Part4: Wider Implications and Future Prospects:

Contributed Papers

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Application of SALT to the Local Group

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Abstract. In collaboration with international partners, South Africa plans to construct a 9-m class telescope for optical/infrared astronomy. This Southern African Large Telescope (SALT) will be a southern hemisphere equivalent of the Hobby-Eberly Telescope at McDonald Observatory, Texas. By limiting the scientific mission to primarily spectroscopic survey studies, with some reduced imaging capability, it is possible to construct SALT for about one-fifth of the cost of a general-purpose telescope of similar aperture. The telescope will be operated in queue-scheduled mode which opens up new applications in the time-dependent domain. A description of SALT, its capabilities, and samples of the science programme are presented.

1. Description of SALT

SALT will be the southern hemisphere equivalent of the Hobby-Eberly Telescope (HET) recently completed at McDonald Observatory, Texas. The HET has been described in detail in a number of publications (Ramsey, Sebring & Sneden 1994; Sebring et al. 1994; Sebring & Ramsey 1997; Ramsey et al. 1998; Ramsey 1998).

Figure 1 gives an overall view of the proposed telescope facility. The mounting is based on a tilted-Arecibo concept, with the telescope at a fixed angle to the zenith (35° in the case of the HET) and full 360° rotation in azimuth. During an observation the telescope remains stationary and a tracker beam at the top end enables an object to be followed for 12° across the sky. Thus an object can be observed in an annulus 12° wide, centred on the tilt angle of the telescope.

The angle of tilt of the HET is 35° to the zenith. At the latitude of Sutherland (32° 22′ 46″ S) and with the ±6° travel of the tracker beam, this means that the southerly limit of the telescope would be 73° 22′ S. This would enable access to the Large Magellanic Cloud and the globular cluster 47 Tucanae, but unfortunately it passes nearly through the middle of the Small Magellanic Cloud (SMC). As the SMC is likely to be one of the prime targets for SALT, it is planned to adopt a baseline design of a 37° tilt in order to accommodate most of the SMC, and to examine the effect of changing the angle of tilt from 35° to 37°.

The primary mirror, of spherical shape, has a maximum diameter of 11 m and consists of 91 hexagonal segments, each 1 m in diameter. At any one time the maximum area of the primary that can be imaged corresponds to a 9.2 m mirror. During an observation the image pupil moves over the primary mirror,

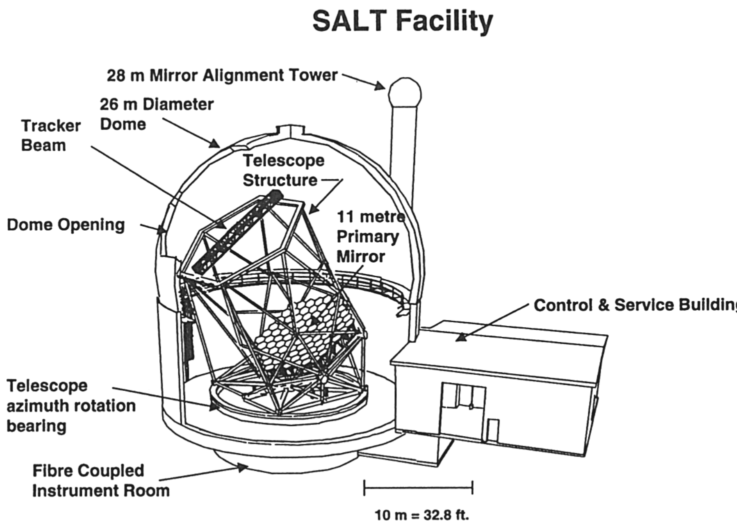

Figure 1. The planned SALT telescope facility.

and in the worst case (6° off axis) the primary area imaged corresponds to a 7 m telescope (Fig. 2). With a 12° motion of the tracker beam, the maximum observation time on the equator is 48 minutes. The observation time increases as the declination moves towards the poles.

The primary mirror is supported on a steel truss, which in turn is kinematically mounted on the telescope frame. Each mirror segment has 3 adjusters for alignment. With the deformation of the steel truss as a function of temperature it is crucial to be able to compensate for this deformation. In the HET system the initial alignment of the primary mirror is achieved by a lateral shearing interferometer positioned at the centre of curvature of the primary mirror, and the intention was to maintain this alignment by modelling the deformation of the truss as a function of temperature and compensating for the deformation. Subsequently, the HET has decided to install edge sensors between the hexagonal segments to improve the maintenance of the alignment. As a result of the HET experience with the alignment of the primary, SALT plans to install a Shack-Hartmann sensor at the centre of curvature of the primary to obtain the initial alignment and to maintain this alignment with the use of edge sensors.

Much of the complexity of the telescope is concentrated at the top end in the tracker beam assembly, the spherical aberration corrector (SAC) and the Prime Focus Instrument Platform (PFIP). The SAC (and PFIP) must move across a focal surface, which is a spherical surface 13.08 metres from the primary mirror centre of curvature, always keeping its optical axis aligned with the centre of curvature. The tracker beam assembly has precision x-y motions and contains a hexapod adjuster to provide the z motion and the two angular axes, θ and ϕ, that in total enable the SAC to follow the focal surface and keep its optical axis aligned. The final axis, ρ, allows a rotation of the focal plane to maintain a constant orientation on the sky.

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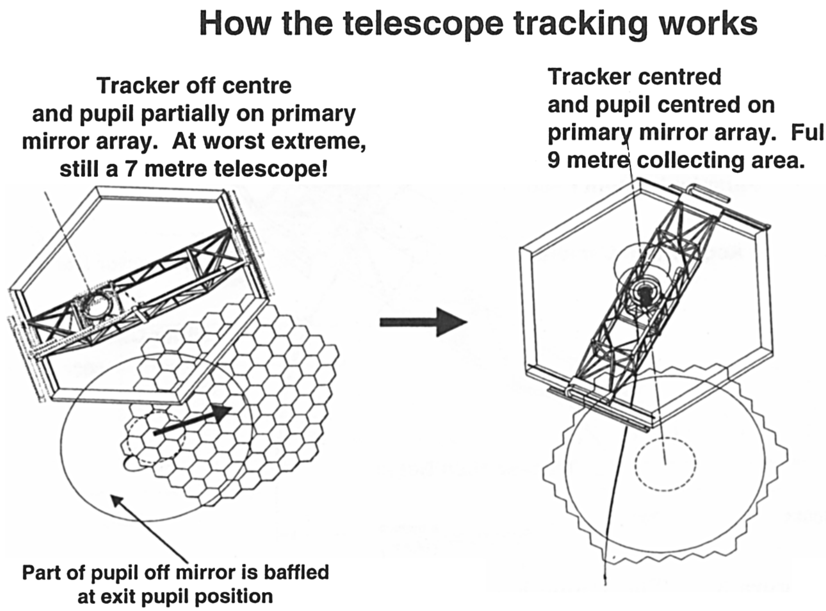

Figure 2. The tracker beam assembly and pupil on primary mirror.

On the HET the SAC is a 4-element reflecting Gregorian corrector (with diameter of optical elements 0.5 m) which produces images with FWHM better than 0.6 arcsec over a 4 arcmin field. On SALT we are examining the possibility of a 2-element corrector (with diameter of optical elements 0.7 m) which will produce good quality images over a larger field (D. O'Donoghue, private communication).

The Prime Focus Instrument Platform (PFIP) provides the interface between the telescope and the instrumentation. The PFIP contains a mechanically isolated *Invar* frame, on which the spherical aberration corrector is mounted. An optical bench on the PFIP contains the acquisition camera, the guiding system, and the exit pupil baffle system. Also attached to the PFIP are the prime focus low resolution spectrograph and the Fibre Instrument Feed (FIF). The FIF provides the link to the medium and high resolution spectrographs in the basement instrument room, via more than 150 optical fibres in a 32 metre cable.

The image size error budget (in arcsec FWHM) has a final goal of 0.6 arcsec FWHM from all contributions. This figure is designed to not significantly degrade the median seeing at the location of the telescope. At Sutherland, DIMM seeing measurements have revealed that for 95% of the time the seeing is within a range 0.5 – 2.0 arcsec with a median seeing of 0.9 arcsec (Buckley 1995).

The effective wavelength range of the SALT is 0.3 to 2.5 μm. Beyond 2.5 μm the thermal background rapidly increases and the telescope is not effective at longer wavelengths. The mirror coatings used by HET are over-coated silver as this provides superior reflectivity over all wavelengths (in comparison to aluminium) except for the bluest wavelengths (< 380 nm). This is especially important as, with the primary and the 4-element reflective corrector, there are 5

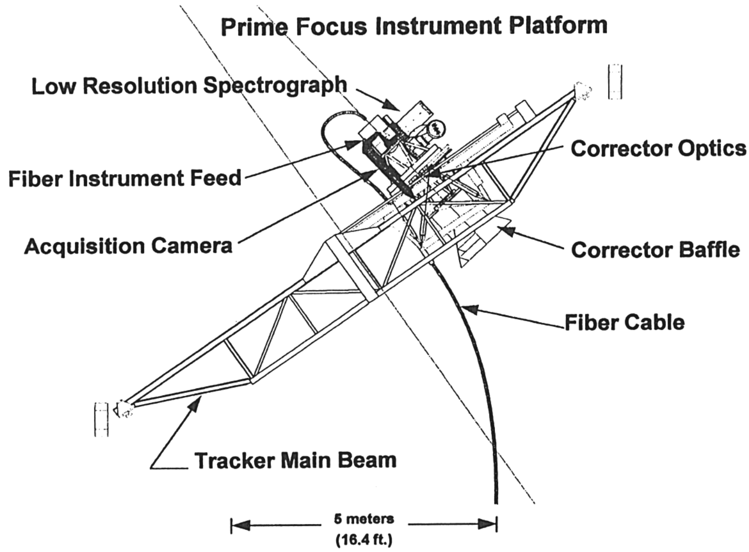

Figure 3. The Prime Focus Instrument Platform (PFIP) *in situ* on the tracker beam.

surfaces before the light enters the fibre system. Thus any reflectivity differences are to the 5th power.

2. Instrumentation Options

The initial instrumentation suite for HET is described by Ramsey (1998). It comprises three main instruments: a low resolution spectrograph (LRS); a medium resolution spectrograph (MRS); and a high resolution spectrograph (HRS). The ranges of wavelengths and resolving powers covered by each instrument are shown in Fig. 4.

The LRS is a grism spectrograph with three modes of operation: imaging, longslit and multi-object (with 13 slitlets) over a 4 arcmin field (Cobos et al. 1998; Hill et al. 1998). The LRS is the only instrument that will be mounted on the tracker beam at the prime focus; all other instruments will be fibre-fed and placed in a thermally controlled basement. The MRS is a versatile, fibre-fed echelle spectrograph covering a wide wavelength range from 0.39 to 1.8 μm (Ramsey 1995; Horner et al. 1998). It is of white pupil design with a beam splitter providing a visible beam and a near-infrared beam. The HRS design is optimized for the 420 to 1100 nm spectral region at resolving powers $30\,000 < R < 120\,000$ (Tull 1998).

Instrumentation options for SALT have been discussed by Buckley (1998). It is likely that some of the SALT instruments will be similar to the HET choice. But in the end it depends on the range of science the partners in SALT wish to accomplish. To define the science requirements for SALT, and hence the instrumentation suite, a Science Working Group has been set up. This will be

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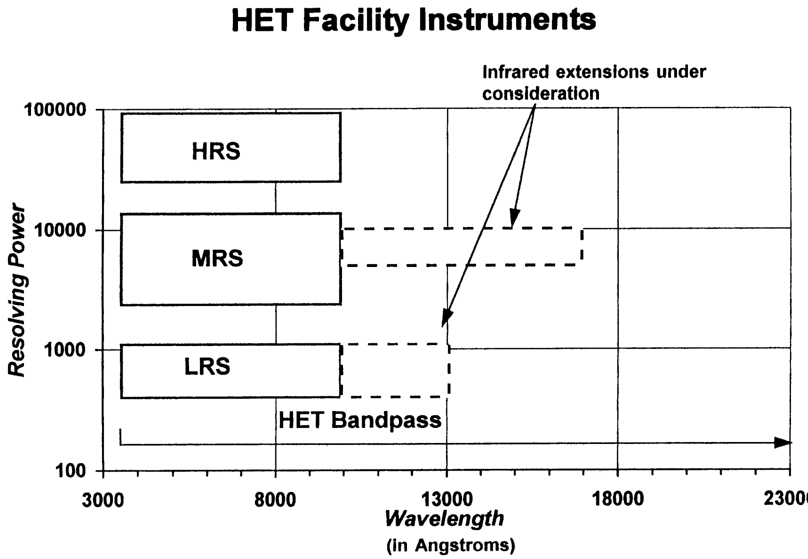

Figure 4. Attributes of the three HET spectrographs.

chaired by the SALT Project Scientist, Dr D. Buckley, with representatives from each of the partner countries/institutions participating in SALT.

Some of the options include high time resolution ($\Delta t \sim 5 - 10\,\mathrm{s}$) studies of accretion phenomena, involving both photometry and spectroscopy. This could be part of the LRS capability. There is also interest in imaging spectroscopy, with a Fabry-Perot spectrometer for the dynamical and evolutionary studies of stellar systems, galaxy formation and the study of dark matter (Williams, 1998). This could be achieved by incorporating a set of etalons in the collimated beam of an LRS-like instrument.

Higher time resolution ($10^{-6}\,\mathrm{s} < \Delta t < 1\,\mathrm{s}$) photometric studies of, for example, periodic phenomena (e.g. pulsations, eclipses, etc.), could also be addressed by appropriate fibre-fed instrumentation using photon counting detectors (e.g. photomultipliers, avalanche photodiodes).

The ultimate performance of a telescope is best measured in terms of the signal-to-noise (S/N) ratio of the resulting science observations. This depends on a large number of parameters. The HET performance with the LRS, MRS and HRS instruments is shown in Fig. 5 (Ramsey 1998). This shows the S/N ratio per pixel as a function of R magnitude based on the quoted spectrograph efficiencies, 1000 s integration, 1 arcsec seeing and sky brightness $V = 21.97\,\mathrm{arcsec}^{-2}$.

3. Samples of Science Programmes

Because of the limitation of sky access to an annulus 12° wide centred on a tilt angle of 37° to the zenith, the SALT telescope will be queue-scheduled. This

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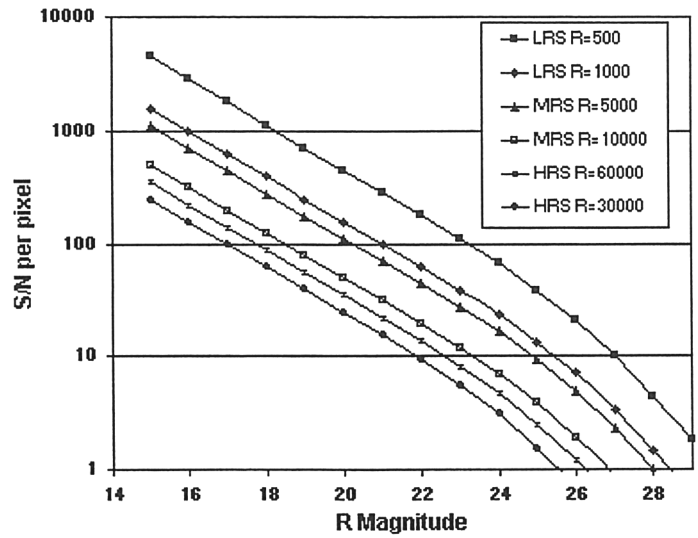

Figure 5. The modelled S/N performance of the HET facility instruments.

also opens up the possibilities of extending scientific studies in the time domain, which are not possible with a conventionally scheduled telescope.

The SALT is designed primarily as a spectroscopic survey telescope. Bearing this in mind the SALT will be most competitive and efficient when:

- target classes are uniformly distributed on the sky
- target objects have sky surface densities of a few per square degree or are clustered on a scale of a few arc minutes
- time critical observations with time scales of days and longer are of interest
- spectroscopy from 0.35 to 2.0 μm maximises the astrophysical insights to be gained

SALT and HET also plan to trade time so that science programmes that require coverage both in the northern and southern hemispheres can be accomplished.

At the SALT/HET Workshop in Cape Town (2-6 March 1998) a number of scientific programmes which are planned for SALT or HET were described. The proceedings of this Workshop have been published in "Science with SALT", a special publication of the South African Astronomical Observatory (see Buckley 1998b). This Workshop does not claim to present a complete picture of the science, but rather represents the interests of those who attended.

As can be seen from the Workshop proceedings the range of science with SALT/HET is broad. It encompasses studies of the early Universe, active galactic nuclei, the study of nearby galaxy populations, planetary searches, galactic and extragalactic distance scales, spectroscopic follow-up of HST deep fields in north and south, spectroscopic studies of X-ray objects discovered by AXAF and XMM, the 3-dimensional structure of the Universe, imaging spectroscopy with a Fabry-Perot interferometer, spectroscopy of gravitational microlensing sources, optical pulsar studies, galactic black holes and neutron stars, eclipse mapping of accretion disks and streams, study of faint hot stars, and the study of time variable phenomena in low mass star formation, to name but some of the examples.

SALT (and HET) will be used to study the stellar populations of nearby galaxies in greater depth than before. It will be important to study nearby galaxies with different evolutionary chemical enrichment histories from our own Milky Way in order to understand better the processes of star formation and galaxy evolution. During the present Local Group Symposium we have heard often how spectroscopic studies to fainter limits are required. One of the remarkable results presented at this Symposium is how the star formation history of each dwarf elliptical in the Local Group appears to be unique.

Obviously the Magellanic Clouds will be of special interest to users of SALT. In the SALT/HET Workshop, Balona (1998) presented a paper on "The Magellanic Clouds: a backyard laboratory" where SALT can contribute to the knowledge of abundances in the Magellanic Clouds, spectroscopic observations of B stars, the peculiar "bumpers" discovered in the MACHO project, and determination of radial velocity curves of Cepheid variables to assist in securing the zero point calibration of the distance scale of the Universe. Tylenda (1998) presented a paper on the late stages of stellar evolution with special emphasis on observations of evolved stars in the Galactic Bulge, Magellanic Clouds and other nearby galaxies.

The above represent only some samples of science that can be achieved with SALT (and HET). Unquestionably there will be many other projects carried out with these telescopes, and ones not even presently thought of, only limited by the imagination and creativity of the astronomers themselves.

4. Status of SALT Project

SALT presents a highly cost-effective solution to large telescope capability. The estimated construction cost of SALT is $20 million, about one-fifth that of a general-purpose telescope of similar aperture. The construction time scale is expected to take five years.

The motivation for SALT and the benefits to South Africa were presented in a document to the South African government (Stobie 1998). On 1 June 1998 the Minister of Arts, Culture, Science & Technology, Mr L. P. H. M. Mtshali, announced in his budget speech in Parliament that the South African government had agreed to fund 50% of the construction costs and 50% of the operational costs. The remaining 50% had to be found from international partners willing to participate in SALT.

Good progress has been made in identifying the likely partners in SALT. The HET Board has agreed to make the plans and documentation relating to the HET available to the SALT project in return for telescope time. In addition, Carnegie Mellon University, Rutgers University, Göttingen University and the countries of Poland and New Zealand have all expressed a strong interest in participating. They are all actively raising funds. South Africa's goal is to achieve a commitment from the international partners by March 1999.

An Interim SALT Board has been set up comprising representatives of all partners. This SALT Board is the principal governing body. It will be responsible for determining all policy matters, long-term strategic planning goals, approving scientific specifications of telescope and instrumentation, the policy on allocation of telescope time, approving construction budget and annual operating budget.

The SALT Board has set up a Science Working Group, chaired by the SALT Project Scientist, Dr D. Buckley, to advise the Board on all scientific matters. This Science Working Group will have members from each of the partners institutions/countries who have to represent the interests of their scientific community.

During 1998, progress on SALT has involved much development work, including a site assessment study, meteorological characterisation of sites, reviewing the science specification of the telescope, a concept phase design review, and obtaining a better cost estimate that will include the construction of major subsystems by South African companies.

Acknowledgements. We gratefully acknowledge the help of the HET Board and Prof Larry Ramsey for the five figures in this paper, which are based on the HET.

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Discussion

Pritchet: (1) What fraction of the total cost is in the primary mirrors? (2) Is there any fundamental reason why you could not extend the viewing time by moving the telescope in azimuth during an observation?

Stobie: (1) The primary mirrors account for about 20% of the total cost. (2) There is no fundamental reason why the length of exposure could not be extended to fill the annulus within which an object is accessible. However, the observation may need to be interrupted while the telescope is moved to a new azimuth and the tracker beam reset in order for the observation to continue.