter, *67,* Sept. 2001, p 32). The new "VPH" grism employs a sinusodial varying index of refraction medium produced by holographic interference as the disperser.



The undeviated central wavelength (UDCW) depends upon the wedge-angle and refractive index of the prism, and the particular ruling used. When the vertex of the prism equals the groove angle of the rulings, maximum energy throughput is obtained.

Available Grisms

Grism Number	4950-400	5970-300	8010-300	8050-450**	9700-300	9700-300	7300-300
Old Grism Number	650	770	730	none	780-1	780-1	780-2
g/mm	400	300	300	450	300	300	300
Order	1	1	1	1	1	2	1
UDCW* - Angstroms	4950	5970	8010	8050	9700	4850	7300
Resolution - Angstroms@	12	15	15	8	15	8	15
Dispersion - A/Pixel	3.2	4.3	4.3	2.0	4.3	2.2	4.3
Spectral Range - Angstroms	~4000-8100	~4000-10,000	~5400-10,800	~5500-10,800	~4000->11,000	~4000-7100	~4000->11,000

* Undeviated central wavelength
@ With a 2.5" aperture
** New Volume-Phase Holographic Grism, see NOAO Newsletter #67, September 2001, p. 32. Has a built-in OG-550 filter.
Note(5/04): Grism 6560-300 (old#810) out-of-service

The Upper Filter Bolt

The upper filter bolt is normally reserved for up to four order separation filters. These filters are 3-1/2 inches square and are NOT interchangeable with the lower filter bolt.

Order Separation Filter List

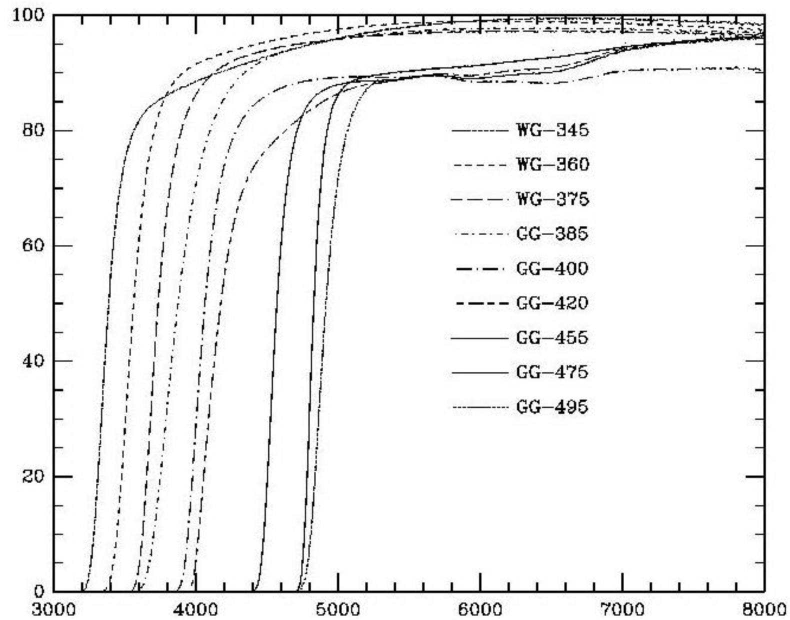
- Click here for individual filter curves.

ORDER SEPARATION FILTERS FOR MARS/RCSP

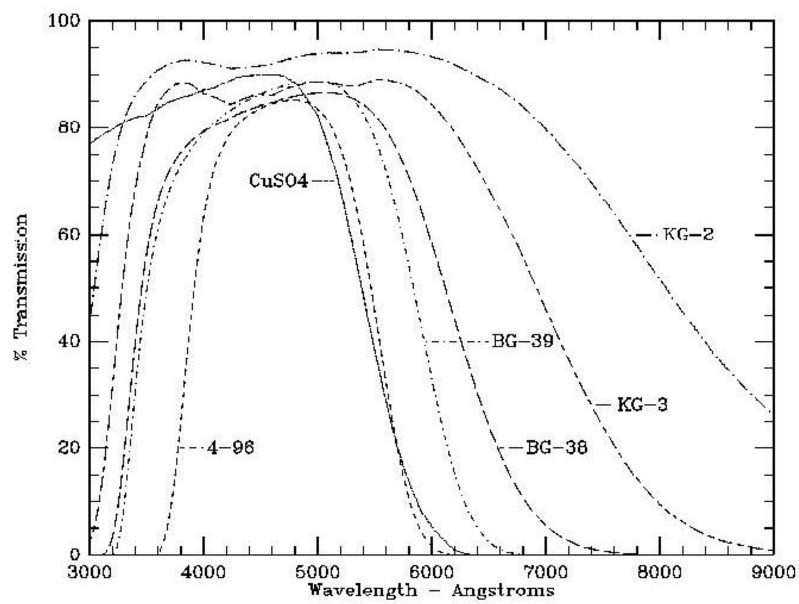
Filter	Thickness	Filter	Thickness
WG-345	1mm	OG-515	3mm*
WG-360	2mm	OG-530	3mm*
GG-375	3mm	OG-550	3mm
GG-385	3mm	OG-570	3mm
GG-400	3mm*	OG-590	3mm*
GG-420	3mm	RG-610	3mm*
GG-455	3mm	RG-645	3mm
GG-475	3mm	RG-695	3mm*
GG-495	3mm	RG-830	3mm*
CuSO4 **	8mm*	KG-2	2mm
BG-38	2mm	KG-3	2mm
BG-39	2mm	Kopp 4-96	5mm

* Uncoated filter, all others are hard AR coated
** See the section below for special information on this filter
These 3.5-inch square filters can be used in the upper filter slide ONLY

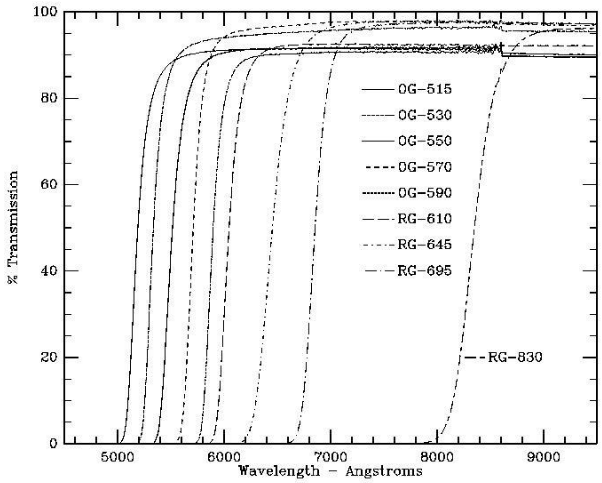
Filter Transmission Curves



UV-Blue sharp-cut filters.



Bandpass filters.



Red sharp-cut filters

- Click here for individual filter curves.

The Copper Sulfate Crystal Filter

The Copper Sulfate Crystal Filter - Precautions

Blue copper sulfate has some of the best red-blocking properties of any known substance. This crystal filter is a mosaic of three pieces of crystal mounted between two quartz cover windows. Some precautions to using this filter are:

- The filter is very fragile and should not be removed from the filter slide.
- Due its rectangular clear aperture, the filter should not be used for multislit observations (which require a round clear aperture).
- Due it its construction, the filter is particularly sensitive to shearing by temperature variations. Do not take this filter from the cold dome into the warm control room.

The Lower Filter Bolt

The lower filter bolt (four slots plus an open position) normally contains neutral density attenutors or direct imaging filters. The normal filter size is 3-7/8 inches square but two slots have been enlarged to hold 4x4-inch filters. Consult with your Instrument Assistant for proper filter installation, if you want to use this bolt . Be aware that even though a filter list appears in the Spectrograph Setup GUI the bolt itself may NOT be installed in the instrument.

The Camera Optics

For best matching between an image at the focal plane of the 4-meter telescope (1 arcsec = 150 microns) and the detector (1 pixel = 15 microns), a demagnification of ~10 is required to give an image scale of 1 arcsec per pixel. This requires that the camera optics have an effective focal length of 4 inches, resulting in an f/1.0 optical system. A Schmidt-type design was selected because it introduced a minimum amount of glass to the optical path. In addition, a fused silica corrector is used for aspheric correction and as an entrance window for the cryogenically cooled dewar that houses the detector. The Cervit primary mirror has a spherical figure with a radius of curvature of 8 inches. It is held in position by a specially designed kinematic mount to ensure that the optical alignment is independent of temperature. The field flattener is mounted almost in contact with the detector to compensate for the field curvature produced by the Schmidt design. The images produced by the original design contain ~75 percent of the energy within a 25 micron diameter circle. A new corrector was installed in December 1983 and improved the imaging beyond the above figures. A new LBNL 1980x800 CCD was installed in December 2001. As with most fast camera systems, there is significant distortion that must be calibrated out in the reduction process.

Some important parameters of the system are:

Telescope Scale	6.6245 arcsec/mm
Camera Demagnification	~8.4x
Spatial Scale on CCD	~0.86 arcsec/pixel

The CCD Detector

The CCD is a Lawrence Berkeley National Labs 1980x800 chip with a readout noise of ~6-8 electrons rms.. The device is a thick chip (~300 microns) and, as a consequence, has a significant cosmic-ray hit rate. Exposures should be limited to 30-40 minutes to avoid excessive number of hits. The pixel size is 15x15 microns and the scale on the chip is ~0.86 arcsec/pixel. The chip operates at a gain of 2.0 electrons/adu. and the dark current is ~70 electrons/hour/pixel. The current device shows no appreciable fringing.

Click here for a system DQE curve.

Click here for measured DQE values

Click here for a link to the LBNL CCD website.

Nod-and-Shuffle Observing Mode

The CCD can be operated in a standard single exposue mode or in a multiple-exposure "nod-and-shuffle" mode. In the "nod-and-shuffle" mode, the central one-third of the CCD is used as the active collection area while the top and bottom thirds are used as sky and target collection areas. The telescope then nods between the target and sky fields while the charge is shuffled into the appropriate accumulation area. Note that this mode restricts the available field of view for either long slit or multislit observing modes, but results in excellent sky subtraction. The following links provide additional information.

- REPORT ON THE NOD-AND-SHUFFLE T&E RUN ON THE MAYALL TELESCOPE - 2000 MARCH 15 AND 16, UT

  [Under Construction - Figures did not convert from LATEX]

- Some Notes on Slitmask Design and Construction
- A Future Newsletter Article - Optical Spectroscopy Learns the Nod-&-Shuffle

ICE Observing Commands

COMMAND	ACTION
observe	Take an object, zero, dark, flat, or comp image
more <*n*>	Repeat the last 'observe' n times
flpr	Flush the process after a control-c abort
zero	Take a series of zero or bias images
object	Take a series of object images
flat	Take a series of flat images
comp	Take a series of comparison spectra images
dark	Take a series of darks
test	Take a test image and overwrite previous *test* image
detpars	Set the detector parameters for CCD format and gain
instrpars	Set the instrument parameters & header keywords, such as grism, filters and DISPAXIS=1
obspars	Set observing paramenter; image root name and sequence number
ccdinfo	Display current CCD format, gain, binning, temperatures etc.
wfits	Write FITS format data frames to tape
tele	Test TCS link for transmission of telescope header data

References

Recent Documentation:

"Report on the Nod-and-Shuffle T&E Run on the Mayall Telescope – 2000 March 15 and 16, UT", internal NOAO report

"Upgrading the Cryogenic Camera", NOAO Newsletter *65*, March 2001, p35.

"The Multi-Aperture Red Spectrometer: CryoCam Resurrected!", NOAO Newsletter 67, Sept. 2001, p31.

"Update on the Performance of MARS", NOAO Newsletter *68*, December 2001, p 25.

Older Dated Documentation:

"Multi-Slits at Kitt Peak: A Manual for Designing and Using Entrance Masks for Low/Moderate-Resolution Spectroscopy", March 1996, KPNO documentation website.

"A Setup and Reference Manual for the Kitt Peak Cryogenic Camera", August 1998, KPNO documentation website

Click here for the previous version (ver1) of this manual (no figures).