KOSMOS

Final Science Requirements Document

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KOSMOS SRD Table of Contents

1. Introduction

The ReSTAR committee identified upgrading the optical spectroscopic capabilities of the NOAO 4-m telescopes as one of the highest priorities for funding. It also suggested that copying or adapting existing state-of-the-art instruments would be a quick and cost-effective way of providing such capabilities. KOSMOS is an adaptation of the Ohio State instrument, OSMOS, intended to be installed on the 4-m Mayall telescope at KPNO in response to that need. COSMOS is a duplicate of KOSMOS for the 4-m Blanco telescope at CTIO. Both have been funded through a proposal to the NSF in response to the ReSTAR committee recommendations.

The requirements listed here were met by the OSMOS design or have been verified by actual design work. This SRD is therefore considered final. *The SRD was placed under configuration control as of the start of the design study. Henceforth, modifications to the requirements were made only in response to results from the design effort.*

1.1. Science Cases

The Science Requirements for KOSMOS can be thought of as derived from three main groups of science cases:

1. The ReSTAR report itself summarized science for such a capability, identified by surveying the community. See Appendix A
2. The new instrument is intended to provide improved capabilities over the existing spectrographs. Since the KOSMOS is intended for use on the Mayall 4-m telescope, the current use of those spectrographs was considered. See Appendix B.
3. Finally, KOSMOS on the Mayall could in principle substitute for GMOS on Gemini for multi-object spectroscopy programs covering moderate areas of sky, where a larger field of view would compensate for a smaller telescope collecting area. See GMOS instrument web pages at www.gemini.edu .

The requirements derived from these three groups of science cases heavily overlap, so their relative priority is not important. It is important to understand that these requirements are essentially statistical in nature, as they are derived from surveys of the community's aspirations (ReSTAR) or actual use of current facilities. Furthermore, since the purpose of this document is primarily to identify requirements that involve *changes* to the OSMOS design, a rigorous flow-down via a "design reference mission" approach is not particularly helpful. The requirements for a southern copy of the instrument are similar if not identical, so they are not discussed separately here.

1.2. Operational Considerations

The NOAO 4-m telescopes are currently scheduled for "classical" observing, and are likely to be used in this way for the foreseeable future. Accordingly, the instrument should:

4. Support efficient use by observers under average conditions, including the ability to make use of better-than-average conditions. Use under exceptional conditions should not drive the design of the instrument.
5. Be flexible enough to rapidly reconfigure to support a given observer's program during a night or observing run.
6. Also be configured at the telescope by observatory staff to support changes from one observer to the next.

2. Science Requirements

The top-level requirements are listed below. It is also indicated whether the requirements were met by the OSMOS design, or required re-design.

The following requirements apply:

- *Pixel scale.* The pixel scale should be approximately 0.3 arcsec/pixel, with a target scale of 0.36 arcsec/pixel. This pixel scale matches a 3-pixel slit to typical seeing conditions (req. 4). **Required re-design of the spectrograph camera.**
- *Input field of view.* The field of view for multi-object mode should be at least 100 $arcmin^2$. This is approximately 4 times the GMOS field of view, and therefore meets the requirement of providing equivalent AΩ to GMOS on Gemini (req. 3). A larger field of view is desirable. The field of view can be rectangular or circular. **A circular field of 12 arcmin diameter (~110 $arcmin^2$) was provided by the OSMOS design. A larger field would have required substantial re-design.**
- *Image quality.* The instrument image quality should be good enough to allow effective use of a 2-pixel slit, and also should not significantly degrade spatial resolution along the slit in typical seeing (req. 4). **This requirement was met by the OSMOS design, and was verified with the redesigned camera. It is possible that the requirement will be met except in the 350-400 nm wavelength region for "as-built" optics.**
- *Wavelength coverage.* The useful wavelength coverage should be 350-1000 nm (reqs. 1-3 all need this). Coverage from 400-1000 nm is a requirement, while coverage between 350 and 400 nm is a goal. It may be necessary to exchange detectors to achieve maximum efficiency at one extreme or the other of the wavelength range. **This requirement is met by the current design, but it must be verified with the "as-built" camera.**
- *Maximum resolution.* The maximum resolution with a 1 arcsec slit should be at least R=2300. Proportionately higher resolution should be achievable with a 2-pixel slit (reqs. 1-2 need this). **These requirements are met by the current design. Significantly higher resolutions are not possible.**
- *Low resolution mode.* A low-resolution mode (R~200-400) should be feasible, ideally one that covers the full wavelength range of the instrument (planetary science in req. 1). **The design solution in OSMOS (triple prism) does not meet this requirement with the re-designed camera; a grism design appears satisfactory.**
- *Spectral coverage.* The spectral coverage should be at least 1000 resolution elements, with a goal of fully using a 4k array (approximately 1350 3-pixel

resolution elements). Spectral coverage would be enhanced if a cross-dispersion option can be implemented, but this is not a requirement. The lower-resolution use of the RC Spectrograph is driven in part by the desire for more spectral coverage with a smaller detector – thus more spectral coverage will reduce the variety of dispersers that must be provided (compare req. 1 & 2). **This requirement, as well as the goal, is met by the current design.**

- *Throughput.* System throughput should be around 40% for an optimum disperser + detector combination, measured at the peak of the disperser blaze function and at the peak of the detector response. This requirement is one of the key reasons for the ReSTAR recommendation for replacing the existing spectrographs (req. 1). **This requirement is met by the current design.**
- *Modes supported.* The instrument should support the following 3 modes of operation simultaneously, meaning that an observer can switch quickly between any one of them during the night:
    - *Direct imaging.* The direct imaging mode is intended primarily for use in acquiring objects for spectroscopy, but it should provide science-quality imaging for programs that combine imaging and spectroscopy. Good imaging performance is also needed for efficient acquisition of targets.
    - *Long-slit spectroscopy*. The instrument should provide a range of slits allowing observers to adapt to current conditions.
    - *Multi-object spectroscopy.* The instrument should allow multi-object spectroscopic programs to be carried out with a reasonable number of masks installed in the instrument at once. This number should be such that for *most* programs masks will not need to be changed during the night.
    - *Slit/mask exchange.* It should be possible to changes masks in the strument during the night, as well as during the day.

  Both spectroscopic modes are needed for reqs. 1 & 2 (MOS mode is essential to req. 3) and the imaging mode is needed for operational reasons. The ability to switch between the modes is needed for reqs. 5 & 6. The ability to change masks easily is needed for reqs. 5 & 6. **This set of requirements is met by the current design.**
- *Filters and dispersers.* The instrument should allow enough filters and dispersers to be installed simultaneously that *most* programs will not require filter or disperser changes. At the same time, filters and dispersers should be exchangeable at the telescope by observatory staff, so that the instrument can be reconfigured between observers (req. 5 & 6). The instrument will almost certainly not be commissioned with the full set of dispersers and filters that would ultimately be desired; the highest priority for the initial disperser set is a “red” and a “blue” disperser at R~2000 (req. 1 & 2, see discussion under spectral coverage for req. 2). **This requirement is met by the current design.**
- *Detector exchanges.* It is desirable but not a requirement to make use of a standard CCD dewar, allowing exchange of detectors on KOSMOS and exchange between KOSMOS and other Mayall instruments. This is mainly driven by the desire to support re-configuration matched to individual observing programs (req. 6). **This requirement is met by the current design.**

- *Use of existing telescope capabilities.* The instrument should make use of the existing rotator/guider capabilities for guiding and field rotation. It should also make use of the existing wavelength and flat-field calibration capabilities of the telescope. Finally, the instrument should be able to operate with and without the existing atmospheric dispersion compensator (ADC – "Risley prisms" or Hydra ADC). It is *strongly desirable* to ensure that use of these capabilities does not compromise overall system performance; prioritization of any upgrades will depend on available resources and evaluation of the science impact of such upgrades. This is a "science" requirement mainly because it is likely that a more limited set of capabilities would be provided if they have to be designed and built. There would also be less flexibility in supporting the instrument (more intensive block scheduling) if the installation was more complicated (req. 6). **This requirement is met by the current design. However, performance of the instrument with the existing capabilities must be verified.**

3. Revision History

Revision No.	Date	Changes
1.0	October 29, 2009	Initial draft for distribution
1.1	October 30, 2009	Added discussions matching requirements to science summaries and discussing relation of requirements to existing OSMOS design
1.2	November 19, 2009	Clarification of wavelength response and throughput requirements. Statements added where current design meets both goals and requirements.
1.3	December 1, 2009	Placed under revision control. No changes from V1.2 otherwise.
1.4	November 9, 2010	Removed “preliminary” from title, replaced with “final”. Clarified spectral resolution requirements and goals based on design study. Adjusted pixel scale requirement to reflect design study. Added mention of COSMOS.

Appendix A – ReSTAR Science

Introduction

Low and medium resolution optical spectroscopy is a basic tool that is critically important for a broad range of astronomical research. Measurement of stellar radial velocities and galaxy redshifts, object classification, confirmation of photometrically identified candidates, and determination of physical properties such as temperature and metallicity all depend on obtaining optical spectra. Low and medium spectroscopy on NOAO's 4-m telescopes remains in demand, and will likely increase as future survey facilities, such as LSST, PanSTARRS, and GAIA, come into service. Mid-sized telescopes will continue to be very valuable for their ability to acquire spectra in the V~15-21 magnitude range, allowing the larger telescopes to be reserved for the faintest targets. As the ReSTAR committee noted, the continued demand for spectroscopy on mid-sized telescopes provides strong motivation for delivering modern spectroscopic capabilities on NOAO's 4-m telescopes. The proposed KOSMOS spectrograph represents a substantial upgrade over the current 4-m R-C spectrograph, as the completely transmissive design has significantly higher throughput, allowing it to reach fainter magnitudes in the same exposure time. With multi-object slit masks available over a several arcmin field of view, it will also be a capable instrument for survey follow-up, as it should have comparable A-Ω to the GMOS spectrographs on Gemini. These features make OSMOS an excellent match to many of the science cases outlined in the ReSTAR report.

Spectral Requirements for KOSMOS for specific ReSTAR science cases

Low-resolution spectroscopy

The ReSTAR science cases requiring low-resolution spectroscopy are the studies of Kuiper Belt objects and asteroids in the solar system. Asteroid spectra contain broad reflectance features that are used to classify them according to their composition. The typical resolution requirements are R~200 over wavelengths $\sim 0.4<\lambda<1$ µm (e.g. Moskovitz et al. 2008). For KBOs, the typical features seen in optical spectra are CH4 and O2 ice absorption bands at wavelengths of $\sim 0.5<\lambda<0.95$ µm, which have widths in excess of 20 nm. The resolution requirement is R~200 – 400, in order to have 10 – 20 resolution elements across these bands (e.g. Licandro et al. 2006, Alvarez-Candal et al. 2008).

The ReSTAR document mentions the need for high-resolution spectroscopy to support the study of asteroids in the solar system; no papers in the literature support this need.

Medium-resolution spectroscopy (R~1600–2250)

The majority of ReSTAR optical spectroscopic science cases require medium spectral resolution. Examples cases are:

- Stellar spectral classification for measurements of the IMF requires R~2250 spectroscopy in the blue, $390<\lambda<500$ nm (e.g. Massey et al. 1995). The need is to resolve particular absorption lines that are sensitive to temperature and luminosity.
- The confirmation and characterization of brown dwarfs requires R~2000 spectroscopy in the red, $0.6<\lambda<1$ μm (e.g. Burgasser et al. 2009).
- Spectroscopy for confirmation and characterization of novae requires R~2000 with a wavelength range of $\sim450<l<700$ nm. The requirement is based on the need to identify the typical emission lines present in novae and on the need to resolve velocity widths of the lines down to ~300 km s^{-1} (e.g. Neill & Shara 2005).
- Spectroscopy of AGN has similar requirements to those of observations of novae, but generally extending to longer wavelengths to account for the typically higher redshifts of AGN. For example, the recent discovery of a possible binary supermassive black hole AGN system by Boroson & Lauer (2009) employed R~2000 spectroscopy in the wavelength region $\sim400<\lambda<900$nm. The spectral resolution allowed measurement of emission line widths down to ~300 km s^{-1}.
- Spectroscopy for galaxy redshifts and absorption line strengths is typically done with R~1500–2000, over wavelengths $\sim370<\lambda<950$nm (e.g. Brown et al. 2009). The resolution is required for the measurement of spectral indices and to avoid excessive smearing of the bright night sky emission lines present at red wavelengths.
- Galaxy rotation curves can be measured with R~2000 spectroscopy; the ~10 km s^{-1} delivered velocity accuracy is sufficient for rotation curves galaxies as small as massive dwarf galaxies.
- Studies of extragalactic globular cluster systems are generally done with R~2000 spectroscopy over wavelengths $370<l<600$nm, where the requirements are for measurement of integrated age and metallicity-sensitive spectral indices, and velocities good to ~10 km s^{-1} (e.g. Olsen et al. 2004).

Cases requiring R~3000 or higher resolution

A few ReSTAR optical spectroscopy science cases require higher resolution:

- Measurement of the Ca triplet in giant stars in Local Group galaxies requires R>2800 at 850nm (e.g. Cole et al. 2004). This resolution is needed to separate the individual lines in the triplet. The Ca triplet is a particularly useful metallicity indicator for Local Group galaxies.
- Stellar kinematics with ~5 km s^{-1} accuracy is well-served with R~3000 spectroscopy. Such velocity accuracy is needed for the study of kinematics in many dwarf galaxies, which have rotation curve velocities <50 km s^{-1}.
- For red spectroscopy, R~3000 avoids blending of the bright night sky emission lines, which can be important for spectroscopy of faint targets in the red, such as extragalactic supernovae.
- Radial velocity curves in eclipsing binary systems become possible to do at

R~4500 for massive binary systems. Low-mass (~1 M_{sun}) eclipsing binary systems require R~20000–40000 for <1 km s^{-1} velocity accuracy (e.g. Meibom et al. 2009).

Appendix B – Mayall RC Spectrograph Use

Introduction

Dianne Harmer reviewed KP 4m proposals for RCSP in its primary mode, and as the vehicle for MARS, long slit and multi-slit proposals, that were submitted to TAC in semesters 07A through 09B. These statistics are intended as one point of reference for defining OSMOS maximum spectral resolution and individual dispersers.

Proposal Data

There were 107 proposals; 16 of which were for MARS (3 of those were multi-slit proposals); 91 were RCSP (2 of which were multi-slit proposals).

Several proposals required more than one wavelength region, and chose to do this by selecting a grating that could be used in 2nd order - thereby minimizing physical reconfigurations. In several other cases, it was necessary to carry out a mid-run configuration change. RCSP's large grating suite allows configurations to be tailored to most requirements, offering good selection, especially when dispersions are high enough that the wavelength range covered may be only 1000Å or less.

MARS proposals. The 16 proposals requested use of 20 setups, equally divided between the new VPH-red grating (10) and a mixture of "bluer" options from the regular grism sets (10). The nominal resolution of these configurations is R=1500 or less.

RCSP proposals show a desire to exploit most of the available facilities, at the physical ruling frequencies, and the "effective" ruling frequencies drawn from gratings used in 2nd order where practical. As noted, some proposals requested more than one wavelength region and/or change of configuration - 101 setups for 91 proposals. These are summarized in the table below. Some possible configurations are not listed if they were not requested.

Where the wavelength ranges recorded were less than 2000Å, there was considerable variety in the wavelength ranges selected for observing.

The resolution listed corresponds to 2 pixels on the detector, though observers typically use a somewhat wider slit and therefore low resolution. Note that the useful coverage on the detector is ~800 resolution elements (2-pixel slit) or less (wider slit or lowest resolution gratings).

The second table provide a breakdown of the setups by approximate resolution and color (separating “red” and “blue” at 5000Å).

RC Spectrograph Grating Requests

Grating	g/mm	Blaze[a]	Order	Range	Resolution (2 pixels)[b]	No.of Proposals	Notes
250	158	4000	1	>octave	360	3	Not needed for a T2K
400	158	7000	1	>octave	630	2	Not needed for a T2K
10A	316	4000	1	<4100	720	18	
181	316	7500 3750	1 2	4100 2000	1350	13 3	
17B	527	5540	1	2500	1650	6	
420	600	7500 3750	1 2	2300 1150	2470	5 4	
007	632	5200	1	2100	1870	8	
22B	632	8500 4250	1 2	2100 1050	2950	3 7	
450	632	5500	2	1050	3900	10	
18C	790	9500	1	1700	4170	1	
24	860	5400	2	800	5050	6	
380	1200	9000 4500	1 2	1100 550	6080	6 6	

[a]Blaze listed for the order in which grating is used
[b]Resolution specified is for 2 pixel slit at blaze wavelength (approximately 1.6 arcsec).

Setup Categories (RCSP + MARS) – Percentage

Resolution	Blue	Red	Blue+Red
<2000	28%	32%	60%
2000-3000	9%	7%	16%
3800-4200	0%	9%	9%
>5000	5%	10%	15%

The summary table reveals, first of all, that the bulk of the setups requested are for resolutions under 2000; an instrument offering a maximum resolution of ~3000 would satisfy 76% of requests. The highest resolution available with the spectrograph is roughly 6000 (requested roughly 10% of setups). At lower resolutions the proportions between red and blue setups are roughly equal (remembering that the division is specified as 5000Å). At the higher resolutions there are more “red” setups.

It is also worth remembering that the RC spectrograph slit widths normally used are greater than 1 arcsec, whereas the KOSMOS specifications assume a 1 arcsec slit. This implies an increase in slit losses with the new instrument, or else use of a wider slit. In the latter case the spectral resolution will be reduced by a corresponding amount. This suggests that, in order to provide maximum flexibility, it should be possible to achieve at least R=2000 with a 1.5 arcsec slit on KOSMOS.