HSC Design Review Report

Review Panel:

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Executive Summary:

HyperSuprime Cam is an exciting instrument that will provide Subaru astronomers with a world-leading capability for exploring the nature of the universe. We recommend proceeding with HSC to complete the design and begin construction as soon as feasible. The primary risk to HSC appears to be budgetary, not technical, and we encourage NAOJ to seek closure with Mitsubishi on the design, interfaces, and budget for the top-end modifications and prime focus unit for HSC as soon as possible.

Charge I. Science Goals

HyperSuprime Cam will be a unique instrument for producing high-quality, legacy data and high-impact science results. The combination of excellent image quality over a wide field of view and the large collecting aperture of the Subaru 8-m telescope make HSC truly revolutionary. The panel recognizes the importance of the key science cases (Dark Energy measured via weak lensing and photometric redshifts), but we also appreciate the broad range of other science projects that the Subaru community and their colleagues in Taiwan and at Princeton are anxious to begin. Some of the panel members attended the Subaru Users' meeting held in Mitaka in Jan. 2009 where these other science projects were discussed. Other programs such as galaxy evolution, surveys of stars in the Galaxy and M31, surveys of clusters of galaxies, QSOs, AGNs, and SNe can either be done through open "PI" access to HSC, or as a "piggy-back" part of a large DE campaign. The HSC science capability will be unique in the world when it is installed on Subaru in 2011. There is no other proposed facility that will be capable of the sky coverage and depth that HSC will achieve.

Recommendations:

We recommend doing a full simulation of the HSC data including realistic aberrations, field rotation (with respect to the corrector), dynamic and static errors, and from that simulated data extract the weak lensing signal to see what the uncertainty is on the shear measurement.

Photometric redshifts are very difficult to measure with the accuracy needed (1% in redshift). Spectroscopic redshifts from WFMOS may provide a strong complementary data set if WFMOS is built. We recommend that emphasis be placed on extending the HSC wavelength coverage as red as possible, at least to Y-band (since other IR surveys are not expected to go deep enough to help with the HSC data

set). In this regard the HSC survey is not at any disadvantage compared to the competition, as the other proposed surveys also rely on photometric redshifts measured at optical wavelengths. More attention will need to be paid to calibration issues (photometric, astrometric, throughput, photo-z training sets, etc.) to achieve desired precision. It is our opinion that with careful calibration the HSC data will support higher accuracy than the presentations indicated. The panel recommends that the HSC team demonstrate how photometric accuracy sufficient to meet the scientific requirements of a broader range of possible future science cases may be achieved. The software needed to achieve the best science results with HSC is discussed further in section III below.

We understand the sensitivity of the Japanese community to large amounts of observing time being allocated to dedicated campaigns. We would like to emphasize that HSC will have its greatest impact in the time frame prior to LSST being completed. Resources and observing time should be allocated to make sure that HSC and its primary science goals are not significantly delayed, and that software be in place to make the HSC data available to the community as soon as the camera begins science observations.

Charge II. Technical Design

HyperSuprime Cam has been successfully designed to meet the top-level science goals. Designs for most subsystems are mature and ready for further development and/or prototype construction. The HSC team has used early prototypes to minimize risk in several technically challenging areas: new Hamamatsu CCDs were installed and tested in Suprime Cam; a shutter prototype was used to explore design options for this critical mechanical component; glass for some of the most challenging wide field corrector elements has been purchased and tested.

Recommendations:

It was not clear what top-end modifications were needed, and what would be provided by Mitsubishi. This appears to be a big uncertainty in the project. We did not see any design details for the HSC prime focus unit, and it's associated hexapod alignment system, instrument field rotator, cable wrap, etc. Given the large cost of the top-end modifications and HSC PFU construction, it is difficult to say if there are technical issues with these systems. The designs for the wide field corrector, the camera, dewar, shutter, filter unit, etc. were much more mature. If the cost of the Mitsubishi work has to be reduced, what requirements will be relaxed? What impact will that have on the science mission or on the other subsystem requirements? We recommend that NAOJ work with Mitsubishi to finalize the design and interface requirements, the budget, and the schedule as soon as possible, so that the technical risk to the project can be understood and any adjustments in other areas made as quickly as possible. The HSC team repeatedly told the panel that the Mitsubishi work is not technically demanding. The panel concluded that the technical risk due to lack of definition in the top-end modification work and PFU development is smaller than the budget risk resulting from uncertain costs for Mitsubishi to do the work.

It wasn't entirely clear which specifications have been demonstrated to be satisfied through prototype testing, and which are met by design. The key question is what happens if some subsystem doesn't meet specification? How is the overall error budget affected, or how do the requirements for other subsystems change? A careful systems engineering approach to error budgets and requirements is needed as the design is finalized.

One area of particular technical concern was the filter exchange mechanism. This is an extremely complex mechanism, with many motors, encoders, limit switches, precision interfaces, tight positioning tolerances, and with complex optics and filters inside. It is also handled separately from the rest of HSC, so handling procedures need to be carefully considered and followed. That it can only be changed at zenith suggests lack of sufficient margin on the motor torques or other tolerances, which was the case for the first filter exchange mechanism for Suprime-Cam. Careful prototype testing should be done before the design is finalized. The panel also suggests that the HSC team think about what it would take to swap filters manually during the daytime if required due to an exchanger failure during an observing run. The panel also recommends baffling the filter exchange mechanism to prevent scattered light since it extends into the light path.

The review panel was concerned about the camera thermal performance with so many electronics in the dewar. The analog circuit boards are predicted to operate at about 20 degrees above ambient, which will produce severe outgassing problems that may well overwhelm the proposed small ion pump. We recommend looking for ways to ensure that heat is removed effectively from the electronics in the dewar, in particular investigating liquid cooling and moving the high-dissipation parts on the boards nearer the thermal contacts. The panel noted the choice of brittle SiC for the dewar plate; there isn't any viable alternative, so safety procedures should be carefully considered to minimize risk.

The panel strongly recommends testing the shutter prototype more thoroughly at typical Mauna Kea operating temperatures (0 C) in a variety of orientations, and under typical humidity and dust conditions.

The wide field corrector ceramic enclosure may be somewhat fragile. We appreciated the safety discussion, but recommend taking the safety precautions one step further. Instead of protecting against bumps, we recommend mechanical alignment guide rods, centering sensors or other guarantees that it never contacts the top end ring unexpectedly. The WFC is a large and delicate optic, and key to both HSC and possibly WFMOS. There should be no margin for error. We noted with some horror that the control system for the TUE was proprietary and the observatory does not have documentation. It would seem absolutely necessary for the safety of HSC that the horizontal motion of the TUE be disabled when HSC is being lowered into place.

Optical design of the WFC seems to be quite mature. Current ghost analysis assumes 10% reflectivity of most of glass surfaces, which may underestimate reflectivity of the interference filters. We were generally satisfied with the careful treatment of possible ghost that has already been done.

Given how important image quality is to HSC, the reviewers felt it was important to understand how residual flexure errors translate into errors in the weak lensing shear measurements. The target

error budget is very demanding. Similarly, we could not judge how far off the optical axis is from the WFC or camera axis due to static flexure with elevation. We recommend that adding a way to adjust the position of the camera dewar with respect to the WFC axis in addition to the hexapod (which aligns the WFC to the telescope) would allow for better control of residual aberrations. For example, piezo flexures on the camera legs might give some additional flexibility in refining the camera-to-WFC alignment. The current design requires that this flexure be controlled by passive flexure of the mounting cone, and therefore any further adjustments would require modifying or replacing a key piece of hardware, and therefore significant work disassembling and reassembling the instrument.

The review panel noted that one of the largest single sources of instrumental image quality degradation is charge diffusion in the detectors (which is almost as large as all aberrations and guiding errors put together). We suggest that the HSC team work with Hamamatsu and other CCD experts in the world (e.g., LBNL) to find a way to reliably run the CCDs at higher bias voltage to minimize charge diffusion.

The high image quality of HSC should not be compromised by poor tracking accuracy of the telescope. Several problems with tracking have been recently reported, which might be caused by wear after ten years of operation. Care should be taken to make sure that the added load of HSC not degrade the tracking accuracy of the telescope.

Analysis Software and Calibration Recommendations:

The panel felt that the state of the planned software design was very far behind that of the design of the camera. The camera design was accompanied by detailed schedules, error budgets, and implementation plans, none of which were seen in the software planning. Likewise, plans for the important task of survey calibration were essentially missing. NAOJ must realize that this instrument and the surveys which will be accomplished with it require a very large investment in software and careful planning for photometric and astrometric calibration. Luckily, within the HSC collaboration there is a great deal of talent and experience in both of these areas, but there is little evidence that even planning for its use is in place. There is evidently some confusion about software for the HSC team weak lensing science and general software for HSC surveys. While the specific requirements and goals may be somewhat different, the commonality is very large, and separate development of software for the various types of observations seems neither wise nor even possible, given the limited resources.

We recommend several steps toward this goal:

1. A set of scientific, functional, and performance requirements for the software be generated on as short a timescale as feasible; these requirements should be guided by the planned surveys with HSC as well as specifically the lensing science, and should certainly involve the developers and scientists throughout the consortium.

2. Plans should be put into place quickly for developing the framework for the software so that individual tasks which can be separated and accomplished efficiently can be assigned to developers.

3. Progress must be measured by regular phonecons/videocons/meetings, and a series of reviews and demonstrations (which might also be accomplished by videocons, but ideally would be face-to-face) should be held.

Without vigorous development on this front, we feel that it is quite likely that the camera will be on the sky in October 2011 and there will be completely inadequate software support. This should in no way be construed as a criticism of the individuals in the current effort; the resources currently being utilized are, we feel, simply inadequate to the task. The consortium was only established recently, probably too recently to impact this review, but it needs to get into high gear very quickly.

A calibration plan also needs to be developed in parallel. At the minimum, this plan needs to encompass:

1. Site-monitoring instrumentation to establish photometricity. There is evidently in existence a 10-micron cloud camera which is not functional. It needs to be repaired or replaced with some way of determining if clouds are present during an observation.

2. Instrumentation to measure the response function and linearity of the camera. This can probably be accomplished with the HSC while in storage off the telescope with a relatively simple monochromater, but such issues as filter installation need to be considered very carefully.

3. A plan and tests for photometric calibration using transformations from SDSS or other (e.g., PanSTARRS) sources. This may involve negotiations with other survey teams to obtain early photometric data.

4. A plan and tests for astrometric calibration using SDSS, UCAC, 2MASS, USNO-B, and other sources.

Charge III. Uniqueness of HSC

As discussed in Section I above, the HSC science mission is unique and world-leading. HSC provides a unique capability in that it samples a larger area more deeply than competing instruments. Projects with similar goals like PanSTARRS will not be able to compete with HSC's sensitivity. LSST will not be built for ~10 years, giving HSC a clear advantage for the next decade. The HSC surveys will achieve an exceptionally faint limiting magnitude both because of the large telescope aperture and the excellent image quality.

Recommendation:

The current HSC error budget and tolerances appear sufficient to meet the top-level science goals, but care should be taken during the final design phase, when cost and performance trades are considered, to retain very high efficiency (throughput) and excellent image quality.

Charge IV. Recommendation to Proceed with HSC

We recommend continuing with design and manufacture of HSC. Many details of the final design depend on interfaces with the new HSC PFU, so these should get top priority. The technically risky areas are getting adequate attention, and prototypes are being built and tested. Other technical risks should be retired quickly and the design finalized. As noted above, the budget risk is largest for the technically least challenging area (top-end modifications and PFU), but it is still the largest uncertainty in the project. We recommend continuing with the design work and technical risk mitigation while waiting for the agreement with Mitsubishi to be finalized.

Charge V. Schedule and Risk

The review panel is concerned by the extremely aggressive schedule, with no schedule or budget contingency explicitly included. We recognize that the HSC team has mitigated many of the most significant technical risks by seeking early funding for prototyping of key subsystems (detectors in Suprime Cam, the shutter mechanism, and filters, for example).

Many of the subsystems appear to have insufficient schedule contingency. Most subsystems are expected to be complete at the same time, about 1 year from now. The human resources needed for those parts were not clearly identified in the presentations. The review panel would have liked to have seen who will be involved in each part, and how many hours can be allocated for each one. The schedule is very tight, and it wasn't clear if the HSC team members will have enough time to complete the work they have been assigned.

Traditionally, astronomical instruments are built in Japan with significant contributions from students. The level of student involvement in HSC design and construction should be carefully considered. The panel recommends allowing involvement of students in the design, construction, assembly, and testing of the instrument, which greatly helps the education of students in instrumentation and science.

We congratulate the HSC team leadership for allocating resources early-on to mitigate the largest technical risks. The panel feels that the largest risk to the project, and the largest potential for schedule slip, arises from the uncertainties in the Mitsubishi top-end and PFU work. These risks can only be mitigated by concluding negotiations with Mitsubishi as quickly as possible.

The current budget contains no contingency at present. Budget contingency will certainly be needed, probably for all subsystems and tasks.