KOSMOS Review Panel Response

Acknowledgement

The KOSMOS Design Review was held August 2-3, 2010 at OSU, with presentations from OSU and NOAO project participants. The review panel provided us with an initial de-brief, followed soon thereafter by a written report. This document contains the project team's response to the recommendations of the written report.

Before embarking on a detailed discussion of the recommendations, we would like to express our appreciation for the panel members' willingness to assist us by reviewing the project, taking the time to attend the review and read through the documentation we assembled prior to the review. Both the written report and the discussions during the review will help ensure that KOSMOS and its sibling for CTIO, COSMOS, are scientifically productive instruments. In addition to the efforts on the instruments themselves, the guidance will help us focus NOAO's efforts on improvements to the telescopes on which they will be installed.

This response has been delayed because we decided to focus our efforts post-review on a couple of the key time-critical areas (in particular, initiating the optics bid process); this does not mean that we took either the committee report or the response lightly.

Detailed Response

The KOSMOS review panel report contains five recommendations and a number of associated findings. In this document, we describe our proposed responses to the recommendations, and comment on the related findings. Recommendations (numbers) and findings (letters) are listed below in italics.

Recommendation 1. *Revisit the current optical design, include the existing ADCs (north and south), and analyze the system performance implications with regard to a consistent SRD and FPRD for revising the collimator, disperser, and camera optical designs to balance cost and performance under the best seeing conditions at the best site (CTIO vs. KPNO). Formally review the final optical design prior to starting the purchasing process.*

Response to Recommendation 1: The KOSMOS optical design meets the requirements described in the FPRD and we have therefore decided to not revisit the design. The Panel clearly did not find that the optical design was sufficiently robust to proceed, nor did they find that it met the requirements. Our interpretation of this inconsistency is that it originates from poor communication, rather than being reflective of any deficiencies in the design itself. Below we provide further details in response to each of the Panel's findings to demonstrate that the present design does meet the requirements.

A. Instrument performance analysis. *We are concerned that the overall design of the instrument has not been optimized to obtain the most desirable performance on a 4m. For* *example, it is very likely that users will attempt to obtain higher resolution by using smaller slits; it would make a significantly more powerful instrument to have camera image quality that allows sharp imaging of a <0.5 arcsec slit. Evidence from WIYN suggests the native seeing at Kitt Peak site may be better than that currently delivered by the Mayall telescope. It would be useful to design the instrument to be capable of using the best native seeing as dome and telescope upgrades are implemented in the future. Moreover if the goal is to put a copy of the KOSMOS instrument on the Blanco telescope at CTIO (COSMOS), then the final optical design should not compromise the best seeing conditions at the best site (which we suspect may be CTIO, rather than KPNO).*

Response to Finding A: Image quality data for the CTIO and KPNO sites have not been systematically nor uniformly collected (though the situation is changing) and as a consequence the native seeing distribution is not very well known for either KPNO or CTIO. Comparisons between CTIO and Cerro Pachón indicate that the latter is comparable or slightly better, so we can use the more extensive Pachón data as a reference. These indicate median seeing of just under 0.7 arcsec and 25% percentile values of 0.55 arcsec. SOAR performance is comparable to the site (a recent compilation based on science imaging gives 50%/25% values of 0.71/0.59 arcsec). SOAR has a (limited) tip/tilt correction, so this should be taken as an indication of how well a real telescope can match the site. WIYN DIQ (30 sec images) has a reported median value of 0.78 arcsec. All of these image quality distributions are asymmetric, with the mode being somewhat less than the median values. Image quality reported for the telescopes is typically R band. All of these data are based on imaging at either bent Cassegrain or Nasmyth and both the SOAR and WIYN telescopes include active optics.

Performance of the Mayall and Blanco telescopes is not as good. Neither telescope was originally designed with any active optics compensation, though limited lower-order compensation has been subsequently retrofitted. The image quality data are for prime focus imaging; given the lack of active control of the secondaries, Cassegrain image quality will not be better and may be somewhat worse. Some reported median/25% values for the Blanco and Mayall are ~0.85/0.75 and 0.98/0.77 arcsec respectively. Although it is difficult to be certain, it is likely that the primary limitation on the performance of the telescopes is the thermal mass of the optics and the difficulties of applying active optics compensation.

These data suggest that, barring a major upgrade of the 4-m optics (such as GLAO), science instruments should be optimized for image quality around 0.9 arcsec and should be able to take advantage of images around 0.6-0.7 arcsec. Image quality significantly better than that is rare and should not drive the design of instruments. For the specific case of KOSMOS (and COSMOS), some users may be willing to make the trade between throughput and spectral resolution implied by a slit less than 0.9 arcsec, but it's as likely that there will be significant use of a wider slit (4 pixels = 1.2 arcsec) by observers who care more about throughput than resolution. Given the practical limitations on detector size (a format >4k implies significant additional design and hardware cost), a finer pixel scale in practice would result in reduced spectral coverage for a given spectral resolution.

The present optical design produces a scale of 0.29" per pixel that is well matched to these image quality data. The image quality delivered by the present optical design can readily take advantage of (and measure) site conditions that exceed the 25% value of both telescopes. The average instrument image quality is 0.25" FWHM or better over the full imaging FOV from 400-1000nm (see pg 6, as well as Figure 6 on pg 10 of the KOSMOS Optical Design Document). If the telescope's delivered image quality is as good as 0.5" FWHM, for example, the measured image quality will be 0.56" FWHM, or slightly less than 2 pixels. We also trivially note that the delivered image quality of the telescope, rather than the instrument, ultimately determines the slit losses associated with narrow slits.

B. Camera and Collimator Optical design. *A fundamental concern is that the optical design does not meet the spectroscopic resolution or image quality requirements as specified in the FPRD. The final optical design should be described in a report and presentation, which provide sufficient explanation to convince the instrument team and reviewers that the full range of glass choices, surface shapes, and element groupings has been thoroughly considered.*

Response to Finding B: The optical design does meet the spectroscopic resolution and image quality requirements specified in the FPRD. The image quality requirement is specified in subsection 313 of the FPRD. The optical design performance was provided on pg 6 of the KOSMOS Optical Design Document and meets this requirement (see also the response to Panel Finding A).

The design also meets the spectroscopic resolution requirement (subsection 315 in the FPRD) of at least R=2300 with a 1" slit, although we acknowledge that this was not clearly communicated to the Panel. A disperser design that demonstrated compliance was only completed immediately before the review and consequently was not discussed in the KOSMOS Optical Design Document, although one was mentioned in the presentation slides and shown in more detail in the actual presentation. The figure below illustrates a disperser design that achieves the required performance with a 1" slit. Specifically, the resolution is R=2300 from 400 to 450nm and somewhat higher at longer and shorter wavelengths. The performance with a 2-pixel slit is also shown, which demonstrates that higher resolutions can be achieved with slits as narrow as 2-pixels.

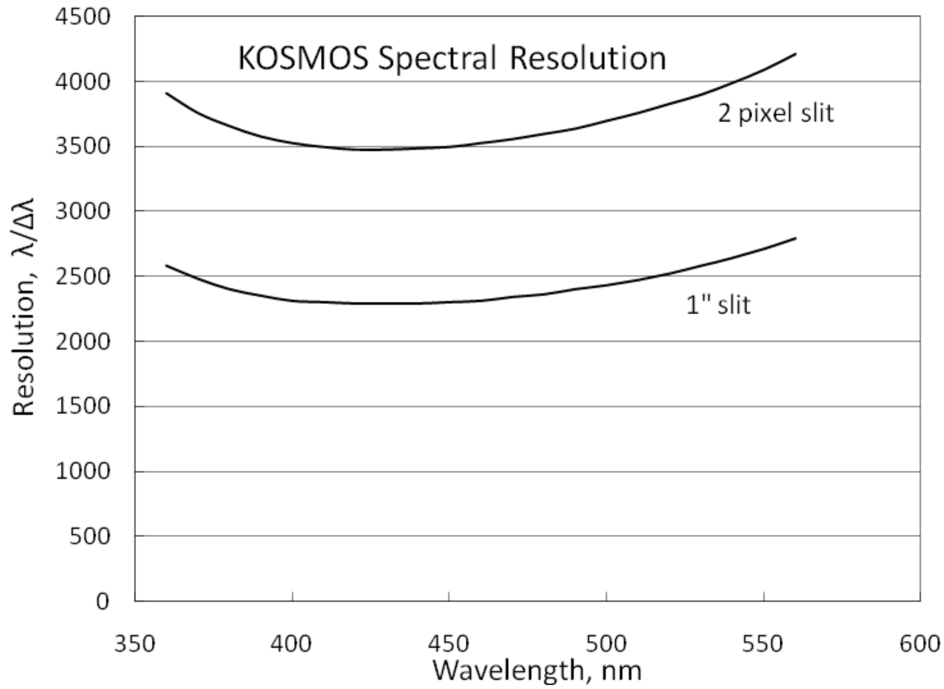

Figure 1: Resolution vs. wavelength for a VPH grism with peak efficiency at 450nm. The lower curve is for a 1 arcsec slit and the upper curve is for a 2-pixel slit. These calculations include the expected as-built instrumental image quality.

The resolution is defined to be $\lambda/\Delta\lambda$, where $\Delta\lambda$ corresponds to the FWHM of a single wavelength that has been convolved with a pair of Gaussians that represent the slit and the instrumental image quality. The slit was approximated by a Gaussian with FWHM = 1” (or 2-pixels for the upper curve) to represent a stellar object, while the instrumental image quality was approximated by a Gaussian with FWHM = 0.5”. Both of these assumptions are fairly conservative. The first is conservative because apodization by the slit (e.g. use of a square slit function) will decrease the width if the slit is matched to atmospheric seeing, while the second represents the worst-case image quality at the edge of the detector for the expected as-built performance, that is including random fabrication and assembly errors. As noted in the KOSMOS Optical Design Document and the response to Finding A, the image quality is <0.25” or better over the imaging FOV. We note that we did not use the Rayleigh criterion, as recommended in Finding G below, because that measure is appropriate for diffraction-limited optical systems.

The VPH grism design used for this calculation is comprised of a grating with 1560 lines per mm that is sandwiched between two 30 degree Ohara PBM2Y prisms. The spectral coverage on the CCD is 360-558 nm. A blue-optimized design was chosen for this demonstration because this proved to be the most challenging wavelength regime in which to meet the requirement. Higher index materials than PBM2Y (n=1.64 at 450nm), such as N-LAK34 (n=1.74) and N-SF11 (n=1.82), would allow higher line densities and consequently higher resolutions, but blue transmission generally decreases for higher index glasses. These materials can be employed for grisms optimized for longer wavelengths and consequently make it easier to meet the resolution requirements at redder wavelengths.

The panel also made a list of additional suggestions regarding finalizing the optical design. Here are each of these suggestions and our comments:

- *It will typically reduce the optical elements by a significant fraction in diameter, weight, and volume if the design vignettes the outer 5% of rays. This is generally a good compromise in terms of both optical and mechanical performance of the instrument. We recommend that some vignetting be allowed here.*

We have carefully considered this suggestion, but given that the present optical design meets all of the requirements provided in the FPRD, as well as the twin goals to maximize performance and minimize construction time, we propose that we do not perform additional optical design work. While it is possible that a vignetted design would remove an element, this would not result in sufficient improvements in throughput to compensate for the vignetting. This is because the primary reflection losses are at air-glass interfaces, and the number of lens groups is unlikely to change by more than one or two. Also, the weight reduction is plausibly 10% or less, thus overall flexure performance is not significantly affected. Our efforts on flexure reduction are described below in response to recommendation 4.

- *It would be useful to understand the system throughput based on material transmission, AR coatings, dispersion elements, and the ADC. A plot of such as a function of wavelength may provide important information for the final optimization in terms of dispersion choices and optical materials.*

The instrument throughput was one of the requirements of the design and was specified as item 318 in the FPRD. The throughput as a function of wavelength for the present design is described in section 400 of the KOSMOS Optical Design document, and specifically addresses material transmission and AR coatings. The performance of a blue disperser was provided in section 920 on page 32 of the KOSMOS Optical Design Document. These estimates, in conjunction with the expected performance of the detector system, indicate that the performance meets the FPRD requirement. While the ADC was explicitly excluded from this requirement as part of the telescope, it can be incorporated into total telescope plus instrument sensitivity estimates for use cases that require the ADC.

We will explore the possibility of copying the Blanco ADC at KPNO. However, the resources required for such an effort are significant, and, given existing commitments, not likely to be available until FY2012 at the earliest. Also, the situation remains unchanged that the task of upgrading the Mayall ADC is beyond the scope of the KOSMOS project, by executive decision. We may choose to compare use at the two telescopes to assess the true science impact of the undersized ADC. Incidentally, the CTIO design also has slightly better transmission than the Risley prisms (~95% above 400nm; falls to ~85% at 350nm).

- Lens materials should be selected to minimize the curvature of the strongest elements, to reduce optomechanical risk, improve optical and mechanical performance, and the security/longevity of the bonded multiplets. (Glass choices in all elements, not just the specific element in question, will influence the strength of these curvatures.)

These were all considerations that influenced the present optical design. For example, the aspheric surface was placed on a high-index material in order to reduce the departure from a best-fit sphere.

- We recommend consideration of modifications to the collimator optical design to improve overall optical performance.

We chose not to modify the f/7.9 collimator because the system's performance is dominated by the much faster f/2.7 camera.

- Please clarify the impacts and implications of the under-sized ADC for observing strategies.

We note that only the Mayall ADC is undersized relative to the KOSMOS FOV; the Blanco ADC does not vignette the COSMOS FOV. The undersized ADC at the Mayall will not limit single-object spectroscopy, which was the primary science driver identified in the ReSTAR report. The main impact will be on multi-object spectroscopy, for which the ADC could not be used. The absence of an ADC will not be a limitation for velocity or redshift measurements, which are one of the main uses of multi-object instruments. This will be a limitation for accurate flux calibration, although prescriptions do exist to correct for losses due to atmospheric dispersions.

- Only peak efficiencies were presented. Please clarify the system efficiency, including telescope and ADC, as a function of wavelength. Are there efficiency requirements from the FPRD, and are they clearly met by the design?

Estimates of the system throughput as a function of wavelength are provided in the KOSMOS Optical Design Document (e.g. pgs. 16, 17, and pg 32 for an illustrative disperser design). The throughput requirement is specified as item 318 in the FPRD and the present design meets this requirement.

G: Requirements. *The instrument does not appear to meet the basic spectrograph resolution requirements. As per SRD requirement:*

****** START OF QUOTED SRD TEXT *******

- *Maximum resolution. The maximum resolution with a 1 arcsec slit should be at least R=2300, with a goal of at least R=4000. Higher resolutions should be achievable with a 2-pixel slit (reqs. 1-2 need this). This requirement, as well as the goal, is met by the current design.*

- *Low resolution mode. A low-resolution mode (R~200-400) should be available, ideally one that covers the full wavelength range of the instrument (planetary science in req. 1). The design solution in OSMOS (triple prism) probably will not meet this requirement if the camera is redesigned. Alternate approaches will need to be explored.*

******** END OF QUOTED SRD TEXT ********

We note that the SRD and FPRD are not consistent in that the SRD requires a low resolution mode and the FPRD lists it as a goal. We believe that the low resolution mode should be maintained as a requirement.

Slide 23, KOSMOS_Optical_Design.pdf:
The R=400 GRISM disperses light into the both the 1st and 2nd orders, requiring a cross-disperser and coadding of the spectra. A design for the GRISM with cross-dispersion was not presented.

Slide 24, KOSMOS_Optical_Design.pdf:
States that R=2300 can be achieved with a 2 pixel slit. The requirement is that R=2300 be acheived with a 1 arcsec slit. A 2 pixel slit (0.6") should achieve higher resolutions (goal of R=4000). Does the camera image quality enable resolution of a 0.6" slit? We disagree with the statement in the SRD that the requirement and goal are met by the KOSMOS design as presented. It would be useful to present actual achievable resolution plots as a function of wavelength for different slit widths. The plots should have the design image quality, with random fabrication and assembly errors (at the level prescribed by the assembly plan) convolved with a square slit function. Resolution can then be quoted at some reasonable criterion such as the Rayleigh limit.

Response to Finding G: We agree that there is an inconsistency between the SRD and the FPRD with regard to the requirement for a low-resolution mode; however, the FPRD states (pg 5) that "Should there be any discrepancies between this document and any other design and fabrication documents, the FPRD takes precedence." The low-resolution mode is consequently only a goal, as stated in the FPRD. Nevertheless, the R=400 grism design presented on slide #23 can meet this goal with the relatively simple addition of either cross-dispersion or order-sorting filters. The compliance of the R=2300 mode was described above in response to Panel Finding B.

Recommendation 2. *We endorse the existing plan to review the Torrent CCD controller system design, and recommend that the review panel include 2-3 external members with appropriate controller knowledge and background.*

C. Detector Controller. *This review committee does not include any electrical engineers, and so are we unable to fully judge the design maturity of the Torrent detector control system. During the review, it was stated that prototype systems are operating in the northern and southern observatories, but no Torrent system is currently operating on a working instrument. An NOAO internal review of the Torrent system was mentioned. We* *strongly recommend that the Torrent review include external members with sufficient detector controller experience to properly assess the controller design. Possible external reviewer candidates include Greg Bredthauer (greg.bredthauer@sta-inc.net) and Greg Burley (greg.burley@gmail.com).*

Response: The Torrent review was held August 20, as scheduled. This was a video review that included two external reviewers (Greg Bredthauer, STA and Gustavo Rahmer, Caltech), both of whom have extensive experience with CCDs and controllers. Rahmer's prior experience at CTIO also ensures he has familiarity with the NOAO operational environment. The review of the design was generally favorable, however the panel did identify a few specific issues that needed further work, and also recommended development of a detailed production plan. Compliance with these recommendations should delay production by several weeks, but should not significantly impact KOSMOS construction.

Recommendation 3. *We recommend that a Project Scientist be added to the project team as soon as possible, and that the PS participate actively in the execution of (1) and (2) above.*

E. Project Scientist. *The committee is concerned that the project scientist position has been vacant for some time, and no plans for finding a replacement were mentioned. We are concerned that the current management structure may not be adequately considering users needs in the design choices that will significantly impact the operation and utility of the instrument.*

I. Requirements Documentation. *We recommend a review of the SRD versus FPRD for consistency, and to specify which document takes precedence, and verify that the instrument design meets the key performance requirements.*

We recommend development of a formal compliance matrix of expected system performance versus requirements.

Response: Sean Points has been appointed as project scientist, and will also provide a necessary interface with staff at CTIO. It should be pointed out that we have obtained helpful input from the NOAO Users' Committee and will continue to do so as relevant. There was significant participation by NOAO scientific staff in writing the SRD prior to the start of the project.

We "froze" the SRD at the start of the design process, and have amended the FPRD (sparingly) as the design progressed. Formally, the FPRD takes precedence, although it is our intent to revise both documents over the next few weeks and return them to consistency.

We believe that participation of the Project Scientist in this activity is important, which is why we are listing our response to Finding "I" in this portion of the response.

Recommendation 4. *Fully analyze the flexure requirements and the performance implications of the known OSMOS flexural image motion for both the northern and southern observatories. Review (and improve if necessary) the KOSMOS/COSMOS instrument flexure performance.*

F. Flexure. *The panel was concerned that the flexure performance of OSMOS is less than optimal given the increased performance requirements associated with going to a larger telescope. We feel that this, coupled with the desire to build two systems, may be a larger issue than the efficiency of observation as stated in the review, in that reducing the flexure may obviate the need for additional nightly calibration, and the associated need to upgrade at least one calibration system to cover the full FOV.*

We recommend that the team develop an optical model of instrument flexure of the key elements (slit, collimator, camera, and detector) and their relative motion based on the FEA model of the enclosure and stage/mechanism flexure to better understand the source of the image motion. This model can be utilized to drive the design towards a better performing system.

- *We encourage the early procurement and testing of a stiffer precision grade stage for the camera.*
- *We recommend considering the removal of the collimator focus stage and replacement with a more direct and stiffer attachment to the optical bench.*
- *We recommend that the KOSMOS team seriously consider flexure testing at the NOAO facilities in Tucson, prior to shipping the instrument to Kitt Peak. Any flexure issues discovered in this process will be far easier to diagnose and repair in the lab, than on the telescope.*

Response: We agree that improved flexure performance is highly desirable, but we are reluctant to turn a specific improved flexure into a requirement (as opposed to a goal), in that, logically, failure to meet a requirement means the instrument is unacceptable, which is not the case. We propose instead to proceed as follows (following several of the detailed recommendations above):

(1) Procure the stiffer stages right away (this was always part of the plan).
(2) Engage in careful testing of flexure using calibrated forces and a dummy camera or collimator assembly. We have experience performing this kind of tests on OSMOS and on GNIRS, and in the latter case found it to be invaluable in identifying, diagnosing and curing flexure problems. We believe that effort early on at the component/sub-system level is more productive than system-level flexure testing after delivery.
(3) We wish to retain the ability to focus the collimator, but since re-focus is infrequent we could add a clamp (manual) if there were significant performance gains. Note that the initial optical modeling indicates that image motion due to the collimator focus stage should be significantly less than for the camera focus stage (by a factor of 2 or more).

(4) The impact of flexure on image motion has, in fact, already been calculated, although it was not well documented in the report. The new laboratory measurements will be fed into this optical model.
(5) If the testing and FEA analysis indicates that the goal can be met (or some value in between the current requirement and the goal), we will revise the requirement in the FPRD.
(6) We investigated the wide-field calibration system used for Hydra on the Mayall and found it to be unsuitable for KOSMOS. However, the system in use at CTIO for their copy of Hydra appears more promising. We will explore the possibility of copying it for KPNO during a site visit in late September.

Recommendation 5. *Solicit updated budgetary quotations for optical fabrication. Consider whether there is sufficient contingency allocated for optical fabrication.*

H. Cost Estimating and Contingency. *The overall contingency of ~15% may be appropriate for an exact copy of the OSMOS design. However, the uncertainty in the optical design and the changes in the camera, especially the larger lenses (the second triplet in the camera is 25 mm larger in diameter than the OSMOS camera) and aspheric surface lead us to conclude that additional contingency should be included in the estimate. We note that budgetary quotations have not been solicited for the updated camera design.*

A possible cost savings may result from the procurement of both sets of KOSMOS and COSMOS optics at the same time. Since the COSMOS optics are not required until a later date there is an opportunity to use the second set of optics as a backup in case of damage to the first set.

We note that the cost and schedule assumptions were based on the vendor having a QED polishing machine and SSI (sub-aperture stitching interferometer) to fabricate the aspheric optical surface. We also note that the team wishes to procure complete tested lens barrel systems. We agree with this approach but note that it severely limits the potential vendors, which may increase the cost and cost uncertainty.

The mechanical components are low cost and schedule risk since they are either exact copies of OSMOS designs or minor modifications. The method of prioritizing the design and fabrication of mechanical parts is sound.

Similarly, the electronics design is nearly identical to OSMOS and is of low cost risk.

Response: It is clear that the best way to reduce uncertainty with regard to cost and schedule is to obtain quotes from vendors, based on the current design. We will then be in a position to interact with potential vendors regarding cost, schedule, and fabrication issues (both those raised here and those raised under Recommendation 1 and the associated findings). If there are serious issues in any of these areas, we would be prepared to revisit the design to address them; our expectation is, however, that this will not be the case.

We have solicited quotes for both sets of optics from a wide range of vendors, including all of those suggested by the panel, and have clearly stated that the delivery needs are different for the two sets of optics.