Keck MOSFIRE Detailed Design Review Report
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Introduction and Context

The MOSFIRE instrument Detailed Design Review (DDR) was held at UCLA on April 19 – 20, 2007. The authors of this report served as the review committee, and T. Greene was the committee chair. The MOSFIRE team issued a Detailed Design Report and gave the committee access to the library of MOSFIRE Design Notes in advance of the review, and the MOSFIRE team also provided written answers to individual committee members' questions before the review. The MOSFIRE team gave presentations on the instrument overview and usage, the optical and mechanical designs, subsystem assembly and alignment, the configurable slit unit (CSU), electronics and detectors, software, integration and test, and the budget and schedule all on April 19. The MOSFIRE team also gave the review committee a tour of the MOSFIRE laboratory facilities at UCLA on April 19.

The DDR committee has considered all of these inputs in writing this report. We have endeavored to make this report responsive to the MOSFIRE DDR Process and Charter (S. Adkins, Jan. 9 and Feb. 7, 2007) and as helpful as possible to the MOSFIRE team and the Keck Observatory Instrument Program Manager. No formal Requests for Action or Review Item Discrepancies were solicited during the review, so we have based the material in this report on our meeting notes and the MOSFIRE team's written responses to our submitted questions. Nevertheless, we encourage the Keck Observatory to track and follow up the findings and recommendations expressed in this report to closure in order to ensure that MOSFIRE is completed with a prudently low level of risk.

We group our findings and suggested actions into several sections. We first discuss a few systemic findings about the overall state of the MOSFIRE instrument design and completion plan. Next we report 3 major findings that have systemic implications for MOSFIRE where more work is needed to reduce risk. Then we detail a set of more specific findings and concerns. Recommendations are provided for all of these findings. The next section of the report consists of explicit answers to the questions asked in the MOSFIRE DDR Process and Charter, and we conclude with a brief summary assessment and provide a concise list of recommended actions.

Systemic Findings

The MOSFIRE team did an excellent job of documenting its detailed design activities in its Detailed Design Report and an accompanying set of well organized MOSFIRE Design

Notes. The instrument design was judged to be excellent overall, and very good and thorough performance analyses were generally performed (with some exceptions noted subsequently). The MOSFIRE team has also identified the instrument's key technical risks and is generally doing a good job at mitigating them (also with a few exceptions to follow). The review committee also notes that the MOSFIRE design has been improved in several key areas since PDR. Instrument delivery is likely to be at least several months later than planned due to an overly optimistic optics delivery schedule and likely delays during integration and test (i.e. need for additional thermal cycles).

The design is likely to meet most or nearly all of its technical requirements, but the review committee found that the MOSFIRE systems engineering effort to be relatively weak. The top-level scientific requirements, intermediate derived requirements, and requirements traceability are not included in the MOSFIRE requirements document. However, the MOSFIRE team does seem to be doing many systems engineering functions (requirements determination, flowdown, verification) in an informal way and is certainly on top of many critical issues. Nevertheless the review committee is concerned that the lack of a more formal process may result in either key requirements being overlooked (for example the CSU stray light requirement is not in the requirements document) or else excess effort may be put into meeting a requirement that is overly strict. We recommend that the MOSFIRE systems engineering tasks be given slightly more effort for the duration of the project.

Significant Risk Areas

In addition to these systemic findings, the review committee identified 3 areas where risk was judged to be unacceptably high, and we recommend that action be taken soon to mitigate them. Fixing these problems during or after commissioning will likely be less effective, more costly, take longer, and will waste much valuable telescope time. We identify these as the highest priority findings and recommendations in this report:

A. Science risk. The MOSFIRE team has done a good job of starting to document some likely science observations in the Detailed Design Report and in a few MOSFIRE General Design Notes. The general observing scheme including CSU setup, captured wavelength range, guiding, and notional calibration plans are documented for both extragalactic and galactic example cases. These are very good cases to study because they are likely to bound MOSFIRE's observations at both low and high signal-to-noise. A preliminary operations concept is also provided in section 5.6 of the Detailed Design Report as well. This demonstrates that the MOSFIRE team understands how the instrument is likely to be used, which is very good.

However, the sample cases are not detailed well enough to determine whether the MOSFIRE design will be adequate to collect data good enough to achieve their scientific objectives. We recommend that the MOSFIRE team further document both the extragalactic and galactic science cases to include what data quality are needed to achieve their science objectives. This data quality can be specified in terms of high frequency signal-to-noise, low order spectral shapes, quality of telluric correction, wavelength accuracy, and spectrophotometric accuracy and perhaps other parameters depending on the science needs. The results of the detailed design analyses (i.e. flexures, optics performance) should be used to determine whether the expected performance of MOSFIRE is adequate to achieve the needed data quality. Calibration plans should also be further developed, and they should include some basic analysis to determine and demonstrate that they are sufficient for achieving the needed data quality. For example, obtaining high signal-to-noise reduced data may require that flat field or wavelength calibrations be acquired temporally adjacent to the science observations. The MOSFIRE team has evaluated the optical impacts of flexure, and these could be applied to flat field, telluric star, and object data to simulate the resultant data quality in different field (slit) locations. The operations concept should also be amended to include all such calibration scenarios that are likely to be needed. The team has done a lot of work determining how MOSFIRE will perform on the telescope, and it is very important for them to determine whether this performance is adequate to achieve its required data quality / scientific performance.

B. Flexure risk. The analysis of MOSFIRE's detailed design predicts that uncompensated instrument flexure will result in a maximum image displacement of 3 pixels in either axis in either imaging or spectroscopic mode. The MOSFIRE team expects to achieve a 10:1 reduction in this flexure with an open-loop flexure compensation system (FCS; tip / tilt mirror) whose position will be determined by a lookup table. This system is expected to meet MOSFIRE's corrected flexure requirement of less than 0.3 pixels in 2 hours of observing. This flexure compensation scheme assumes that the instrument structure flexes with low hysteresis and smooth elastic behavior, but the actual MOSFIRE instrument is not likely to behave in this manner. Given that the flexure performance is so close to the requirement, we recommend that the MOSFIRE team consider how to implement active correction if the lookup table system does not work well. It may be possible to track the locations of stars (imaging mode), bright sky emission lines (spectroscopic mode; could allow partial correction), or use other techniques to actively correct for flexure, and these should be investigated soon to ensure that MOSFIRE has an adequate fallback plan.

The review committee also found that the MOSFIRE flexure analysis did not include any forces exerted upon the MOSFIRE dewar from either the rotator bearing or the telescope. LRIS has been found to have flexure induced by either the rotator or the telescope, so it is likely that MOSFIRE will too. These forces may be sufficient to cause MOSFIRE to fail to meet its compensated image motion requirement, to be unable to adequately correct for flexure due to the limited motion of the FCS (only 6 pixels on the detector), deliver unsatisfactory image quality, or some combination of these outcomes. We recommend that the MOSFIRE team make a minor design change to the dewar outer shell to allow kinematic mounting on the telescope and also that the Keck Observatory staff thoroughly investigate and characterize the magnitude and direction of forces transferred to Keck 1 Cassegrain instruments by either the telescope and / or the instrument rotator.

C. CSU Risk. The review committee was generally very impressed with the progress made on the CSU design and prototyping efforts and applauds both the MOSFIRE team and CSEM for their work on this novel and very useful mechanism. As detailed in the separate CSU CDR report, the CSU currently fails to meet its requirements in only a few areas, and the delivered unit is likely to be fully compliant. However, we were concerned that the verification of the CSU lifetime operation requirement is based on lifetime testing the ESA prototype CSU. We are concerned that the MOSFIRE and ESA prototype CSUs have several design and materials differences that may impact the applicability of the earlier lifetime testing results. We recommend that the applicability of the earlier CSU lifetime testing be analyzed in detail, that a realistic CSU test unit be tested over a range of gravity orientations, and that CSU stray light, flexure, and positioning repeatability be evaluated during and after testing. MOSFIRE is designed with a goal of 10 years minimum service prior to maintenance, so proper lifetime qualification of the CSU is very important.

Other Specific Findings

In addition to the systemic and major findings noted above, the review committee also found issues with a number of design, analysis, and planning details that warrant discussion and corrective action:

The predicted flexure of the rotator module was not completed and incorporated into the MOSFIRE flexure analysis (Detailed Design Report p. 75). Some flexure due to gravity is guaranteed, and this will cause both the guider and CSU to be displaced and tilted away from the rotator axis, worsening pointing performance. We recommend that the rotator module flexure be analyzed and provided to the MOSFIRE team ASAP for inclusion in their overall analysis model.

The optical design has not been analyzed for sensitivity to axial displacements, so the expected (as-built) optical performance of MOSFIRE is uncertain and may be worse than currently predicted. We recommend that the optical design be analyzed for sensitivity to axial displacements.

No comprehensive stray light analysis has been done, and the system impact of optical ghosts has not been evaluated. One specific problem identified during the review is that a narcissistic ghost is likely to arise from bright objects being reflected off of the detector (or its surroundings), passing back through the camera, and then reflecting off the grating in other spectral orders (including zero) to be reimaged upon the detector. We recommend that a stray light analysis be performed and that the ghosting be analyzed for the complete MOSFIRE optical system and mitigated to the extent possible (including the identified narcissistic grating ghost).

The chosen architecture for interfacing between the detector server and the detector ASIC is complex, and not all of the software components have yet interoperated successfully. It appears that much of this complexity is being driven by the desire to use Java RMI for inter-platform operability. We recommend that the MOSFIRE team and Keck staff reconsider the trade of whether the benefits of using RMI justifies the complexity of the current design given that the alternatives of creating a C interface to the COM object results in a less risky design.

The MOSFIRE schedule and test plan show that the MOSFIRE software is not tested with the CSU until well after the CSU is installed in the instrument. The review committee judged this plan to have unnecessarily high schedule risk. We recommend that the MOSFIRE software testing of the end-to-end serial communication link start before the CSU is even delivered and that functionality be completely verified before integrating the CSU into the instrument. It is understandable that further testing will be required in the integrated instrument when cold.

There are no requirements defined for the Data Reduction Pipeline (DRP). This is a concern given that the DRP is a deliverable item and the instrument is expected to have detailed designs (not just requirements) for all subsystems at this time. We recommend that the DRP requirements be established soon and that its development work be planned immediately thereafter.

The operational impacts of failure modes were not discussed in the Detailed Design Report or at the review. The committee is concerned that without adequate planning and software design, mechanism failures may unduly compromise operations. We expect that the MOSFIRE team is implementing engineering mode software to allow minimizing the impact of any rotary mechanism failures during observing. We note that MOSFIRE has 2 new mechanisms, the linear detector focus stage and the CSU bars. We recommend that the MOSFIRE team implement software that will allow graceful recovery from failures in any of its mechanisms (such as a stuck or unresponsive CSU bar) as well as continued user-transparent operation in the event of such failures.

Answers to DDR Charter Questions

We now list the explicit questions asked in the MOSFIRE DDR Process and Charter document and provide concise answers. Some of these questions address issues noted in the previous sections of this report, but we also provide new findings in response to some questions. We do not provide any recommended actions to accompany those new findings but would be happy to provide clarification or advisement.

Detailed Designs

a. Do the final specifications meet the science requirements?

   Probably, but there are concerns:

   1. Good design but systems engineering not documented well
   2. Requirements not established for science data quality, and likely data quality has not been modeled.

b. Do the final designs meet the requirements given in the instrument requirements document?

   i. Yes, if all assumptions are correct (i.e. flexure)

   ii. Requirements document seems incomplete in some areas (see above)

c. Do the performance predictions given for the final design indicate that the instrument will achieve the final specifications?
   i. Mechanical specs will likely be met, but CSU bars are not there yet (we agree with CSU CDR report that this development is on-track).
   ii. Likely data quality has not been analyzed
   iii. Limited analysis or predictions presented on software performance (delays, latencies, throughput etc). Some problem areas identified in written responses but not deemed to be of significant risk.
d. Based on the reviewer's knowledge and experience are the final designs feasible?
   i. YES
e. Based on the reviewer's knowledge and experience are the final designs based on sound scientific principles and best engineering practices?
   i. YES
f. Do the detailed designs appear to be complete and ready to be released for fabrication?
   i. Mostly. Not all drawings finished. We did not scrutinize drawings.
g. Are all of the interfaces to the instrument well defined?
   i. Yes. However the interface to the telescope should be re-examined (see above)
h. Are all of the interfaces between subsystems internal to the instrument well defined?
   i. Yes
i. Are the plans for integration and test clear and well thought out?
   i. Instrument I&T plan is only at an outline level. Software I&T is more advanced – and well defined – in many areas, though notably not so in some of the higher risk areas such as ASIC and CSU comm. interfaces.
j. Is the risk identification complete, and if not, what additional risks should be considered?
   i. Mostly. Stray light, optics displacements, and science should be added (see text)
k. Are the all critical risks retired, and if not are the planned risk mitigation efforts likely to result in retirement of the remaining risks?
   i. Major risks identified but more mitigation is needed in critical areas (science, flexure, optics [axial sensitivity analysis], CSU lifetime: see text)

Documents and Reports

l. Does the detailed design report provide adequate information on the detailed design activities?
   i. YES. This was done very well.
m. Are the interface design documents clear and sufficiently detailed?
   i. YES

n. If the predicted performance for the designs does not meet the science requirements or the final specifications are the plans for addressing this sufficient?
    i. YES and no. See text
o. Are the plans for completion of the project, including schedule and budget, sufficiently detailed and complete?
    i. WBS and Schedule were not adequately detailed in some areas (science, commissioning) but team has performed well relative to plan so far.

p. Based on the reviewer's knowledge and experience is the proposed schedule and budget to completion realistic?
    i. The schedule is optimistic and has no reserve, so it will likely not be met by at least several months. Optics delivery is optimistic and I&T is not planned well enough to evaluate. Budget is judged to be adequate to cover a modest slip. The recommended actions also need to be taken to ensure delivery without further delay.

<u>Summary</u>

The MOSFIRE team has made excellent progress on the instrument's detailed design, but several risks need to be addressed soon to ensure that the instrument is scientifically successful as soon as possible after delivery and commissioning. We note that the project schedule is optimistic and has no reserve. Instrument delivery is likely to be at least several months later than planned due to an overly optimistic optics delivery schedule and likely delays during integration and test (i.e. need for additional thermal cycles).

We recap our recommendations here to provide a concise list to aid the Keck Observatory Instrument Program Manager and the MOSFIRE team in their closure. Closure is important since several of these recommendations also appeared in the MOSFIRE PDR report (kinematic mounting and stray light nearly verbatim and variations of several others). We consider the first 4 recommendations to be most critical but have not otherwise ranked this list:

1. We recommend that the MOSFIRE team further document both the extragalactic and galactic science cases to include what data quality are needed to achieve their science objectives. The results of the detailed design analyses (i.e. flexures, optics performance) should be used to determine whether the expected performance of MOSFIRE is adequate to achieve the needed data quality after applying planned calibrations.

2. Given that the flexure performance is so close to the requirement, we recommend that the MOSFIRE team consider how to implement active correction if the lookup table system does not work well.

3. We recommend that the MOSFIRE team make a minor design change to the dewar outer shell to allow kinematic mounting on the telescope and also that the Keck Observatory staff thoroughly investigate and characterize the magnitude and direction of forces transferred to Keck 1 Cassegrain instruments by either the telescope and / or the instrument rotator.

4. We recommend that the applicability of the earlier CSU lifetime testing be analyzed in detail, that a realistic CSU test unit be tested over a range of gravity orientations, and that CSU stray light, flexure, and positioning repeatability be evaluated during and after testing.

5. We recommend that the rotator module flexure be analyzed and provided to the MOSFIRE team ASAP for inclusion in their overall analysis model.

6. We recommend that the optical design be analyzed for sensitivity to axial displacements.

7. We recommend that a stray light analysis be performed and that the ghosting be analyzed for the complete MOSFIRE optical system and mitigated to the extent possible (including the identified narcissistic grating ghost).

8. We recommend that the MOSFIRE team and Keck staff reconsider the trade of whether the desire to use RMI justifies the complexity of the current design given that the alternatives of creating a C interface to the COM object results in a less risky design.

9. We recommend that the MOSFIRE software testing of the end-to-end serial communication link start before the CSU is even delivered and that functionality be completely verified before integrating the CSU into the instrument.

10. We recommend that the DRP requirements be established soon and that its development work be planned immediately thereafter.

11. We recommend that the MOSFIRE team implement software that will allow graceful recovery from failures in any of its mechanisms (such as a stuck or unresponsive CSU bar) as well as continued user-transparent operation in the event of such failures.

12 We recommend that the MOSFIRE systems engineering tasks be given slightly more effort for the duration of the project.