The Southern African Large Telescope: an alternative paradigm for an 8-m class telescope

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Abstract

South Africa plans to build an 8-m class telescope — the Southern African Large Telescope (SALT) — based on the novel design of the Hobby Eberly Telescope. These telescopes represent a different paradigm in design, at $\sim 20\%$ of the cost of more conventional telescopes. Primarily designed for spectroscopic observations, the telescopes are restricted in what targets can be observed at any particular moment, necessitating a queue-scheduled observing mode. The telescope design concept is reviewed and the observing constraints discussed. The science goals for SALT are maximized when certain observational criteria apply.

Key words: large telescopes; novel design; Arecibo

1 Introduction

On 1 June 1998 the South African Government announced that it was funding 50% of the construction and running costs of a new large (8-m class) optical telescope — the Southern African Large Telescope (SALT). This telescope is modelled closely on the Hobby Eberly Telescope, currently being commissioned at McDonald Observatory, Texas (Ramsey et al. 1998). This historic announcement has heralded a new era for astronomy in the country, where currently the largest telescope is the 50 year old 1.9-m Radcliffe reflector.

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1.1 *Background*

For some years now South African astronomers have been discussing new telescope options. In the era of 4-m class telescopes, South Africa has remained relevant and competitive through the regular access by the astronomical community to telescope time at a good observing site (canonical figures for Sutherland are: 75% spectroscopic, 50% photometric and median DIMM seeing of 0.9 arcsec FWHM). Minimum weekly telescope allocations, coupled with a relatively low over-subscription rate, has in part made up for the lack of aperture. Many long-term observing programs have also been possible using the South African Astronomical Observatory (SAAO) facilities, which have not been feasible at most other observatories.

However, with the advent of 8-m class telescopes it was increasingly apparent that South Africa needed access to a new, larger ($\gtrsim$4-m), telescope to remain relevant. Initial investigations (during the period up to 1994/95) centred around an NTT-like telescope, with two sites being considered: SAAO's Sutherland station and the Gamsberg Mountain in Namibia, an observatory site owned by the Max Planck Institute (MPI). This option failed to materialize when it became clear that the German and Namibian partners were unable to raise any significant funding. Attempts at interesting other potential partners met with no success. About this time (1995/1996) we became aware of the Hobby Eberly Telescope (HET) project, formerly called the Spectroscopic Survey Telescope. After initial approaches and visits, a proposal was put to the astronomical community in South Africa that SALT should be modelled on the HET, which could be built at a similar cost to a modern 4-m class telescope (or even cheaper). This proposal was subsequently adopted, and since then efforts have focussed on securing funding and partnerships. The current partnership[2] consists of South Africa, the HET Board, Poland, Rutgers University, University of Göttingen, Carnegie Mellon University and New Zealand.

1.2 *South African Government support*

The SA Government support, through the Department of Arts, Culture, Science and Technology, announced in June 1998, came after a careful consideration of the various issues, including the costs and benefits to the country. SALT was seen as a major 'flagship' project which could have wide ramifications, such as interesting and enthusing young people in science and technology. The announcement, during the Government-sponsored *Year of Science and Technology*, has been widely supported in South Africa. It is a natural project for

[2] This interim partnership is at varying stages of success in terms of raising funds.

South Africa, because of both the favourable climate for astronomy and the high standing of the astronomical research output, but also because it is consistent with the Government's science policy, and specifically the conclusions of the 1996 *White Paper on Science and Technology*, which stated:

"Scientific endeavour is not purely utilitarian in its objectives and has important cultural and social values... Not to offer 'flagship' sciences (such as physics and astronomy) would be to take a negative view of our future — the view that we are a second-class nation, chained forever to the treadmill of feeding and clothing ourselves."

2 The SALT/HET concept

The basic features of the HET (Ramsey et al. 1998) and SALT are discussed in the recently published (November 1998) proceedings of the SALT/HET Workshop, entitled *Science with SALT* (e.g. Buckley 1998). In summary, the HET/SALT design has the following attributes:

- spherical primary mirror mosaic of 91 identical 1-m wide hexagons
- telescope tilted at constant zenith distance (37° for SALT)
- azimuth rotation only for target acquisition
- target tracked using moving payload at the telescope focus

The latter is why the design is referred to as a 'tilted Arecibo'. The tracker unit has 10 degrees of freedom: 6 in a hexapod positioner, 3 in x, y & z motions (where z is co-alligned with the optical axis of the mirror array), and 1 for rotation. Targets can be tracked over 12° of the focal surface, which translates to a range of motion of 3.9 m in x & y and 0.18 m in z. When the tracker is at its limit, the entrance pupil actually falls off the mirror array [3], resulting in an effective collecting area equivalent to a 7-m diameter mirror, compared to a a 9.2-m diameter pupil when the tracker is centred.

The 91 identical spherical mirror segments are finished to an accuracy of $\lambda/15$ and each have radii of curvature within 0.5 mm of the nominal value of 26.165 m. To keep the correct mirror figure, the individual mirror segments have three actuators allowing tip, tilt and piston motion. The error budget for the telescope is such that the images delivered should not substantially degrade the *median* seeing at the site (0.9″). This puts a requirement of $\sim$0.6″ FWHM images delivered by the telescope (including the optics, alignment errors, tracking, dome seeing, etc). Thus the phasing requirements for the individual segments is relaxed such that they only need to be positioned to an accuracy

[3] This requires that the exit pupil be baffled.

of 25μm (i.e. they are un-phased). An instrument situated in a tower at the radius of curvature is used to measure the positions of return images in order to ensure optimal positioning of the segments. The mirror support truss is a bolted steel space frame, and thermal variations and gradients within this truss are mainly responsible for the mirror segments drifting out of alignment over time. For SALT, edge sensors (inductive or capacitative) will be installed [4] which will keep track of the relative motions of segments. This should allow the array to maintain its figure for many days at a time, rather than the few hours currently experienced with the HET.

The total collecting area of the mirror array is 78.8 m^2, although the secondary optics deliver an effective maximum entrance pupil of 9.2 m in diameter. Because of the significant aberrations (mainly spherical) inherent in this design, correcting optics are required, and in the case of the HET consists of a 4-element double Gregorian reflector, which delivers an f/4.6 beam (well suited for injection into an optical fibre). These optics are mounted, together with the acquisition/guide cameras, fibre-feed system and a low resolution spectrograph/imager (the LRS), on the prime focus instrument platform. They deliver a 4 arcmin diameter science field, which can be accessed by fibres or directly imaged.

3 Cost versus performance

The cost of building the HET was \$13.5M, and SALT is estimated to be \$15.7M [5]. These costs are typically 20% of the cost of a more conventionally designed 8-m telescope. The major trade-off is that HET/SALT *cannot* access targets at *any* time that they happen to be in the sky (i.e. above a certain altitude). Rather they can only be observed during specific windows of opportunity, when the targets are within an annulus 12° wide and offset 37° from the zenith (35° for the HET [6]). Even with this restriction, ~70% of the entire sky can be observed *at some time* with these telescopes. Thus any object in the declination range $+10°37' \gtrsim \delta \gtrsim -75°23'$ will be observable by SALT at some time. The length of time an object can be observed is determined by how long it takes to drift through the 12° wide annulus, and is thus dependent on declination. Objects at the most southerly limit can be observed by SALT for up to 2.5 hours, while the most northerly targets can only be observed for ~40 minutes. Objects with intermediate declinations can potentially be observed *twice* during a night, as they pass into the observing annulus in the east and

[4] They are also being retro-fitted to the HET where they were not initially installed for budgetary reasons.
[5] Both these figures exclude the cost of scientific instrumentation.
[6] The extra 2° for SALT is to enable the whole of the SMC to be observable.

again, after they culminate, when they pass into the annulus in the west.

These restrictions may sound severe, but those with experience of satellite observations will be familiar with this type of observing scenario. The unique design of these telescopes makes them ideally suited for single exposures of $\lesssim$1 hour or so at moderate zenith distance (the airmass range is 1.16–1.36 for SALT). Such an observing method is actually well suited to the majority of observations currently undertaken at most observatories, and is ideal for surveys. Benn & Martin (1987), reporting on observing statistics of the INT, showed that the majority of observations ($\sim$46%) were 'one-off' single exposures, and the mean integration time for all observations was 655 sec (for a given S/N ratio, this number is likely to *decrease* given the higher DQE's of modern detectors).

4 Science drivers for SALT

The SALT/HET design maximizes the science achievable when the following criteria apply:

- uniformly distributed targets on the sky.
- targets have surface densities of a few degree^{-2} or $\sim$1 arcmin^{-2}. [7]
- variability studies confined to the time domain $\lesssim$2 hours or $\gtrsim$a day.
- high-spatial resolution (i.e. substantially sub-arcsec) not required.
- observations limited to the wavelength domain 350 nm $\lesssim\lambda\lesssim$2500 nm.

The restrictive nature of the SALT/HET design means the telescopes will primarily be operated in a queue-scheduled mode. Spectroscopy in the visible/near-infra red (i.e. 350–1800 nm) will be the major observational mode suiting the above criteria and delivering the best astrophysical returns. The short wavelength capability is determined by the mirror coatings and fibre transmissions (for the fibre-fed spectrographs), while the infra red capability is limited to below the thermal infra red due to the aforementioned requirement of baffling the exit pupil [8] as it migrates off the primary mirror array as the tracker moves. Because of the 5 reflections before the focal plane, the HET has over-coated silver coatings on all the mirrors. Whether or not SALT follows suit will depend on the design of the spherical aberration corrector (i.e. a 2- or 4-element system) and the logistics of doing protected silver coatings in South Africa. The pressure for greater short wavelength sensitivity for SALT may

[7] The two figures apply, respectively, to targets accessible to the tracker *without* requiring any azimuth motion (i.e. within $\pm$ 6 degrees) and targets accessible by the $\sim$10 multi-object fibres/slitlets over the $4'$ field of view.
[8] The baffle is not a cold stop.

lead to aluminium coatings being adopted, at least on the primary mirror segments (Buckley 1998).

5 SALT instrumentation & science

The choice for instrumentation for SALT is yet to be decided [9], but is likely to follow closely the HET example in terms of the Resolving Power — Wavelength Coverage 'phase space' covered by HET instruments. The HET will have an initial suite of three facility instruments: low (R = 600–3,000), medium (R = 3,500–20,000) and high (R = 30,000–120,000) resolution spectrographs, the latter two fed by optical fibres. At least two of these spectrographs (the LRS and MRS) have planned near-infra red extensions, giving them capability into the H-band [10]. SALT instruments have to be chosen both to match the observing criteria, discussed above, and the science goals. The latter were the subject of a Workshop held in March 1998 and published in the proceedings [11]. As might be expected, there was considerable overlap with the science drivers for the HET, published in a similar workshop proceedings [12]. Key SALT programs discussed included: stellar population studies in nearby galaxies (i.e. the Magellanic Clouds and Local Group), extra-galactic surveys (e.g. in support of HST Medium Deep Survey, XMM and AXAF), improvement in distance scales (e.g. from Cepheids, RR Lyrae stars and Supernovae), dynamical studies of stellar systems (clusters and galaxies) and characterizing the dark matter content of the latter.

The SALT/HET design is limiting in many respects — which is why such a project is affordable to us. Clearly not all observing programs will be feasible or competitive with other 8-m class telescopes. However, there are many projects that will be particularly well suited to SALT's queue-scheduling *modus operandi* (in fact many can *only* be done using this observing approach). If the science programs for SALT utilize its capabilities to the best possible advantage, then excellent scientific results will be guaranteed for decades to come.

References

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[9] Currently this issue is being debated by the SALT Science Working Group.
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