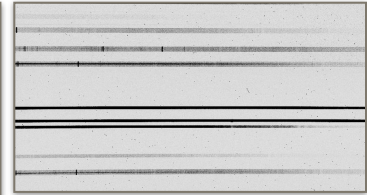
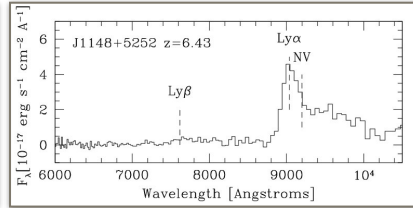


OSMOS User's Manual

Rick Pogge (OSU) & Eric Galayda (MDM Observatory)



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Summary

OSMOS (Ohio State Multi-Object Spectrograph) is a wide field imager and multi-object spectrograph that was commissioned at the 2.4m Hiltner telescope at the [MDM Observatory](#) in April 2010. OSMOS employs an all-refractive, zero-deviation design that projects a plate scale of 0.3 arcsec/pixel and a 20 arcmin diameter FOV onto the MDM4K or R4K detector systems. There is a 6-position slit wheel, a 6-position disperser wheel, and two 6-position filter wheels. The slit wheel may contain either (or both) long slits and customized masks that are laser-cut into spherical, NiColoy masks that match the curvature of the 2.4m focal surface. Up to 50 to 100 slitlets should be

feasible per mask. Dispersing elements include a very low resolution triple prism, a low-resolution VPH “blue” grism (R=1600, peak at 450nm) and a low-resolution VPH “red” grism (R=1600, peak at 800nm). Anyone interested in contributing additional dispersers is encouraged to contact Paul Martini at OSU.

Quick Reference

Imaging

- **Plate scale:** 0.273 arc seconds per pixel
- **Unvignetted Field-of-View:** 20 arc minute diameter circle, subtends a 18.5x18.5 arc minute square.
- **Filters:** All [MDM Filters](#) (4” filter cell). See table 2 for standard configuration. Please specify other choices as needed on your [run preparation form](#).
- **Performance:** See the magnitude zero points in the [Performance](#) section below.
- **Image Quality:** [FWHM in UBVRI as a function of field angle](#) for OSMOS only (atmosphere not included).
- **Finding Charts:** An easy way to generate them on the fly is with ds9 (Analysis->Image Servers->SAO-DSS).

Spectroscopy

- **Long Slits:** See table 1 below for information on widths and positional availability. Slits are ~20’ long. Refer to table 2 below for default configuration. Please specify other choices as needed on your run preparation form.

Slit-Width (arcseconds)	Center	Inner	Outer
0.9	yes	yes	yes
1.0	no	no	yes
1.2	yes	yes	no
1.4	yes	yes	no
3.0	yes	yes	no
4.0	no	yes	no
10	yes	no	no

Table 1: Available Slits

- **Triple Prism:** R=100-400 (highest resolution in the UV), 360-1000nm [[Resolution vs. Wavelength for a 3-pixel slit](#)].
- **VPH “Blue” Grism:** R=1600 (0.7 Å/pix), ranges of 310-590nm (peak @ 500nm) and 390-680nm (peak @ 640nm). See the [Wavelength Calibration](#) section for more information. [[Predicted efficiency for a centered long-slit](#)]
- **VPH “Red” Grism:** R=1600, ranges of 600-1,000nm (peak @ 750nm), 800-1,100nm (peak @ 950nm) and 420-800nm (peak @ 620nm). See the [Wavelength Calibration](#) section for more information.

Position	Slit	Disperser	Filter 1	Filter 2
1	1.2” center	Blue Grism	SDSS-g	U
2	1.2” inner	open	SDSS-r	B
3	3.0” center	open	SDSS-i	V
4	4.0” inner	Triple Prism	SDSS-z	R
5	1.0” outer	open	OG530	I
6	open	Red Grism	open	open

Table 2: Standard Configuration for Slit, Disperser & Filter Wheels

- **Acquisition:** There is currently no slit viewer. See the [Long-Slit Acquisition](#) or [Multi-Object Acquisition](#) sections for more details on how to acquire objects for spectroscopy.
- **Multi-Slit Masks:** Custom, laser-cut slits in electroformed spherical shells of NiColoy coated with copper oxide (CuO) black. Please see the section on [Multi-Object Spectroscopy](#) for information on mask design.
- **Orientation:** Slits are aligned in an N-S orientation (with rotator at 0°). To achieve E-W orientation, the rotator would be set to ±90°. Note that the wavelength solution zero point varies more with the N-S orientation due to instrument flexure.

Here is an OSMOS [log sheet](#).

There are numerous useful Prospero scripts in the *Scripts/* directory on the 2.4m observer's workstation, *mdm24ws1*. Observers are encouraged to look through these scripts.

Performance

• Photometry

Photometric magnitude zero points for OSMOS were measured in April 2010 with the MDM4K detector and in September 2011 with the R4K. These zero points correspond to 1 e⁻ per second.

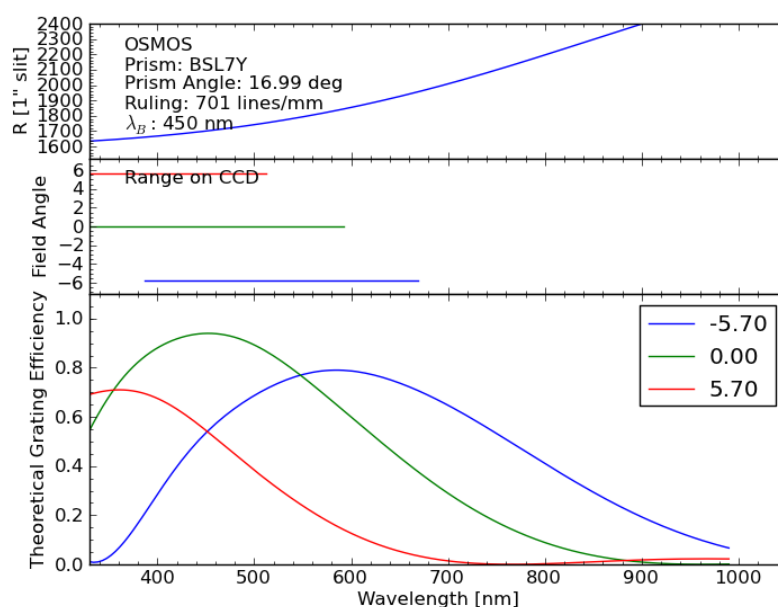
Paul Martini's page on [Useful Astronomical Data](#) has information about [Flux Zero Points](#).

Vega magnitudes, MDM4K				
U	B	V	R	I
...	24.5	25.0	25.3	24.8

AB magnitudes, R4K				
g	r	i	z	Y
...	...	25.5	25.0	23.7

• Spectroscopy

Basic information about wavelength coverage and resolution is available in the [Quick Reference](#) section. Theoretical spectral resolution and coverage for each grism can be found below for a 1" slit. Figure 1 shows data for the "blue" grism while Figure 2 shows data for the "red" grism. The -5.70 curves correspond to the inner slit while the +5.70 curves correspond to the outer slit. 0.00 is the center slit.



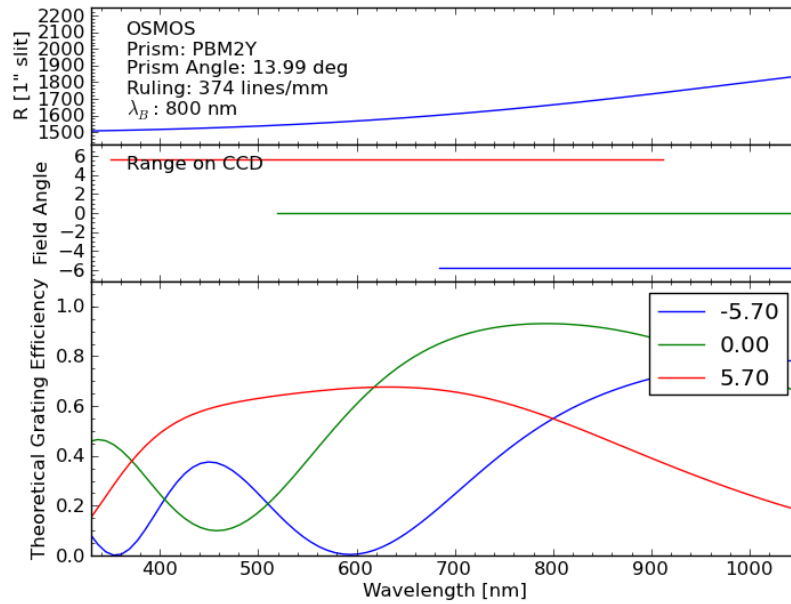


Figure 2: Red Grism Theory

Empirical comparison plots have been obtained by Ryan Chornock (OU) and are available [here](#) as well.

Overheads

The OSMOS slit, disperser, and filter wheels require up to 3 seconds to change configuration states. Detector readout varies from tens of seconds to two minutes, depending on binning and whether the full chip is read out. Long-slit acquisition takes approximately five minutes, although may require more time if there are problems with the telescope offsets. To summarize:

Action	Time (seconds)
slit/disperser/filter wheel move	3
full detector readout (binned 1x1)	134
full detector readout (binned 4x4)	16
1k x 1k detector readout (binned 1x1)	15
long-slit acquisition	300 (variable)

Detectors

OSMOS may be used with either the [MDM4K](#) or the [R4K](#) detector. Figure 3, below, shows a QE comparison based on data from the manufacturers. The R4K also exhibits substantially less fringing, but does have a higher rate of radiation events (a.k.a. cosmic rays).

● Region of Interest

One may configure either detector to read out a specific *Region of Interest* (ROI) rather than the full detector. This mode has the advantages of faster readout and smaller image files and may be particularly valuable for judging when to start twilight flats, focus sequences and spectroscopic observations. Configuration files are limited to 1k square, 2k square, 1x2k and 1x4k regions centered on the detector. To implement an ROI in *Prospero* for the MDM4K, type:

```
pr> call roi1k
pr> call roi2k
pr> call roi2x1k
pr> call roi4x1k
```

and type:

```
pr> call roi4k
```

to return to full-frame readout. For the R4K detector, the command equivalents are:

```
pr> call rroi1k
pr> call rroi4k
```

etc.

Note that the 2x1k ROI is well-suited to single-object spectroscopy with the triple-prism and the 4x1k ROI is well-suited to the single-object spectroscopy with the VPH grisms.

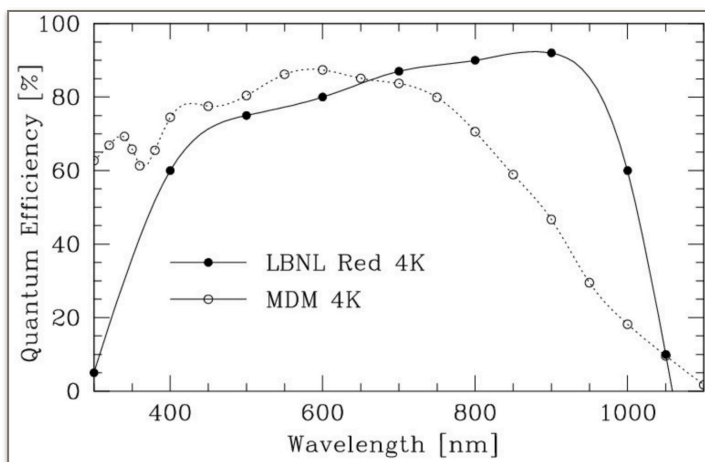


Figure 3: MDM4K vs. R4K QE Comparison

● Shutter Timing

OSMOS uses a Prontor/E100 shutter. This is a leaf shutter that may introduce timing errors in short exposures. To attain better than 1% measurement precision, one should employ exposures longer than 10 seconds (including for twilight flats). Figure 4 demonstrates the shutter timing error for a 1s exposure. In the image, the peak at the center of the field is ~5% higher than at the edges.

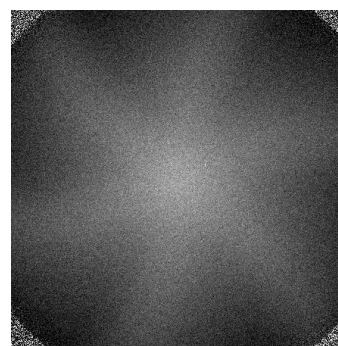


Figure 4: Shutter Artifact for exp=1s

Multi-Object Spectroscopy

• Mask Preparation

Observers interested in multi-object masks should contact [Paul Martini](#) (OSU) at least two months prior to their scheduled time on the telescope.

OSMOS masks may be designed with a software package called [OSMOS Mask Simulator \(OMS\)](#). OMS is a slightly modified version of [MMS](#), which is the mask design software for MODS (MMS is in turn a slightly modified version of *LMS*, which is the mask design software for LUCI). In addition to the OMS webpage, the web page for MMS contains additional documentation.

Mask alignment is performed with alignment stars. Square apertures that line up with reference stars are placed in the mask at locations relative to the slits. While in principle, only two reference stars are necessary to solve for the rotation and translation offsets required for mask alignment, at least four are recommended to guarantee a good solution. It is recommended that these stars be placed with the central 4x1k region of the detector. This allows for ROI acquisition, thus speeding up the alignment process. Reference stars should also be well distributed across the field, maximizing the lever arm for the rotation offset calculation.

The outputs of OMS include a file in *gerber* (.gbr) format that contains instructions to the laser cutting machine on how to cut the mask. Also contained is a mask description file (.oms extension) that describes the mapping between targets and the slit mask. Observers need to submit final mask designs to Paul Martini at least one month in advance of their scheduled telescope time to guarantee that enough time is allotted for mask production and procurement. Cost per mask to cover the electroformed spherical shell and labor for the laser machine operation is \$187, payable [here](#), through the MDM Observatory website.

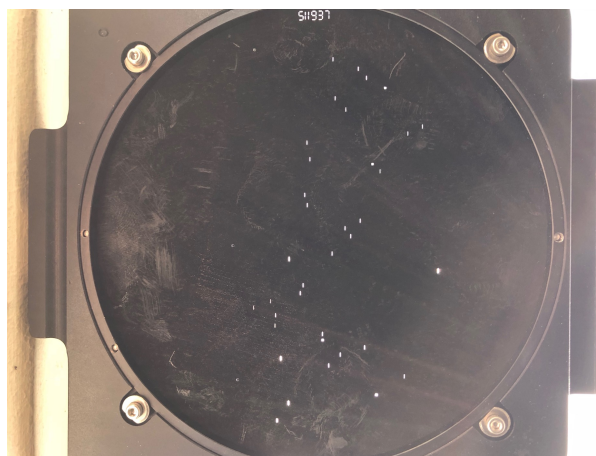


Figure 5: Multi-Object Slit (MOS) Mask

• Multi-Object Observations

Multi-object observations are similar to long-slit observations, with the exception that the rotator angle must also be set very precisely (to within 0.01°). This can be achieved with custom mask alignment software available at the telescope, described in the section on [Multi-Object Acquisition](#).

• Guidelines for Calibration

The MIS calibration system does not uniformly illuminate the entire OSMOS FOV. A reasonable solution is to simply take very long exposures during the afternoon, allowing for sufficient signal to be obtained in all of the slits. This should be performed for both arc lamps and spectroscopic flats. Twilight spectroscopic flats could be used to remove the non-uniformity of the illumination by the MIS flat lamps. For more detailed information, visit the section on [Flat Fields](#).

It is important to note that instrument flexure can result in the zero-point of the wavelength solution drifting between afternoon calibrations and nighttime observations. Sky lines could be used to compute this zero-point offset. See the section on [Wavelength Calibration](#) for information on specific dispersers.

Startup

Typically, MDM staff will ensure that all telescope systems, including OSMOS, are ready for operation prior to the arrival of observers. Still, in the event that systems need to be restarted, it is worthwhile to know the procedures.

- Turn on the [IC PC](#) in the computer room.
- Turn on the Head Electronics (HE) Box on the south side of OSMOS. This is the red box.
- Turn on the Instrument Electronics (IE) Box on the north face of OSMOS.
- In the computer room, type *O* for OSMOS and choose the appropriate detector (*4* or *R*) on the [Baritan](#) keyboard.

Next, launch the various control clients on the 2.4m Observing Workstation (typically *mdm24ws1*). On *workspace 4*, open a terminal window and type:

- `mdmTools start bridge` - opens the interface that allows the DFM TCS, telescope and instrumentation to communicate
- `mdmTools start isis` - data handling
- `mdmTools start caliban` - data handling
- `mdmTools start tcs` - telescope header information link
- `mdmTools start osmos` - OSMOS hardware com link

Performing these commands will open various new terminal windows. Typically you will not need to perform any tasks in any of these terminals. If you do not receive a prompt after performing any of the commands above, simply hit the <enter> key to return the prompt.

Lastly, restart the User Interface (Prospero) by choosing it from the pull-down menu tree: *Applications>Data Acquisition>Prospero*. Choose the option to view both windows that open on all workspaces. Type *startup* to load the current instrument configuration. Initialize the OSMOS mechanisms, including setting the collimator and camera lens barrels to their nominal 15°C positions by typing:

```
pr> call ossetup
```

Details on how to set the nominal focus of the camera and collimator lenses for different seasons are described in the [focus section](#) of this manual.

Finally, make sure the OSMOS instrument hatch is open. This is separate from the MIS dark hatch. The lever to cycle this hatch is on the opposite (west) side of the instrument from the access doors for the slit and filter wheels. *In* is open, *out* is closed.

Collimator and Camera Focus

OSMOS has two internal focus stages, one for the collimator and one for the camera. If the IE power is cycled, these stages need to be reset with the following commands:

```
pr> colfoc reset 2300
pr> camfoc reset NNNN
```

where NNNN is the temperature-dependent focus value for the camera. A good tool for determining the appropriate camera focus (camfoc) value based on the current bench temperature can be found by opening:

Applications>OpenOffice.org>LibreOffice Calc

and opening the file “Observing_Data.ods”. Figure 6 shows this spreadsheet and equation below.

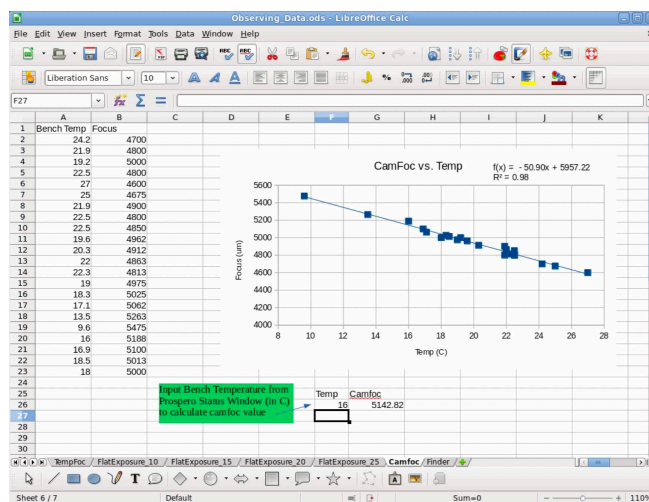


Figure 6: Camera Focus vs. OSMOS Bench Temperature

User Interface and Prospero

OSMOS is operated with the [Prospero User Interface](#), written by [Rick Pogge](#). Please refer to his extensive online documentation for general information about how to use this software. Below is a brief synopsis of the most commonly used commands.

• Basic Commands

The instrument configuration is controlled with six basic commands:

```
pr> slit N
pr> disp N
pr> filter1 N
pr> filter2 N
pr> colfoc FFFF
pr> camfoc GGGG
```

The slit, disperser and filters take an integer argument [1 through 6] that corresponds to the desired aperture position. Executing the command with no arguments will return the current position of the wheel. The collimator and camera focus stages are controlled with the `colfoc` and `camfoc` commands respectively. An integer argument to these commands (i.e. the FFFF or GGGG variables above) moves the appropriate stage to that absolute position in microns.

• Data Acquisition

```
pr> go                take an exposure
pr> go n              take n number of exposures
pr> exp T             set the exposure time to T seconds
pr> object name       set the object name to name
pr> filename name     set the filename to name
pr> print wheel       display the current population of wheel [slit, disp or filter]
pr> call script       run the Prospero script named script.pro
pr> snap              take an image without writing to disk
pr> movie             streams continuous images without writing to disk (stopmovie to end)
pr> newext num        change the file number to num
```

The `tedit` command may also be used to update the tables that map wheel positions to their contents (e.g. that position 6 is open). *Please do not edit these tables without good reason.* If you suspect the tables are incorrect, please double check the listings, preferably with observatory staff assistance.

• Prospero Scripts

Prospero has a powerful scripting capability that can be used to automate many common tasks. Examples include mask alignment (via [oalign.pro](#)), telescope focus automation (via [focus4k.pro](#)), guider dither sequences for deep imaging (via [four.pro](#) & [nine.pro](#)) and changing the ROI (e.g. [roi1k.pro](#) & [roi4k.pro](#)). These and many other scripts are available in the `Scripts/` subdirectory on `mdm24ws1`. Further details on how to write Prospero scripts are available in the Prospero online documentation. Should the OSMOS-related scripts discussed here become compromised, here is a [backup.tgz archive](#) of some scripts.

• Telescope Focus

A quick way to get close to the best focus is to find a reasonably bright star, switch to the 1k ROI, turn on movie mode (type the `movie` command), and focus by eye until the star appears reasonably in focus. (Type `stopmovie` to exit movie mode.)

A simple Prospero script called [focus4k.pro](#) is available to help refine the telescope focus once it is close. This script takes a sequence of 5 focus frames in steps of 50 units starting with an input, minimum value. The syntax is:

```
pr> call focus4k focmin
```

where `focmin` is the desired starting value. Note that it is important to set the instrument configuration (filter, ROI, etc.) before you start this script.

Guiding

Guide stars are best chosen through the [JSkyCalc24mGS](#) (Thorstensen, Dartmouth) interface. It is recommended to choose stars with magnitude 13-14, although it is possible to go as faint as 16 mag. Further detail is available from the guide, [Autoguiding and Acquisition at MDM](#) by John Thorstensen.

[JSkyCalc24mGS](#) is also used for spectroscopic acquisition, described further in the next sections on [Long-slit Acquisition](#) and [Multi-Object Acquisition](#).

It is important to note that the OSMOS FOV includes nearly the entire unvignetted footprint of the MIS. This means that guide stars need to be near (or ideally in) the partially vignetted beam for imaging (or potentially multi-slit spectroscopy).

Long-Slit Acquisition

OSMOS does not have a slit-viewing camera. Instead, targets are placed in a slit with the use of telescope offsets to the known position of the slit projected onto the sky. The object can then be imaged through the slit after acquisition to confirm that it has been acquired.

Guider offsets are much more precise than telescope offsets at the 2.4m and consequently it is much more efficient to offset the guide box by the desired amount and then move the telescope to put the guide star back in the guide box. There are two algorithms for long-slit acquisition. The first uses a pyraf code (Thorstensen, Dartmouth), described in [Appendix A - Acquisition Scripts](#), below.

Alternatively, one may use the `-l` option in [oalign.py](#), which is also used for Multi-Object Acquisition. There is also a Prospero script called [olsalign.pro](#) that performs a similar function. Usage of these scripts is described in the next section on [Multi-Object Acquisition](#).

Finally, a description of a more manual (and less efficient) method is described in appendix B, detailing the [old long-slit acquisition procedure](#).

Multi-Object Acquisition

Acquisition of targets in a multi-object slit (MOS) mask requires precise translation (on order of 0.1-arcsec in x & y) and rotation (on order of 0.01°) offsets. This requires an image of the slit mask, which should be obtained immediately prior to alignment to minimize flexure, as well as an image of the field. The relative positions of the alignment boxes and the alignment stars may then be used to calculate the translation and rotation offsets.

There are two scripts that aid in efficient mask alignment: [oalign.pro](#) and [oalign.py](#). These scripts are meant to be used in conjunction with one another. [oalign.pro](#) is a Prospero script that facilitates the acquisition of the images necessary for mask alignment and the proper configuration of the instrument. [oalign.py](#) is a python script that is used to calculate the offsets needed for mask alignment. The rotation offset is sent via the Rotator GUI and the translation offsets are best sent by moving the guider stage. Please read the [Rotator Manual](#) for usage instructions for the rotator. [oalign.py](#) must be run in a separate terminal from Prospero.

A step-by-step guide to mask alignment is provided in the appendix titled [OSMOS Mask Alignment Cookbook](#).

Instrument Configuration

The instrument configuration will be set by the MDM staff before the start of the observing run. Use the print command in Prospero to view the current configuration of a given mechanism. For example:

```
pr> print slit
pr> print filter
pr> print disp
```

For all mechanisms, including camfoc and colfoc, typing the command with no arguments returns the current configuration. This information is also listed on the Prospero Status Window. Cheatsheets are also affixed to the workstation monitors. See the section on the [User Interface and Prospero](#) for more information.

• Filter and Slit Exchanges

Filter and slit exchanges should only be performed by Observatory staff. You should contact MDM Observatory with any special configuration information in advance of your run, preferably in your [Run Preparation Form](#).

Flat Fields

• Imaging Flats

Twilight flats are the most reliable flats for calibrating imaging data. A good strategy for evening twilights is to use movie mode and 1k Region of Interest until the sky is no longer saturated. For example, if you are using the MDM4K (B4K), type:

```
pr> call roi1k
pr> movie
```

To exit movie mode and return to full array readout type:

```
pr> stopmovie
pr> call roi4k
```

For the R4K the equivalent commands are call rroi1k and call rroi4k.

Note that exposure times longer than 10s are recommended for flats to avoid significant [shutter timing](#) errors. Note also that for the standard BVRI set (Harris set), the order of the filters from most sensitive to least sensitive is IRVB.

• Spectroscopic Flats

The MIS flat lamp is useful for the removal of small-scale spatial variations along the slit. However since illumination across the slit is not uniform, they are not useful for large-scale variations. Spectroscopic twilight flats should provide an adequate measure of large-scale variations along the slit.

Wavelength Calibration

• Triple Prism

The best wavelength calibration source for the triple prism is a bright, compact planetary nebula. None of the MIS lamps offer a good selection of unblended lines over the entire wavelength range accessible with the prism. The best wavelength solution obtained during commissioning employed a 4th-order spline and yielded an rms of about 1 nm. Figure 7, below, shows a plot of the identify task in IRAF with planetary nebula lines labeled. Table 3 shows a list of emission lines. Many of these lines are actually blends, particularly towards the red. In other words, there is room for improvement.

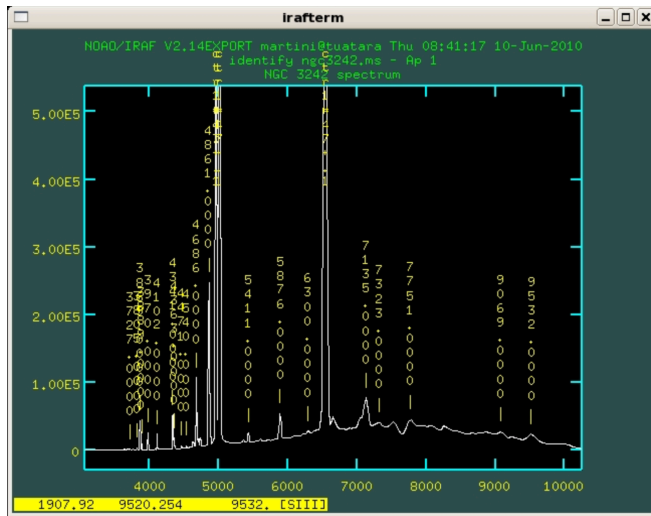


Figure 7: Planetary Nebula Spectrum with the Triple Prism

Angstroms	Line	Angstroms	Line
10832	HeI	5007	[OIII]
9532	[SIII]	4959	[OIII]
9069	[SIII]	4861	Hbeta
8438	P18	4686	HeII
7751	[ArIII]	4540	HeII
7323	[OII]	4471	HeI
7135	[ArIII]	4341	Hgamma
7065	HeI	4363	[OIII]
7005	[ArV]	4102	Hdelta
6678	HeI	4070	[SII]
6584	[NII]	4026	HeI
6563	Halpha	3968	[NeIII]+Hepsilon
6548	[NII]	3889	HeI
6300	[OI]	3869	[NeIII]
5876	HeI	3835	H9
5755	[NII]	3805	HeI
5411	HeII	3727	[OII]

Table 3

● Medium VPH Grisms

In addition to a long-slit through the center of the field, slits can also be oriented ± 30 mm (roughly ± 5.7 arcmin) from the center slit (but parallel to it). These offset slits allow one to take advantage of one of the unique properties of VPH grisms, namely that the wavelength of peak diffraction efficiency varies as a function of the angle of incidence inside the grating with respect to the fringe plane. These offset slits are referred to as the *inner slit* and the *outer slit* to differentiate them from the *center slit*. This notation refers to their position in the slit wheel, i.e. the slit closest to the axis of rotation is the inner slit. The wavelength ranges and approximate wavelengths of peak efficiency for each position can be found in Table 4, below. [Figures 1, 2 & 3](#), found above, are also useful references for transmission and bandpass information for each slit position and grism.

Blue Grism		
Slit Position	Bandpass (nm)	Approximate Efficiency Peak (nm)
Inner ("Red")	390 - 680	640
Center ("Blue")	310 - 595	500
Outer	220 - 490	420

Red Grism		
Slit Position	Bandpass (nm)	Approximate Efficiency Peak (nm)
Inner ("Red")	800 - 1,200	1,000
Center ("Blue")	600 - 1,000	710
Outer	400 - 800	600

Table 4: Coverage Parameters for Slit Positions

Matthias Dietrich (OSU) has created a series of [Wavelength Calibration Figures and Tables](#) for the MIS lamps. Please see this information for further details.

• Spatial Extent

The calibration lamps in the MIS do not fully or uniformly illuminate the entire OSMOS field. This will result in lower illumination at the ends of the slits. There is an approximate factor-of-two decrease in a long-slit lamp at 5 arcminutes from the center of the field. Some points that are still farther off-axis appear completely vignetted. Complete vignetting does not occur for the long slit, but may impact multi-slit observations. Figure 8 is an image of the Ne lamp through the U filter that shows the illumination pattern.



Figure 8

Data Analysis

There is no comprehensive data analysis package for OSMOS. Jason Eastman however has written an IDL package that should be suitable for processing imaging data. This package is described at the bottom of his [manual](#) for the 4k detector.

John Thorstensen has also adapted his [qccds.html](#) script for OSMOS.

The IRAF script [bias4k.cl](#) may be useful for quick-look bias subtraction at the telescope.

More recently (late 2020), a couple software packages have surfaced with support for OSMOS data processing. One is called [Pypelt](#) and the other, developed by John Thorstensen, is [thorosmos](#). Both of these are available for general use.

Technical Information

• Recommended Specifications for New Filters

Anyone interested in purchasing new filters for OSMOS is strongly encouraged to contact [Paul Martini](#).

It is worthwhile to note that there is potential to borrow filters as described [here](#) and [here](#) from KPNO for use with OSMOS. Not all of their filters may be flat enough for use in OSMOS. For an incomplete list of filters known to work with OSMOS, click [here](#).

• Instrument Characteristics

Physical Parameters	Optical Parameters
Size: 101.5 x 101.5 mm (± 0.5 mm)	Clear Aperture: 90% of physical size
Thickness: 7mm (± 0.5 mm)	Angle of Incidence: 8°
Parallelism: < 2 arcminutes	Surface Flatness: 1 wave PV @ 633nm over clear aperture
Chamfer: 0.5mm on all edges	Surface Quality: 80/50 scratch dig
Edge: Fine ground, painted black	
Operating temperatures: -10°C to +20°C	

Physical Characteristics

Design	All refractive, spherical optics
Focal Station	f/7.8 RC @ Hiltner 2.4m telescope
Focal Surface Scale	11.528 arcsec/mm
Approximate Dimensions	1.5 x 0.5 m
Approximate Mass	160 kg
Construction	Optical bench supported by welded steel frame
Flexure Goal	4 μ m P-V (~1/4 pixel) over a 1 hr integration
Slit Masks	6-position mask wheel, spherical surface to match focal-plane curvature, slits laser-machined in electroformed NiColloy masks ~ 105mm in diameter
Long Slits	Fixed long slits (0.9, 1.2, 1.4, 3.0, 4.0, 10-arcsec width)
Slitlets	Arbitrary size, shape & orientation
Dispersers	6-position disperser wheel with one 100x85mm triple prism, one blue-biased grism & one red-biased grism
Imaging	Open aperture in slit and disperser wheels
Filters	Two 6-position filter wheels tilted by 8°, 100x100mm cells (compatible with MDM and some KPNO filters)
Collimator Design	f/7.8, 14° FOV Double Gauss optimized for telescope input
Collimator Pupil Relief ¹	70mm
Collimator Focal Length	430mm
Collimated Beam Diameter	55mm
Camera Design	f/4.9, 18° FOV Petzval with pupil relief and focal plane relief
Camera Focal Length	270mm
Camera Pupil Relief ¹	100mm
Detector Focal Plane Relief ¹	50mm
Detector Focal Plane Scale	18 arcsec/mm, 55 microns/arcsec
Imaging Pixel Scale	0.273 arcsec/pixel (15 micron pixels)
(De)magnification	1.6x reimaging of telescope focal surface
CCD	4096x4096 (15 micron pixels) STA0500A silicon (MDM4K, thinned; R4K thick)
Guider/Acquisition	MDM guider/acquisition via imaging through slit
Calibration System	Existing MIS calibration lamps (Ne, Hg-Ne, Ar, Xe, Ar)
User Access	Filter wheels, Slit Mask cassette

Table 6: Physical Characteristics

Note: ¹ relief is the distance from a given location to the nearest optical element.

Expected Imaging Performance

Wavelength Range	350 - 1,000 nm
Field of View	20 arcminute diameter circle
CCD Pixel Scale	0.273 arcsec/pixel (15μm pixels)
Standard Filters	SDSS-griz, OG530 order blocker (filter1); UBVRI (filter 2)
Throughput ¹	52% @ 350nm, 62% from 400 - 1,000nm
Designed Image Quality 80% EE	U band: 0.6" (zenith ²), 0.9" (40° zenith angle ²) ; BVR bands: 0.3" ; I band: 0.4" 350 - 1,000nm (polychromatic): 0.5"

Table 7: Imaging Performance Theory

Note: ¹ Transmission through OSMOS collimator and camera only, excluding atmospheric transmission, telescope coating and CCD quantum efficiency. 2% AR coatings on all air-glass surfaces are assumed (although the goal is 1.5% coatings).
² Includes atmospheric dispersion.

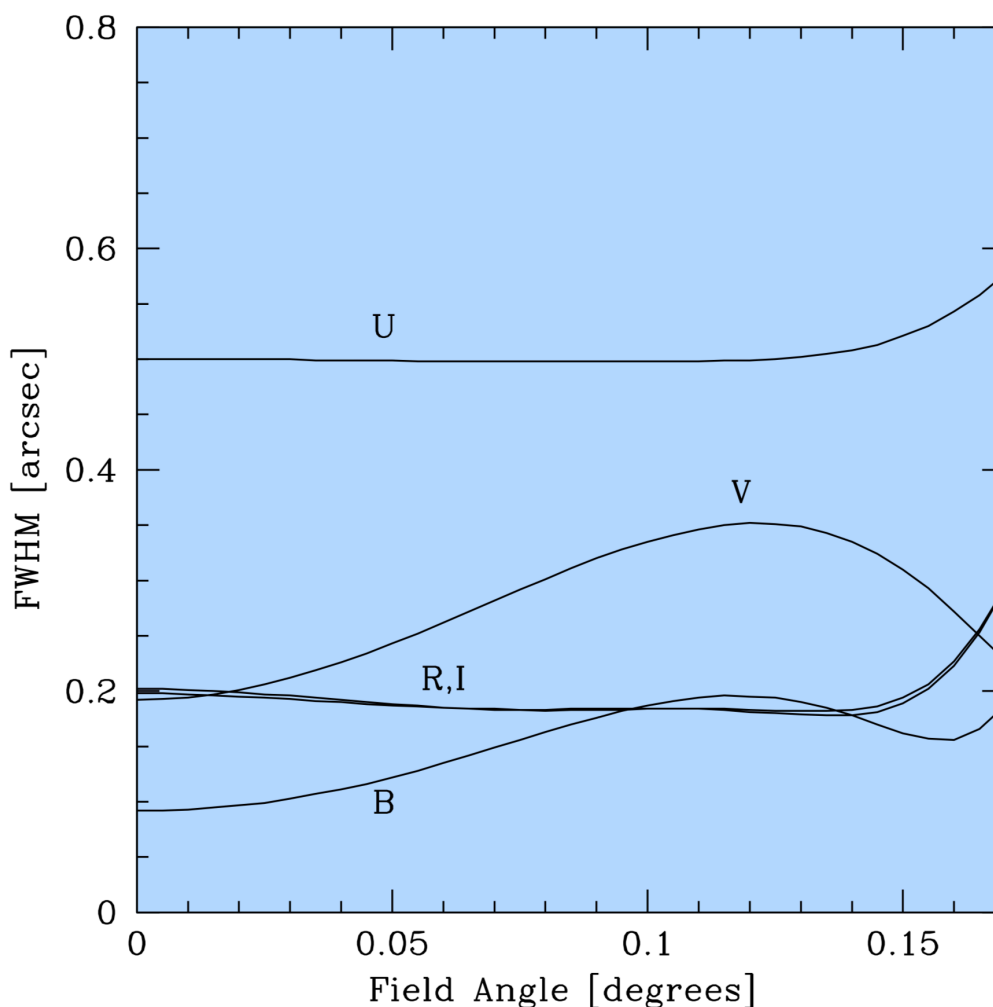


Figure 9: FWHM for UBVRI as a Function of Field Angle (atmosphere not included)

Expected Spectroscopic Performance

Max Slit Length	20 arcminutes
Total Slitlets (MOS)	50 - 100 slits per mask
CCD Pixel Scale	0.273 arcsec/pixel (15 μ m pixels)
Wavelength Range	350 - 1,000 nm
Fixed Long-Slits	0.9", 1.2", 1.4", 3.0", 4.0", 10" (somewhat configurable inner, center & outer)
Grisms	Up to 4 ports. Currently mounted red- & blue-biased grisms
Resolution (grism)	1,600
Low Resolution Prism	Triple Prism
Resolution (prism)	100 - 400

Table 8: Spectroscopic Performance Theory

Multi-Object Slit Masks

Mask Surface Shape	Spherical, matching f/7.8 focal plane
Slitlet Shape	Arbitrary shape & size
Slitlet Orientation	Tilted up to $\pm 30^\circ$ from vertical
Slitlet Length	> 0.6" (> 52 μ m), typically < 20" (1.73mm)
Slit Widths	> 0.6" (> 52 μ m), typically 1.2" (104 μ m)
Edge Smoothness	~1.8 μ m rms (2% of 1.2" slit)
Slit-to-Slit Position Tolerance	5 μ m rms perpendicular (5% of 1.2" width) 150 μ m rms perpendicular (10% of 20" length)
End Shapes	Square or round
Cost per Mask	\$187
Mask Generation	Laser machined at the University of Arizona

Table 9: Multi-Object Slit Masks

Telescope Installation & Removal Procedures

Troubleshooting

- **The slit [or disperser or a filter] wheel does not turn to a valid position:**

Move the wheel to the nearest position with the command

```
[aperture] reset
```

where [aperture] is slit/disp/filter1/filter2.

- **One of the wheels (filter, slit or disperser) times out:**

If a wheel mechanism returns an error such as:

```
ERROR: DISPERSER DISPERSE=TIMEOUT cannot read from ...
```

then the instrument electronics (IE) is not communicating with that mechanism's [controller](#).

1. Stop observing and stow to zenith. Note the camera focus (camfoc) value if it differs from default.
2. Shut down the OSMOS IE agent by finding the OSMOS IE console xterm (typically on work space 4) and typing `quit` at the prompt. OR open an xterm and type `mdmTools stop osmos`.
3. On the instrument, power off the OSMOS IE (make sure it is the IE and not the detector controller (HE)!). Refer to [OSMOS Electronics Boxes & Control Programs](#) for more information. Count to 20 and power it back on.
4. Restart the OSMOS IE agent as described in the [startup procedure](#) above.
5. Type `startup` in the prospero command window to restart the OSMOS session.
6. Run the setup script by typing `call ossetup`. This reinitializes the instrument. Reset camera focus if needed.

- **The connection to the IC is lost:**

This may happen due to a timeout in waiting for the IC to respond. If this does occur while an exposure is in progress, let the exposure finish. It will still be written to the disk. To reestablish the link, type:

```
pr> restart
```

If this is unsuccessful, try the steps outlined next in *The IC stops responding*.

- **The IC stops responding:**

1. Quit prospero (`pr> quit, are you sure? y`).
2. On the [Raritan](#) in the computer room, type `quit` then power down the [IC PC](#). Count to 10 and power it back up again.
3. Using the Raritan, when prompted, type `O` to choose OSMOS, then `4` (or `R`) for the MDM4K (or R4K).
4. Restart the necessary OSMOS programs as described in the Startup section above.

If this does not work, repeat the lightning shutdown procedure but also power off the HE (red box) on OSMOS. Count to 10, power up the HE then proceed as described above.

- **Instrument Status Window in prospero does not appear:**

Type `startup` in the prospero command window. Make sure that "Always on Visible Workspace" is selected for both of these windows to ensure it does not go blank again.

- **Shutter does not open fully in cold weather:**

In early January of 2011, this problem was reported. It manifests as partial to complete vignetting of the detector. The temperature at the time was roughly -7°C . While conditions like this are rare, observers are strongly encouraged to be alert to this problem under comparable conditions.



The Ohio State University Team

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Sponsors

OSU has been generously funded by the [National Science Foundation](#) and the [Center for Cosmology and AstroParticle Physics](#) at [The Ohio State University](#). Additional support has also been provided by the [Department of Astronomy](#) at The Ohio State University and the [Department of Physics and Astronomy](#) at [Ohio University](#).

Related Publications

Please consider citing these papers in any publications that employ new data from OSMOS:

- [Mechanisms and Instrument Electronics for the Ohio State Multi-Object Spectrograph](#) by Stoll et al. 2010, SPIE, 7735, 154
 - [The Ohio State Multi-Object Spectrograph](#) by Martini et al. 2011, PASP, 123, 187
-

Appendix A - Acquisition Scripts

Thanks to Rubab Khan & Rebecca Stoll for ample input to this appendix

Open a terminal window on mdm24ws1:

- `$ cd /lhome/obs24m/Scripts`
- `$ pyraf`
- `$ pyexecute('osctrtask.py')` (Centering task)
- `$ pyexecute('osqlsp.py')` (For quick-look spectral reduction)
- `$ pyexecute('osbias.py')` (For focusing)
- `$!ds9 &`

It may be necessary to verify that no other instances of ds9 are running.

Long Slit Acquisition

It is strongly recommended that `osctrtask` in `pyraf` is used. Although it is possible to line up the object in the slit by hand using telescope offsets in `prospero`, the telescope's small-scale offsets lack precision. `osctrtask` instead calculates a guider stage offset, which is much more precise. The telescope is then moved by hand in order to realign the guide star with its original position and resume guiding without re-exposing in the *Guide* tab in Maxim.

While guiding, take an acquisition image of the field as well as a slit image. An easy way to do this is with one of the following prospero scripts. *[Warning: please check that the scripts have correctly identified the slits and filters you plan to use as the filters and slits may change over time.]* Choose the exposure time, NN appropriate for object identification. Exposure times of ~30 seconds will often yield enough objects for the oscrtask to find a WCS solution and identify your object in the field.

- `$ call fieldctr NN` (for center slit, uses 1k ROI)
- `$ call fieldctr2 NN` (for inner, or red slit, uses 4x1k ROI)

From the pyraf window which you previously opened:

- `$ par oscrtask`

to modify the file numbers for the field image and the slit image. Verify that the prefix is correct and ends in '.'.

If you wish to use the WCS capability, either enter the object coordinates your catalog file and the name of your object. Click *execute*.

If an IRAF window with a WCS solution pops up, hit 'q'. Now look at ds9.

If a WCS solution was found, verify that the circle on the field image is centered on your object. If not, your coordinates are not accurate or precise enough. Run oscrtask again without WCS. Otherwise, continue and use the resulting dy. Hit 'x' on the center of the slit, then hit 'q'.

If no WCS solution was found, hit 'x' on the center of the slit, use tab or the ds9 button to switch frames. Hit 'a' on the center of your object and hit 'q'. Write down the dy shift. Check to make sure the dx shift is less than ~700. If so, then you may ignore it.

To put the object in the slit, first draw a box around the guide star's current position (click and drag a rectangle). Now you have two options:

- Option 1:
 - Stop guiding - on the *Maxim Guide* tab, click *Stop*
 - Go to the *Expose* tab and start exposing. Make sure the rectangle is around the guide star's current position.
 - Enter the calculated dy in the xmis guider dy box. Move the telescope by hand until the guide star is back in the box.
 - Stop exposing. Go back to the *Guide* tab. Make sure the track is still selected and restart tracking. Do *not* take an initial exposure in the guide tab. This would set a new expected location of the guide star!
- Option 2:
 - Do not stop tracking. Enter the calculated dy offset in small increments (~50 at a time) and wait for the guide star to be pulled to the center again before entering the next increment.
 - When you have entered the complete dy, are once again guiding, and the guide star has settled into the center, you are ready to take your spectrum.

It is useful to take another image through the slit after completion of these steps to confirm that the object is indeed in the slit. For bright objects, this will be obvious. For faint objects, it may be necessary to run a second iteration. In either instance, an image of the object in the slit may be useful for future reference.

Taking a Spectrum

Verify:

- The correct slit is in the path
- The correct disperser is in the path
- Filter1 is "open" or on an order-blocker if needed
- Filter2 is "open"
- Object name is accurate
- Exposure time is correct
- Region of Interest is correctly set (4x1k for VPH spectra, 2x1k for prism)

This can all be streamlined by writing a prospero script to do everything. Thorstensen has written one called 'gotospec' for setting up to take spectra with the VPH Blue grism and the center 1.2" slit:

- `$ call gotospec [objectname] [exptime]` (for VPH Blue and 1.2" center slit)
- `$ call gotospec2 [objectname] [expt]` (for VPH Blue and 1.2" inner (red) slit)
- `$ call gotospec3 [objectname] [expt]` (for prism and 1.2" center slit)

Appendix B - Old Long-Slit Acquisition Procedure

For general information, here is the old recipe for acquisition with a single slit.

1. Point to the desired field
2. Image through the slit to measure its projected position on the detector (making sure the disperser is not in the beam)
3. Acquire a guide star and start guiding
4. Obtain an image of the field
5. Measure the required offset to move the target into the slit
6. Stop guiding and *offset the guider* the desired amount
7. Move the telescope so the guide star is back in the box
8. Take an image to verify that the offset was successful

To increase efficiency, consider:

- Use 1k ROI or the slit image and acquisition image (see [Detectors](#) section for more information)
- Do not forget to switch back to the appropriate ROI for spectroscopy

The image of the long-slit on the detector is repeatable at the level of 1 micron or better (vs. 15 μ pixels) and therefore moving the slit in and out of the beam does not impact acquisition. The wavelength solution is similarly unaffected if the disperser wheel is moved.

Appendix C - OSMOS Mask Alignment Cookbook

A typical mask (or long-slit) acquisition proceeds as follows:

1. Set rotator angle to appropriate orientation and slew telescope to field.
2. Start guiding, remembering to set the angle in MaximDL as well (rotation angle = -1 * rotator position).
3. Start oalign.pro in prospero:

```
call oalign.pro SLITNUM FILT1 FILT2 TARGNAME
```

where SLITNUM is the slit number of the multi-object mask (or long-slit if this is a long-slit acquisition), FILT1 & FILT2 are the filters that will be used for acquisition images (the image through the mask is obtained with no filter), and TARGNAME is the name of the target. This script will confirm the configuration, take an image through the mask, take an acquisition image (no mask) of the field through the specified filters, and then pause so you may run the mask alignment code oalign.py (type oalign.py with no arguments to get basic usage information).

4. Run oalign.py in a separate terminal:

```
oalign.py OMSFILE MASKIMAGE ACQIMAGE
```

where OMSFILE is one of the outputs of OMS, MASKIMAGE is an image through the mask and is the first image obtained by oalign.pro, and ACQIMAGE is an image of the field and is the second image obtained by oalign.pro. oalign.py will open the MASKIMAGE in ds9 and prompt the user to mark each alignment box with the 'x' key and press 'q' when finished. For example:

```
oalign.py a267pmask.oms os20111029.0042b.fits os20111029.0043b.fits
```


will print the following to the screen (note that these images have been bias-subtracted which is helpful but not strictly necessary):

no

Maskimage os20111029.0042b.fits title is: A267 P-Mask Mask Image

Alignment box coordinates files

os20111029.0042b.box and/or os20111029.0042b.reg do not exist

z1=-28.61814 z2=29.67649

** Mark Alignment Star Boxes to use with a 'x'.
and then preset 'q' when finished.

*** You must mark at least two (2) boxes ***

Log file _oalign.log open

and display the image found in Figure 10. Click [here](#) for a full-resolution version of Figure 10.

This image has a total of 13 alignment boxes (four are recommended—this image was for testing). The approximate locations of these alignment boxes were computed from the .oms file specified on the command line (a267pmask.oms in this example). All or any subset may be identified with the 'x' key. They may also be chosen in any order. Picking the first three in this example (and typing 'q') would result in the following:

2482.02 2711.24 1014.5

2382.36 1380.78 1144.5

1256.21 1510.34 1045.

0 Median at xc,yc is 1023.25

1 Median at xc,yc is 1103.75

2 Median at xc,yc is 1084.00

Min for all boxes is 1023.25

z1=-4.76159 z2=241.5081

** Mark the center of each alignment star with an 'a'
and then press 'q' when finished.
Stars must be selected in the "SAME
ORDER" as the boxes.

Log file _oalign.log open

The acquisition image will now be displayed in ds9, as shown in Figure 11. Click [here](#) for a full-resolution version of Figure 11.

The first three rows of the output in the terminal are the x, y pixel position of the cursor when the 'x' key was typed and the counts in that pixel. After the 'q' key was pressed, the remaining lines print some debugging information. The ACQIMAGE will show the field, along with boxes identified in the previous step. Note that in the

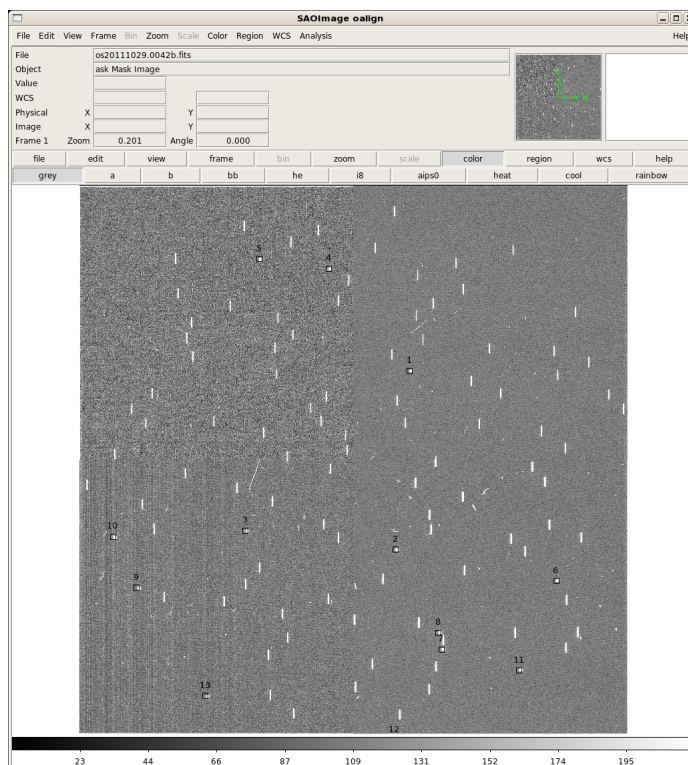


Figure 10: Alignment

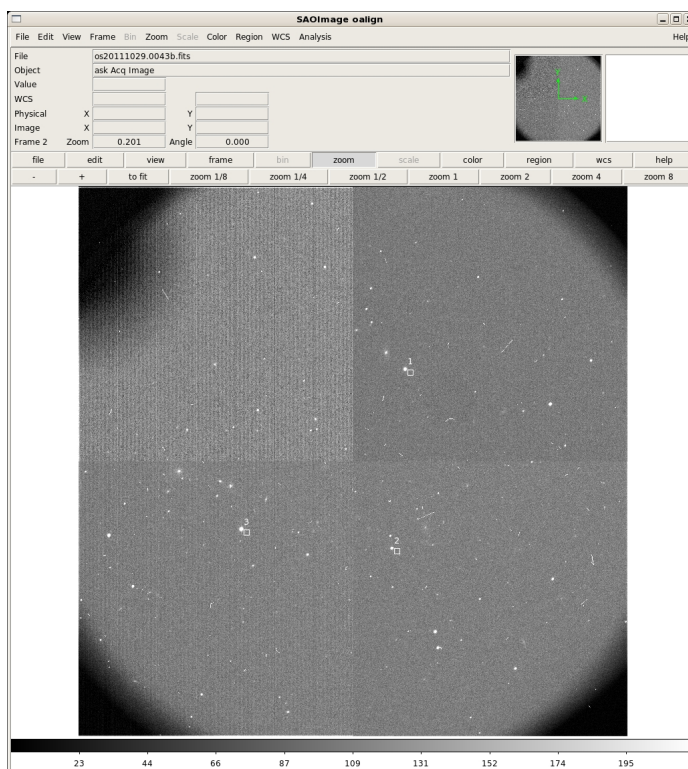


Figure 11: Acquisition Image

example, only three boxes are shown, rather than all of them. They are also numbered in the order that they were identified in the previous step rather than the order they are listed in the .oms file. Identify the corresponding alignment stars in the same order with the 'a' key. Press 'q' when finished. oalign.py will then solve for and report the rotation and translation offsets. After you type 'q', oalign.py will solve for and report the rotation and translation offsets. In this example, the following is output to the screen after the 'a' key is pressed:

```
# COL LINE COORDINATES
# R MAG FLUX SKY PEAK E PA ENCLOSED GAUSSIAN DIRECT
2437.50 2736.96 2437.50 2736.96
 19.28 -15.13 1.124E6 118. 21809. 0.19 44 6.83 6.36 6.43
2339.00 1403.59 2339.00 1403.59
 18.54 -14.19 473884. 122. 9226. 0.17 48 6.92 6.22 6.17
1215.46 1544.12 1215.46 1544.12
 19.30 -15.88 2.243E6 128. 40413. 0.21 45 7.12 6.57 6.43
```

Then, once the 'q' key is pressed the following output gives the solution:

```
Geomap fit
0 2478.52 2712.74 2437.50 2736.96 2477.96 2712.32 -0.56 -0.42
1 2377.89 1379.30 2339.00 1403.59 2379.85 1378.92 1.96 -0.38
2 1257.67 1518.31 1215.46 1544.12 1256.27 1519.12 -1.40 0.81
# Geomap fit yields dx = 40.68 dy = -24.77 theta = 0.0169
Mean offset relative to solution is 1.44 pixels
ID BOX_X BOX_Y Star_X Star_Y New_Star_X New_Star_Y Delta_X Delta_Y Delta_S
0 2478.52 2712.74 2437.50 2736.96 2477.96 2712.32 -0.56 -0.42 0.70
1 2377.89 1379.30 2339.00 1403.59 2379.85 1378.92 1.96 -0.38 2.00
2 1257.67 1518.31 1215.46 1544.12 1256.27 1519.12 -1.40 0.81 1.61
```

Computed Mask Alignment Offset:

dx: 11.104 arcsec
dy: -6.763 arcsec
dPA: -0.0169 degrees

These are the guider offsets to apply:

gdx: 86.2606 steps
gdy: 141.6363 steps

And enter this rotation offset in the Rotator GUI:

dPA: -0.0169 degrees

/home/tuatara/martini/programs/python/oalign.py done.

Figure 12 shows what the final image will look like. Click [here](#) for a full-resolution version of the image.

The guider offsets are the 'gdx' and 'gdy' values. The rotation offset is the 'dPA' value. Before you apply them, inspect the output to determine if the solution is reasonable. First, look at the numbers in the columns labeled "Delta_X Delta_Y Delta_S." These are the dx, dy, and $\sqrt{dx^2+dy^2}$ residuals between the star and box positions in pixels after the solution is applied. Note that a pixel is 0.273", so more than two pixel offsets (particularly in x) is cause for concern. A second piece of useful information is to inspect the final image from oalign.py. There will now be a magenta 'x' at the location where each alignment star will fall once the offset is applied. This should hopefully be at the center of the each box. Figure 13 shows a zoom-in to box 1 that demonstrates a good solution. For a full-resolution version of the image, click [here](#).

If one star has a substantially larger offset than the others, try to rerun oalign.py without that box/star (no need to

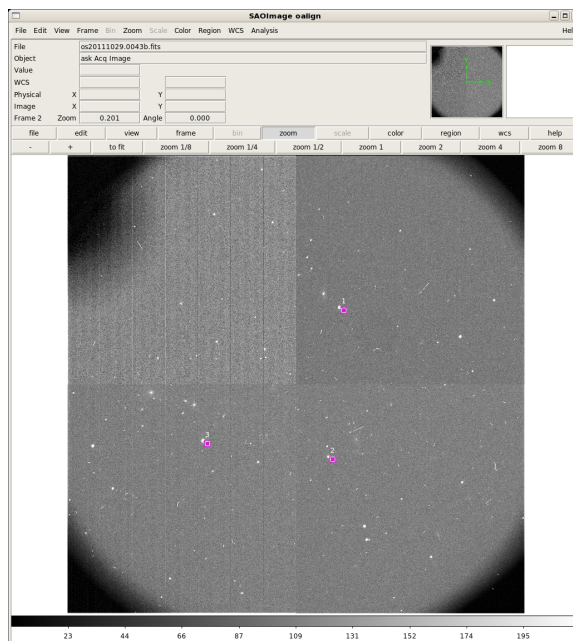


Figure 12: Final Image

take new observations).

Note that if this is a longslit acquisition, the syntax is:

```
oalign.py -l SLITIMAGE ACQIMAGE
```

5. To apply the offsets: Turn off the guider, enter the rotation offset from oalign.py in the Rotator GUI (check the units are degrees), press the SEND button, and *turn the guider back on*. Provided the rotation offset is less than a degree (which is well within the capabilities of the rotator encoder), the guide star should not have moved substantially on the guider chip.
6. Apply the dx and dy guider offsets reported by oalign.py *with the guider on* with the guider GUI. If either offset is greater than a hundred units, *break the offset into steps of no more than a hundred* so that the guide star is not lost as the guider 'drags' the telescope to the correct coordinates. Note that rotation offsets of less than 0.01 degrees are probably not worth applying. Similarly, offsets less than 0.2 arcseconds, particularly in y, are probably not necessary. (The ultimate criterion is of course to insure your brighter targets appear to be visible in their slits.)
7. Press the RETURN key in the Prospero window and oalign.pro will take another image and prompt you to run oalign.py again with the new ACQIMAGE. At this point the rotation offset should be negligible and the x,y offsets should be small. Apply these offsets as in step 5 (if necessary) and step 6.
8. Return to the Prospero window. If the offset was only a few arcseconds, answer N for another iteration (such small offsets are quite reliable). Otherwise answer Y and repeat step 7.
9. The mask should now be aligned and oalign.pro will put the mask into position and exit. It is a good idea to take an image through the mask to confirm the mask alignment. Run oalign.py one last time (if necessary) to confirm that the stars are centered in the alignment boxes and at least the brighter targets are visible in their slits. You are now ready to insert the disperser and begin to take spectra.

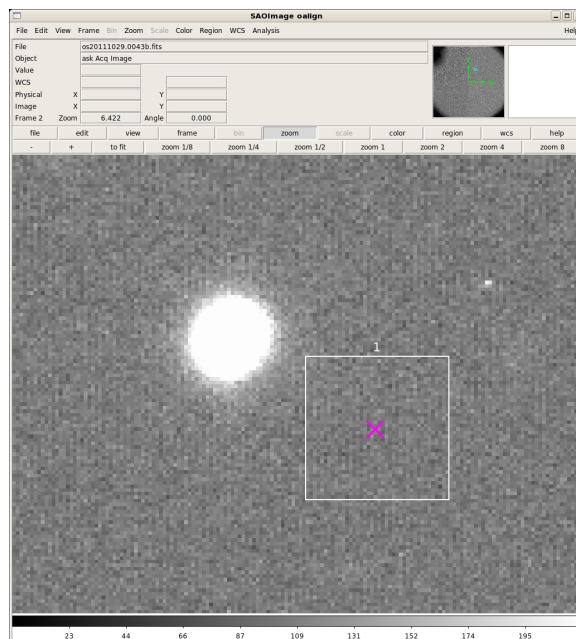


Figure 13: Detail on Box 1 from Figure 11

Here are the files used in this example to practice using oalign.py:

- [oalign.py](#)
- [a267pmask.oms](#)
- [os20111029.0042b.fits](#)
- [os20111029.0043b.fits](#)

Appendix D - Electronics Boxes & Control Programs

Which Box is Which?

Figure 14 labels which box is the Head Electronics (HE) and which is the Instrument Electronics (IE). Click [here](#) for a full-resolution version of the image. Note that this image is rotated 90° from standard OSMOS alignment at rotator angle=0°. The HE is *south* and the IE is *north*.

The HE is the smaller red cube. It connects to and controls the CCD detector. The HE is controlled by the IC computer running the IC program.

The IE is the long black box and may also be referred to as the IEB. It connects to and controls the instrument mechanisms (slit, disp, filter1, filter2, camfoc, colfoc). The IE box is controlled by the IE agent program.

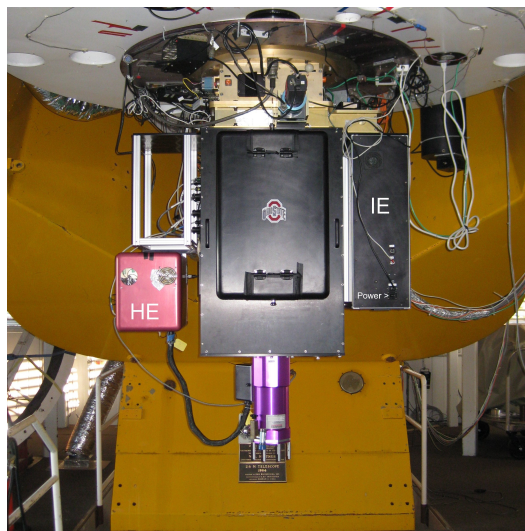


Figure 14

Figure 15 is a block diagram demonstrating the OSMOS control system. Click [here](#) for a full-resolution version of the image.

How the different electronics subsystems and their control programs interact is a guide to beginning troubleshooting. In general, the ISIS and Prospero programs should be kept running most of the time during normal troubleshooting.

CCD Head Electronics Box (HEB) Problems

The CCD controller HEB is connected via a pair of optical fibers to the DOS IC computer located in the computer room. Problems acquiring CCD images, setting exposure parameters (e.g., exposure time, object name, readout region, binning, etc.) should first be investigated by looking at the IC computer or the HEB.

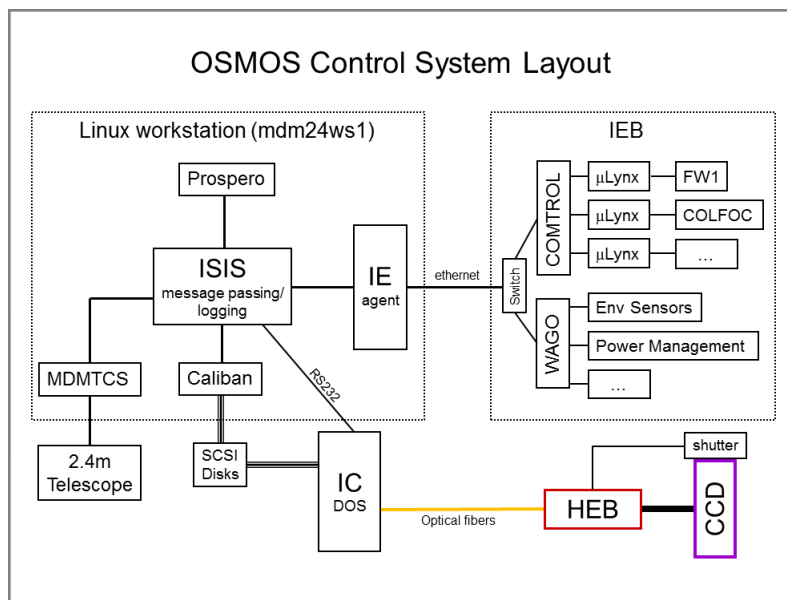


Figure 15

Instrument Mechanism (IEB) Problems

The instrument mechanisms are controlled by the IE Box (IEB) via the IE agent program running on the Linux workstations. Problems operating instrument mechanisms, reading instrument temperature sensors, or querying instrument positions should be investigated by looking at the IE program or the IEB box proper. The IEB and IE agent program operate independently of the IC, HEB, ISIS, or Prospero.

Raw Data Transfer Problems

Raw CCD images are transferred from the CCD to memory on the IC, then passed to SCSI transfer disks shared by the IC and the Caliban program running on the Linux workstation. Problems with data failing to transfer from the IC to the Linux workstation are likely on either the IC or the Caliban sides.

Telescope Interaction Problems

The instrument interacts with the MDM telescope controller via the MDMTCS agent program. Problems with telescope interaction should first be addressed by looking at the MDMTCS program, the xtcs program (common telescope control console at the 2.4m), or the telescope computer proper.

While the ISIS and Prospero programs should be kept running most of the time, restarting either is only indicated if you have to do a full system shutdown (e.g., for recovery from a lightning shutdown, or recovering after loss of power to the site). A full restart including restarting ISIS and Prospero is usually an all-else-fails action.