12 March 2003

To: LSST Project

From: Optical Design Review Committee
Daniel Schroeder, Chair
Eli Atad, Alan DeCew, Harland Epps, Roderick Willstrop

Subj: Final Report

The LSST Optical Design Review Committee (ODRC) met on Wednesday, 26 February, to learn about the current status of the LSST optical design and to begin formulating a suggested plan for future work. Specifically, the ODRC was presented with an optical design for a monolithic LSST and asked to respond to specific questions regarding this design and to recommend the next steps to be taken in the LSST Program. The members of the ODRC are listed in Attachment A, specific items on the agenda of the meeting are in Attachment B, and the instructions to the ODRC are given in Attachment C, "Charge to the Review Committee (revised 2/24/03)."

The report following is our response to the five items in the charge to the committee, with the report divided into sections corresponding to each of these items. Each section was written following input from the members of the ODRC and comments given in the open meeting. In addition, a detailed and thorough statement of recommendations and concerns from Harland Epps is included in its entirety as an appendix. This statement is an integral part of our report. Now for our response to each item in the charge to the committee.

(1) Does the optical design as presented meet the NRC recommendation for the LSST facility?

The starting point for addressing this question is a section on the LSST from the NRC report "Astronomy and Astrophysics in the New Millenium," (Attachment D). For our purposes the pertinent statement from this report is,

> "The committee recommends the Large-aperture Synoptic Survey Telescope (LSST), a 6.5-m-class very-wide-field (~3 deg) telescope that will produce a deep (~24th magnitude in a single optical band) digital map of the visible sky every week."

We believe that the basic optical design presented to the ODRC for an 8.4-m 3-mirror telescope based on the Paul-Baker concept meets the stated requirement. Key features of this design are given in the report by Lynn Seppala "NOAO LSST Optical Design Study, Final Report, 21 Feb 2003," especially section 4 (see Attachment E). The pertinent numbers include image diameters with 80% enclosed energy in the V, R, I bands <0.20 arc-sec, Z band <0.22 arc-sec, and B band <0.24 arc-sec. A second important result is optical throughput exceeding 62% over the full 3-deg field of the 8.4-m telescope, or the equivalent of a 6.5-m unobscured telescope. Given these numbers, we believe the design presented does meet the NRC recommendation.

(2) Is the basic 3-mirror design concept mature enough to allow us to proceed towards a cost-estimated conceptual design for the LSST facility?

We believe the answer to this question is yes. The current design is the outcome of an extensive examination of a large range of 3-mirror designs. Attention was given to many issues including telescope length, complexity of focus adjustments needed when changing bands, departure from asphericity for the secondary and tertiary mirrors, stray light, sensitivities to misalignments, and vignetting, as noted in Attachment E.

We recommend that the current optical design be considered as a "Baseline Optical Design" (BOD) and that the Project proceed with detailed mechanical and system analysis and other activities needed for a conceptual facility design. (See also recommendation 1 in the Appendix.)

In further support of the committee response to questions 1 and 2, is the following paraphrase of comments by Alan DeCew. 'This optical design is likely not the one that will be built. Even if every LSST requirement is immutable and the current design demonstrates their attainability, aspects of the system design will inevitably cause perturbations. No optical design survives unchanged once subjected to the realities of the opto-mechanical design. This is why it is time to put forward this design as the baseline for telescope and system design, and to assess the ability of a mechanical structure and all the attendant control systems to keep the optics performing as predicted through a typical observational environment.'

(3) Assess the areas of highest risk and where early investment would be most useful in terms of mitigating this risk; (4) Suggest alternatives, if any, which would reduce the highest risk areas.

Notwithstanding the quality of the BOD, there are a number of concerns which have been raised and should be addressed as soon as practical. Following is a list of these concerns, in no particular order of importance, with brief comments as appropriate:

a) manufacturing and testing of a large (~3.2-m diameter) convex secondary mirror (This mirror diameter is ~2x larger than the largest secondary made to date.),
b) producing highly homogeneous fused silica blanks for the large corrector lenses (See recommendation 7 in the Appendix and the concern with the large thermo-optical coefficient of fused silica and the possibility that another glass type might be required.),
c) manufacturing and testing of thin (flexible) refractive elements with aspheric surfaces,
d) manufacturing of large, thin filters,
e) mounting large lenses subject to variable gravity loading, especially the leading lens element in the corrector group (see recommendation 5 in Appendix),
f) mechanisms needed to change filters and adjust focus in a confined space,
g) stability of an 8.4-m primary mirror with a large central hole,
h) potential ghost images (See recommendation 4 in Appendix and comments in section (5)).
i) flatness of the CCD mosaic array over the 55-cm diameter field.

For those items that involve the manufacture and testing of optical elements, we urge that the Project work closely with manufacturers in identifying problems and solutions. Optical and mechanical analyses needed to address other concerns, should be part of the work needed to arrive at a conceptual design for an LSST facility.

The committee believes that none of the items listed as a concern presents an insurmountable challenge. The important thing is to take note of these items and to take steps to ensure that none of them becomes a "show stopper."

(5) What further studies does the committee recommend be completed prior to a Conceptual Design Review?

Ghosts and Stray Light - The potential degradation produced by ghost images and ghost pupils could be a serious problem and needs thorough study. A systematic investigation of stray light and possible ghosts produced by light reflected from the detector to surfaces of optical elements within the corrector group, and back to the detector, should be undertaken promptly.

PSF Stability - The stability of the point spread function over the FOV depends on the tolerances with which the various elements within the telescope are held in place. Mechanical and optical modeling are needed to establish the limits of misalignments which can be tolerated. Effects to consider include variable gravity loading, wind buffeting, and thermal changes.

Realized Image Quality in the NIR Spectral Bands - DeCew states the following: "Silicon CCDs do not absorb all the incident photons on the device surface. In fact, there is a penetration depth that is highly dependent on wavelength. The F/1.25 cone that hits the surface fortunately is refracted into a much slower beam inside the silicon. After a penetration of 50 microns, a 10 micron diameter spot has expanded to near 20 micron diameter. It could also be that the depletion depth of the CCD is shallow, in which case the QE of the detector in the NIR will be very low. This issue and the resulting image degradation in the NIR should be studied."

Ease of Change in Spectral Band vs. Optical Performance - In order to achieve the excellent image quality of the BOD, sacrifices have been made. The focus position for each band is different and lens L2 must be moved relative to the other elements in the corrector group to retain this performance. The tradeoff between the ease with which a filter change/refocus is made and optical performance needs further study.

Effects of Atmospheric Dispersion - A study of the effects of atmospheric dispersion on overall image quality within each of the filter bands is recommended. The results from such a study would be important in the site selection process.

Mirror Coatings - The importance of throughput suggests that an effort be undertaken to determine the practicality of coating the three large mirror with overcoated silver rather than aluminum. The potential availability of an additional 50% in throughput is so significant that we urge the Project to invest heavily in its development. (See recommendation 6 in Appendix.)

Guidance for Proposed Recommendations

The Optical Design Review Committee has recommended taking steps to move towards a cost-estimated conceptual design for the LSST facility. In recommendation 2 of the Appendix, Epps proposes that a group should be charged with formulating a set of "Baseline Optical System Specifications" (BOSS) for LSST. The ODRC endorses this proposal.

There exist many science-related reports which discuss the scientific goals for LSST. We believe that a group of scientists should translate these goals into a set of system specifications that LSST must have in order to accomplish the intended goals. The work of this group should be informed and guided by technical experts who can help insure that the requirements are self-consistent and not physically impractical. We urge that the LSST Project pursue a BOSS as soon as possible to serve as the basis for the further engineering studies called for in this report.

Recommendation for a Parallel Study

The final presentation at the meeting was titled "Aperture vs. Field of View Optimization - An Argument for Wider Field?", included here as Attachment F. The analysis by Morgan and Stubbs indicated that a 3-mirror/corrector design could be extended to fields as large as 4.5-deg diameter. Their preliminary analysis indicated that vignetting and image quality were acceptable over this larger field, with a gain in the figure of merit as they defined it. For the same primary mirror aperture and plate scale, it was noted that the remaining optical elements would be larger, especially in the corrector group, raising even greater concerns about manufacturing and testing.

The ODRC concluded that some additional study of a larger FOV was needed before making any judgement about its practicality. We recommend that a study be done in parallel with the main effort of proceeding toward a conceptual design for an LSST facility, with the latter proceeding without delay. We suggest this parallel study be done at a single field angle, say 4-deg diameter, to assess its possible relevance to this program. (See recommendation 3 in Appendix.)

Concluding Remarks

The recommendations of the ODRC can be summarized succinctly as, "Proceed without delay toward a cost-estimated conceptual design for the LSST facility." It is clear from the comments above that there many issues to be studied and resolved. But we believe that the greatest risk to the program is not moving forward with confidence that all of the technical concerns raised can be dealt with. Given the work done so far, we are also confident that the LSST project concept will evolve into a truly impressive scientific facility.