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Contents

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Southern African Large Telescope (SALT)

Science with SALT in the ELT era: a “low-cost” option

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Abstract

The 10m-class Southern African Large Telescope (SALT) is now in the final stages of commissioning. This new paradigm in low-cost, large-telescope construction is based on the HET prototype but with significant improvements to its optical design. Amongst current large telescope designs SALT has special capabilities in terms of UV throughput, temporal resolution and polarimetry. The key technical constraint is the fixed elevation, which significantly restricts sky access, making 100% queue-scheduled operation a necessity. However, this can be turned into a number of scientific advantages which are much harder to implement in classical schedules, examples of which include long-term monitoring and ToO programs. Furthermore, the in-house staff control of data acquisition has benefits for quality control and the definition of data archiving and reduction standards and procedures. SALT also needs support from SAAO's small telescopes (which include a variety of classically and robotically operated facilities), not just in the provision of photometric calibration observations, but in a wide variety of ways which will be reviewed and discussed.

1. Introduction

SALT, the Southern African Large Telescope, is at the forefront of a major bid by South Africa to establish a suite of multi-wavelength, ground-based observing facilities. HESS, the High Energy Stereoscopic System, began operating in Namibia in 2004, and the radio astronomy technology demonstrator, KAT, the Karoo Array Telescope means that Africa will soon offer front-rank astronomical observing from ultra-high energy γ-rays, through optical to radio wavelengths. That this is possible is a result of this region's clear, dark skies and quiet radio environment, both of which are due to low population density. These sites are now protected by the Astronomy Geographic Advantage Act, making South Africa only the third country to promulgate such a Bill.

SALT was constructed by a partnership of South Africa and 11 other international institutions (located in USA, Poland, Germany, India, UK and New Zealand). Constructed in just 5 years, the subsequent commissioning and testing of SALT over the last 3 years has revealed a number of areas that require redesign, upgrade or repair. This should not be surprising given the significant number of changes that were made to the HET design paradigm on which SALT was based. HET is the Hobby Eberly Telescope, at McDonald Observatory in Texas (one of the SALT partners). Even with the additional costs incurred by the extended commissioning period, the approximate construction cost of \$22M (plus a further \$9M for the suite of first-generation instruments) is extremely low compared to conventional (both single mirror and segmented mirror design) 8-10m telescopes around the world. This is principally due to the small and simple, spherical mirror segments, the fixed elevation angle and that the primary is stationary during actual observing. For more details

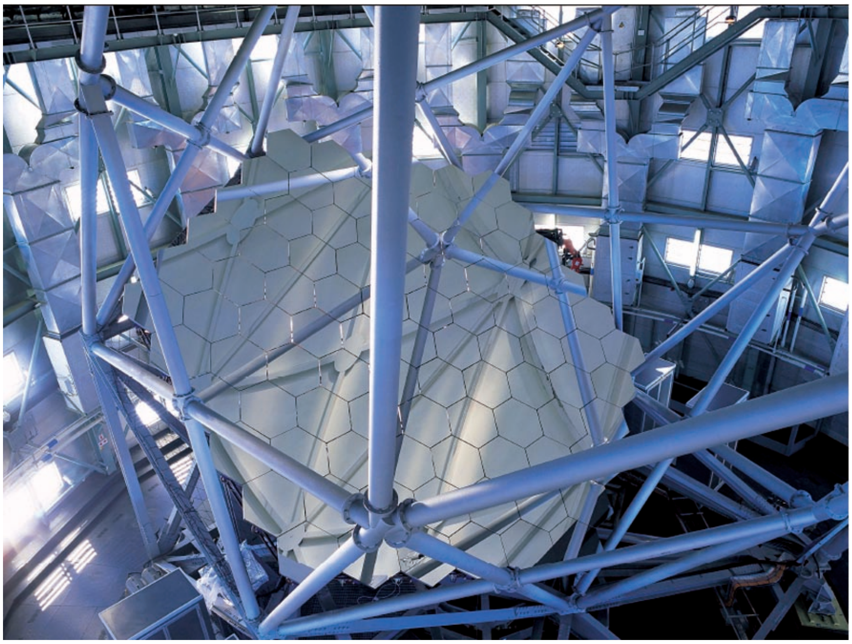


***Figure 1:** Photo of SALT's primary mirror array. There are 91 hexagonal, 1 m segments.*

see Buckley et al (2008) and references therein. It should be noted that this design ought to be capable of straightforward scaling to larger mirror areas at comparable cost-saving factors.

2. Basic SALT Design, and Enhancements over HET

Formed in 1999, the SALT Foundation aimed to produce a southern hemisphere equivalent of HET. While the last decade has seen a remarkable number of 8-10m class facilities come to fruition, HET's design was radically different as it endeavoured to produce a large collecting area at very low cost. The design is based on the principle of operation of the Arecibo radio telescope, except that the radio dish is replaced by a segmented, spherical primary mirror. Furthermore, the SALT primary is held at a fixed elevation of 53^{o} (slightly different from HET, in order to fully access both Magellanic Clouds), but the primary can be rotated to any azimuth. A unique feature of this design is that the primary is stationary during observing, requiring the target field to be observed with instrumentation on a Tracker unit that moves across the primary's wide focal surface (Figure 2).

Figure 2: Cutaway schematic of SALT and its environs, showing the key elements of the segmented primary mirror, which can rotate in azimuth, but is at a fixed elevation of 53º, and the Tracker (which carries the instrument payload). Image courtesy SALT Foundation.

However, even before construction of SALT began, testing of HET had revealed that a number of design enhancements were essential. The most challenging of these was the need to improve the performance of the spherical aberration corrector (SAC), that is critical for this optical design. The SAC design of O'Donoghue (2000) was dramatically better than that of HET, demonstrating much improved image quality, a much wider field of view, a larger effective collecting area (because of the increased pupil size) and a larger back-focal distance. Indeed, an extended version of the SALT SAC design is now at the heart of a new instrument (HETDEX) currently under development for HET.

Combined with the use of carbon composites in the Tracker's moving mass, the new SAC design permitted an increased mass budget and easier servicing access. In order to achieve high throughput in the UV (down to 320nm), the presence of the SAC's 4 mirrors in the optical path made it necessary to use advanced multi-layer coatings.

The building design also differs substantially from HET, with careful attention to heat control (a cooled glycol system operates throughout) and louvres (for natural ventilation at night) to deliver a target image quality of 0.7 arcsecs (FWHM).

3. Instrumentation Suite

3.1 Imaging Camera, SALTICAM

The first light (and principle telescope commissioning) instrument has been SALT's imaging camera, SALTICAM (O'Donoghue et al 2003, Buckley et al 2006). Based on a pair of mosaiced E2V 4096x2048x15μ frame-transfer CCDs, SALTICAM acts as both an efficient acquisition camera (it covers SALT's 10 arcmin diameter field of view, consisting of the central 8 arcmin science field and surrounding 1 arcmin annulus for autoguiding) and science instrument. Equipped with a range of broad and narrow band filters, SALTICAM's CCDs have high throughput down to ~320nm. When operated in frame-transfer mode SALTICAM can provide 2.5s time-resolved images, or even faster (approx 60ms) when used with a special 20 arcsec wide occulting mask ("slot" mode). To date, this has been applied to observations of relatively bright (V<20) targets, as SALTICAM's autoguider has not yet been installed (and hence precludes deep imaging exposures).

3.2 Imaging Spectrograph, RSS

Intended as its "workhorse" instrument, the principal spectrograph on SALT is RSS (the Robert Stobie Spectrograph), named after the former SAAO Director, one of SALT's original driving forces. Formerly known as PFIS (the Prime Focus and Imaging Spectrograph), RSS is a low to intermediate dispersion spectrograph that was designed and constructed by the University of Wisconsin (UW, see Nordsieck et al 2003), together with Rutgers University (mechanical structure and Fabry-Perot optical subsystem) and SAAO (CCD detectors). RSS offers a wide range of modes to exploit SALT's very good UV performance and wide wavelength capability. These include long and multi-slit capabilities, plus tunable Fabry-Perot imaging and spectropolarimetry (Table 1).

RSS was installed on SALT in late 2005, and most of its observing modes have been exercised. The poor image quality of the telescope precluded comprehensive testing of its wide field capabilities, but the major problem exhibited by RSS was in its poor UV/blue throughput. Eventually traced to an optical flaw (degraded lens coupling fluid in the multiplets), RSS was removed from SALT in late 2006 and its optics were repaired by its manufacturers (see Buckley et al (2008) for more details). At the time of writing, the repaired optics have been re-integrated into RSS and re-aligned, and a full program of ground tests are underway prior to its being re-installed on SALT later this year. For an example of RSS science that was accomplished during its initial commissioning see Väisänen et al (2008).

	Mode	λ Range (Å)	Resolving power
RSS	long-slit/multi-slit	3200-9000 (-1.7μ with NIR*)	800-6000
	spectropolarimetry	"	"
	Fabry-Perot	4300-9000 (-1.7μ with NIR*)	320-770; 1250-1650; 9000
HRS*	Single target (fibre-fed)	3700-8700	16,000-65,000

Table 1: SALT Spectroscopic Capabilities
**** under construction***

The original mechanical and optical design of RSS included room for its extension into the near-IR band. This was to be accomplished with a dichroic which allows light beyond 900nm to enter a separate NIR arm. At present a folding flat is in place, as the NIR arm was not part of SALT's suite of first generation instruments. However, the RSS/NIR arm has now been funded and designed at UW, with the aim of extending the wavelength coverage to close to 1.7μ. The NIR arm will have a similar range of operating modes as in the optical, and should be completed by 2011.

3.3 Fibre-fed High Resolution Spectrograph, HRS

The first-generation suite is completed by a high resolution spectrograph, HRS. In order to reach resolving powers of up to 65,000 (as is needed for precision radial velocity work), the spectrograph is housed in a vacuum tank to provide extreme stability against temperature and pressure variations. Such a scale dictates that HRS be located in the spectrograph room underneath the main telescope observing floor, where fibres from the Tracker feed light from the single target plus sky region. The dual-beam design which is now under construction (at Durham University's Centre for Astronomical Instrumentation) uses an R4 echelle, after which a dichroic splits the spectrum into blue and red arms, each of which has its own VPH cross-disperser and camera giving a range of resolving powers (from 16,000 to 65,000, depending on the use of image slicers; see table1). HRS is expected to enter commissioning in early 2010.

4. SALT Commissioning and Performance Verification

Simultaneous imaging over the full SALT 8 arcmin field of view was first obtained in late 2005, and demonstrated that there was a field-dependent image quality (IQ) problem, appearing as a focus gradient. There were additional time-dependent effects associated with the instrument rotator angle and temperature. A detailed study of this problem was able to rule out the instruments (SALTICAM, RSS) and the primary mirror array as the source, implying that it must reside in the opto-mechanics of the SAC. A full report on this can be found in O'Donoghue et al (2008), who established that (i) the last pair of mirrors in the SAC are mis-aligned with respect to the optical axis of the telescope, and (ii) there are significant mechanical stresses transmitted into the SAC via the Tracker interface due to thermal effects (at the SAC/non-rotating structure interface) and instrument rotation. Since high quality (0.85 arcsec) images have been obtained within SALT images, there is no reason to doubt the overall SAC optical design and quality of the individual SAC mirrors. A complete mechanical redesign of the SAC-Tracker interface has been performed and new components recently installed on the SAC, which was removed from SALT in mid-April 2009. At the time of writing, the SAC mirrors are being fully tested and re-aligned, with the aim of remounting the SAC within a matter of weeks. All this work is being performed in the SALT building at Sutherland by Observatory staff, exploiting recent developments in testing such advanced optical components by using a specially designed computer generated hologram.

Despite the extended commissioning period of SALT, the total project timescale actually compares favourably with other large-telescope projects. Also, the recent recruitment of additional partners (AMNH, the American Museum of Natural History in New York, and IUCAA, the Inter-University Centre for Astronomy and Astrophysics in Pune, India) has brought new investment into the SALT Foundation, demonstrating confidence in the direction of the project. Furthermore, all the partners recognise the enormous importance of promoting and stimulating science education in South Africa (see Whitelock 2008), for which SALT acts as an iconic stimulus.

5. SALT Key Science Areas

With its limited resources and constrained sky-access, the instrumentation suite on SALT has necessarily focussed in ways that are of particular interest to the partnership, yet are intended to be internationally competitive. The key science areas are:

- *Time Domain Astrophysics*: already an important component of SAAO's existing facilities, the detectors on both SALTICAM and RSS allow for fast operation (up to 60ms), thereby allowing time-resolved photometry, spectroscopy, polarimetry up to a few hours, and synoptic monitoring on much longer timescales. The Q-scheduled mode of operation is particularly powerful for ToO programs, such as rapid follow-up of GRBs.
- *Multi-wavelength Studies*: the flexible scheduling of SALT is ideal for contemporaneous observing with other ground-based facilities (e.g. South Africa's SKA demonstrator, KAT) and space observatories (e.g. RXTE, XMM, JWST...)
- *Survey Science*: where objects are uniformly distributed with densities of a few per square degree or are clustered on a scale of a few arcmins (e.g. follow-up of XMM, CXO, Vista, KAT surveys), which exploit either the Tracker's 12^{o}x12^{o} or SALT 8 arcmin fields.
- *SALT's rare capabilities*: spectroscopy and polarimetry from 320-900nm (eventually extending to 1.7μ). The prime focus instruments cover a wide region in parameter space in terms of wavelength coverage, resolving power (R~370-13,000) and multiplex advantage (MOS of ~100 objects, F-P imaging spectroscopy).

All of the above have the ability to provide excellent support and drive new science initiatives for ELT programs.

6. Constraints and Benefits of Queue-mode Scheduling

SALT's queue-scheduled mode of operation is obviously an unavoidable restriction to sky access (imposed by the fixed elevation angle) and the duration/timing of observing any given target. Indeed, scheduling SALT, which has therefore been planned to be 100% queue-mode from the beginning, is much more akin to a space than a ground-based telescope. However, whilst imposing clear scientific limitations on SALT observations, it also opens up an enormous range of new scientific possibilities as well as technical and operational advantages:

- ToO (Target of Opportunity) programs for fast follow-up of transient phenomena. The observing schedule can be very flexible, as the majority of programs in the queue will not depend on being executed at particular times, thereby allowing

ToOs to be implemented on the basis of established trigger criteria. This could be the state of a target variable star or AGN, or the notification of occurrence of unpredictable events such as supernovae or GRBs (Gamma-Ray Bursters).

- Synoptic monitoring, especially on timescales of weeks to months. Many galactic and extragalactic systems display long-term variations which require widely-spaced observations (particularly spectra) in order to investigate fully. Such observations are very difficult to accommodate through classical mode scheduling.
- Survey follow-up. Many surveys cover a large fraction of the sky and hence generate targets for follow-up which are similarly widely spread. Obtaining systematic sampling of such targets is much more straightforward through queue-scheduling than classical mode.
- Multi-wavelength observing campaigns. Both on the ground (particularly in SA with the soon-to-be-operational KAT radio telescope, and the already functioning HESS) and in space (with X-ray, UV and IR facilities), SALT's instruments can provide a powerful component in simultaneous observing campaigns. Most spacecraft generate short intervals of potential simultaneity, but they can repeat over many weeks, again making queue-scheduling far more effective than classical mode.
- Instrumentation quality control. With only in-house staff observers executing the queue, their familiarity and experience with the instrumentation can translate into much better levels of performance quality control.
- Data quality and consistency control. The establishment of standard setups and archiving procedures is also much easier to implement with staff observers, thus ensuring data uniformity in the final archive. This has the added benefit of making it easier to define data reduction pipeline procedures for the most commonly used instrument/detector configurations. The ability to offer essentially science-ready reduced data to PIs is particularly important for a small, low-resourced community such as in SA.

Whilst SALT has not yet completed its commissioning and acceptance phase, for the reasons described earlier, the software group have developed proposal preparation tools which will be part of the scheduling and execution of SALT observations. The benefits for SALT of the queue-schedule are considered to be:

- maximise the efficiency of use of the telescope (minimise overheads, maximise shutter-open time, check remaining track time, etc.)
- match the selected program to the current observing conditions
- quality control of instrument/detector performance and uniformity/consistency of data

- maximise program completion rates
- ensure distribution of time is proportional to partner shareholding

However, the software to generate this is still at an elementary stage, as our limited software resources have been focussed on the proposal preparation tools, the observation control software (which links the program setups into the instrument and telescope control systems) and the data reduction pipeline.

The observing programs will be selected by individual partner TACs and then combined in SA by the Astronomy Operations Team, in the process resolving any conflicts that arise. Programs will be rated under a simple, 4-level scheme: 0 (the highest, for ToO programs), 1 (for top-rated normal programs), 2 (mid-rating) and 3 (to be used as "fillers" for poor observing conditions). All proposals enter the SALT database, which acts as a repository for the program proposal, observing implementation details and data that is obtained. The actual observations are undertaken by one of the 6-strong group of SALT Astronomers, all of whom are fully trained in the performance and capabilities of the SALT instrumentation.

While "Service" mode (an earlier term, which has now largely been superceded by Queue mode) has been offered on a variety of telescopes for almost 3 decades, it was mostly used as a minor adjunct to classical (or "visitor" mode) telescope schedules. The aim under Service was mostly to use it for "trial" observations in order to test the feasibility of a potential program, or, occasionally, to obtain a small number of additional observations in order to complete a program (e.g. one that had been adversely affected by weather). It is only in the last decade that optical telescopes have appeared where queue mode was planned to be a significant component from the beginning. The best example of this is Gemini, and it is instructive to consider their experiences of Queue (hereafter, "Q") mode operations.

6.1 Gemini Queue-scheduling

Both Gemini telescopes and their instrumentation suites were designed from the start to be capable of exploiting the finest conditions available at the Mauna Kea and Cerro Pachon sites. In order to do this, it was essential to use flexible scheduling in order to optimise program selection to the extant conditions. Hence their initial target of 50:50 between Q and Classical mode observing. But, as reported by Puxley & Jørgensen (2006), demand for Classical mode was much lower (only ~10%) and this consequently had a serious impact on their staffing capacity. They also found that the average time request per Q-proposal was ~12hr, significantly less than the typical 2-4 night request under Classical. This was attributed to absence of any weather factor, or "padding" in order to justify the number of nights.

With 7 partners (and national TACs), Gemini found that multi-partner programs quickly developed, reaching ~50% of the total. They also found that multiple TACs have a large overhead and duplication of effort, something that might appear worse for the 12-partner SALT consortium. However, the "closed" nature of (most of) the SALT partnership means that the individual TAC operation is much simpler, and multi-partner programs have been strongly encouraged.

Gemini proposals are assigned into 3 Bands, essentially analogous to the ratings 1-3 described above, and in the proportions of 20:30:50% of the total. While beginning operations in 2001 with the aim of maximising the number of programs that actually receive some data (which can be beneficial in demonstrating the capabilities of the facility to a wide audience), it not surprisingly led to low completion rates. Gemini now aim to complete all of Band 1, most of Band 2 and most of those in Band 3 that are actually started, and are very close (mostly ~90%) to achieving this.

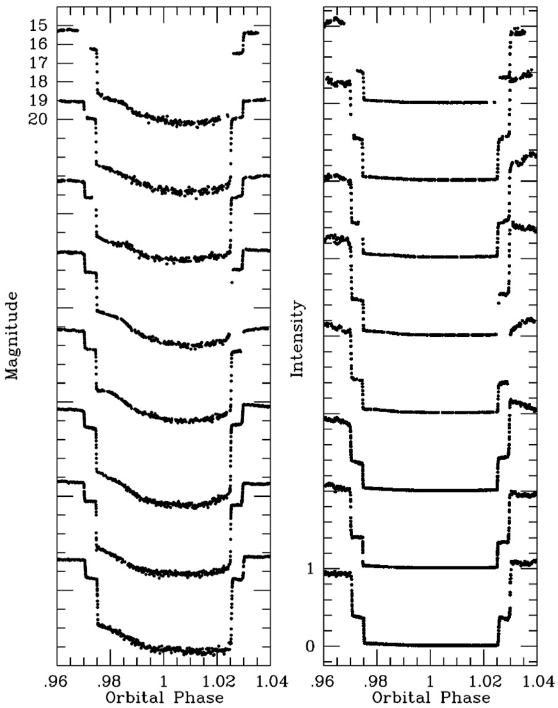
The Gemini Q has aims very similar to those listed above for SALT, but their much larger and more diverse instrumentation suite leads to an additional constraint on any given night that is linked to the staff astronomer's capability to actually use the instrument that would be dictated by the conditions. They also found that they were unable to achieve a distribution of telescope time according to the partners' shares as they had hoped to do within 2-3 semesters of beginning operations. There were a number of reasons for this, but the unpredictable creation of multi-partner collaborations is a component. With SALT's larger partnership (12, many with small, <4%, holdings) this is likely to be a similar problem. However, if large collaborations dominate the time allocations and these include all the partners, then holding strictly to the shareholdings is unlikely to be as serious an issue.

7. SALT Science Examples Exploiting Flexible Scheduling

7.1 Resolving the Magnetic Caps on Polars

Accreting white dwarfs in interacting binaries with short orbital periods (few hours), are common in the galaxy (several hundred are known within a few hundred parsecs, see Warner 1995). A subgroup of this class (the AM Her systems, or polars) contains white dwarfs with very powerful magnetic fields (10-200 MGauss) along which the mass transfer stream flows directly onto the white dwarf's polar caps. Although relatively nearby (~100pc), direct spatial resolution of the mass transfer process is impossible. Instead, spatial information is encoded within the structure of the eclipse light-curve in high inclination polars. However, this requires short exposure times, as the fine scale of the accretion geometry (such as the polar caps) produces structure in the light curves lasting only a few seconds. The combination of the intrinsic faintness of even the nearest polars, and the need for short (sub-second) exposures, requires the use of very large telescopes.

Initially discovered through their X-ray emission, the polar SDSS J015543.40+002807.2 (hereafter J015543) was identified through the Sloan Digital Sky Survey (Szkody et al 2002) and subsequently found to be eclipsing. It was subsequently confirmed



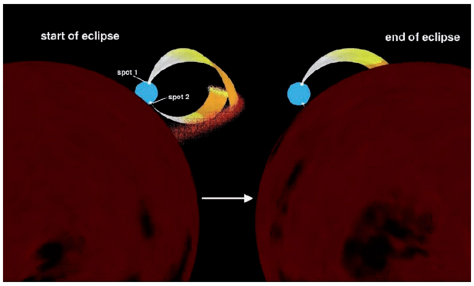


Figure 3: SALTICAM high time resolution light-curves of the magnetic polar SDSS J015543+002807 (left) showing the two "steps"' into and out of eclipse, that are only clearly resolved at sub-second time resolution. The 8 observations were made between 2005 Aug 5 and Sep 7, and are shown in both magnitudes and linearly, so as to emphasise detail during eclipse and the ingress/egress respectively. The schematic of this interacting binary (right) shows the two polar caps (the accreting hot spots) that dominate the optical output and that are sequentially eclipsed and revealed by the passage of the donor. From O'Donoghue et al (2006).

as a polar through follow-up optical spectroscopy and X-ray observations (Schmidt et al 2005). SALTICAM observed J015543 on several nights in 2005 Aug/Sep, producing high time resolution (down to 112ms) light curves of the white dwarf eclipse which revealed intricate detail of the accretion process through both the ingress and egress (see Figure 3 (left)). These results were the highest temporal resolution and highest S/N yet obtained on such a system. For a full description and analysis see O'Donoghue et al (2006). The light curves clearly show that the optical emission of J015543 is dominated by two small, approximately equally bright regions (the polar caps) as depicted in Figure 3 (right). These regions are fully resolved in the SALTICAM data, with eclipse ingress/egress durations of 1.2s and 1.5s, which correspond to spot radii of a few hundred km. There is no detection of the white dwarf eclipse itself in these data, as the spots dominate the output in the high accretion state. Observations in the low state will reveal the extent of the white dwarf directly, and can then be combined with these data to constrain the physical size, and hence mass of the white dwarf.

A particularly interesting future prospect is to use RSS to undertake time-resolved spectropolarimetry through the eclipses. The strong and broad H, He emission-line spectra of polars are known to show complex variations as a function of orbital phase, but the eclipse detail observed by SALTICAM, particularly with polarimetry as well, has never been attempted as it is essentially beyond the capability of instrumentation on 4m-class telescopes.

7.2 ToO Programs: Fast Follow-up to GRBs

Observations over the last two decades indicate at least two classes of GRB, one of which is associated with the supernova explosions of massive stars, the other is suspected of arising when a pair of orbiting neutron stars (or possibly neutron star - black hole binary) eventually merge (see Mèszàros (2006) for a recent review). Both appear to require special orientation with respect to our line of sight, as the rapid rotation of the collapsing star produces an extended disc of material around the forming black hole, which then leads to a super-Eddington accretion rate of matter, and a consequent ultra-relativistic jet being ejected along the spin axis. Alignment of our line of sight with, or close to, that axis produces the extreme brightness seen in a number of GRBs (such as GRB990123 which famously peaked in the visible at almost 8th magnitude for a few minutes, Akerlof et al 1999). Nevertheless, the ejected material is only (apparently) bright while it is relativistic, and so it decays rapidly, making prompt (at least within hours, preferably minutes) follow-up crucial in order to observe the interval during which the physical processes occurring are at their most extreme.

During RSS' initial commissioning year, it was therefore gratifying that GRB060605, which was detected by SWIFT could be observed by SALT just 8 hours after the burst, when it was still at R ~ 19. The resulting 40 min RSS low-resolution spectrum is shown in Figure 4 and was reported by Still et al (2006). The featureless afterglow from the burst is viewed through a forest of Lyman α absorption due to intervening clouds. While the broad, damped Lyman α seen at 575 nm indicates a dense system at (the large redshift of) z=3.7, this may not in fact be the host galaxy. Assuming that the Lyman edge is unambiguously detected at 440 nm, then the redshift of

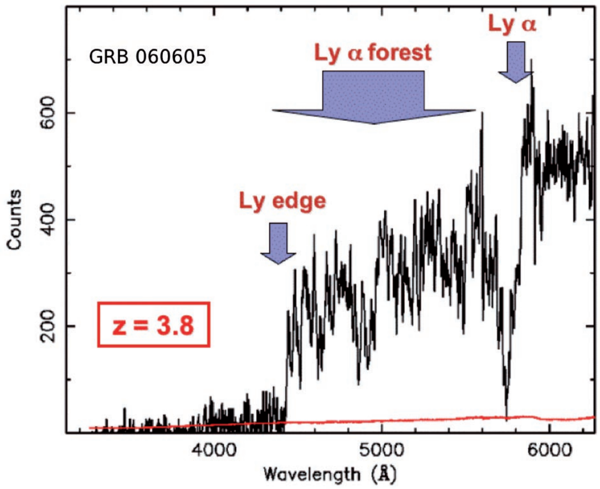


Figure 4: RSS spectrum of GRB060605 obtained just 8 hours after the initial alert, by which time the afterglow had faded to V~20.

the GRB is actually z=3.8. The Lyman α line from the host galaxy is blended with the red wing of the damped system at 483 nm.

The observation of GRB 060605 represented a significant scientific milestone for SALT and demonstrates how important it is to have queue-scheduled telescopes such as SALT involved in programs to study these enigmatic objects.

A key feature of all GRB models is that the radiation produced is highly directional and hence should be strongly polarised. Consequently some of the most important contributions to GRB physics will come from spectropolarimetry, and these must be done rapidly in order to have sufficient flux to be feasible, even with very large telescopes. SALT should be ideal for this given RSS' capabilities, and a demonstration of this was provided in Figure 5 when spectropolarimetry was performed on SN2006mq. While the systematic calibration of these data is still at a very early stage, and the results are not unusual, these spectra are a clear demonstration of SALT's great potential in this field.

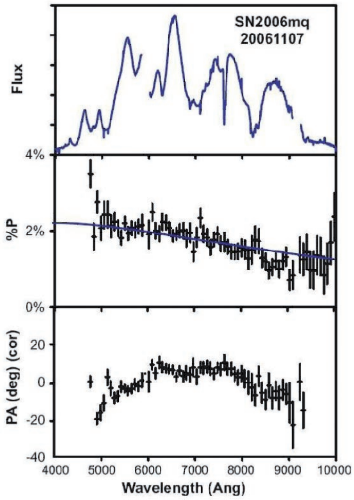


Figure 5: Demonstration of RSS's spectropolarimetric capability with the spectrum of SN2006mq (top), its linear polarisation (middle) and position angle (bottom) as a function of wavelength.

8. Role of Small Telescopes in Supporting Large Telescope Science

Whilst many small telescopes around the world have been closed or mothballed as a result of financial constraints brought on by the need to support the largest (and newest) facilities, it is interesting to note the simultaneous growth in development of new small telescopes! Examples of the latter include the Liverpool and Faulkes Telescopes, Las Cumbres Observatory Global Telescope Network, SuperWASP and PanSTARRS projects, all of which use telescopes with apertures in the range 0.1-2m. However, these are all either robotic in operation or designed with very specific science goals in mind, making them very different facilities from the small telescopes of old.

However, with appropriate maintenance and regular instrumentation/detector refurbishment, even some of the older small telescopes can have a role to play in parallel with these new robotic facilities in support of very large telescopes, such as SALT.

Key points to note here include:

- the SAAO 1.9m and 1m telescopes will provide calibration data to complement SALT imaging and spectroscopy (SALT's time-varying pupil means it cannot provide absolute photometry)
- the SAAO 1.9m's Newtonian focus and the IRSF 1.9m IR telescopes both have fields of view that are identical to that of SALT, and can thus be used to free up SALT time in providing images for preparing MOS masks, and obtain JHK images to broaden the wavelength coverage of SALT images
- provision of survey or monitoring capacity in feeding targets into the SALT Q, e.g.
    - searching for targets with particular properties (e.g. locating AGB stars in nearby galaxies, Whitelock et al 2009)
    - checking states of time-variable targets (e.g. CVs in particular activity states can be easily monitored by Monet)
- by participating in global campaigns (e.g. the Whole Earth Telescope, Nather et al 1990) programs can be undertaken that are impossible at single sites (e.g. Sullivan et al 2007), and yet require very large telescopes for detailed follow-up spectroscopy
- provision of student training opportunities, from undergraduate through to graduate student programs. The (relatively) easy availability of time and the lack of staff telescope operators, means that students gain hands-on practical experience that is simply not possible with the large and very large telescope facilities. This is particularly important at SAAO where many graduate students come from backgrounds that provided no practical astronomy opportunities whatsoever. Hence we run regular summer and winter school programs which make extensive use of our smallest (0.5m, 0.75m) telescopes. A recent PhD student (just completing) succeeded in making the 0.75m telescope remotely operable. A current MSc student is participating fully in the installation and commissioning of KELT-S.

It is thus becoming clear that small telescopes in future will be operating in a variety of different ways, all of which can contribute to "feeding" the SALT Q. These can be summarised as operating in one of the following ways:

- General-purpose, multi-instrumented, taking part in both multi-site (global) and long-term campaigns e.g. WET. Operate in Classical mode.
- General-purpose, single-instrument, available for many programs which can extend over long periods e.g. SMARTS. Operate in Q mode.
- General-purpose, single-instrument, available for long (multi-week) runs e.g. IRSF. Operate in Classical mode.

- General-purpose, survey mode capable of producing fundamental catalogs e.g. WFCAM, Vista, PanSTARRS. Operated by observatory staff.
- Dedicated science projects, survey mode which generates huge databases with spin-off potential e.g. SuperWASP, KELT. Robotic operation.
- General-purpose, single-instrument, available for many programs which can extend over long periods e.g. Monet. Robotic operation.

9. Final Thoughts

Gemini was driven to Q-scheduled mode by the obvious desire to always exploit the best observing conditions with the optimal science programs, but was then surprised by the alacrity with which this was taken up by the astronomy community. Given the huge investment contemplated for the current ELT designs, the need to exploit the extant conditions at all times will be even stronger, making 100% Q-mode operation inevitable.

Does this mean that the current 8-10m suite of telescopes will undergo a dramatic change in their modus operandi once the ELTs are functional, in the same way as has happened for 2-4m class telescopes? It is interesting to note that there are as many 8-10m class telescopes (nine) as there are 4m-class, a situation that was not anticipated 20 years ago. However, the cost of the ELTs and their associated technologies is vastly greater than that of the 8-10m telescopes, and so we consider it unlikely that there will be a comparable growth in the number of ELTs. Consequently, and bearing in mind that the first of the ELTs (TMT) is still a decade away from commencing operations (http://www.tmt.org/timeline/index.html), we believe that the 8-10m telescopes will be at the forefront of ground-based optical/IR astronomy for a substantial period of time.

Nevertheless, the ELTs will need supporting research and survey material from which to optimise their observing programs, and the 8-10m telescopes will play a large role in this, in much the way that the small telescopes described in section 8 are doing right now. There will be a need, for example, for narrow-field surveys and faint object monitoring, both of which SALT would be well suited to.

Hence, in 2020 and beyond, we expect the ground-based telescope population to have evolved into 4 basic classes:

- ELTs (probably just 3, TMT, GMT and E-ELT), operating in Q-mode
- 8-10m (~10-15), mostly Q, some classical
- 2-4m (~30), mostly classical, some Q
- <2m small/robotic (hundreds, possibly thousands).

As we have attempted to describe here, the modes of operation, and hence the scientific areas addressed, will be very different. But we fully expect them to function in a highly complementary way, and all to be doing world-class science.

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11. References

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