IMACS Project Reply to the
PDR Committee Report

May 24, 1999

The following is a formal response by the IMACS project to the PDR committee report. The original report by the Fabricant Committee is included here in this typeface. The IMACS project replies are shown in this typeface.

1 Summary

The committee's overall reaction to the Preliminary Design Review (PDR) presentation is quite positive. The Inamori-Magellan Areal Camera and Spectrograph (IMACS) team presented a clear description of their design strategy for all the major instrument subsystems. The instrument concept and initial layout look sound. The IMACS team is ready to proceed to more detailed designs. Below, we present our detailed comments organized by instrument subsystem, but we first summarize our most important comments. We recognize that the IMACS team would plan to address many of these issues in due course, but we risk repetition for the sake of completeness.

We again thank the committee members for their time and contributions to the review.

1. During the presentation, there were some inconsistencies and vagueness about several of the key specifications for major subsystems. It is natural for the specifications to evolve following an initial look at the design, but it would be appropriate for the PI and instrument scientist to now revisit and flesh out the instrument specifications. It is particularly important for the outside designers of the dewar and optics mounts to have clear and complete specifications, because there will be fewer opportunities to catch oversights.

   We have revised many of the individual subsystem specifications following the PDR, and particularly the dewar specs. A detailed revision of the camera and collimator specs. will be completed prior to contracting any of that work.

2. One of the key IMACS specifications is flexure, and the performance of the instrument in detail here is unclear. It will be important to tie the finite element analysis more tightly to the optical analysis to correctly track the image motion from structural deflections. As finite element models for the sub-assemblies become available, these deflections should be added to the analysis to make sure that local subassembly motion is acceptable.

This has been planned from the outset and will be done as the subsystem designs become available.

3. The wavefront analysis feedback required to maintain appropriate telescope collimation should be worked out in detail with the telescope project staff. Two wavefront sensors are probably required to measure field dependent errors.

   We have added a second WFS optical system to the center-field guide camera. We will continue to work closely with the telescope project staff on the design and analysis of the WFS systems.

4. It appears that the instrument scientist is currently expected to carry the main burden of the project management as well as to provide the technical leadership for the project. Our experience is that project management is likely to occupy a large amount of time ($\sim 1/3$ to $1/2$ time) and that placing this additional burden on the instrument scientist will slow progress. It would also be appropriate to add an additional mechanical designer if schedule is a priority.

   We are monitoring this situation closely! Project management responsibilities so far have consumed time as suggested here, but we do not expect the 1/3 to 1/2 time fraction to be constant over the life of the project. The instrument scientist has 10-15% of his time currently allocated to management functions. If this proves insufficient, we will change the allocation and consider additional staffing.

5. We would recommend waiting to build the instrument structure until the detailed designs of the sub-assemblies are clear. Attempting to freeze all the mounting interfaces before the subassembly designs are worked out is likely to add cost and slow progress.

   We have revised the schedule to reflect this suggestion.

6. We recommend that the project work out the entire software effort required to make productive scientific use of the instrument, even if much of that software is expected to come from resources outside the project. Someone has to produce this software, and the effort may be significant. Currently the project is intending to supply only the instrument control software.

   We have started this process, and identified about 18 months of additional programming effort. We are considering ways to incorporate this time into the project scope and schedule.

7. The committee was unimpressed by the demonstrated carbon fiber slit masks. We recommend that the IMACS team make test slits of the requisite quality before settling on this material. The laser cutting system discussed could also cut metal masks. MJ suggests that clear specifications for the slits be developed, including: width uniformity, position accuracy, slit edge profile, and limits on "fuzz" or other contaminants.

We are taking this comment very seriously. Detailed specifications for the slit masks existed at the time of the PDR, but were not presented explicitly. We are continuing the mask development with the following steps:

(a) Analysis by Sutin has shown that the telescope-plus-ADC focal surface changes at a rate of 8 PPM/C. A mask material CTE of 4 ± 4 PPM/C has been shown to be a good compromise between the telescope and instrument thermal scale rates. CF composite masks can be designed to closely match that value, and hence be cut and used throughout the 20C operating range. Aluminum masks will be acceptable over a smaller (less than 20C) temperature range.

(b) Two local laser cutting shops have agreed to cut samples of our carbon fiber (CF) and aluminum material candidates. We will obtain images of the cuts with both materials to establish conformance with the specs.

(c) Two local CF shops are providing addition material samples for the cutting experiments.

(d) One of the challenges of the slit masks is to accurately match the spherical f/11 focal surface. We are having sample aluminum masks "spun" by a local metal spinning shop. We will be evaluating the quality of the spinning process for the mask blanks, as well as the quality of slits laser-cut in aluminum.

8. The committee is quite skeptical that the two-year instrument schedule is realistic. Our experience suggests that even a three-year schedule would be quite impressive for an instrument of this complexity, and that a four-year schedule would not be unreasonable. The schedule clearly will affect the budget. Our brief look through the budget leads us to believe that it is optimistic if it is meant to account for all costs. The total cost of the instrument might well approach \$5 million if no features are deleted, but this is not excessive for an instrument of this complexity in our view.

   We agree that the current schedule is ambitious. The schedule is based on design, drafting, and fabrication time estimates which have not yet been calibrated at OCIW. We will be monitoring the design time estimates, and will revise both the schedule and budget as we gain experience.

   The budget has been revised to include unlisted costs identified in the review. The current budget, including fabrication of the short camera and contingency, is close to \$5 million. We will be watching closely the task durations and costs in order to identify (and address) errors in the estimates.

9. The CCD controller for the 8-CCD mosaic is a new design, and the plan is to develop the controller on an aggressive schedule with very modest resources. It might be prudent to organize a brief review of this system, drawing upon specialists who have recently completed similar designs.

Thompson and Burley have agreed to conduct a review of the CCD controller. Documentation will be produced and distributed to a review committee of controller experts for their comment. We expect this review to be informal, without a formal meeting.

10. The stated plan is to provide all optical baffling within the instrument. This approach is unusual and has the potential for some surprises. It would be prudent to do a careful job of searching for the usual ghost images and ghost pupils, and to extend this work to include strongly off-axis light sources. This work should be carried out quickly given that the optics are already under production. Non-sequential ray trace software is available for this purpose. MJ points out that additional baffles may be required in front of the instrument to block the view of moon-lit telescope structure.

    A detailed ghost analysis has been completed by Sutin. The analysis includes the following ghost types:

    - stellar
    - pupil
    - wide-angle
    - sky-to-tertiary
    - sky-to-field lens

    A summary can be obtained from Sutin (sutin@ociw.edu). The primary conclusion is that the worst ghosts can be minimized by insuring that the back of the slit masks have a low-reflectivity, high-scattering surface. A detailed baffling design will be developed from the ghost analysis.

We now turn to more detailed comments.

2 Optics

In addition to the baffling issue mentioned in the overview above, the committee recommends that the gravity-induced axial displacement tolerance of the lenses in the long camera be examined. These axial shifts may result in noticeable focus changes. SR warns that thin edges on CaF_2 elements may prove troublesome; GMOS specifies a minimum of 15 mm.

The axial sensitivities for each optical element will be rechecked. We expect thermal defocus to dominate; the detector focus stage will be used to correct thermal focus errors.

3 Electronics

no comments

4 Instrument Control

JN suggests that the details of the thermal sensing system be fleshed out in the next stages of the design. He, as well as several other committee members, prefers a pair of home sensors or encoders (SR) to check the performance of the stepper motors. JN suggests that the one minute reconfiguration speed specification of the instrument should be made more concrete by analyzing and listing times to complete all anticipated operations.

The thermal sensing and control system will be fleshed out in the detail design phase. We will base the final decisions on encoders and limit switches based on the accuracy and repeatability requirements of the individual motion stages. We currently anticipate encoding grating tilts (3), and guide camera motions (4) with Renishaw tape encoders, and using steppers with multiple home/limit switches elsewhere.

5 Guiders and Science Array Controller

The mechanical design of the guider cameras should be analyzed to make sure that motion of the CCD in the guider package doesn't contribute to guiding errors. Because the guider package dissipates about 25 watts, it is anticipated that this heat will be removed with a liquid cooler. This system must be carefully designed to avoid condensation problems and must be designed to allow free motion of the guider stages. The expected readout time for the SITE science array CCDs is expected to be about 2 minutes. This is slow by current standards, but the readout time is set by the requirements of the SITE CCDs and not the array controller. With other CCDs it is expected that the readout time can be reduced to $\sim$30 seconds.

We will use these suggestions in the design of the guide cameras.

6 Dewar, Focus and Flexure Control Stages

The basic layout of the dewar is based on an existing University of Hawaii system, with addition of a two-axis flexure stage and a focus stage. We recommend that the stepper motor used to drive the focus stage be placed outside the dewar and a linear motion vacuum feed-through be employed. DF wonders how much power is dissipated by the flexure control stage. If this is significant, a different arrangement with the flexure stage drive outside the dewar might be preferable. Thermal analysis of the CCD system should undertaken in any case.

The focus motor and drive have been moved outside of the dewar as suggested. The PI X-Y stage is driven by PZT actuators which are essentially capacitors in our system. Nevertheless, the heat dissipation will be checked. A thermal analysis of the detector system will also be completed prior to fabrication of the dewar.

The flexure introduced by the flexure control stage should be analyzed or measured to make sure that this is not a major error source. Several committee members noted that the cooling straps in the current design may be too stiff in one of the desired flexure control axes. MR, seconded by several other committee members, suggests that a G-10 truss rather than the G-10 pins shown should be used to support the cold plate. SV suggests that the radiative coupling between the flexure control stage and the CCD cold plate be blocked with a layer of Mylar insulation.

The stiffness of the cooling straps will be checked. A G10 truss has been incorporated into the array support as suggested. Radiative heat shields will be added as appropriate.

7 Guider Stages

The use of two curved THK rails for the guider motion is a good start towards attaining a stiff stage. However, the stages with a wavefront sensor are quite complex, with two additional motions. The design of these stages will be challenging if the specified maximum 25 μm motion with respect to the slit masks is to be attained. These assemblies should be carefully analyzed with a finite element model. It may prove to be advantageous to move the stage brake from the drive gear to an alternate location. SV suggests that the effect of temperature gradients and changes encountered in this section of the instrument be studied carefully to make sure that the desired stability specification is met.

We will carefully consider each of these suggestions in the detailed design of the guiders.

8 Slit Masks

As discussed previously, the use of formed graphite-epoxy slit masks met with considerable skepticism based on the poor test slits shown to the committee. The effects of differential thermal expansion between the graphite slit masks and the steel mounting surface should be examined. The quasi-kinematic mounting system proposed for the slit masks is likely to have sufficient friction to prevent free radial motion of the masks. Charlie Hull reminded us that moisture absorption and release in the graphite-epoxy masks may also prevent them from attaining the stability suggested by the low graphite-epoxy coefficient of thermal expansion.

Several committee members recommend that an approach similar to the filter handler be considered for this mechanism, replacing the current three point kinematic mount with V-rollers. SR further recommends that the defining roller be placed closest to the (main) guider to minimize pointing offsets. JN suggests that the telescope optics may define the optimum coefficient of thermal expansion for the slit masks. He also likes the idea of a slit carousel that moves slit plates along the spherical surface defined by the focal surface.

Additional slit mask material development is underway as mentioned above. The mask handling system is being revised to operate like the filter mechanism (no kinematics). The ideal mask CTE has been determined as mentioned above. For simplicity, the mask server will be similar to the filter servers, and will move along straight, rather than curved lines.

9 Collimator, Camera and Field Lens Optical Mounts

The IMACS team is currently planning to hold the singlet elements in slotted fingerstock flexures and the oil-coupled multiplets in athermalized mounts. The reviewers had a range of opinions about the details of the optics mounts. DF prefers using RTV athermalized mounts for all the optics, using a single metal outer ring, rather than a mix of fingerstock flexures and the complex multi-element rings in the current design. He believes that fingerstocks can be made to work, but that assembly of the optics into the fingerstocks may prove difficult and that machining the fingerstocks to the requisite tolerances may be costly.

SR mentions that GMOS has abandoned the use of lens adhesives stiffer than RTV because these adhesives typically have thermally-dependent mechanical properties. JN also expressed skepticism about the multi-element rings but likes the fingerstock flexures. PH suggests that if fingerstock flexures are used, they should be made more radially compliant by increasing their length to width ratio. He also suggests EDM as possible fabrication technique.

We are proceeding carefully with the lens mounts. We still prefer the fingerstock supports for the singlets due to their simplicity. The fingerstocks will be made more compliant as suggested, and we will investigate EDM for fabrication of the fingers. We will build a prototype multi-element cell to test the two-ring mounting concept.

Athermalization of the camera and collimator is accomplished with a Delrin rod controlling the position of a flexure-mounted lens group. Several committee members wonder if the axial flexures will produce a noticeable tilt of the lens group. PH points out that the current flexures produce a rotation about the optical axis as they displace and so the flexure pairs must be oriented correctly.

Calculations have shown that tilt due to the single control rod are acceptable. Flexure orientation will be checked.

JN notes that the stability and accuracy of the placement of optical elements in the camera and collimator barrels is an issue that should be carefully considered, as these issues have been a problem on other projects. He also suggests, strongly seconded by DF, that a careful thermal analysis of the optics and the rest of the instrument be carried out in the next stages of the design.

A detailed thermal analysis is planned as part of the instrument housing and cooling system design task.

It was not clear to the committee that the plan to use adjustable shims between the lens bezels will prove simpler and cheaper than machining the fit between lens bezels to the requisite tolerances.

Several committee members are skeptical that shiny baffle blades are a good idea. We suggest that this approach be tested with the intended materials. It may be prudent to engage a consultant with experience in optical baffling. PH notes that there is a tradeoff to be considered: the more baffles, the more effectively light is trapped between the baffles and the more scattered light is produced at the baffle edges.

Further analysis of the baffle concepts will be completed.

10 Filter Server and Shutter

If the filters are to be positioned with magnets, the magnets should be recessed slightly to avoid small filings from interfering with the positioning and to avoid damage to the magnets. PH would prefer to see another type of latching system, perhaps a ball catch or roller detent.

The magnets will be recessed. An additional latching system using the filter frame keyways is planned.

11 Structure

The structural concept of using the instrument rotator to define the position of the instrument while using a constant force actuator at the rear of the instrument seems to have a good chance of performing satisfactorily. Because the force actuator is supported from the Nasmyth platform, it must be designed to deliver a constant force even if the Nasmyth platform deflects with respect to the mounting flange. It currently appears that the instrument flexure caused by actuator force errors is relatively benign, so the required force accuracy may be modest. It will be important to track this sensitivity as the design proceeds. One area that the IMACS team plans to address is the connection of the main truss to the instrument rotator. The current load path is unfavorable since it relies on the poor bending stiffness of the front mounting disk. In addition, DF, MR, MJ and Steve Shectman stress that the finite stiffness of the instrument rotator should be included in the finite element model.

The force off-loader actuator may be difficult to design because it must support a rotating part. As the structure becomes better defined it will be important to make sure that the force accuracy remains sufficient to prevent harmful flexure. It would also be a good idea to explore the consequences of a force actuator failure.

MR suggests looking at replacing the current disks at the rotator and the MOSS with a truss structure, and checking into buckling of the truss members and node details. PH likes the welded structure for the MOSS, partly because this is easier to make and modify. He suggests avoiding three-way corners by using a cutout where necessary.

These concerns will be addressed in the detail design of the structure.

12 Disperser Server

The concept of providing the required grating stability by transferring the grating from the disperser wheel to a fixed matrix ring strikes the committee as a good idea. The committee expects that the transfer mechanism may be amenable to simplification as the design matures; PH suggests studying the tool changer mechanisms on multi-axis machine tools for ideas. The control of grating tilt to the specified 1° resolution is likely to be too coarse.

We expect to drive and encode grating tilt to much better than 1°.

PH has some detailed comments:

"If there is space, I would recommend that the wheel be made as a flat disk rather than a cone and that it should be made as one piece with a large central hole. The MOSS structure can protrude through the hole to give the necessary support for the fixed index ring and the short camera. Rather than cam followers you might like to consider the V-groove rollers used with linear slides (HEPCO?). Hard anodize the working surfaces with a PTFE-loaded coating (Tiodize can do this). The whole mechanism will need to be enclosed in a dust proof housing to protect the matrix rings from damage by grit."

The original design for the disperser wheel was a flat disc; space and balance constraints make the cone shape a better choice for IMACS. We will consider V-rollers for the wheel support. Dust-tight covers for the disperser server will be provided.

13 Schedule, Budget and Management

MJ suggests that a document control system be implemented to ensure that specifications and interface information is transmitted effectively between the project and vendors. JN believes that the project should create a list of descope options in case of budget problems, as well as a list of high risk items as part of a risk analysis.

We plan to follow the Magellan document control system example. We will continue to address descope options and high-risk issues as the project progresses.