The Hobby-Eberly Telescope medium resolution spectrograph and fiber instrument feed

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ABSTRACT

The Medium Resolution Spectrograph (MRS) is a versatile, fiber-fed echelle spectrograph for the Hobby-Eberly Telescope (HET). This instrument is designed for a wide range of scientific investigations and includes single-fiber inputs for the study of point-like sources, synthetic slits of fibers for long slit spectroscopy, 9 independently positionable probes for multi-object spectroscopy, and a circular fiber integral field unit. The MRS consists of two beams. The visible beam has wavelength coverage from 450 - 900 nm in a single exposure with resolving power between 5,300 and 20,000 depending on the fibers configuration selected. This beam also has capability in the ranges 380 - 950 nm by altering the angles of the cross-disperser gratings. A second beam operating in the near-infrared has coverage of 900 - 1300 nm with resolving power between 5,300 and 10,000. Both beams can be used simultaneously and are fed by the HET Fiber Instrument Feed (FIF) which is mounted at the prime focus of the telescope and positions the fibers feeding the MRS . The MRS started commissioning summer 2002.

Keywords: instrumentation: spectrographs, fibers

1. INTRODUCTION

The Hobby-Eberly telescope (HET) is a unique large telescope design which makes use of an Arecibo-like tracking scheme to allow the implementation of a large aperture telescope for moderate cost by keeping the primiary mirror at a fixed elevation. The design, performance goals and early testing has been described by Ramsey et al.[1], Sebring et al. [2,3], and Ramsey et al.[4]. Current status and performance is presented by Booth et al.[5]. HET is a collaboration of the University of Texas at Austin, Pennsylvania State University, Stanford University, Georg-August-Universität, Göttingen, and Ludwig-Maximillians-Universität, München. The facility instrumentation for the HET consists of three instruments; a prime focus Low resolution ($600 < R=\lambda/\Delta\lambda < 3000$) spectrograph (Hill et al [6]), a high resolution ($15000 < R < 120000$) spectrograph (Tull et al.[7]) and the MRS discussed here. Both the HRS And the MRS are fiber fed instruments; a fact driven by the basic principles of the HET. The performance of the HET with current facility is reviewed elsewhere in this conference (Hill et. al.[8].) At present both the LRS and the HRS are operated in a queue scheduled mode. The science time on the HET is averaging about 75% so far in 2002. The remaining time is used for telescope engineering and instrument commissioning. The MRS is a key component of the initial HET facility instrument suite, and will be the last to be implemented. Engineering tests and commissioning are expected to continue through Fall 2002 with limited science availability in basic modes by the end of the year. The commissioning of all the modes is expected to continue through summer 2003.

2. TOP LEVEL MRS DESCRIPTION

The science requirements and basic design approach for the MRS is detailed in Ramsey[9] and Horner, Engel and Ramsey[10]. This paper will focus on the as built configuration of the MRS and the progress of the site installation and engineering tests that began in summer 2002. Several significant design changes have been implemented which have largely been driven by cost considerations.

The MRS is a dual beam instrument with the top level attributes tabulated in Table 1. The dual visible and near infrared (NIR) spectrographs are mounted on optical benches in an environmentally controlled light-tight room under the telescope. A common collimator and slit system is used to allow spectra to be obtained in both beams simultaneously or

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in rapid sequence. There is a provision for a beamsplitter to be mounted in the collimated beam although tests are currently being done using a fold mirror to select the NIR beam. The NIR beam is reflected at a 90^o angle by a mirror or a future beamsplitter that transmits at λ < 950 nm. Both the visible and NIR spectrographs employ echelle gratings and grating cross-dispersers. Both visible and NIR beams will have basic resolution modes of 5000, 7000 and 10000. The visible beam will, with also have a 20000 mode. The resolutions depend on the combination of fibers and intermediate slit selected as discussed in section 3.2.1.

Table 1. Properties of the MRS

Medium Resolution Spectrograph (MRS)		
	Visible Beam	**NIR Beam**
Fiber Fed MOS: Maximum number of Objects	9	5
Wavelength range (nm)		
Typical	430-880	1000-1300
Blue Limit	380	900
Red limit	900	1350
Resolution-slit product (Rf arc-sec)	10,400	10,400
Max. resolution	~20,000	10,400
Camera	dioptric F/1.6	dioptric F/1.6
Detectors	Two 2K x 4K, Marconi 15 μm pixels	1k x1k HgCdTe Hawaii 18 μm pixels
Echelle	79 or 110 g/mm, R2	31.6 g/mm, R2
Crossdispersers (g/mm and wavelength of max. efficiency)	#1: 220 g/mm, 590 nm	#1: 400 g/mm, 1200 nm
	#2: 600 g/mm, 650nm	#2 TBD
	#3: 900 g/mm, 515 nm	
	#4: 1200 g/mm, 560 nm	
Maximum wavelength range/frame	450 nm	300 nm

3. THE MRS SYSTEM

Like all modern astronomical instruments, The MRS is a complex system. Broadly speaking the MRS can be divided into three major subsystems; the Fiber Instrument Feed (FIF), the spectrograph itself and the control systems. Figure 1 is a top level schematic of the MRS system. The interface with the sky is through the FIF. The FIF contains the fibers and positioning stages. The FIF is located at the telescope focus on the HET Prime Focus instrument Platform (PFIP). The FIF control electronics is nearby on the HET tracker. 35-meter fiber cables go to a spectrograph room underneath the telescope were the spectrograph and spectrograph control system is located.

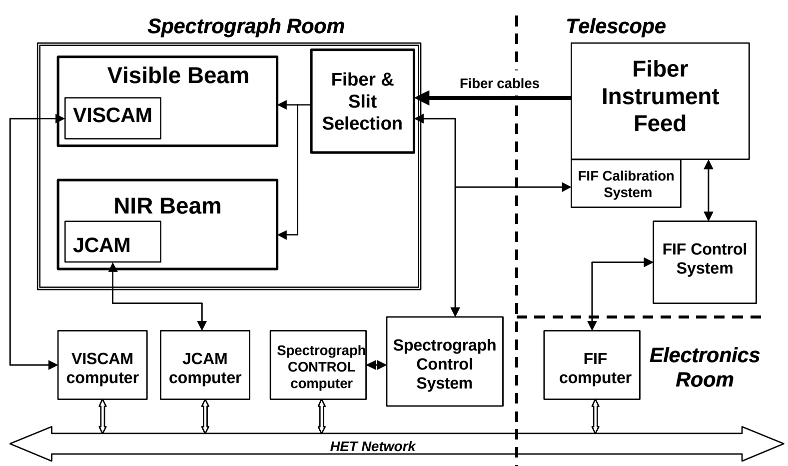


Figure 1: The Medium Resolution Spectrograph System

The MRS spectrograph has two major components, a visible beam and a NIR beam, fed by a common fiber and slit selection system. The Visible Beam is a cross-dispersed echelle white pupil system whose design is derived from the UVES. The camera-detector system, VISCAM, is all-refracting camera with a CCD mosaic. The NIR Beam is similarly a white pupil cross-dispersed echelle spectrograph. However, the white pupil optics is different here in an attempt to save cost while maintaining performance. The camera-detector system in the NIR beam is called JCAM as it is designed for use in the J spectral region. The camera is again an all-refracting system. The detector is a 1024^2 HgCdTe "Hawaii" array. The MRS control has separate computer for the CCD system in VISCAM, the NIR array in JCAM and one each for the spectrograph control and FIF control. The spectrograph and FIF control computers and electronics are separate from the rest of the MRS control system due to the large physical separation of the FIF and the spectrograph proper.

3.1. The Fiber Instrument Feed

The Fiber Instrument Feed (FIF) has been on the HET since 1999 and the feed geometry basically has not changed from that describe by Horner, Engel and Ramsey[10]. Figure 2 shows the stages on a jig in the laboratory. There are four stages on each of three levels. The lower level contains two MOS probes as well as a probe each for the long slits and HRS input. There are four MOS probes each on the bottom (mid level) and top (upper level) side of a raised plate. All the probes on the bottom level hold the fiber axis normal to the focal plane (Type 0) while the mid and upper level probes have hold to fiber at 1 degree to the focal plane (Type 1) to minimize focal ratio degradation due to the telecentric angle variation across the HET field of view (Horner, Engel and Ramsey[10]). While the mechanical layout of the probes has not changed, we have changed the distribution and types of fibers. The most significant change is the elimination of all 3 arc-second (600 micron) fibers from all the MOS probes. They have been replaced by 1.5 and 2 arc-second NIR optimized fibers on alternate probes. Each MOS probe still retains a pair of 1.5 and 2 arc-sec STU fibers (Lu, Schötz and Fabricant[11]). In addition the height of the long slits were decreased. The only 3 arc-second fibers will be used for an image slicer and future applications and this is thus re-designated the *Aux/slicer*. An IFU is still in the plans but it is much simplified and the sky fibers are integral to it and not on one of the MOS probes as described by Horner, Engel and Ramsey[10].

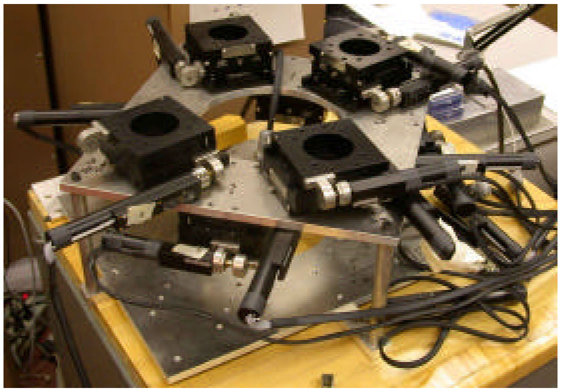


Figure 2: FIF stage layout

Table 2 A list of the fiber types on the FIF probes that can be used with the MRS.

MOS Probe fiber distribution

	Lower		Mid				Upper			
	Type 0		Type 1				Type 1			
Fiber description	**MOS 0**	**MOS 1**	**MOS 2**	**MOS 3**	**MOS 4**	**MOS 5**	**MOS 6**	**MOS 7**	**MOS 8**	**MOS 9**
STU 300330370500		2	2	2	2	2	2	2	2	2
STU 400440480900		2	2	2	2	2	2	2	2	2
FVP300330370500	2									
FVP400440480900	1									
FIP 300330370500	2	2	2		2		2		2	
FIP 400440480900	1			2		2		2		2

Long Slit Fiber distribution

	Long Slit # 1	Long slit # 2	Aux/slicer
FIP 300330370500	15		
FIP 400440480900		9	
FIP 6006607101200			3

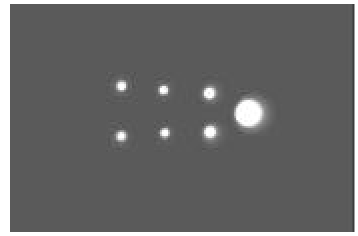
Integral Field Circle

FIP200230260	51

Table 2 summarizes the FIF fiber implementation. The fibers and the cabling for the MRS were done by Polymicro Technologies of Phoenix Az. The end preparation and final assembly is done at Penn State University. We utilized three types of fibers all of which have Polymicro catalog numbers. As an example, the numbers in the form

FVP300330370500 is a high OH fiber with a 300 micron fused silica core, 330 micron doped fused silica cladding, 370 micron diameter polyimide buffer and a 500 micron Nylon jacket. Polymicro draws fibers using the Heraeus Tenevo STU preforms (Lu, Schötz and Fabricant[11]) which have a balance of visible and NIR properties and these are the STU numbers. We prefer the FIP fibers for NIR work as the STU fibers have an absorption feature in the J band. The FVP (blue) fibers are slightly better shortward of 400 nm and may be of use for the rare observation where that may be attempted. The image scale of the HET is 0.205 mm/arc-second so the 300 micron and 400 microns fibers correspond to 1.5 and 2 arc-seconds respectively.

The layout of a MOS probe is given in Figure 3 where the fibers are back-illuminated. The large circle on the right it the 5-arc-second (1mm) coherent bundle. Each MOS probe has such a bundle for image acquisition and guiding. The next vertical pair going left are the 2 arc-second (0.4 mm) fibers. Continuing left we have a sky/object pair of each of blue optimized (Polymicro FVP) and red optimized (FIP) 1.5 arc-second (0.3 mm) fibers. The illustrated probe is MOS 0 which we have designated as the initial commissioning probe. MOS 1-9 will be similar but have STU fibers as per table 2.



FFigure 3: MOS Probe layout

When each MOS probe is fabricated the precise relative positions of the fibers and a 5 arc-second coherent bundle is measured. This is accomplished in a jig that alternatively places the fiber probe and a calibrated target in the image plane of a simple CCD system. The calibrated target has spots on 1 mm centers which not only gives the scale on the probe but any field distortion due to the re-imaging optics. The probe layout given in Figure 3 allows centering of the science target in the coherent bundle. Once this is done and the telescope is focused, the probes will do a precision 2-axis translation transferring the target from the coherent bundle to the selected fiber. Any of the unused MOS probes can be used as a guide probe for other MOS probes, slit probe or HRS probe.

The slit probe and the HRS probe also have coherent imaging bundles. The slit probe has a 5 arc-second bundle and the HRS/AUX probe has a 32 x 24 arc-second (6.7 x 5 mm) bundle. For the slit probe a target can be positioned in the bundle and a precision single axis translation will allow placement of the target at the center of the slit array. For the HRS/AUX probe the target can be positioned anywhere in the imaging bundle that corresponds to the desired final location with a precision single axis translation of the probe.

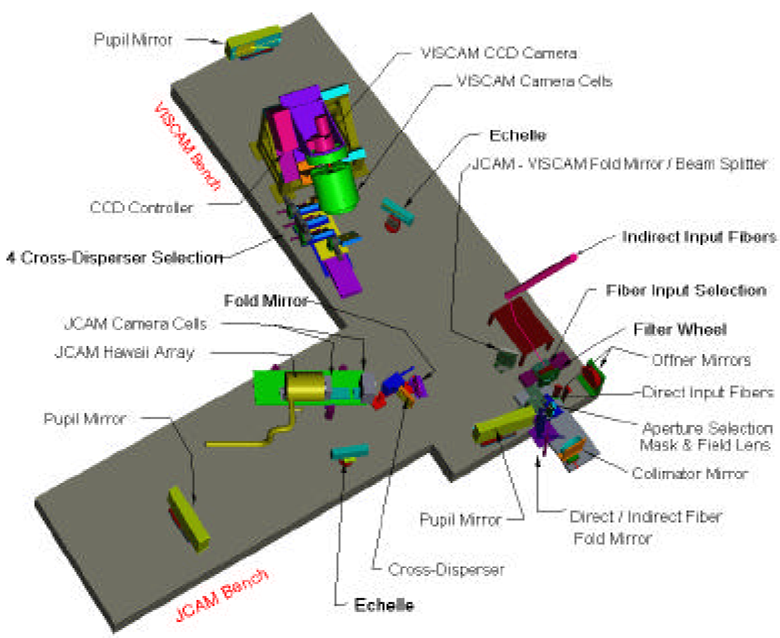


Figure 4: Mechanical layout of the MRS spectrograph on two optical benches

3.2. MRS Spectrograph

The dual visible and near infrared (NIR) spectrographs are mounted on an optical bench in an environmentally controlled light-tight room under the telescope. The mechanical implementation of the cross-beam geometry of the two white pupil spectrographs is illustrated in Figure 4. A common collimator and slit system can be used with a beamsplitter to allow spectra to be obtained in both beams simultaneously although this mode has not yet been tested. A beamsplitter or fold mirror is mounted in the collimated beam. The NIR beam is reflected at a 90^o angle by a mirror or a beamsplitter that transmits at λ < 950 nm. Both the visible and NIR spectrographs employ echelle gratings and grating cross-dispersers. Figure 4 gives the mechanical layout of the MRS spectrographs.

3.2.1. Fiber and slit selection system

The design we presented in Horner, Engel and Ramsey[10] had all the fibers at the collimator prime focus behind a 10 mm wide variable slit followed by a field lens to place a pupil on the echelle grating. This required moving all the fibers vertically with a precision of < 10 microns over more than 300 mm with a small obstruction in the beam. That design became to complex, risky and very expensive so we adopted a more conventional approach in 2000 where the fiber outputs are re-imaged onto slits by an optical transfer system. As a transfer system with a no achromatism from 380 to 1700 nm is required, we chose to use an all-reflecting Offner system. Offner relays are often used in IR instruments but they are ideal for our application as, in addition to being an all reflecting system, they have virtually no aberrations over the 13 mm maximum field of views defined by the fiber slits. The optical layout of the visible beam with this system is illustrated in Fig 6.

The FIF probes terminate at the spectrograph end in 12 fiber *slits*. Four of these are permanently at the collimator prime focus without intervening slits and selected by precision 25 mm stage. These are the “direct feed” configurations and all theses fibers originate in the MOS 0 probe. The 2.0 arc-second direct fibers result in a resolution of R=5300 and the 1.5 arc-second fibers have a resolution of 7000.

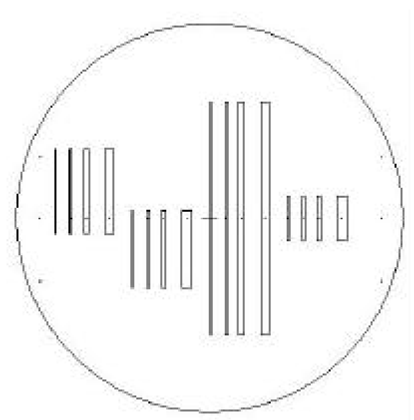


Figure 5: Slit Mask

The remaining 8 fiber inputs are imaged on a slit mask using the Offner relay (see Figure 6). The slit mask, shown in Figure 5, has three basic slit sizes; 100, 200 and 300 microns and an “open” (600 microns). There are four groupings of these sizes to select (right to left in Figure 5) the center, full, bottom or top portions of the fiber input slits. The 100 micron size yield a resolution ($\lambda/\Delta\lambda$) of 20,000 on the VISCAM. Using this slit with the NIR beam will lead to an under-sampled spectrum as the JCAM has a shorter focal length than the VISCAM and the detector has slightly larger pixels. The 200 micron slit can be used with any of the fibers and yields a resolution of 10,000. The 300 micron slit is intended to be used with the 400 micron fibers to obtain a resolution of 7,000. With the 600 micron slit the 400 micron fibers will yield a resolution of 5,300. These resolutions for the visible and NIR beams are summarized in Table 3. The first column is the fiber configuration and the next four columns are the resulting resolutions for the 100, 200, 300 and 600 micron slits respectively. We intend to implement a 5-slice image slicer with the 600 micron (3-arc-second) fiber that will allow a resolution of about 17,000.

Table 3 The resolutions are given in the format VISCAM/JCAM where a x means that mode is not available.

	Resolution (VISCAM/JCAM)			
Configuration	**100**	**200**	**300**	**600**
2.0 arc-sec Slit	20000/x	10000/10000	7000/7000	5300/5300
1.5 arc-sec Slit	20000/x	10000/10000	7000/7000	7000/7000
2.0 arc-sec MOS-STU	20000/x	10000/10000	7000/7000	5300/5300
1.5 arc-sec MOS-STU	20000/x	10000/10000	7000/7000	7000/7000
2.0 arc-sec MOS-FIF	20000/x	10000/10000	7000/7000	5300/5300
1.5 arc-sec MOS-FIF	20000/x	10000/10000	7000/7000	7000/7000
Sliced 3.0 arc-sec fiber	20000/x	x	x	17000/x
Full IFU	20000/x	10000/10000	7000/7000	7000/7000

3.2.2. The Visible beam

The visible beam is the most complex sub-subsystem on the MRS. An optical layout of the visible beam and the Offner transfer and collimator system viewed normal to the primary dispersion is given in Figure 6. The visible beam begins after the beamsplitter. The combination of a field lens at the slit and the collimator effectively places a pupil on the echelle grating. The design approach and drivers for the visible beam layout remains that given in Horner et al. With the initial 220 groove/mm cross disperser grating (#1 in Table 1) it yields a full octave of spectral coverage from 450 to 900 nm. The system is also designed to allow extended coverage down to 380 nm and up to 900 nm with different cross-disperser settings.

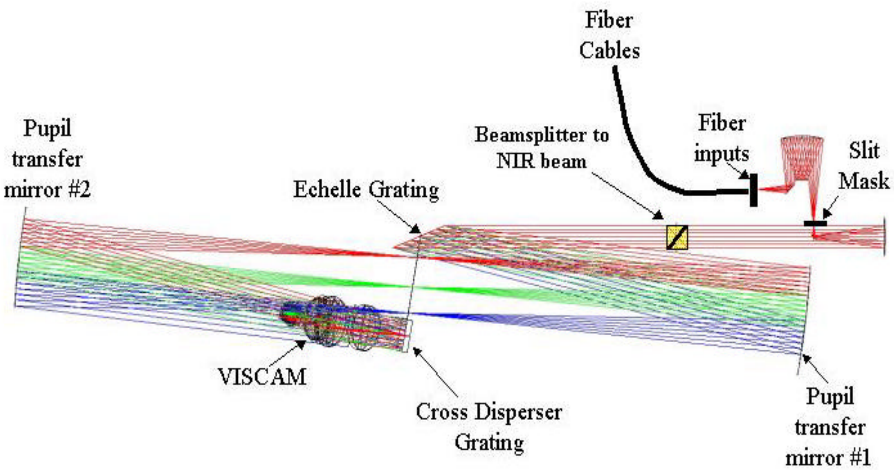


Figure 6: MRS Visible beam optical layout

To allow clean order separation when the long slits, MOS probes or IFU are used, different cross dispersers must be employed. Table 1 gives the four options possible with the visible beam. The 600 groove/mm (#2 in Table 1) is best used in the 550-900 nm range and when the center, top or bottom slits are selected (Figure 3). Similarly the 900 groove/mm (#3 in Table 1) grating is selected for the 390-700nm range and center, top or bottom slits. Only the 1200 groove/mm cross disperser (#4) has sufficient power to allow use of all MOS probes but it can be effectively used over the 450-900 nm rage. There are potentially a large number of combinations of fiber inputs, slit width and height and cross disperser combination. It is not currently planned that all such combinations will be enabled in the control system. In practice we expect only a fraction of the possible configurations that are science driven will be fully characterized during commissioning.

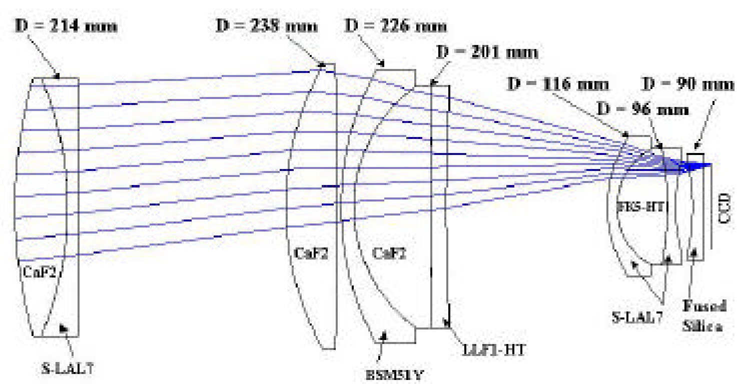


Figure 7: VISCAM

Dr. Harland Epps designed the visible camera which we designate VISCAM. It is a 10 element all refracting system and is illustrated in Figure 7. It is a 320 mm focal length f/1.63 system. The optics were fabricated by Costal Optical Systems, Inc in West Palm Beach FL. All exposed surfaces have been coated by Spectrum Thin Films in Bohemia NY. They employed a pulsed ion beam technology which allows near room temperature coatings that are ideal for the relatively fragile CAF2 elements. The VISCAM cell was designed by Alan Shrier, The Pilot Group, in Monrovia Ca. This cell is mounted at 40^{o} from the horizontal.

The CCD detector system is a mosaic of two Marconi CCD44-82-1-952 CCDs in a dewar cooled by a PT-30 gas Cryotiger. A Gen II Leach controller is used with this CCD system. The CCD system was assembled by GL Scientific in Honolulu HI.

3.2.3. The NIR Beam

The NIR beam was in the baseline design with an optical configuration nearly identical to that of the visible beam; two off-axis parabolas re-imaging the pupil on the echelle on cross disperser grating. It was always planned that this beam would be implemented after the visible beam. As the project neared the end of the design phase, it was clear that the financial resources would not allow implementation as planned and a de-scope was required. As procurement of most costly visible beam components was well advanced we were forced to look at the NIR beam to meet our cost limitations.

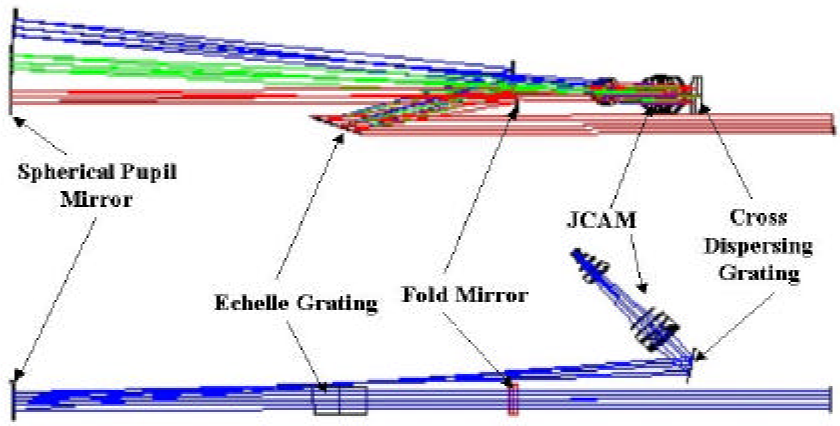


Figure 8: NIR beam optical layout as viewed from above (top) and from the side (bottom)

The fact that the visible beam and the NIR beams are essentially independent spectrographs sharing the same fiber input and collimator has allowed the ready implementation of a de-scope option. The only optical constraint on the NIR beam design is that the echelle grating be placed at the collimator pupil image. Thus we were able to adapt a largely existing spectrograph, called JCAM to become the NIR beam. JCAM is now the MRS NIR beam. The optical layout of the NIR beam from the beamsplitter on is given in Figure 8. The NIR beam is still white pupil design where but in this case the echelle is re-imaged onto a cross disperser at the camera entrance pupil using a single spherical mirror. A fold mirror between the echelle and the cross disperser adapts the system to the MRS bench. The spherical pupil mirror is tilted 2^o to allow the beam to pass above the fold mirror to the camera.

The camera is a simple 5 element Petzvel-like design (not including the window and filer) and is illustrated in Figure 9. The last SFL57 element is in the dewar as is the filter. The filter and the last element are kept at LN2 temperature to minimize NIR background on the detector. Preliminary test spectra of the JCAM configuration were obtained in late 2001 using an engineering Hawaii array.

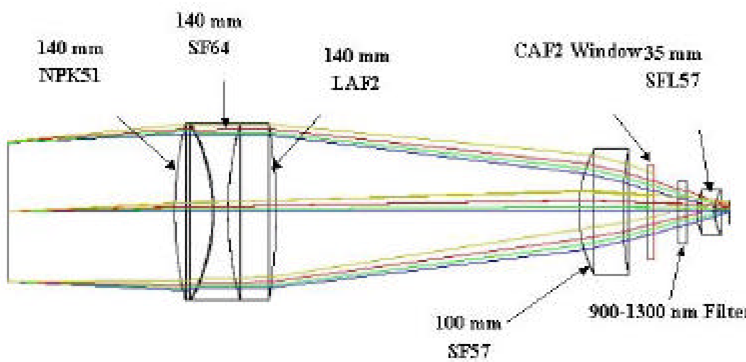


Figure 9: JCAM optical layout. JCAM is the camera for the NIR beam

3.2.4. The Control System

The MRS control system is in two parts, the division being due to the location of the two subsystems: the FIF atop the telescope and the spectrograph at the basement level The electronics for the FIF control are contained in a glycol cooled, thermally insulated box near the prime focus where the FIF itself is located. A remote computer connects with the electronics using RS-232 communications on a fiber optic modem. The MRS control electronics for the spectrograph benches is located in a 19 inch rack outside the spectrograph enclosure. The rack contains a computer to communicate with these electronics and includes the CCD and Hawaii array computes, power supplies, inteface units, and other associated electronics equipment.

All the motors in the entire MRS system are DC Servos (either Newport or US EuroTek neé DynaOptic Motion), controlled with Delta-Tau's PMAC-PC controllers and whose control signal is amplified using in-house drive amplifiers. PMACs digital Input / Output channels are used to trigger solenoids for control of numerous pneumatic actuators on the bench, to read limit switches on dust covers on the optics, to determine whether the lights in the enclosure are on or the doors are open, together with other functions. The spectrograph bench computer has a PCI COM port expansion board to extend the number of RS-232 ports, allowing interfacing with peripherals including a LakeShore temperature monitor, ThermoOriel filter wheel on the spectrograph fiber input, Hamamatsu photon counting Photo Multiplier Tube used as an exposure meter.

Software presiding over both the subsystems is written in National Instrument's LabVIEW with the PMAC Panel to assist interfacing with the controllers. At this point in time, only engineering GUIs have been written. These allow full access to all features providing comprehensive control and monitoring. Units are raw, so control of actuators at this point is in encoder counts. It is planned such that the user interface, at a higher level than the engineering GUI, will do the conversions from arc-seconds on the sky to counts.

4. MRS STATUS AND PLANS

The MRS achieved engineering first light in early August 2002 using a test fiber feed injecting daytime sky. At this time only the direct feed fibers are enabled using the lower MOS 0 probe. First light on the HET was accomplished in Mid September 2002. During that run weather and telescope problems limited us to about ½ night on the sky with

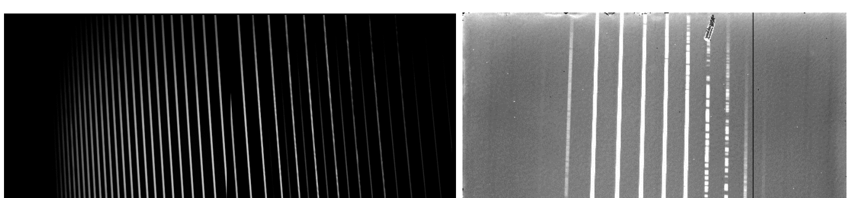


Figure 10: Spectrum from VISCAM (left) and JCAM right. Note the JCAM spectrum is magnified relative to the VICAM. The VISCAM CCD is approximately 61.5x61.5 mm where as the Hawaii HgCdTe array is 18.5x18.5 mm

significant cirrus so very limited characterization was possible. However this data indicates the visible beam is performing at least at level consistent with specifications. The spectra in Figure 10 are representative for test data taken on the MRS. As is clear from the description of the instrument, there are a large number of possible configurations. In the coming year, we will be implementing in those configuration in most demand by the HET user community.

5. ACKNOWLEDGMENTS

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