

KOSMOS

Preliminary Operations Concept Document

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1. Introduction

This document provides a preliminary description of the operation of the KOSMOS instrument. KOSMOS is a modified version of the Ohio State Multi-Object Spectrograph (OSMOS) optimized for use on the 4-m Mayall telescope.

KOSMOS (and OSMOS) can be thought of as having three main science modes: direct imaging, long-slit spectroscopy, and multi-object spectroscopy. Unlike OSMOS, direct imaging with KOSMOS is not a primary science use, though it is anticipated that there will be programs where direct imaging takes place in conjunction with spectroscopic observations (for example, to obtain photometry of variable objects).

This operation concept document is organized first of all by phase of the science program, and within each phase by science mode. There are three main phases – preparation for observation, observation, and data reduction. However, the observation itself is further broken down into calibration, acquisition, and science observation. In this version of the document data reduction is not addressed in any detail.

Each major section has an “issues” sub-section describing issues related to that particular operational phase. These may describe areas where specifications are uncertain, telescope or instrument performance is unknown. These sub-sections should be eliminated once the instrument and operations concepts are more mature.

1.1. Configurations & Issues

KOSMOS will have several potentially interchangeable elements in its configuration. Specifically, there are two filter wheels and a disperser wheel, which can carry up to 10 filters and 5 dispersers. In addition, there is potentially a choice of CCD detectors; this requires that the available detectors be installed in separate dewars (and probably controllers).

If the full complement of available filters and dispersers will fit in the wheels, observers desiring any combination of these items will always have them available and need not specify them in detail prior to observing. If there are more available filters or dispersers, or more than one CCD can be used as a detector, then provisions must be made for installing filters, dispersers, or CCDs as needed by specific observing programs. It is expected that filter and disperser changes will be relatively routine day-time activities, preferable carried out by mountain support staff but not requiring significant advance scheduling. Advance notice *will* be required for CCD changes (if any).

Initial discussion have identified the following dispersers as high priority, but the list may well be incomplete:

- Low resolution, broad wavelength coverage (resolution 200-400 out to 9000Å)
- R~1600 (probably a red disperser given similarity to next item)
- R~2250 in blue
- R~3000 or somewhat higher in red (this and preceding could both be ~2Å resolution)

- There will likely be interest in pushing above $R=3000$ but details very much TBD.

Also, OSMOS has a relatively limited selection of long slits (2/3/4 pixels, corresponding to roughly 0.6, 0.9 and 1.2 arcsec at MDM; the 4-m values will be similar [see SDN 1.04 for a discussion – Mayall values might end up at ~0.7, 1.1, 1.4 arcsec]). There is likely to be a desire for at least one more slit wide enough for good flux measurements (5 arcsec will transmit 99% of the light in 1.25 arcsec seeing, which is somewhat worse than median but not a lot) and possibly equivalent to ~6 pixels (1.8 arcsec with OSMOS scale, ~2.1 with possible Mayall scale).

An additional consideration is [possible] use of the Risley prisms (ADC). These introduce a few percent light loss (5-8%) but significantly reduce the effects of atmospheric dispersion. [The quoted FOV of the ADC is listed on the KPNO website as two rather different values so the utility with KOSMOS is uncertain. *This needs to be resolved early on*]

2. Preparation for Observation

Preparation for observation with KOSMOS will normally take place after time has been assigned (i.e., there is no need for a detailed “Phase I” submission as part of the initial proposal for telescope time.)

There is potentially one exception to this: if there is a choice of CCD detectors, the CCD required for the program should be specified in advance, ideally when the telescope schedule is made up.

2.1. Direct Imaging

For direct imaging, the observer should have identified a suitable guide star for each field to be observed. The observer should also have enough information to ensure that fields can be identified and centered to the desired accuracy.

As noted above, it is expected that direct imaging with KOSMOS will almost always take place in conjunction with spectroscopic observations of an object or objects in the field. The preparations for these spectroscopic observations will also suffice for associated direct imaging.

2.2. Long-Slit Spectroscopy

For long-slit spectroscopy, the observer should have identified a suitable guide star for each field to be observed. The observer should also have enough information to ensure that fields can be identified and the correct target centered on the slit.

In addition, there are three options for dealing with atmospheric dispersion which must be considered:

- If the built-in atmospheric dispersion compensators are used, the field of view is limited. [[What else?]]
- The slit can be oriented at the parallactic angle (so atmospheric dispersion runs along the slit). This requires rotating the spectrograph to an angle determined by the time of observation. If the orientation of the slit on the object does not matter, no further preparation is needed, but if a particular position angle is desired the observer should work out the range of times during the night that the parallactic angle is close to the desired position angle.
- Atmospheric dispersion is ignored. This approach is OK if spectra don't extend into the blue and/or zenith distances are small and/or spectral coverage is limited (high resolution). Acquisition should be done through a filter that is approximately centered on the wavelength region of interest (so the observer needs to verify that such a filter will be available).

2.3. Multi-Object Spectroscopy

Multi-object spectroscopy, unlike the other two modes, requires fabrication of a mask prior to the observation. There are three steps in this process:

- 1) The observer should obtain accurate coordinates of all the objects of interest in each field (technically, accurate relative coordinates). In addition, a small number of brighter point sources should be identified for use in aligning the masks at the telescope (minimum 3). Although in principle 2 stars suffice, redundancy to ensure good alignment is important.
- 2) The astrometric coordinates should be converted to physical coordinates in the mask plane. The slitlets associated with each object are defined. As part of this process, the orientation of the mask relative to the dispersion direction is also specified; this is normally done to minimize overlapping spectra. [Many programs to do this exist but we need to specify the details for KOSMOS.]
- 3) The output from the mask program is then used to fabricate the masks required for the observations. In general, mask information should be provided TBD days in advance of the run. [Under what circumstances, if any, would there be faster turn-around? What is the justification for fast turn-around.]

It should be noted that the mask design implies a specific orientation of the cassegrain rotator, which in turn implies a limited range observation times if it is important to minimize the effects of atmospheric dispersion. The observer may need to consider possible parallactic angles when laying out masks.

A suitable guide star should be identified for each field.

2.4. Issues

Issues identified:

- Process for mask fabrication undefined – both process and fabrication location. Lead time is also TBD
- Need to identify/adapt/develop software for mask generation from (a) images and (b) coordinate catalog (note that generating coordinates from images reduces the final task to (b)).
- Implications if more than one CCD available

3. Calibration

Several types of calibration data are required. These comprise:

- Flat-field data
- Wavelength calibration (spectroscopy only)
- Detector zero-point data (bias/dark)
- Flux calibration

If flexure in the instrument is minimal *and* mechanisms are highly repeatable (see “issues” below), all calibration data except the flux calibrations can be obtained in the afternoon or morning. If this is not the case, flat-field and wavelength data will need to be obtained immediately before and/or after observations in order to ensure that mechanisms are at the same positions and flexure is the same as for the science observations.

Instrument efficiency is maximized if calibration observations do not have to be done during the night; a 10% time overhead is equivalent to a 10% loss in instrument throughput.

Flux calibrations for all modes comprise night-time observations of photometric standards (or standard fields for imaging). The bright limit for standards is likely set by the properties of the KOSMOS shutter.

3.1. *Direct Imaging*

Daytime direct imaging calibrations would normally consist of flat fields taken through any filters that will be used during the night, together with detector zero-point observations (bias). Dark current will be negligible for direct imaging exposures so dark frames are not needed.

The requirements for flat-fielding KOSMOS are less stringent or equivalent to those for flat-fielding MOSAIC. Thus KOSMOS does not impose additional requirements on the Mayall calibration systems.

3.2. *Long-Slit Spectroscopy*

Daytime long-slit calibrations would normally consist of flat fields taken with any filter/disperser/slit combinations that will be used during the night. (Possible small irregularities in the slits make it desirable to obtain flats for each slit to be used.) Depending on the properties of the KOSMOS CCD, it may be necessary to obtain dark frames in addition to standard bias frames.

It is important to have flat-field illumination that is both flat across the field and uniform enough in wavelength to allow a single flat field to have acceptable signal to noise over full spectral coverage of any configuration.

If wavelength calibrations using lamps are desired, then the “arc” lamps must illuminate the full field of view more or less uniformly.

3.3. Multi-Object Spectroscopy

The requirements for multi-object calibrations are essentially the same as for long-slit observations, except that calibrations must be done for each mask that is likely to be used during the night rather than the suite of potential slits.

3.4. Issues

The two main issues are:

- Stability/repeatability of instrument – these requirements need to be defined in addition to understanding the various sources of flexure and instability. In the absence of severe fringing flexure can probably be a large fraction of a pixel (so only flat-fielding at the ends of slits is affected) but if fringing as bad enough flexure at even the 0.1 pixel level could seriously limit the ability to flat-field data.
- Uniform illumination of field (flat field more important, wavelength calibration currently may be poor in this regard)

Can the Risley prisms be easily removed/inserted? If so, then there may be 2 sets of calibrations during the day if observers contemplate using both configurations.

4. Acquisition

It is assumed for the purposes of this section that the observer has identified a suitable guide star beforehand. Coordinates should be accurate to a few arcsec or better (astrometric accuracy is not required).

Acquisition of science targets and standard stars is the same.

The discussion below assumes that initial field acquisition is done with the instrument in imaging mode. However, the direct viewing TV (mirror in guider inserted ahead of instrument) is an alternative option that provides quick readout. The time to move the pickoff mirror in and out is not negligible, however.

4.1. *Direct Imaging*

The steps involved in acquisition are as follows:

- 1) Slew telescope to nominal target coordinates.
- 2) Move offset guider probe to its nominal location for the guide star, while telescope is slewing.
- 3) When telescope has arrived at the nominal position, take a short exposure (normally with a filter to be used for the observing sequence).
- 4) If the telescope is more than a few arcsec from the field center, offset [should have software tool to make this easy to do].
- 5) Once telescope is centered on field, verify that guide star can be acquired with guide probe and start guiding

Note that for direct imaging the cassegrain rotator does not require adjustment, since the field is approximately circular.

4.2. *Long-Slit Spectroscopy*

The steps involved in acquisition are as follows:

- 1) Slew telescope to nominal target coordinates.
- 2) Move offset guider probe to its nominal location for the guide star, while telescope is slewing.
- 3) Rotate cassegrain rotator so slit will be at desired position angle. The precision of rotation depends on the length of slit to be used. The overall precision requirement is set by the MOS mode (see below).
- 4) When telescope has arrived at the nominal position, take a short exposure in imaging mode (normally with a filter to be used for the observing sequence or covering a similar wavelength range).
- 5) If the telescope is more than a few arcsec from the field center, offset [should have software tool to make this easy to do]. The slit position in the imaging field of view must be known beforehand, so in principle the target can be positioned at the location where the slit will be when it is inserted in the beam. This step can be skipped if the guide star can be acquired.
- 6) Verify that guide star can be acquired with guide probe and start guiding.

- 7) Verify that the target is precisely centered on the slit position (this may require a somewhat longer exposure). Offset telescope and guide probe if required.
- 8) Move slit into position
- 9) Optionally, take an image to verify that the slit positioned correctly. If the instrument performs as expected (need the slit to be mechanically reproducible at ~ 0.2 pixel level [TBD] or better), this step will be superfluous (though periodic daytime checks of slit position should be carried out).
- 10) Move filter and disperser wheels as needed for observing. Note that if the slit verification is *not* needed this step can be done at the same time as the slit wheel is positioned.

The steps above assume that the target is visible in an exposure of reasonable duration. This should be the case for the vast majority of science programs, since objects so faint they can't be seen in direct imaging will for the most part require prohibitively long spectroscopic observations (better done on larger telescopes). There are exceptions to every rule, and if the object itself is not visible, the observer should carry out steps 1-10 using a nearby object that is visible, and whose offset from the target is *accurately* known (to ~ 0.1 arcsec ideally). Then, the telescope and guider should be offset from the reference object to the target (can be done as part of step 10). The accuracy of such offsets over distances less than TBD arcmin is TBD arcsec.

4.3. Multi-Object Spectroscopy

The steps involved in acquisition are as follows:

- 1) Slew telescope to nominal target coordinates.
- 2) Move offset guider probe to its nominal location for the guide star, while telescope is slewing.
- 3) Rotate cassegrain rotator so mask will be at desired position angle
- 4) When telescope has arrived at the nominal position, take a short exposure (normally with a filter to be used for the observing sequence or covering a similar wavelength range).
- 5) If the telescope is more than a few arcsec from the field center, offset [should have software tool to make this easy to do]. The position of the alignment stars in the imaging field of view should be known beforehand, so in principle the field can be approximately aligned with the mask during this step. Potentially, steps 5 and 6 can be reversed.
- 6) Verify that guide star can be acquired with guide probe and start guiding.
- 7) Move mask into position and take a short exposure. The alignment stars (probably 3-4) should be visible in the alignment boxes on the mask.
- 8) Using the software tool [needed] determine the offsets in RA, dec, and rotation and apply them.
- 9) Take another exposure; iterate as needed (hopefully once).
- 10) Move filter and disperser wheels as needed for observing.

If the MOS field covers ~ 12 arcmin, for a typical slit width of about 1 arcsec (and comparable seeing), it is desirable to align objects with slitlets to about 0.2 arcsec or better. This implies a rotation error no more than 0.03 degrees.

4.4. Issues

There are several issues:

- Is the direct viewing TV useful?
- Can the slit-viewing system be implemented for long slit mode and is it sensitive enough to be useful (as compared with direct imaging)?
- Ability to do blind offsets (center invisible objects in long slit mode). Can the current guider support this? Or can it support this with a modest additional effort by NOAO staff?
- Various software tasks needed to be written to keep acquisition overheads low.
- Some of the listed steps are not needed if the instrument mechanisms are as repeatable as expected.
- Is the specification on the cassegrain rotator achievable?

5. Science Observations

Observations of science targets and standard stars are the same, except that the latter are fairly quick so flexure is not a consideration.

5.1. Direct Imaging

Direct imaging observations are not affected by flexure, which will be insignificant for all plausible individual exposure times. It will not affect long series of exposures, since these can be shifted if necessary (some allowance for differential refraction must be made for longer exposure sequences, especially over the full field of view).

The observing sequence is therefore as follows:

- 1) Take required exposure or exposures with desired filter
- 2) If additional filters are to be used, insert next filter in sequence
- 3) Continue observing

5.2. Long-Slit Spectroscopy

Although the instrument is designed to be rigid, flexure within the instrument and flexure in the guide probe will cause the target to move off the slit after a sufficiently long [TBD] time interval. In addition, refraction effects will also shift the target position at wavelengths different from those at which guiding is taking place. At that point, the target should be re-centered on the slit.

The discussion below assumes that the slit viewing camera is *not* being used. If it is available, then flexure correction can be done during the course of the observing without the need to re-center via step (2).

The observing sequence is therefore as follows:

- 1) Take required exposure or exposures with desired filter/disperser combination. Total time should not exceed [TBD] hours.
- 2) If [TBD] has elapsed:
 - a. remove slit, disperser and change filter if necessary;
 - b. verify field position and adjust as necessary; and
 - c. return to spectroscopic configuration.
- 3) Continue observing. If additional spectroscopic configurations are required, change.

Note that if you are changing between two quite different wavelengths, it may be desirable to re-center to compensate for atmospheric dispersion. Also, for long time series, especially at larger zenith distances, it may be desirable to change the rotator position to keep the slit position close to the parallactic angle.

5.3. Multi-Object Spectroscopy

Although the instrument is designed to be rigid, flexure within the instrument and flexure in the guide probe will cause the targets to move off the mask slitlets after a sufficiently long [TBD] time interval. In addition, refraction effects will also shift the target position at wavelengths different from those at which guiding is taking place. At that point, the field should be re-centered on the mask.

The observing sequence is therefore as follows:

- 1) Take required exposure or exposures with desired filter/disperser combination. Total time should not exceed [TBD] hours.
- 2) If [TBD] has elapsed:
 - a. remove disperser and change filter if necessary;
 - b. verify field position using alignment stars, and adjust as necessary; and
 - c. return to spectroscopic configuration.
- 3) Continue observing. If additional spectroscopic configurations are required, change.

5.4. Issues

There are two main issues:

- Availability of atmospheric dispersion compensation. Do the Risleys have a large enough field? How far into the blue do they work (data on website suggests below 375 nm, which should be OK)? It's probably the case that even if they don't have enough FOV for the full MOS field, they will be good enough for most long slit work.
- Flexure between guide probe and slit. The extent of flexure is largely anecdotal (but the anecdotes all point to it being significant). Where does it come from and can it be corrected? In terms of the steps listed above it doesn't matter whether one needs to recenter every hour or every six hours, but from a practical point of view it matters quite a bit.

Also:

- Can the slit-viewing system be implemented, and would it be a useful way of dealing with flexure. It is likely only to be feasible for long-slit mode.

6. Data Reduction

[This section is a place-holder]

Data reduction can be done using any standard software package for the reduction of imaging or spectroscopic data. The procedures described below use IRAF as an illustration.

The steps outlined below cover:

- Removing the instrumental signature
- Removing first-order background (sky) effects
- Extracting photometry or spectra from the images
- First order photometric/spectrophotometric calibration

Observers with specialized needs may need to follow somewhat different procedures to obtain optimally-reduced data; the descriptions below are not intended to explore such alternative reduction procedures.¹

6.1. *Imaging Mode*

6.2. *Long-Slit Mode*

6.3. *Multi-Object Mode*

6.4. *Issues*

¹ Examples include reduction of spectra in the vicinity of strong atmospheric absorptions and time series photometry or spectroscopy.

7. Revision History

Revision No.	Date	Changes
1.0	Sept. 18, 2009	Initial draft for distribution
1.1	Oct. 2, 2009	Comments from Paul Martini, Knut Olsen and John Glaspey incorporated or addressed