Southern African Large Telescope
SALTICAM
Preliminary Design Review

Document Number 3300AE0003:
Description of the Instrument

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1 Scope

This document is the Instrument Description Document for the Preliminary Design Review of SALTICAM, the Verification Instrument, Acquisition Camera, and Scientific Imager of the Southern African Large Telescope (SALT). It will describe the requirements for the instrument as a Verification Instrument, as an Acquisition camera, and present the user survey which defines the scientific requirements of the consortium user community. It will give a technical overview of the instrument, finishing with a discussion of the instrument program and risk.

2 Instrument Requirements

SALTICAM addresses requirements from two distinct interest groups: (i) the SALT Project team has requirements for the telescope as expressed in SALT Commissioning and Acquisition Instrument Requirements (D.A.H. Buckley, 10 September 2001, Final Version); (ii) the scientific user community of the SALT Foundation partnership wishes to make use of SALTICAM for astronomical observations.

2.1 Verification Instrument

From the outset it has been recognized that the SALT Project team will need an instrument with which to commission the telescope. This instrument (hereafter called the Verification Instrument (VI)) should, at its heart, be an imager capable of providing the SALT Project team with images of celestial point sources so that they can obtain image quality information as they "shake down" the various telescope systems. Ideally, it should be sensitive over as broad a bandpass as possible (this essentially means from the atmospheric cutoff around 320 nm to the longest wavelength at which optical CCDs are sensitive (around 1000 nm); cover as large a fraction of the SALT field of view as possible (science field of 8 arcmin in diameter); and contain no additional optics (so that the image quality measured is that delivered by the telescope and not a combination of the telescope and VI). In essence, a straightforward CCD camera comprising a large CCD detector in a cryostat with filter wheel and shutter would succinctly describe the requirement. Of course technical specifications and quality are issues and these are described in the SALTICAM Specification (agreed between the SALTICAM team and the SALT Project team), as well as in SALT Commissioning and Acquisition Instrument Requirements. The VI will be mounted at the Prime Focus Imaging Spectrograph focal station: i.e. at the focus of the "straight-through" beam.

A significant role for the Verification Instrument is obtaining images suitable for early Public Relations releases to demonstrate progress or capability with the new telescope.

2.2 Acquisition Camera

SALT also needs an acquisition camera to enable the telescope operators to recognize celestial targets and place them in the entrance apertures of the scientific instruments. Acquisition cameras on telescopes are often Cinderella instruments. For example, on HET the acquisition camera is unable to recognize objects as faint as can be observed with the Low Resolution Spectrograph, so that acquisition using the imaging mode of that instrument is required. However, telescope efficiency is greatly improved if a top class acquisition camera is available and this all the more urgent in a telescope of the design of SALT which has access to a given celestial target for only a limited time. Multi-object observations also require excellent imaging capability over a wide field of view to facilitate setting up the instrument. Further details for the SALT Project's requirements for an Acquisition camera can be found in the SALTICAM Specification and in SALT Commissioning and Acquisition Instrument Requirements.

The principal difference between the Verification Instrument and Acquisition camera is the addition of focal conversion optics: the beam emerging from the SALT spherical aberration corrector/ADC will be f/4.2. SALTICAM as Acquisition/Science Imager (hereafter ACSI) will be garnished with lenses to provide an f/2 focal ratio. The ACSI will be fed by a 90^{o} fold mirror mounted just after the exit pupil of the telescope.

For both the VI and ACSI modes of SALTICAM, the instrument must be capable of performing closed loop guiding, either for itself if the exposures are sufficiently short, or for another instrument in which case it will be fed by a dichroic. This will require repeated, rapid imaging, determination of centroids of one or more guide stars, and communication with the SALT Telescope Control System to correct the pointing of the telescope.

2.3 Science Imager

Two questionnaires were sent out through the SALT Science Working Group to all potential users of the telescope. The first of these contained four simple questions, was in multiple choice format and was intended to assess the requirements for wavelength range and time resolution. Eighteen replies were received. The questions and replies received are listed in Appendix 1 and show that:

- The major scientific requirement is for support of another instrument (14 out of 18) but with 6 out of 18 asking for high time resolution
- Half the users want time resolution of better than 10 sec
- The vast majority of the users (15/18) want wavelength coverage to at least 360 nm (this question was poorly phrased: the effective wavelength of the Johnson U band is 360 nm but it extends considerably shortward of this so it is not clear if a user's requirement for 360 nm implies throughput shortward of this)

A second solicitation was sent out in September 2001, asking potential users for titles for scientific program that they envisage carrying out with SALTICAM. Twenty-one separate replies were received, some containing multiple scientific programs. They are listed in Appendix 2. Broadly speaking they can be summarized as:

- Long term photometric monitoring of point sources (faint SNe, novae, extragalactic pulsators, AGN)
- Studies of resolved stellar population in the Milky Way and nearby galaxies
- Surface photometry or narrow band imaging of galaxies
- Colour searches for faint stars or high redshift galaxies and AGN
- High time resolution photometry of rapid variables (cataclysmic variables and X-ray binaries)
- Drift scanning

At the end of Appendix 2 is a table of guesstimates of requirements for field of view, wavelength range and high time resolution by the listed programs. To a large extent all programs involving point source photometry will require field of view in order to refer the photometry to other objects in the field.

The imaging mode of the Prime Focus Imaging Spectrograph might, in principle, be able to carry out many of the scientific programs listed. However, discussions with the PI, Dr. Ken Nordsieck, revealed a number of objections: (i) the PFIS camera has residual lateral colour so broad band imaging would be slightly compromised; (ii) PFIS already has a huge complement of mechanisms: imaging photometry would exacerbate this complexity; (iii) programs which require photometry of a target followed by a spectrum can very efficiently be carried out by the combination of SALTICAM and PFIS. The absence of SALTICAM would require repeated articulations of PFIS's camera arm to switch between imaging and spectroscopic mode and this would cost considerable observing time during a track.

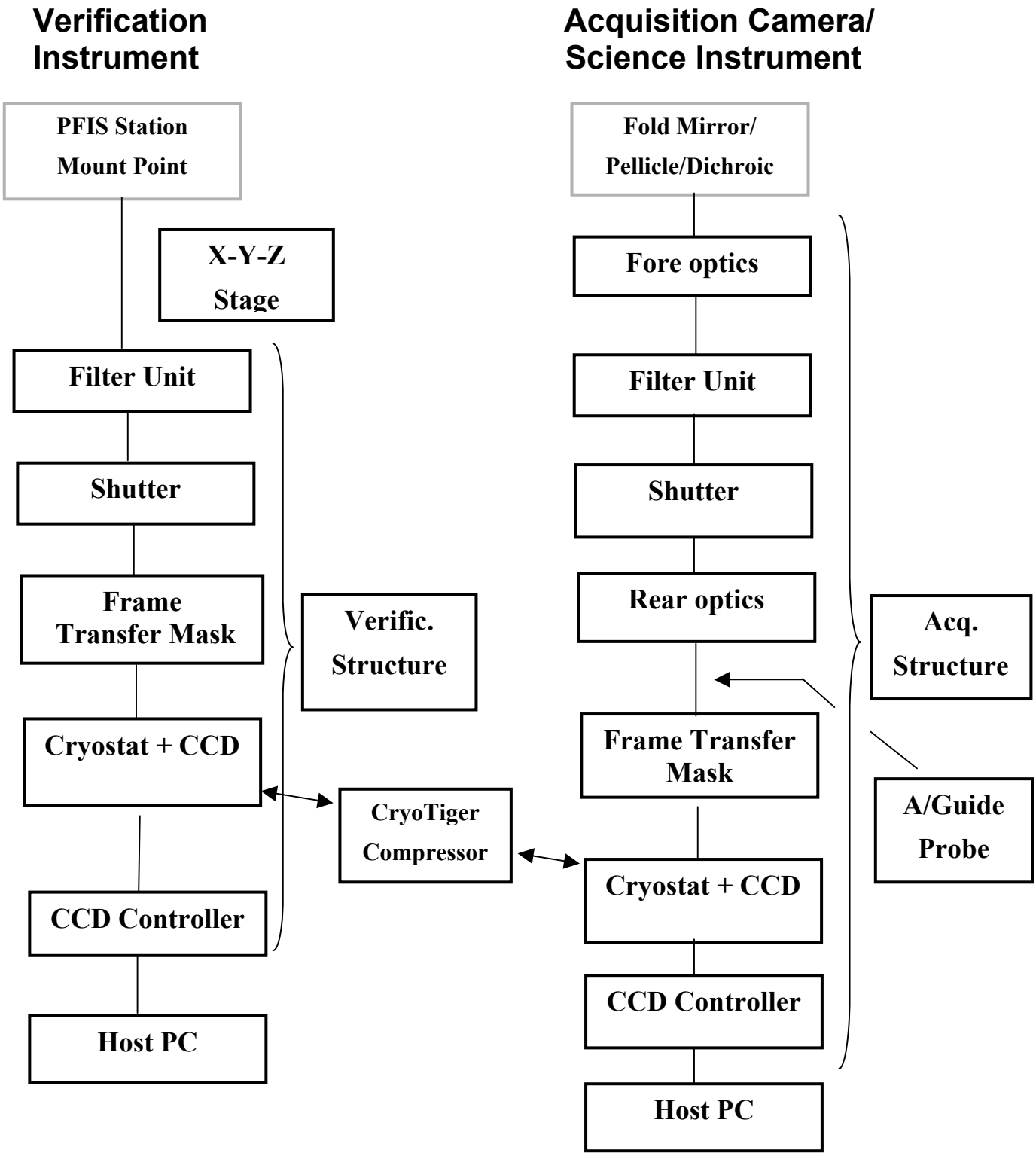


Figure 1. SALTICAM Instrument Layout

One user was interested in very low dispersion grism survey science. Inquiries with Richardson Grating Lab (formerly Milton Roy and Bausch & Lomb before them) revealed that a custom grism would have to be fabricated at quite some cost (~$20k). Worse still, it would only have a peak efficiency of about 30 per cent. As a result, this idea has been shelved. It seems to us that PFIS would be more suited to tackling this kind of science.

Another possible scientific application suggested by a user is "parasitic" observations in conjunction with another instrument. In this mode, a dichroic would be inserted at the position of the fold mirror, allowing some light to proceed to SALTICAM, and the rest to a downstream instrument (probably PFIS). This would be scientifically advantageous for UV imaging by SALTICAM.

Overall, it should thus be clear that there is ample science for SALTICAM to perform: high time resolution imaging is a particular niche area. We now move on to a technical overview of the instrument at the preliminary design stage.

3 Technical Overview

This technical overview will describe the transfer of information into the SALTICAM system, starting off in the form of light, then electrical signals, and finally digital data. As mentioned already, two distinct configurations of the instrument should be recognized:

- in the Verification Instrument (VI) mode, the instrument will be mounted at the PFIS focal station. The optical axis of the instrument will thus be collinear with the optical axis of the telescope. The major components of the instrument include the filter unit, the shutter, the cryostat, the CCD controller and the control PC.
- in the Acquisition Camera/Science Imager (ACSI) mode, the optical axis of the instrument will be perpendicular to the telescope optical axis. The instrument will be fed by a fold mirror just after the exit pupil of the telescope. The instrument will be mounted about 100 mm from the telescope optical axis (so as to avoid vignetting the beam traveling to the PFIS focal station). The major components of the instrument include all those listed for the Verification Instrument, along with focal conversion optics.

The two configurations are illustrated in Figure 1 and further elaborated in the next few subsections. A succinct tabulation of the performance required for SALTICAM appears in the Functional Performance Requirements Document (3300AE0004 FPRD.pdf).

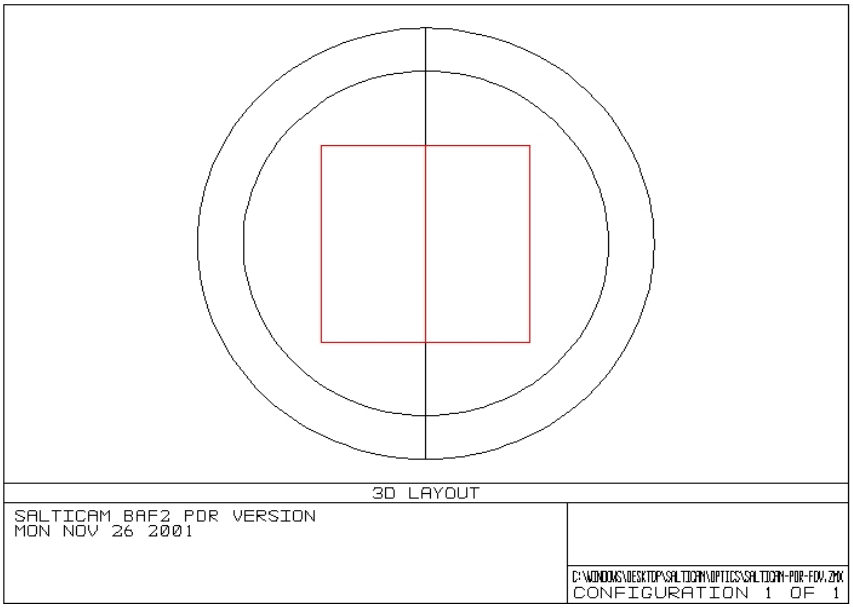


Figure 2. SALTICAM Fields of View. The outer circle above is the edge of the 10 arcmin diameter guide star field of view. The inner circle is the edge of the 8 arcmin diameter science field of view. The rectangle is the area covered by the CCD detector in VI mode.

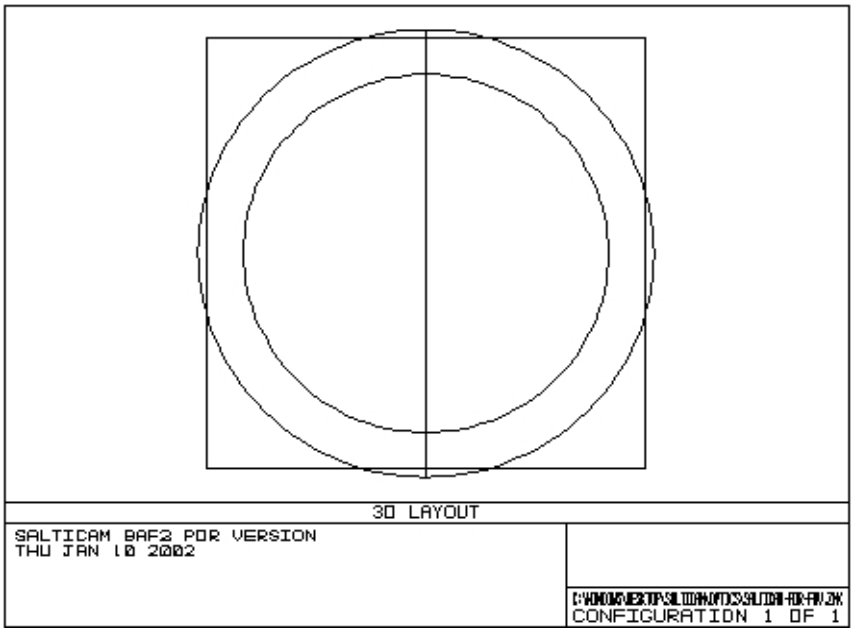


Figure 3. SALTICAM Fields of View. The circles are as in Figure 2. The rectangle is the area covered by the CCD detector in ACSI mode.

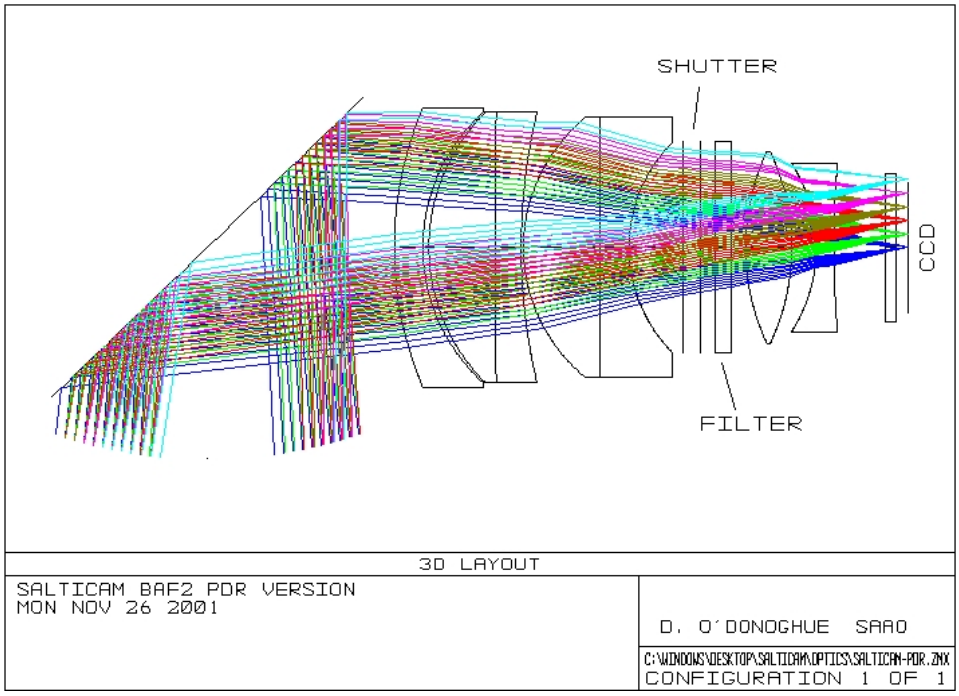


Figure 4. SALTICAM Optical Layout in Acquisition Camera and Scientific Imager mode. The exit pupil is shown at lower left. Immediately above it is the folding flat mirror feeding light into the optical re-imaging system. Filter, shutter and CCD detectors are marked.

3.1 Fields of View

In VI mode, the instrument has no re-imaging optics. The only optical elements are the filters and the cryostat window, both plano-plano surfaces. The detector is therefore most suited to testing the image quality of SALT. Filters will be needed to test image quality and throughput across limited wavelength ranges, and the frame transfer mask is required to enable rapid imaging during the testing phase. Coverage of the VI field of view is shown in Figure 2. It is envisaged that the configuration shown will be used to test the center of the field of view. Simultaneous testing of the center to the edge of the science field of view will be enabled by moving the verification instrument around on an X-Y stage or attaching it to the prime focus at a discrete number of different mounting positions.

In ACSI mode, re-imaging optics map the entire science field, and most of the guide star field, on to the CCD detectors: coverage of the ACSI field of view is shown in Figure 3.

3.2 Light

Light will enter SALTICAM after it emerges from the exit pupil of the telescope on the SALT Payload. In ACSI mode, a folding flat mirror immediately after the exit pupil will feed the light into the instrument. When used for closed-loop guiding, the folding flat mirror must be replaced by a pellicle which sends a small fraction of the light to SALTICAM while allowing the balance to proceed to the PFIS or other focal stations. Should parasitic scientific observations be approved, the folding flat mirror must be replaced by a dichroic.

In VI mode, no folding flat is used and instead the light will proceed into the instrument at its mounting position at the PFIS focal station.

In VI mode, the light passes through a filter unit containing filters of ~100 mm in diameter, as well as a shutter (all mechanisms are described in the Structure and Mechanisms Document: 3320AE0001 mechanical.pdf), before proceeding into the cryostat with the focal ratio, f/4.2, of the beam emerging from the spherical aberration corrector (SAC) and atmospheric dispersion corrector (ADC) system.

In ACSI mode, the filter unit and shutter are also traversed, but in order to capture the whole science field of view on the CCD detectors, focal conversion is required. Thus, filter and shutter are interspersed with re-imaging optics which yield a focal ratio of f/2.0 going into the cryostat. Figure 4 shows a layout of these optics. The optical design of the instrument is presented in the Optical Design (3310AE0001 optical.pdf) document.

Frame transfer operation is required to deliver high time resolution; after the light passes through the flat fused silica window into the cryostat (see the Cryostat Document: 3370AE0001 cryostat.pdf for details), it may be intercepted by the frame transfer mask (if that is deployed). The mask is constructed in such a way that either half of each CCD detector is shielded from light (normal frame transfer mode) for exposures of a few sec, or that all the CCD detector is shielded except for a narrow slot located just above the frame transfer boundary, allowing exposures as short as 100 msec.

Finally, the photons will be absorbed in the silicon of the CCD detectors where they are converted to electrons. Discussion of the instrument efficiency appears in the Functional Performance Requirements Document: 3300AE0004 FPRD.pdf.

3.3 Electrons

The CCDs are described in the Detector Document (3360AE0001 detector.pdf) and will comprise a 2 x 1 mosaic of Marconi Applied Technologies' thinned, back-illuminated 44-82 devices made from high resistivity silicon, providing not only good UV (320-400 nm) quantum efficiency but also good near infrared (800-1000 nm) quantum efficiency. The

format is 2048 x 4096 x 15 micron pixels. Two readout amplifiers per readout register will be used. The detectors will be controlled by SDSU II CCD controllers (also described in the Detector Document: 3360AE0001 detector.pdf), with readout rates of up to 300 kpix/sec. The detectors will be able to operate in frame transfer mode so that rapid readout of half the detector is possible. The electron packets in each pixel will be digitized with low noise amplifiers, with <4 e^-/pix readout noise guaranteed, and 2.5 e^- /pix typical. The controller allows 4 programmable gains.

3.4 Digital Data

The electron packets will be sent via fibre optic cable down to the instrument PC in the SALT control room (its software is discussed in Software: 3390AE0001 software.pdf) where the data will be displayed on monitors at the operator/ astronomer's console, and stored on disk. Time stamping using time synchronized with a GPS receiver will assure accurate timing for the exposures. The operators will be able to perform simple manipulation of the images on the displays.

3.5 Infrastructure and Interfaces

The information flow described in the last 3 sections will require infrastructure to operate the various mechanisms (filter unit, shutter etc.). These are described in the Control (3380AE0001 control.pdf) document. Physical support will be provided by two frameworks: one for VI mode and one for ACSI mode (described in the Structure and Mechanisms Document: 3320AE0001 mechanical.pdf).

Interfaces to SALT will also be required in the form of:

- Optical. The folding flat mirror, pellicle and perhaps a dichroic will be optical interfaces with SALT.
- Cooling. For the CCDs, this will be provided by a CryoTiger housed in an igloo underneath the telescope structure. Additional cooling to avoid heat sources in the light path will be provided by the SALT Project.
- Electrical power will be provided by a clean UPS source provided by the SALT Project.
- Physical interfaces to the frameworks.
- Data connections to link the instrument computer to other SALT computers
- Fibre optics connections to link the CCD controller to the instrument computer

These are controlled through entries for the SALT Payload ICD listed in the SALTICAM ICD (3300AS0002 ICD.pdf).

3.6 Hardware Breakdown Structure

The HBS for the instrument down to the second level is shown on the next page.

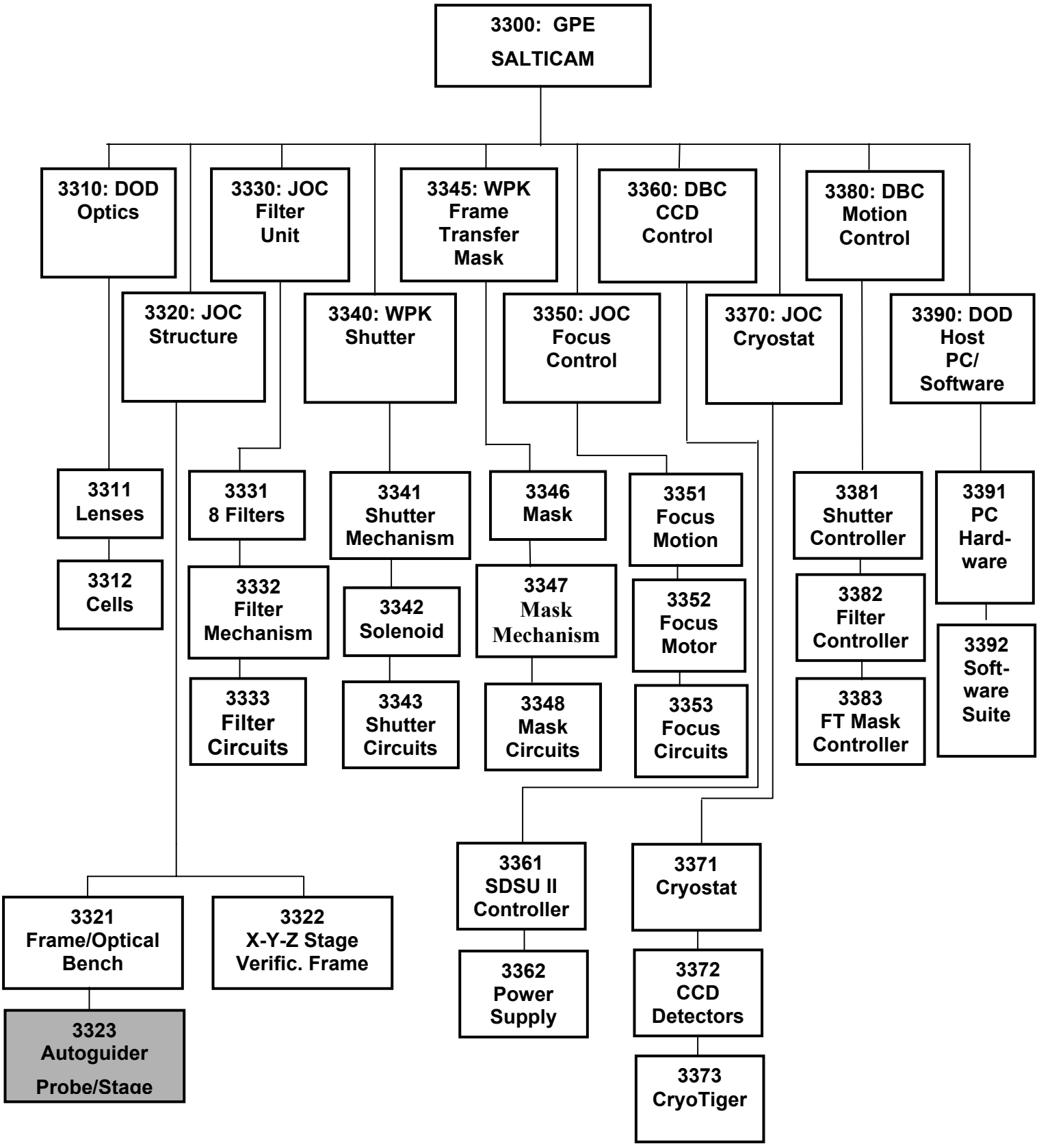
4 Program

The Project will be managed and most of the construction carried out at the South African Astronomical Observatory, PI Darragh O'Donoghue. SAAO has built about a dozen cryostats a developed good understanding of CCD controllers over the last 20 years. Expertise in optics is increasing. The work to be carried out is listed in the Statement of Work for SALTICAM (3300AE0008 SOW.pdf) and the management plans presented in Management Plan (3300AE0007 management.pdf), Schedule (3300AE0009 schedule.pdf) and Budget (3300AE0010 budget.pdf).The project has a 2 year duration and will cost slightly more than half a million US dollars.

5 Risk

The major risks are judged to be:

- **Optics.** The optical materials to be used are fragile and the optical mounting tolerances tight. Mitigation of this risk is through a conservative approach and recruitment of optomechanical expertise.
- **CCD control.** This is a schedule and performance risk arising from the need to replace much of the poor quality of software supplied with SDSU II CCD controllers. Mitigation of this risk is through assignment of two project team members to work on this, and co-operation with colleagues at Rutherford Appleton Lab and the ING group on La Palma.
- **Schedule.** The Verification Instrument is on the critical path for the telescope and delivery delays cannot be tolerated. Mitigation of this risk will be through maximizing the scheduling of final design and manufacturing in parallel.


3300: GPE
SALTICAM
3310: DOD Optics
3330: JOC Filter Unit
3345: WPK Frame Transfer Mask
3360: DBC CCD Control
3380: DBC Motion Control
3320: JOC Structure
3340: WPK Shutter
3350: JOC Focus Control
3370: JOC Cryostat
3390: DOD Host PC/ Software
3311 Lenses
3312 Cells
3331 8 Filters
3332 Filter Mechanism
3333 Filter Circuits
3341 Shutter Mechanism
3342 Solenoid
3343 Shutter Circuits
3346 Mask
3347 Mask Mechanism
3348 Mask Circuits
3351 Focus Motion
3352 Focus Motor
3353 Focus Circuits
3381 Shutter Controller
3382 Filter Controller
3383 FT Mask Controller
3391 PC Hard-ware
3392 Soft-ware Suite
3321 Frame/Optical Bench
3322 X-Y-Z Stage Verific. Frame
3323 Autoguider Probe/Stage
3361 SDSU II Controller
3362 Power Supply
3371 Cryostat
3372 CCD Detectors
3373 CryoTiger

6 Appendix 1: Science Questionnaire 1

In October 2000, a questionnaire was sent to the potential user community. Four simple questions were asked. 18 replies were received, all of which answered Q1 below affirmatively. The number of replies received are shown in parentheses alongside each possible answer underneath the questions in the following listing:

1. Do you foresee using the acquisition camera?

   Yes (18) No ( )

2. If no, don't bother with the rest of the questions. If yes, do you foresee usage:

   In support of another instrument (14) for high time resolution (6)
   another application (3)

3. If yes, what time resolution do you require?

   10 sec or longer (9) 1 sec or longer (4) 0.1 sec or longer (3)
   < 0.1 sec (2)

4. Please tick the shortest wavelength you would require the camera to be designed for (i.e. have decent sensitivity)

   400 nm (4) 360 nm (10) 320 nm (4)

7 Appendix 2: Second Scientific Solicitation

SALTICAM Science Program

Revision 1.2
9 October 2001

A solicitation for scientific program titles took place in late September/early October 2001. Replies were received from 21 potential users (numbered below). Many replies from a given user listed several scientific programs (identified separately by bullets):

1. Photometry of faint SN (coupled with low dispersion spectroscopy), novae, extragalactic Cepheids and eclipsing binaries (for distance scale purposes)
2. Monitoring of extragalactic AGB variables, SNe and Magellanic Cloud novae
3. Broadband colours (U to I) across stellar populations - to constrain ages and metallicities (in conjunction with PFIS spectra)
4. Imaging of galaxies to obtain surface photometry to study galactic structure and dust extinction
5.
   - Grism and drift scanning surveys
   - Locating PN and globular clusters around early-type galaxies for PFIS multi-object spectroscopy.
   - Very deep Milky Way and LMC/SMC globular cluster CMDs
   - Survey fields identified via microwave SZ effect for distant galaxy clusters (Princeton, U. Penn, Rutgers are collaborating on the microwave project, in proposal stage now).
   - TDI + grism survey for large-scale structures (with better-than-photometric redshifts).
6. Search and photometric monitoring of faint members of optically visible star clusters associated with high mass star formation regions
7.
   - Broadband Imaging of Plerions (e.g. Crab) and Unidentified EGRET sources

- Optical Pulsars: optical identification of X-ray and gamma-ray pulsars during best seeing conditions and high speed photometry of new candidates

8.
- Stellar population studies of globular clusters, Local Group galaxies, the Galactic bulge and the Galactic halo
- Searches for halo streams, optical counterparts to high-velocity clouds, low-surface brightness galaxies in nearby groups and clusters

9.
- X-ray/optical campaigns on X-ray burst profiles and delays: echo mapping (needs <1 sec)
- X-ray/optical fast variability in luminous X-ray binaries for echo-mapping (needs <1 sec)
- Fast variability in quiescent soft X-ray transients. Current models have it related to ADAF flows and/or magnetic reconnection in the accretion disc itself (<10 sec)
- TOOs on SXTs in outburst for QPOs and echo mapping (<1 sec)
- optical light curves of X-ray dippers fast enough to resolve detail in the dipping e.g. A1916-05, and then warping/precessing of the disc can be followed (<1 sec)
- nature of fast variability in SSS (<10 sec)
- LMXB pulsars: 1626-67, X1822-37

10.
- High-time resolution high-accuracy monitoring of faint rapidly variable (pulsating) stars in support of worldwide observing campaigns
- High-time resolution multicolour photometry of selected rapid variables (requires reasonable filter change times, preferably <1 sec)
- Monitoring of acquisition fields for discovering new variables (requires sufficient data storage space and automatic reduction capabilities)
- Simultaneous photometric monitoring if pulsating stars are observed with time-series spectroscopy

11. BVRI Photometry of Extragalactic (most likely Magellanic Cloud) Star Clusters and Stellar Fields

12. Deep mapping of galactic H-alpha, or other H lines.
13. High time resolution multicolour photometry of faint Cataclysmic Variables
14.
    - Time resolved photometry of accretion regions on magnetic CVs
    - Detailed eclipse studies of CVs
    - Search for optical pulsations in X-ray powered accretors
    - QPO studies of magnetic CVs
15.
    - Long-term monitoring of variable faint AGN (in particular, Narrow Line Seyfert 1s)
    - Echo mapping (eg follow up on an X-ray event)
    - Search for very high redshift AGN (done using colours)
16. Photometric monitoring of faint Wolf-Rayet stars in the Galaxy and possibly the Magellanic Clouds
17.
    - Identification of morpholocical structures in galaxies and of companion galaxies
    - Photometry of variable AGN
18.
    - Probing the relation between flickering and white dwarf mass in CVs
    - Optical flickering in black-hole candidate binary stars
    - Eclipsing white dwarf/sdB & white dwarf/M dwarf stars
    - Simultaneous X-ray/optical observations of eclipsing magnetic CVs.
19. High speed photometry of accretion regions on magnetic CVs and white dwarfs in non-magnetic CVs
20. High speed photometry of faint southern cataclysmic variables
21. Deep ultraviolet imaging:
    - Searches for high redshift galaxies and quasars from their Lyman break
    - Morphology of distant galaxies
    - Studies of narrow-band OII emission in nearby galaxies

- Redshifted MgII emission and absorption in galaxies and AGN
- Parasitic observations of fields at wavelengths not used by PFIS with SALTICAM fed by a dichroic

Guesses at requirements for field of view, wavelength coverage and time resolution. The numbers in the right column refer to the programs in the above listing of science programs which require the capability listed in the left column:

Large FoV:	All 3 4 5 6 8 11 12 17 21
UV wavelengths:	3 5 6 7 8 9 13 14 16 18 19 20 21
Red wavelengths:	1 2 3 4 5 6 7 8 11 13 14 15 17 19
1-s time resolution (or less):	9 10 13 14 18 19 20