Southern African Large Telescope
SALTICAM
Preliminary Design Review

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Testing And Commissioning Plan

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1 Scope

This document describes the testing and commissioning plan for SALTICAM, the verification instrument, acquisition camera, and scientific imager of the Southern African Large Telescope (SALT). As mentioned in the Instrument Description Document (300AE0003 description.pdf), two distinct modes of SALTICAM are envisaged:

- Verification Instrument (VI) Mode in which the instrument comprises a shutter, filter unit and cryostat mounted at the PFIS focal station
- Acquisition Camera and Science Imager (ACSI) Mode in which the instrument is, in addition, garnished with focal conversion optics and is fed by a fold mirror

Initial delivery will be of the VI with subsequent delivery of the ACSI.

Two distinct phases of testing are envisaged:

- Pre-Delivery Acceptance Testing
- Commissioning and Final Acceptance Testing

Pre-Delivery Acceptance Testing will occur when the relevant instrument mode is ready for delivery to the SALT Project Team. It will take place at SAAO in Cape Town and possibly on SAAO telescopes at Sutherland. The testing will demonstrate the performance of as many aspects of the instrument as possible when it is not attached to SALT. Commissioning and Final Acceptance Testing will take place with the instrument mounted on SALT, repeating all the Pre-Delivery Acceptance Tests possible and verifying the performance of any aspects of the instrument not tested in the Pre-Delivery Acceptance Tests.

This document will describe the Pre-Delivery Acceptance Testing and Commissioning and Final Acceptance Testing for both modes of the instrument. It will largely be based on the requirements listed in the SALTICAM Specification and numbers in parentheses (e.g. SSS 5.3.1.1) will refer to the relevant section of the Specification (in the example SALTICAM Specification Section 5.3.1.1). The acronyms **PDAT** and **CFAT** labeling the discussion of each test will designate whether the relevant test is part of the Pre-Delivery Acceptance Test, or the Commissioning and Final Acceptance Test. A test labeled **PDAT** will, as just mentioned, be repeated in the **CFAT** if it is possible to do so.

2 Verification Instrument

2.1 Detectors (SSS 5.3.1.1)

The SALTICAM Specification calls for a CCD detector with the following properties:

- At least 1920 pixels of 28.2 microns each to cover a diameter of 54 mm (a larger number of smaller pixels covering 54 mm is acceptable).
- Scientific grade 1, thinned and back-illuminated chips.
- Frame-transfer mode available.
- QE of at least 50 per cent at B (440 nm), at least 75 per cent at V (550 nm), at least 75 per cent at R (650 nm) and at least 50 per cent at I (850 nm).

Testing the first three of the above properties will be achieved by using Marconi Applied Technologies' CCD 44-82 devices. Proper functioning of frame transfer mode will be demonstrated. **(PDAT)**

Quantum efficiency can be partially verified by inspecting the test data sheets that Marconi will supply with each chip. However, this property is so crucial to the performance of the camera that it is desirable to verify the quantum efficiency independently. There are two ways to achieve this: (i) measurement in the SAAO electronics lab in Cape Town relative either to a calibrated photodiode or a calibrated radioactive source; (ii) mount the chip on an SAAO telescope (e.g. the 1-m) and obtain observations of standard stars through BVRI filters. These data can be compared to observations of the same stars with SAAO CCD cameras where the QE of the chip is known, or the stellar flux at the top of the atmosphere can be modelled with a suitable extinction law, reflectivity for the telescope mirrors, absorption by the filters and cryostat window and attenuation by the filter bandpass. The recorded number of photons/sec can then be compared with the number estimated to be arriving at the detector and the QE deduced. QE testing will either be demonstrated, or reported in writing at the **PDAT**.

Not addressed in the Specification is the testing of the co-planarity of the 2 x 1 mosaic and flatfielding. The latter can be tested, over small pixel scales only, with the cryostat on the telescope (**PDAT**). The former must be tested. (**TBD1**)

2.2 Cryostat (SSS 5.3.1.2, 6.2.6 and 6.2.7)

The SALTICAM Specification requirement is for:

- An evacuated chamber for the detector
- Poisson noise on the dark current pedestal from the longest exposure should be small compared to readout noise of 5 electrons

- The cryostat window should be optically flat
- A retractable frame transfer mask should be provided
- There should be a drip tray to catch condensation on the outside of the cryostat arising in the event of loss of vacuum

The first two requirements will be tested by demonstrating that the detector reaches the planned operating temperature of 160 K, and that at this temperature, dark current is less than 1 e^-/pix/hr by obtaining a dark exposure (with the detector sealed from light and in a darkened room).

The third requirement is verified by ordering a window from a vendor who guarantees flatness at some suitable (but currently unspecified) level.

The fourth requirement will be tested by demonstrating that the frame transfer mask operates correctly. The fifth requirement will be tested by inspection.

All tests in this subsection are **PDAT** tests.

2.3 Readout Noise (SSS 5.3.1.3)

The SALTICAM Specification requirement is for readout noise of less than 5 electrons at slowest readout speed. This can be tested in the lab either by analysing the variance on exposures of ever increasing duration which simultaneously delivers the gain (slope) and readout noise (intercept), or by analysing the noise on the bias frame of a zero exposure readout. (**PDAT**)

2.4 Readout Speed (SSS 5.3.1.4)

The SALTICAM Specification requirement is for a readout speed which will read out the detector in 5 sec or less. This requirement can be tested in the lab by simply timing readouts (**PDAT**). Rapid readout and 2 x 2 prebinning will be required to achieve this figure.

2.5 Pre-Binning (SSS 5.3.1.5)

The SALTICAM Specification requirement is for software-selected pre-binning from 1x1 to 9x9. Testing will involve demonstrating that the user interface software and SDSU controller software provide this capability. (**PDAT**)

2.6 Shutter (SSS 5.3.1.6 and 6.2.4)

The SALTICAM Specification requirement is:

- The shutter shall be an iris type, not vignette the beam and seal the cryostat from light
- The shutter shall have an open or close time of not more than 100 msec
- The shutter solenoid and its electronics will probably have to be cooled
- The mean no of cycles between failure of the shutter will be 500000
- Replacement of the shutter *in situ* within 2 hr must be feasible

The first requirement is tested by inspection to show that it is iris type, analysis to show that it does not vignette the beam, and by taking a series of dark exposures of lengthening duration and showing that the signal is consistent with the dark current.

The opening and closing time will be demonstrated by test equipment in the lab. (**TBD2**)

The shutter mechanism will be latched in open and closed positions. Therefore the shutter solenoid(s) will not require cooling.

The reliability of the shutter will be enhanced by the design modifications to the Prontor shutter. (**TBC1**)

All the above testing and verification will be at **PDAT**.

Replacement of the shutter *in situ* within 2 hr will be shown to be feasible during **CFAT**.

2.7 Filters (SSS 5.3.1.7, 6.2.5)

The SALTICAM Specification requirement calls for a filter unit containing at least 8 filters. Testing will be done in the lab and involve observing that the filter unit has at least 8 filters and functions properly under software control. (**PDAT**)

2.8 Structure (SSS 4.2.2.11, 5.3.1.9, 6.2.2)

The SALTICAM Specification requires that:

- The Verification framework shall support the instrument sub-systems during operation and shall be sufficiently rigid so as to comply with specific flexure requirements (**TBD3**)
- The structure shall provide a means to align the camera with the telescope as agreed between the SALT Project team and the SALTICAM team during interface meetings: see the 3300AS0002_ICD.pdf as well as the 3320AE0001 mechanical.pdf.

Testing will be done in the SAAO labs, on an SAAO telescope if this is possible, otherwise when the system is mounted on SALT? (**PDAT** or **CFAT**?) (**TBD4**)

2.9 Safety (SSS 5.3.1.10)

This will be discussed in the Safety Report for the instrument, due at the Final Design Review. All features of the design will be evaluated in terms of the requirements in the SALTICAM Specification and the SALT Safety Standards (SALT Safety Analysis: SALT Document 1000AA0030).

2.10 Envelope (SSS 5.3.2.1)

The SALTICAM Specification limit of **TBD5** m above the focal plane and 1.5 m from the optical axis of SALT shall be checked by measuring the dimensions of the VI. (**PDAT**)

2.11 Mass (SSS 5.3.2.2)

The entire VI can be weighed and verified to be less massive than the SALTICAM Specification limit (currently **TBD5** kg). (**PDAT**)

2.12 Instrument Temperature Control (SSS 5.3.2.3-5.3.2.5)

The SALTICAM Specification calls for stringent controls on heat dumping on the payload, as well as control of surface temperatures of all electronics and electrical components. The SALT Project are to provide cooler boxes into which all electronics will be inserted. Testing this is a joint SAAO and SALT Project responsibility? How will it be tested? (**CFAT**) (**TBD6**)

2.13 Component/Module Replacement (SSS 5.3.2.6)

The SALTICAM Specification requirement is for suitable mechanical interfaces to be provided so that handling by the dome crane is possible, and all individual modules to weigh less than 15 kg (so they can be manhandled easily). This will be tested by inspection of the finished framework and weighing of the components prior to assembly. (**PDAT**)

2.14 Electromagnetic Radiation (SSS 5.3.3)

The SALTICAM Specification requirement is for the SALTICAM design to incorporate measures to shield its sensitive electronics from electrical noise. This will be tested HOW? (**PDAT**) (**TBD7**)

2.15 Test Points and Data (SSS 5.3.3.1-5.3.3.2)

The SALTICAM Specification requirement is for the SALTICAM design to incorporate suitable testing points and the transmission of test data. This will be demonstrated at the **PDAT**.

2.16 SDSU II CCD Controller, Subsystem Controller and Power Supply, and CryoTiger Compressor (SSS 6.2.8-6.2.10 and 6.2.12)

These modules provide power, control and cooling for the CCDs and control for all mechanisms. Their correct functioning will be implicit in the tests for the **PDAT** described above.

2.17 Communications with SALT Computers (SSS 4.2.2.1-4.2.2.3)

The SALTICAM Specification requirement is for:

- Communications with the SALT Operator/SALT Astronomer (SO/SA) computers to receive camera setup information (exposure time, prebinning etc.), to receive instructions for interaction with the images on the SALTICAM display, and to transmit compressed versions of the images to these machines.
- Communications with the Telescope Control System (TCS) server to obtain telescope parameters (e.g. RA/Dec etc.), and to transmit instrument status and telescope position offsets for placing targets in the entrance apertures of scientific instruments and closed loop guiding.
- Communications with the data reduction computer to allow that machine to obtain scientific data from the SALTICAM computer.

These functions will be tested when the SALTICAM computer is attached to the SALT network and the other machines are present and operating. (**CFAT**).

2.18 Communication with the Precision Time Source (SSS 4.2.2.4)

The SALTICAM Specification requirement is for the SALTICAM computer to maintain precise time to 1 msec or better. This can be tested to a precision of 1 sec by inspection. Testing to a precision of 1 msec is **TBD8**. (**PDAT**)

2.19 Communication with CCD and Subsystem Controller (SSS 4.2.2.5)

The SALTICAM Specification requirement is for control and status to be exchanged, as well as reading out CCD data at speeds of up to 64 Mbits/sec. This will be tested by

demonstrating that the SALTICAM computer is controlling the camera and subsystems and reading out data at the required speeds. (**PDAT**)

2.20 SALTICAM Man-Machine Interface (MMI) (SSS 4.2.2.6)

The SALTICAM Specification requirement is for the SALTICAM MMI to setup the camera, initiate closed-loop guiding if necessary, initiate the acquisition and readout of images, control the display and storage of the data and manage display interaction. The MMI must be exportable to the SO/SA MMI computers. Testing will involve showing that all this functionality is present in the software and working. (**PDAT**)

2.21 SALTICAM Algorithms (SSS 4.2.2.7)

The SALTICAM Specification requirement is for algorithms for the determination of guide object centroids in closed-loop guiding, and for display interaction (controlling image display, placing markers on the display, fitting Gaussians etc.). Testing will involve showing that all this functionality is present in the software and working. Test images will be used for **PDAT**; real images at the telescope for **CFAT**.

2.22 CCD Controller and Subsystem Controller Functions (SSS 4.2.2.8)

The requirement is for the CCD Controller and Subsystem Controller to control all aspects of the CCD (e.g. download control code, set/unset frame transfer mode, set prebin factor, set windows, readout the CCD) and Subsystems (control frame transfer mask, shutter and filter unit). Testing will involve demonstrating that all this functionality is present in the software and working. (**PDAT**)

2.23 Thermal Control Functions (SSS 4.2.2.9)

The requirement is for the CCD detector temperature to be sensed and controlled, for the CCD controller internal temperature to be sensed, and for the monitoring of the thermal enclosures. The first two functions will be tested by showing that the SALTICAM computer and CCD controller provide this functionality and that it is working (**PDAT**). The last is the responsibility of the SALT Project? (**TBD6**)

2.24 Cryotiger Functions (SSS 4.2.2.10)

The requirement is for the Cryotiger to cool the detectors. Testing will be as per the previous subsection.

3 Acquisition Camera and Science Imager

After the initial usage of the VI by the SALT Project team, the instrument will be returned for conversion to ACSI mode. The current design envisages that entirely different hardware, with only the cryostat and shutter in common, will be required for ACSI mode.

3.1 Detectors (SSS 5.3.1.1)

The corresponding VI testing for FT operation and Q.E. will suffice.

3.2 Cryostat (SSS 5.3.1.2, 6.2.6 and 6.2.7)

The corresponding VI testing will be repeated.

3.3 Readout Noise (SSS 5.3.1.3)

The corresponding VI testing will be repeated.

3.4 Readout Speed (SSS 5.3.1.4)

The corresponding VI testing will be repeated.

3.5 Pre-Binning (SSS 5.3.1.5)

The corresponding VI testing will be repeated.

3.6 Shutter (SSS 5.3.1.6 and 6.2.4)

The corresponding VI testing will be repeated.

3.7 Filters (SSS 5.3.1.7, 6.2.5)

The corresponding VI testing will be repeated.

3.8 Focal Conversion Optics (SSS 4.2.2.12, 5.3.1.8, 6.2.3)

The requirement is that the optics convert the telescope focal ratio of f/4.2 to f/2 or faster, and do not degrade the throughput and image quality delivered by the instrument: instrument throughput must be at least 40 per cent at B (440 nm), at least 60 per cent at V

(550 nm), at least 60 per cent at R (650 nm) and at least 40 per cent at I (850 nm); image quality specification is 0.3 arcsec (EE50).

Testing will involve measuring the focal ratio of SALTICAM when it is on the telescope (by measuring the separation of stars of known position). Testing of throughput will be done when the ACSI is mounted on SALT (whose efficiency is assumed to be measured by the VI). Image quality will be tested as per 3310AE0001 optical.pdf.

3.9 Structure (SSS 4.2.2.11, 5.3.1.9 and 6.2.2)

The SALTICAM Specification requires that:

- The Acquisition/Science framework shall support the instrument sub-systems during operation and shall be sufficiently rigid so as to maintain the image quality requirement for the instrument.
- The structure shall provide a means to align the camera with the telescope as agreed between the SALT Project team and the SALTICAM team during interface meetings: see the 3300AS0002 ICD.pdf and the 3320AE0001 mechanical.pdf.

Testing will be done when the system is mounted on SALT? (**TBD4**)

3.10 Safety (SSS 5.3.1.10)

This will be discussed in the Safety Report for the instrument, due at the Final Design Review. See Section 2.9 for guiding principles.

3.11 Envelope (SSS 5.3.2.1)

The SALTICAM Specification limit of 1.5 m from the optical axis of SALT shall be checked by measuring the length of the ACSI and adding the distance from the entrance aperture to the optical axis. (**PDAT**)

3.12 Mass (SSS 5.3.2.2)

The entire ACSI instrument can be weighed and verified to be less massive than the SALTICAM Specification limit (currently 25 kg). (**PDAT**) **Note that the weight budget in the preliminary design is about 60 kg. The very first concept for the instrument provided a weight of 41 kg and protests at the lowering of this to 25 kg were registered.**

3.13 Instrument Temperature Control (SSS 5.3.2.3-5.3.2.5)

The SALTICAM Specification calls for stringent controls on heat dumping on the payload, as well as control of surface temperatures of all electronics and electrical components. The SALT Project are to provide cooler boxes into which all electronics will be inserted. Testing this is a joint SAAO and SALT Project responsibility? How will it be tested? (**CFAT**) (**TBD6**)

3.14 Component/Module Replacement (SSS 5.3.2.6)

The requirement is for suitable mechanical interfaces to be provided so that handling by the dome crane is possible, and all individual modules to weigh less than 15 kg (so they can be manhandled easily). This will be tested by inspection of the finished framework and weighing of the components prior to assembly. (**PDAT**)

3.15 Focus Control (SSS 6.2.11)

Motorized focus control for the ACSI is to be provided. This will be demonstrated at the **PDAT**.

3.16 Electromagnetic Radiation (SSS 5.3.3)

The corresponding VI testing will be repeated. (**TBD7**)

3.17 Test Points and Data (SSS 5.3.3.1-5.3.3.2)

The VI procedure will be repeated.

3.18 SDSU II CCD Controller, Subsystem Controller and Power Supply, and CryoTiger Compressor (SSS 6.2.8-6.2.10 and 6.2.12)

As before, the correct functioning of these modules will be implicit in the tests described above.

3.19 Communications with SALT Computers (SSS 4.2.2.1-4.2.2.3)

The corresponding VI testing will be repeated.

3.20 Communication with the Precision Time Source (SSS 4.2.2.4)

The corresponding VI testing will be repeated. (**TBD8**)

3.21 Communication with CCD and Subsystem Controller (SSS 4.2.2.5)

The corresponding VI testing will be repeated.

3.22 SALTICAM MMI (SSS 4.2.2.6)

The corresponding VI testing will be repeated.

3.23 SALTICAM Algorithms (SSS 4.2.2.7)

The corresponding VI testing will be repeated.

3.24 CCD Controller and Subsystem Controller Functions (SSS 4.2.2.8)

The corresponding VI testing will be repeated.

3.25 Thermal Control Functions (SSS 4.2.2.9)

The corresponding VI testing will be repeated. (**TBD6**)

3.26 Cryotiger Functions (SSS 4.2.2.10)

Testing will be as per the previous subsection.

4 Telescope And Science Commissioning

The primary task of the VI is to assist the SALT Project team with commissioning the telescope. Usage of the instrument for this purpose will therefore be under their direction.

Images for public relations purposes will be obtained at suitable opportunities to demonstrate progress or capability of the telescope.

Commissioning of ACSI mode will include testing the camera as a fully integrated acquisition camera.

A program of scientific commissioning observations will be developed prior to delivery of the VI. This will primarily center around high time resolution (sub-second) observations of rapid variables, mainly compact objects and close binaries. For example, eclipses of compact objects in close binaries will be observed at 10 Hz. A suitable scientific program will be developed during construction of the instrument. Note that scientific observations can be carried out either with the VI or the ACSI: the field of view of the instrument will obviously be much smaller in VI mode.

5 List of TBD and TBC Issues

TBD1	Testing co-planarity of the mosaic
TBD2	Showing that the shutter opening and closing time is 100 msec or less
TBD3	Verification Instrument framework flexure requirement
TBD4	Method for testing the stiffness of the VI and ACSI structures
TBD5	VI envelope and mass specifications
TBD6	Testing of cooler boxes
TBD7	Electromagnetic radiation shielding of CCD readout
TBD8	Demonstrating that the instrument keeps time to 1 msec accuracy
TBD9	Testing of Acquisition Camera/Science Imager throughput and image quality
TBC1	Showing that the MTBF of the shutter is 500000 cycles