SALT FOUNDATION (PTY) LTD

Southern African Large Telescope

Africa's Giant Eye on the Sky:
Inspiring society by exploring the Universe

SALT Strategic Plan Document (June 2018)

Executive Summary

This document sets out the vision and mission of SALT, briefly discusses the current status of the science and instrumentation highlighting the strengths of the telescope, and presents the SALT strategy for the next five to ten years, as agreed upon in the November 2017 Board meeting. The strategy involves new investments, while at the same time capitalising on SALT's existing strengths and future collaborations, with e.g. MeerKAT/SKA and LSST. The plan specifies ambitious goals for transforming the telescope into a world-leader in carefully selected research domains. In particular, three science focus areas will drive future development and decisions: Transient and time-domain astrophysics, baryon cycle and galaxy evolution, and exoplanet science. Two new spectrographs (a simple high-throughput one, and a large format IFU) are recommended to be built to serve those drivers, current instruments will receive significant upgrades (e.g. the high-stability mode of HRS), and a feasibility study is to be undertaken to explore a way to revolutionise how SALT observes in the future. Furthermore, these science fields are wrapped together in an aggressive plan to increase the level of skills and capacity in local, SAAO-based astronomical instrumentation development, in part by purposefully working together with experts from within the SALT Partnership. Also, the recently approved new SALT and SAAO SARChI positions align extremely well with the science drivers and corresponding instruments. The plan is designed to serve both the SALT Foundation and the knowledge and technology economies of South Africa. An initial implementation plan is outlined, and funding mechanisms are briefly discussed. New South African funding in 2018 has secured the way forward for the next 1-3 years, but the full realization of this Science Strategy will require commitments from other partners as well as attracting new interest.

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1. SALT Vision

Africa's Giant Eye On The Sky:
Inspiring society by exploring the Universe

2. SALT Foundation Mission Statement

- Provide a world-class large telescope research facility cost-effectively to an international community of astronomers.
- Lead the advancement and development of optical astronomy on the African continent, and inspire and educate new generations of scientists and engineers worldwide.

3. Current Status of SALT

For the purposes of benchmarking SALT performance indicators and output, comparisons with the Hobby Eberly Telescope (HET) are useful because of the very similar telescope design, as well as with the Large Binocular Telescope (LBT) and the Gran Telescopio Canarias (GTC) that were completed at approximately the same time as SALT. Performance indicators should be compared as a function of time since the start of full science operations.

3.1. Telescope and Instruments

SALT is a 10-m class fixed-altitude segmented-mirror telescope, located at one of the darkest observing sites in the world, near the town of Sutherland in the Karoo semi-desert region of South Africa. ***Appendix A*** gives a brief history of the project. Detailed ***telescope and site characteristics*** are listed in ***Table B*** in the Appendices.

SALT currently hosts four instruments: the Robert Stobie Spectrograph (*RSS*), the SALT Imaging Camera (*SALTICAM)*, the High Resolution Spectrograph (*HRS*) and a visitor instrument, Berkeley Visible Image Tube camera (*BVIT*). These offer science users a wide range of spectroscopic and imaging capabilities across the optical regime, from 320 nm to 950 nm. These include low and medium resolution long-slit and multi-object spectroscopy, high resolution single object fibre-fed spectroscopy, polarimetric and Fabry-Pérot capabilities, high time resolution modes in both imaging and spectroscopy, and narrow-band imaging.

More detailed ***instrument characteristics*** are listed in ***Table C*** in the Appendices.

3.2. SALT's Forté

- SALT is, first and foremost, a *spectroscopic telescope.* Due to its operating mode and design, it is most efficient when employed as a survey telescope, with a wide range of targets available in the observing queue.
- The telescope's large collecting area and Sutherland's dark skies mean that highly competitive results can be obtained for diffuse, low-surface-brightness objects.
- Brighter targets – where most of the light is above the sky background, regardless of the seeing – can be observed very efficiently.
- There are several spectroscopic options available, including multi-object and Fabry-Pérot capabilities, as well as polarimetric modes, some of which are rare on large telescopes.
- Operationally, SALT is capable of rapidly changing modes and instruments on-the-fly, and can respond to sudden events and requests (e.g. targets of opportunity) during a night.

3.3. Recent SALT Science

The purpose of this section is to *inform* the SALT strategy by presenting examples of successful and efficient science done with the telescope up until late 2017. These programs have often taken advantage of the SALT's strengths. However, this is not a comprehensive list of science projects that SALT ought to be doing, or concentrating on – the SALT science vision is discussed later in this document.

Many types of spectroscopic survey programs, needing dozens, or even hundreds, of targets distributed over the Southern sky, from Galactic stars to quasars, are well served by SALT's capabilities. Surveys in the Magellanic Clouds make use of the long, continuous visibility window of the telescope at that Declination. Large spectroscopic samples of e.g. Symbiotic stars, RR Lyrae and other variables, ultra-cool dwarfs and extremely metal-poor stars have been gathered, while large redshift-determination programs of distant lensing candidates and quasar candidates are underway, as well as variability monitoring of assorted types of objects. Such surveys with the RSS are currently efficient to approximately V~22 mag.

Similarly, transient object science, especially when there are large numbers of targets available, has been highly successful. For example, surveys such as DES, ASSASN, Gaia, and MASTER (which has a telescope on the Sutherland site as well), provide a wide variety of targets for SALT essentially every night, and a number of these have yielded high-profile results. Our rapid spectroscopic follow-up of the GW170817 gravitational wave event is an example of such successful observation. In addition to a significant number of Supernovae, SALT also regularly targets other eruptive variables (particularly novae and X-ray binaries), tidal disruption events, and gamma ray bursts.

Studies of kinematics of diffuse ionised gas and its characteristics in galaxies, of warm and cool gas inflows and outflows, star-formation, AGN, and galaxy evolution feedback processes, as well as chemical abundance studies (of both local and medium-redshift targets) are research areas that capitalise on SALT's strengths. The SALT field of view is ideally suited to galaxy cluster studies that employ the multi-object spectroscopy mode of the RSS. The introduction of active mirror alignment will encourage further growth in this research field.

Fabry-Pérot spectroscopy is rare on large telescopes and offers promising results for kinematics of nearby galaxies, from spirals to dwarfs to star-forming early type galaxies and interacting systems.

It is expected that interest in such studies will rise when all of the FP modes are fully commissioned. Likewise, the polarimetric capabilities now coming online are rare, and both stellar and extragalactic surveys are likely to make an impact in the future. The High Resolution Spectrograph has started to produce its share of papers following the implementation of fully automated data pipelines in early 2017. The instrument's specialised High Stability mode will be exploited for exoplanet science once precision radial velocity data reduction can be made available to users.

Early SALT science concentrated on using the rare high-speed photometric and spectroscopic capabilities of the telescope. Science includes pulsating stars, cataclysmic variables and other types of binary stars. Phase-constraints limit the efficiency of time-domain programs, though larger parent samples in a given program will make such studies more practical.

3.4. SALT Publications

Currently (as of late 2017) there are over 180 refereed publications based on SALT observations in the literature, including four *Nature* or *Science* papers, and a further 20+ refereed SALT papers that are instrumentation related, or survey descriptions. In addition, there are more than 90 SALT papers in the SPIE Astronomical Telescopes and Instrumentation conference series, the world's premier conference on these topics, highlighting the strong record of publishing technical developments at SALT. The annual refereed publication rate has increased steadily and reached 50 papers in the 2017 calendar year.

Statistics of the SALT data publications give an indication of successful SALT science, although many successful but more challenging, and longer-term, programs are underway and have yet to yield published results. Several of the most-cited SALT papers are SDSS SN survey related analyses. Strictly considering the top ten cited papers to date that involve analysis of SALT data (the SALT *data* papers), one is the main gravitational wave multi-messenger paper from 2017, two are traditional extragalactic papers, three involve stellar studies (though one of these analyses an exoplanet signal as well), and four are on Supernovae (performing spectroscopic typing and other analyses).

The table below shows statistics of the number of papers per topic, or category. We have included the several gravitational wave papers in the Supernova category here, representing the bulk of the transient science. Fractions are similar if statistics are done on *programs* contributing to the papers, with the Supernova and extragalactic fractions slightly higher than the respective values below.

N = 180 refereed SALT *data* papers (11/2017)	
Stellar	53%
Extragalactic	30%
Supernova follow-up	13%
Solar System	2%
Target-of-opportunity (ToO)	20%
More than 10 targets/observations	14%

The largest field of SALT science has thus been Galactic stellar objects, dominated by an assortment of variable stars, especially cataclysmic variables, symbiotic stars, white dwarfs and novae.

Of the published extragalactic programs, approximately 60% concern the nearby Universe, local dwarf and early-type galaxies, and star-forming galaxies. Higher redshift objects account for the rest. Two thirds of this latter class of papers deal with active galactic nuclei and quasars, and the other third involve galaxy clusters.

Supernova follow-up has been a successful field, contributing 12-15% of SALT papers, depending on the manner of counting, and making a very large impact when considering citations. ToO observations in general have thus far generated a fifth of all science papers, more than their share of observing time.

Instrument and mode statistics clearly show that the RSS, and its long-slit mode in particular, is SALT's workhorse. Considering programs since the start of science operations in 2011, 88% have been based on RSS. HRS statistics are affected by the fact that the instrument has only been in scientific operation since late 2014 (with its pipeline released in 2017), yet the percentage was already close to 10% near the end of the 2017 calendar year.

N = 240 *programs* contributing to the SALT data publications above (11/2017)		
RSS	88%	
Long-slit		92%
Multi-object		7%
Fabry-Perot		1%
SALTICAM	6%	
High time resolution		50%
HRS	4%	
LR		30%
MR		50%
HR		20%
BVIT	2%	

The vision for future SALT Science is discussed below in Section 6 and in the five- and ten-year strategy sections. A rigorous development of operational and technical capabilities is necessary for SALT to be successful and relevant. The following sections concentrate on these aspects.

3.5. Near-Future Capabilities and Improvements

While SALT is running well in full science operations, there are several recent or on-going projects to maximise efficiency and commission new observing modes.

The details of these items are listed in ***Table D*** in the Appendices. In particular, 2016 saw the full implementation of the active primary mirror alignment system, commissioning of polarimetric modes began in 2017 and continue during 2018, while near-infrared spectroscopic capabilities are scheduled to arrive in 2019.

4. Strategic Goals

1. **Enable world-leading astrophysical research:**

   To provide high-quality data that result in highly-cited papers published in front-rank journals. This is achieved by maximising SALT's scientific productivity, i.e. minimising technical downtime and optimising operational efficiency. The goal is contingent on having the financial resources to support operational needs and to nurture and retain a cohort of skilled and creative staff, and enabling them to identify and pursue key scientific and technical initiatives.

2. **Pursue instrumentation development:**

   To establish the local skills and capacity required to design and build internationally competitive astronomical instrumentation. This calls for leveraging expertise available within the SALT partnership and other international instrumentation groups, to build active collaborations that drive technological innovation and skills transfer, and ultimately enhance SALT's capabilities. This too relies on securing the necessary financial support, for both equipment and people (staff, students, interns and apprentices spanning a broad range of levels).

3. **Drive human capital development and science engagement:**

   To employ this iconic facility and the ubiquitous appeal of astronomy to encourage widespread interest in science and technology. This requires outreach to undergraduates, schools and the general public, and training of graduate-students. There will be a special focus on developing and leading professional astronomy and high-tech astronomical instrumentation on the African continent. The goal also requires promoting SALT as a global flagship optical telescope, increasing its visibility and growing its reputation in the international scientific community, as well as national and international media.

5. SALT Short-Term Priorities

The SALT Operations Team prioritises projects and tasks biannually the better to serve the SALT user community by fixing known issues on the telescope and by making sure that approved projects are efficiently carried out with the available resources. A SALT Scientific and Technical Committee (STC), led by a Telescope Scientist, will be formed in 2018 to oversee these activities. The projects are aimed at improving the telescope's data quality and operational efficiency, in keeping with the strategic goals, and to reach or surpass the design specifications.

The successful integration of the primary mirror alignment system (SAMS), and a project to extend the time SALT can safely observe in humid conditions are examples of recently completed high-priority projects. The latest list of projects was discussed and approved in November 2017 and the highest priority tasks identified for the period until mid-2018 are presented below.

Approved 6-month Top Priority Projects	
Priority Project	**Targeted Capability**
New guider for RSS	MOS mode; higher obs. efficiency
Maintenance shutdown (March/April 2018)	Fix and maintain crucial sub-systems, install new components (e.g. new RSS guider)
HRS HS mode (Iodine Cell)	Extending SALT capabilities
NIR spectrograph development	Extending SALT capabilities
Spherical Aberration Corrector throughput	Faint target science; higher obs. efficiency
Fabry-Pérot operations overhaul	Enhanced science output; higher obs. efficiency
RSS collimator upgrade	Enhanced science output; higher obs. efficiency
HRS software fixes	Higher obs. efficiency
Automatic queue-scheduler	Enhanced science output; higher obs. efficiency

Examples of project topics (likely) to join the short-term list of priorities for the SALT Operations Team during the next 1-2 years include:

SALT 1-2 Year Priorities	
Priority Project	**Targeted capability**
Payload overhaul	More efficient target acquisition; Enabling accurate blind-offsets
Extending automatic data pipelines	Enhanced SALT science output
Laser Frequency Comb for Exoplanet science	Extending SALT science capabilities
NIR spectrograph integration	Extending SALT science capabilities
New high efficiency spectrograph for Transient science	Extending SALT science capabilities
Fully understanding tracker, pupil, payload, instrument and detector issues and effects	Calibrated spectrophotometry; Accurate flat-fielding; Nod-and-shuffle for MOS and long-slit; Accurate relative photometry
Non-sidereal tracking	Solar-system science
Automated Observing Control System	Higher obs. efficiency
New SALTICAM guider	Deeper imaging; quality high-speed data
Feasibility study of a multiple mini-tracker concept	Radically extending SALT science capabilities

Feasibility study of deployable 2nd generation IFU instruments	Radically extending SALT science capabilities

6. SALT Science Strategy into the Future

Increasing numbers of SALT users, having come to understand the telescope and instruments better, are making productive use of the facility and the publication output is increasing steadily. Operational efforts continue to enhance the performance of the entire system, on both the technical and scientific fronts, from the observing proposal phase, all the way through to the daily electronic delivery of pipeline-reduced data products. Data quality is monitored, statistics are captured, new instrument modes are being commissioned on existing instruments, a fibre-fed near-infrared spectrograph is being developed at the University of Wisconsin and regular SALT science workshops are being arranged to facilitate more interaction among SALT users, and between users and the Operations team.

In short, SALT is operating as originally envisaged, and the current mode of operations is highly successful. However, it is also clear that to retain scientific relevance a decade into the future, SALT has to develop more than incrementally. It is inevitable that current instrumentation gradually becomes obsolete, both technically and scientifically. Hence the need for a science-driven strategic plan with which to chart our course.

In 2016 the Board approved the plan that SALT will continue operating largely as a general-purpose telescope doing PI-driven science, but that it would also actively seek to design and execute large scientific projects. Following this decision, the *details* of future SALT science were actively discussed by the SALT community during the following year, and the Board ratified the resulting recommendations in November 2017. Three areas of science were selected to pursue strategic goal 1) set above (Section 4), and the importance of instrumentation development, goal 2) above, was stressed for the strategic sustainability of SALT. Decisions about next-generation instrumentation will be in line with these fundamental drivers.

The strategy involves new investments, while at the same time capitalising on SALT's existing strengths and future collaborations, with e.g. MeerKAT/SKA and LSST. The plan specifies ambitious goals for transforming the telescope into a world-leader in carefully selected research domains. A recent example of the type of science proposed is SALT's significant contribution to the electromagnetic follow-up of the GW170817 gravitational wave event that marked the birth of multi-messenger astronomy.

The plans presented directly benefit the SALT Partnership, as well as a wide range of South African science and technology communities and the knowledge economy. The plan calls for determined development of new instrumentation, by bringing together expertise from within the SALT Partnership, and with the explicit purpose of developing in-house and South African high-tech capacity in support of strategic goal 3).

The various aspects of a long-term sustainable SALT strategy, namely the science focus areas, the type of instrumentation required to support the science, and the development work and funding mechanisms needed to realise these plans, are discussed, in turn, below.

6.1. SALT Science Focus Areas

- ***Understanding fundamental physics and the nature of the Universe: Transient and time-domain astrophysics*.** The SALT community has a firmly established interest in this area. An essential step is to continue optimisation of the observatory to support LSSTcadence time-domain studies, including sophisticated decision-making software and networking with other instruments. The recent LIGO gravitational wave event and the rapid follow-up performed at SALT and SAAO is an example of this science area. MeerKAT, along with the MeerLICHT connection, will soon offer South Africa a globally-unique new window into this exciting field.

- ***Tracking the flow of matter from stars and galaxies to us*: *Baryon cycle and the low-surface-brightness Universe*.** Galaxy evolution remains one of the largest and most active fields in astronomy. The Karoo night sky is extremely dark, while the stability of the atmosphere (seeing) is modest – thus, studying the nearby Universe to extremely faint levels and in great detail is a global niche. A niche that SALT is well placed to exploit, given its massive light-gathering power, and the characteristics of the Sutherland site. Galaxy evolution is also a Key Science driver for SKA/MeerKAT and hence it offers potential for powerful multi-wavelength synergies.

- ***Finding life in the Universe: Exoplanets and their characteristics.*** It may well be that the highest-profile astronomy research in future decades will be dominated by the search for life outside the Solar System – much the way that the largest international astronomy projects of decades past were dominated by the drive to understand the beginning of the Universe. SALT already has an excellent instrument for detecting and characterising classes of exoplanets, in the form of the HRS. Also, in the future, the SKA will make a significant impact in studying complex molecules in "cradles of life". This area must be pursued for the SALT community to be relevant in the decade to come.

6.2. Next Generation SALT Instruments

The identified focus areas will require additional SAAO-based engineering capacity to develop new software and astronomical instrumentation. The transient and baryon cycle fields above call for complementary new SALT instruments in the short- and medium-term, respectively:

- An **extremely efficient**, internationally competitive, **single-object spectrograph** serving the Transient science domain. This will be a "1.5-generation" SALT instrument, required within the next two years if it is to overlap with MeerKAT and capitalise on the enormous scientific potential associated with local multi-wavelength synergies. Immediate funding is necessary if this instrument is to be developed on the required timescale.
- **A large area integral field unit (IFU) spectrograph**, capable of spatially-resolved spectroscopy over a field of view competitive with similar instruments at other international observatories, and deployable over the SALT field of view. The recommended size is at a 1 to 2 arcmin scale. This true 2nd-generation SALT instrument, to serve the baryon cycle science case, will be needed in operation on a five to ten year timescale.

In addition, the exoplanet and transient science fields in particular require significant software engineering development for world-class results. These should be seen as part of the SALT 1.5-generation package, with the transient science software development also extending to longer term.

- Making sure the existing **HRS instrument's High Stability (HS) mode** is ready to observe exoplanet radial velocities in the 1 to 10 m/s range using new pipelines and new and/or upgraded calibration facilities (e.g. a Laser Frequency Comb and a carefully calibrated Iodine cell). This is a short term high priority.
- Making sure the 1.5-gen transient spectrograph is ready to receive automatic triggers from a number of sources and network together intelligently with other

Sutherland based telescopes and instruments. The first part of this project should concentrate on linking the SAAO-owned telescopes together with SALT with versatile remote and/or robotic operations, while the longer term goal would be a "**Sutherland Plateau Artificial Intelligence**" concept.

6.3. Developing Instrumentation and people

In pursuit of the above science focus areas, it is essential that the SALT Foundation emphasises instrumentation development, as a way to support its long-term goals and also to drive high-end skills development within the Partnership, particularly in South Africa.

Becoming self-sufficient in terms of developing new instruments will require an entirely new level of engagement. The new SAAO and SALT SARChI positions will have a significant and extremely timely impact in this regard, since both have a strong instrumentation focus, and their respective science interests align exactly with the two new instruments listed above.

The SALT partnership also hosts a wealth of instrumentation expertise, and past collaborators (such as the HET, Durham University's Centre for Advanced Instrumentation and the Ultrafast Optics group at Heriot-Watt University) remain eager to work with SALT on future projects. It is vital for SALT and SAAO to draw on these worldwide specialists to learn from them, and create opportunities for young scientists, engineers and technical people to spend time embedded in international instrument teams. Such experiences cement long-term collaboration and can lead to projects that will ultimately deliver new capabilities to SALT and the rest of the Observatory, e.g. a laser frequency comb (LFC) for SALT HRS, but which could potentially be distributed to serve other high-resolution spectrographs on the Sutherland plateau.

Aggressively exploring a radical new concept, conceived to capitalise on SALT's highly unconventional spherical primary mirror, will provide a superb opportunity for SALT to pursue hands-on instrumentation research-and-development in the short term. Investigating the possibilities for deploying at least one "mini-tracker" on the telescope will require iterative designing, prototyping and testing in all the major engineering disciplines associated with astronomical instrumentation, creating an ideal environment for student training. This process could proceed without disrupting normal science operations, but if successful it would allow SALT to simultaneously observe a second target located somewhere within several degrees of the main target. The implications of then being able to deploy some number of mini-trackers, each of which effectively yields *another* SALT, are revolutionary in the upcoming era that will be defined by the torrent of LSST transients requiring spectroscopic follow-up. By vastly expanding the available field of view of the telescope, these "mini-trackers" would multiply the number of transients that SALT can observe in a night, opening up swathes of parameter space un-accessible to other telescopes.

6.4. Funding of Future Developments

The SALT Development Fund was closed in November 2017, with approximately 90% of the target value of R76M reached. The Board also agreed that the outstanding balance would be funded by the relevant Partners selling observing time from their time allocations to either other Partners, or outside parties. The originally agreed-upon Development Fund is hence concluded, and most of the Fund has already been used for the successful primary mirror active alignment system (SAMS) and the tracker upgrade project, or committed to near-future projects such as the RSS collimator throughput enhancement work and the new near-infrared spectrograph.

The remaining Development Fund cannot cover new SALT instrumentation on the scale required to support the strategic goals outlined above. The science focus areas and the corresponding instrumentation will require new sources of funding, either from existing Partners, or from new partners. The existing Partners have already agreed to decreasing their time allocations in the event that new Partners are found.

Finding new Partners, as well as securing funding for the immediate instrumentation needs, remains an extremely high priority for the Board.

7. SALT Five-Year Strategic Goals

- Establish SALT as a world-leading Transient object follow-up machine in the 19 to 22 magnitude brightness range, with the help of a new SALT instrument, an extremely efficient work-horse spectrograph (the MaxE proposal), and artificial-intelligence-type algorithms used to network facilities on the Sutherland observing plateau.

- Establish SALT as a world-leading radio-transient follow-up machine in particular, capitalising on MeerLICHT and MeerKAT and synergies.

- Build strong links with cutting-edge science projects due to start towards the end of this time-scale, LSST and SKA in particular.

- Execute regular, active, multi-wavelength surveys together with MeerKAT programs, in all the science focus fields.

- Establish SALT as a key player in southern-hemisphere exoplanet work, by securing 1 to 10 m/s precision radial velocities with HRS, working together with TESS and other Exoplanet space missions.

- Have secured funding for and commenced building a deployable IFU instrument of at least 1 arcmin in field of view.

- After conducting the necessary feasibility studies, be ready to unveil a revolutionary multiple-mini-tracker concept for SALT.

- Have at least one new full-time ≥10% partner join the SALT consortium.

- Have an expanded and active instrumentation development program running at SAAO.

- Have built on the precedent set by the LFC field-trial conducted at SALT in 2016 to establish a culture of hosting and testing experimental astronomical instrumentation.

8. SALT Ten-Year Outlook

It is difficult to imagine the ways in which the various extraordinary new facilities that are due to be online within the coming decade (e.g. MeerKAT, LSST, JWST, additional LIGO experiments, the Extremely Large Telescopes, etc.) will transform the current astrophysical landscape. The SALT Board, together with the STC, the SAAO director, and the SALT Operations team will commit to staying in touch with the cutting-edge of world-wide scientific astrophysics developments to guide 2nd and 3rd generation projects.

Transient follow-up will surely be an enormous industry and SALT will be extremely well placed to contribute significantly, given its long and productive track-record in this field. If the full potential of mini-trackers can be realised, SALT will be *absolutely unique* in its ability to pick off vast numbers of transients – perhaps cornering a specific market by focusing on a particular type of object and observing large numbers of them, or else building up statistics for various classes of objects, possibly even uncovering and characterising entirely new classes of variables that reveal previously-unseen physical phenomena?

Exoplanet science will undoubtedly continue to astound us, particularly once the JWST is able to obtain spectra of planetary atmospheres, to search for biological signatures that indicate the presence of life. It is remarkable that we could be within a decade or two of detecting life elsewhere in the Universe. SALT HRS will hopefully have played a part in the exoplanet gold-rush, by contributing ground-based observations, radial velocities in particular, to support the TESS exoplanet mission responsible for preparing target lists for the JWST.

Although it is virtually impossible to know what the most compelling science will be decades into the future, it is well established that competitive instrumentation always offers a massive advantage. Being able to design and build equipment that leverages technological progress and seeks to address the burning questions of the time sets observatories with strong instrumentation groups aside from those limited to buying instruments from others.

As the host and operator of SALT, the SAAO aspires to ultimately being equipped to drive state-of-the-art instrumentation development on the African continent, providing scientifically productive tools to local and international astronomers. This development channel also produces extremely valuable by-products, in the form of technically-skilled individuals, sensitised to the type of discipline and critical, analytical thinking and team-work that precision instrument work demands. These highly transferrable skills are incredibly important when confronted with real-world problems that desperately need solving, particularly in a country like South Africa.

9. Implementation Plan (updated May 2018)

A detailed implementation plan pertaining to this Strategic Document is presented separately. The (future) Scientific and Technical Committee (STC), together with the SAAO Director and the SALT Operations team, will make recommendations to the Board on the implementation road-map. Only the most immediate steps with broad timescales are summarised here:

- Form the STC to oversee prioritisation of short-term SALT projects and coordinate the implementation of the Strategy discussed in this document (mid 2018)
- Secure funding for the 1.5-generation instrumentation package: MaxE instrument with the associated human resources and software development; software and hardware development for HRS high-stability mode (**secured in April 2018**)
- Start building MaxE (early 2019)
- Obtain 1 – 10 m/s radial velocity accuracy with HRS/HS (mid 2019)
- Integrate RSS NIR arm (mid/late 2019)
- Commence an in-depth feasibility study for the mini-tracker concept (2019)
- Have a detailed plan in place for attracting and securing significant new funding (2019)
- Build a new RSS slitmask IFU (2020)

- Decide on the priorities of Generation 2.0 projects after feasibility studies; in particular consider *large format deployable IFUs* in the normal tracker field-of-view and/or *multiple mini-trackers*. (2020-2021)

Appendices

A – SALT History and Operation Mode

The Southern African Large Telescope (SALT) is the largest single optical telescope in the southern hemisphere and amongst the largest in the world. It has a hexagonal primary mirror array 11-m across, comprising 91 individual 1-m hexagonal mirrors. The light gathered by its huge mirror is fed into a suite of instruments (an imager and two spectrographs) from which astronomers infer the properties of planets, stars and galaxies, as well as the structure of the Universe itself. SALT is the nearly-identical twin of the Hobby-Eberly Telescope (HET) located at McDonald Observatory in west Texas.

SALT is owned by the SALT Foundation, a private company registered in South Africa. The current shareholders of this company include universities and science funding agencies from South Africa, India, Europe and North America. The South African National Research Foundation (NRF) is the major shareholder with an approximately 1/3 stake. Other large shareholders are the University of Wisconsin-Madison, the Nicolaus Copernicus Astronomical Centre of the Polish Academy of Sciences, Dartmouth College, and Rutgers University. Smaller shareholders (<10%) include the Indian Inter-University Centre for Astronomy and Astrophysics, the American Museum of Natural History, the University of North Carolina and the UK SALT Consortium, the latter representing the Universities of Central Lancashire, Keele, Nottingham and Southampton, the Open University and the Armagh Observatory. The size of the shareholding of each partner determines the access to the telescope which they enjoy.

SALT is located at the observing site of the South African Astronomical Observatory (SAAO), near the small town of Sutherland, about 400 km north-east of Cape Town in the Karoo. This site has been host to a number of other smaller telescopes since the early 1970s, and benefits from location in a semi-desert region with clear and very dark skies. The quality of this site for optical astronomy is preserved by South African legislation.

SALT is operated in “service mode”, it is a fully “queue scheduled” observatory without visiting astronomers. The SAAO is tasked with operating SALT with a team of astronomers and engineers funded by the SALT Foundation. Observing time is allocated to astronomers through a competitive peer-reviewed proposal process, per partner, on a 6-month schedule. Accepted programs are submitted to the SALT Operations team who manages the scheduling and execution of the observations, as well as the data reduction and data delivery to all users. In this sense, SALT is a normal general-purpose telescope for the user community. However, there are more and less efficient ways of using SALT, which derive from its characteristics.

B – Telescope and Site Characteristics

Sky Access:	• DEC range: +11 to -76 degrees • Fixed altitude, typically 1 hour tracks, up to 4h, with a moving prime focus
Field of View:	• 8 arcmin science FoV for RSS and SALTICAM
Wavelength coverage:	• The instruments operate in wavelengths between ~3200A and ~9500A.
Image quality:	• Seeing-limited with median effective FWHM of about 1.5 arcsec on the detectors
Tracking accuracy:	• Closed-loop telescope position is stable and offsets can be done with rms 0.3 arcsec accuracy • Rotation is currently open-loop with drifts up to 0.05 deg per hour
Instrument availability:	• Rapid instrument selection makes for flexible operations and increase in science efficiency
Relative (spectro) photometry:	• Telescope pupil changes during an observation • Relative photometry can be done down to a few percent accuracy over the whole field, limited by flat-fielding currently • Higher accuracy can be achieved for individual sources using close-by reference stars, e.g. in high-time resolution observations • Absolute fluxes can be obtained using supplementary calibration information of the target fields

	• Spectral shapes are calibrated using nightly spectrophotometric standard stars
Cost-effective:	• Building and operating costs at level of international 4-m class telescopes • Science output as measured by refereed papers is on a par with international 10-m class telescopes
Sutherland site	• Night sky is very dark, ~22 mag/sq.arcsec in V-band with no artificial sky spectral features • Seeing is modest with intrinsic ~1.4 arcsec zenithal V-band median • Approximately 60% of annual night-time is available for on-sky observations

C – Instrument Characteristics

RSS:	• Low to medium resolution spectroscopy • Observing modes: a. Long-slit spectroscopy b. Multi-object spectroscopy c. High time resolution spectroscopy d. Fabry-Pérot imaging spectroscopy e. Narrow-band imaging • Grating spectroscopy modes (a), (b), and (c) provide spectral resolving power (R=λ/δλ) from 250 to 5500 for 1.25 arc-second slits, over the spectral range 320-900 nm (R to 9000 for 0.6 arc-second slits). • Continuous time-resolved spectroscopy with temporal resolution of a few seconds is available via frame transfer for all grating modes, and long-slit slot mode spectroscopy gives time resolution of 0.05 sec • Fabry-Perot mode provides spectroscopic imaging with R=300 to 8000 over the spectral range 430-860 nm using four different setups • Narrow band imaging (R~50) is available over the spectral range 430-890 nm • Linear and circular polarimetric capabilities associated with each mode
HRS:	• Dual-beam (370-555 nm and 555-890 nm) fibre-fed, white-pupil, échelle spectrograph, employing VPH gratings as cross dispersers • HRS is a single-object spectrograph with simultaneous sky measurement, using pairs of optical fibres • Three resolving power modes

	○ R ~16,000 (unsliced 500 µm fibres), ○ R ~37,000 (sliced 500 µm fibres) ○ R ~67,000 (sliced 350 µm fibres). ○ High stability mode at R~67,000 employing fibre double-scrambling and optional iodine cell or simultaneous ThAr calibration injection
Imaging:	• SALTICAM is the main imaging instrument, also used as the acquisition camera • Provides seeing and image quality-limited imaging over the spectral range 320-900 nm for the full 8-arcminute science field of view of the telescope • Filters include standard Johnson-Cousins, Sloan, and Strömgren sets and also Hα, 380 nm, and neutral density • Operating modes: ○ Full-field normal imaging ○ High speed frame transfer ○ High-speed slot-mode offers high-time-resolution imaging at up to 10 Hz • BVIT ○ Photon-counting camera with a ~1.3-arcmin diameter FoV, capable of very high time resolution (millisec or microsec) photometry with a B, V, R or H-alpha filter ○ Suitable for objects with magnitudes ranging from V~12-20

D – Near-future Capabilities and Improvements

System Throughput:	• The SALT telescope system (including the primary mirror, the spherical aberration corrector SAC and the atmospheric dispersion corrector ADC throughput) is at approximately 65% • The primary mirror is kept clean continuously • A partial SAC clean is scheduled for 2018, with a goal to taking the telescope throughput to the specification level of approximately 75% • RSS optics are cleaned every 2 years to maximise its efficiency
RSS FP modes:	• Dual-etalon mode was commissioned in 2017 to use for HR mode observations, though with reduced throughput pending further repairs • MR etalon coatings have to be repaired for that mode to return
RSS Polarimetry:	• All spectrographic modes of RSS allow spectro-polarimetry • The Wollaston beamsplitter mosaic has been fixed and point-source linear polarimetric modes are available to users. Diffuse object polarimetry and circular polarimetry are being commissioned in 2018
Primary Mirror Alignment System:	• The original system for active alignment of the primary mirror segments failed, primarily due to the effects of site humidity • The new system was delivered and tested and started successful operation in May 2016. This has greatly improved both the delivered image quality and the observing efficiency of the telescope • Deeper imaging by stacking is now possible; flat fielding issues will need to be solved separately

NIR Spectroscopy:	• RSS was designed to accommodate a second near-infrared beam, it will extend the spectrograph wavelength range to 1.7 microns • The current plan has the NIR arm delivered in mid-2019 and to function as a fibre-fed instrument employing a ~25 arcsec IFU system

E – List of Acronyms

ADC atmospheric dispersion compensator
AGN active galactic nucleus
ASASSN All Sky Automated Survey for SuperNovae
BVIT Berkeley Visible Image Tube camera
DES Dark Energy Survey
FP Fabry-Pérot
FWHM full width half maximum
GTC Gran Telescopio Canarias
HET Hobby-Eberly Telescope
HR high resolution
HRS High Resolution Spectrograph
HS high stability
IFU integral field unit
JWST James Webb Space Telescope
KAT Karoo Array Telescope
LBT Large Binocular Telescope
LFC laser frequency comb
LIGO Laser Interferometer Gravitational-wave Observatory
LR low resolution
LSST Large Synoptic Survey Telescope
MASTER Mobile Astronomical System of the Telescope-Robots Network
MaxE Maximum Efficiency (spectrograph)
MeerKAT Meer-Karoo Array Telescope
MeerLICHT More Light (in Dutch), optical slave to MeerKAT
MOS Multi Object Spectroscopy
MR medium resolution
NIR near-infrared
NRF National Research Foundation
PI principal investigator
RSS Robert Stobie Spectrograph
SAAO South African Astronomical Observatory
SAC spherical aberration corrector
SALT Southern African Large Telescope
SAMS SALT array management system (i.e., active mirror alignment system)
SARChI South African Research Chair Initiative
SDSS Sloan Digital Sky Survey
SKA Square Kilometre Array
SN supernova
STC Scientific and Technical Committee
TESS Transiting Exoplanet Survey Satellite
ToO target of opportunity
UK United Kingdom