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

(draft for Nov 2023 Board – version 22 Sep 2023)

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 analyses the science output of the telescope thus far, comparing it to other observatories of the same class. While the high-level SALT operational philosophy and main science fields as agreed upon in 2017/2018 remain in place, the strategy is updated for the next five to ten years, including details and motivations for recommended directions and activities in this timescale. The strategy involves calls for new investments, while at the same time capitalising on SALT's existing strengths and on-going and future collaborations. The plan specifies goals for building the telescope into a world-leader in carefully selected research domains. In particular, the three chosen science focus areas will drive development and future decisions: Transient and time-domain astrophysics, baryon cycle and galaxy evolution, and exoplanet science. Significant capability enhancing work is currently underway based on the recommendations made 3-5 years ago, such as a Laser Frequency Comb for precision radial velocities, and upgraded capability for transient follow-up spectroscopy. SALT's first infrared instrument NIRWALS is also being commissioned. Science-ready data pipelines are being developed for all observing modes. Nevertheless, decisions must now be made for future 2nd Generation instrumentation; a large format deployable IFU has already been recommended as one such option. A major telescope "top-end" upgrade is also recommended to enhance SALT science output and quality. Furthermore, the strategic science fields are wrapped together in an active 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 – this is designed to serve both the SALT Foundation and the knowledge and technology economies of South Africa. SALT funding mechanisms are briefly discussed in the document. New South African funding that started in 2018 (the SALT Generation 1.5 Project) has bridged a gap in development of capabilities for the 2020s, but the full realisation of this Science Strategy will require commitments from other partners as well as attracting new interest. Finally, the vital connection between SALT and African astronomy, and its development, are highlighted in this document.

Table of Contents

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

In this section, we present the current status of the telescope as far as its instrumentation capabilities and, in particular, SALT's strengths are concerned, and also give an indication how these capabilities are being developed further.

3.1. Telescope and Instruments

SALT is a 10-m class fixed-altitude segmented-mirror telescope, located at one of the very darkest observing sites in the world (see *Fig. 1*), near the town of Sutherland in the Karoo semi-desert region of South Africa. ***Appendix A*** gives a brief history of the project, along with the current make-up of the Consortium partners. Detailed ***telescope and site characteristics*** are listed in ***Table B*** in the Appendices.

SALT currently hosts three instruments: the Robert Stobie Spectrograph (***RSS***), the SALT Imaging Camera (***SALTICAM)***, the High Resolution Spectrograph (***HRS***), while a new standalone instrument, ***NIRWALS***, is being commissioned. In the past, the telescope has also hosted a visitor instrument, Berkeley Visible Image Tube camera, *BVIT,* which has since been decommissioned. The instruments offer science users a wide range of spectroscopic and imaging capabilities across the whole optical regime starting from 320 nm, through to 950 nm, and up to 1700 nm including the latest addition of NIRWALS which for the first time extends SALT capabilities into the infrared. Instrument modes include low and medium resolution long-slit and multi-object spectroscopy, high resolution single object fibre-fed spectroscopy, high time resolution modes in both imaging and spectroscopy, and narrow-band imaging. Integral field unit (IFU) spectroscopy is being added currently with the NIRWALS in the infrared, while optical IFU capabilities are expected to become available soon with a new "Slitmask IFU" mode on the RSS. RSS also offers polarimetric capabilities, and the Fabry-Pérot mode (FP) provided imaging spectroscopy over a uniquely large field-of-view for a 10-m class telescope; this latter FP mode stopped working in 2018 for technical reasons and repairs are currently on hold. More detailed ***instrument characteristics*** are listed in ***Table C*** in the Appendices.

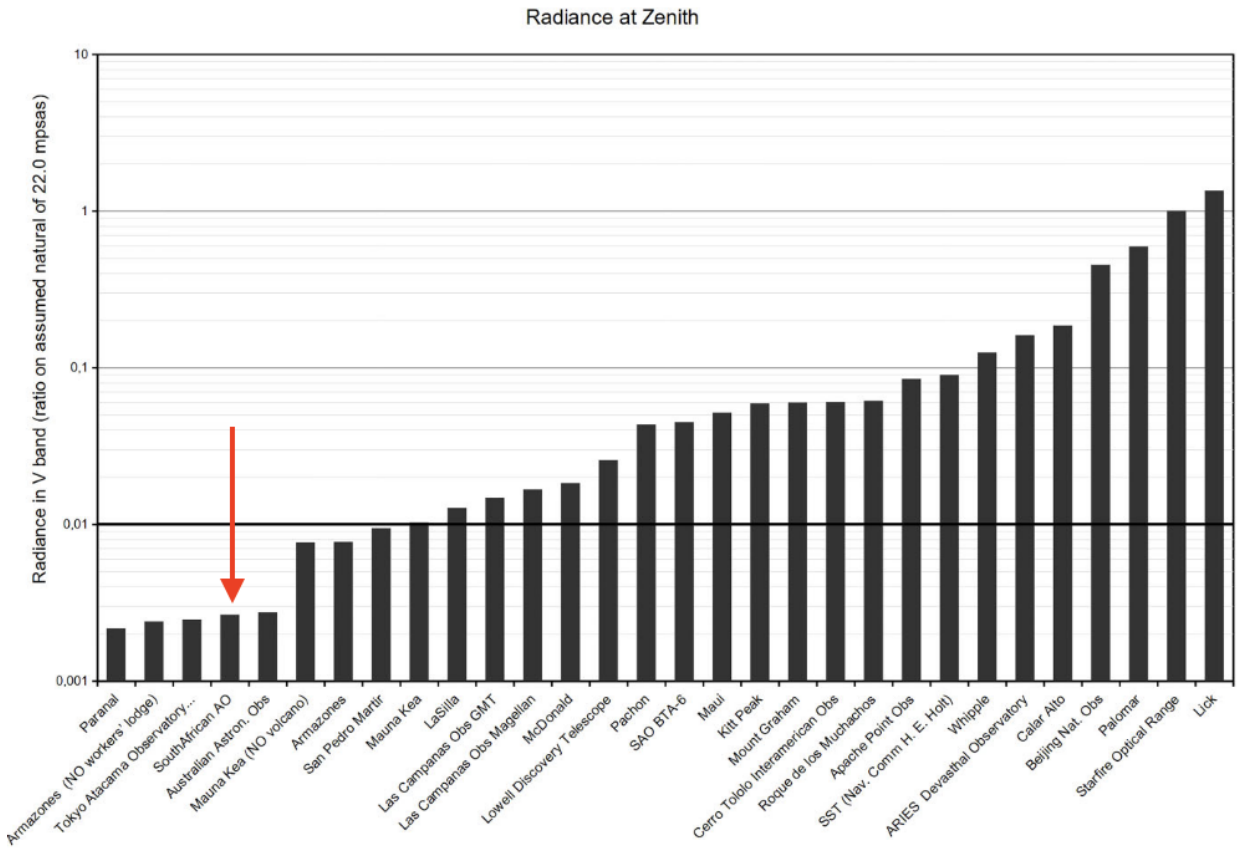

Figure 1. Night sky brightness of all professional observatories in the world. The SALT-site at the SAAO/Sutherland is seen to be among the very darkest together with the VLT and EELT sites in Atacama, and the AAO in Australia. From Falchi et al. (2023), see details therein.

SALT has an on-going program to develop and improve the performance of all the instruments and add new capabilities, as for example, the extension to the NIR through NIRWALS, and the upgrade of the HRS High-Stability (HS) mode for exoplanet work. ***Table D*** in the Appendices summarises both recently completed, and on-going or upcoming ***instrument development*** projects.

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 all over the sky in the observing queue.
- The telescope's large collecting area and Sutherland's exceptionally 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 polarimetric capabilities, as well as high-time resolution 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 the night.

4. Recent SALT Science

This section reviews what kind of science has been done with SALT during the decade of full science operations, and what lessons can possibly be learned regarding future strategy and strategic areas. The purpose is to *inform* the SALT strategy by presenting examples of successful and efficient science done with the telescope up until late 2022. 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.

In general, spectroscopic survey programs, needing dozens, or even hundreds, of targets widely distributed over the Southern sky, ranging from stars in our Galaxy, to Quasars, are well served by SALT's capabilities and observing methods. Such surveys and monitoring programs with the RSS are currently feasible down to approximately V~21-22 mag, and to V~17 mag with HRS lower resolution modes. Surveys in the Magellanic Clouds make use of the long, continuous visibility window of the telescope at that Declination. Large spectroscopic samples have been gathered and published at SALT – these have been both velocity and redshift surveys, or studies of more complex physical characteristics of various types of stars, in particular variable objects, planetary and other nebulae, and many types of galaxies and active galactic nuclei (AGN) in both the local universe and at higher redshifts. Of note are e.g. surveys done in conjunction with MeerKAT Key Science Surveys, the *Laduma*, *MIGHTEE*, and *MALS* programs in particular, but also including other MeerKAT related programs. MeerKAT programs on SALT have typically used over 50h of time per semester, and they typically are multi-partner proposals.

Transient object science has continued to be highly successful at SALT. For example, surveys such as DES, ASSA-SN, Gaia, MASTER, LIGO and eROSITA (two of these projects even have a telescope on the Sutherland site as part of their network), provide a wide variety of targets for SALT essentially every night, and a number of these have yielded high-profile results. SALT's rapid spectroscopic follow-up of the GW170817 gravitational wave event is an example of such high-profile success: the Abbott et al. (2017) paper reporting the electromagnetic counterpart and afterglow of the neutron star merger, which featured the relevant SALT observation as the *very first* spectrum of the event, is by far the most cited SALT paper.

SNe follow-up ToO observations from different SALT Partners are observed very frequently. And in particular, SALT's first Large Science Program (LSP), the multi-partner, SA-driven, "*Observing the Transient Universe*" program has been running since 2017 and has been highly successful in observing and publishing a wide range of eruptive variables and transients, such as 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.

It is worth noting that HRS science has grown significantly since the HRS science pipeline became available for users over 2017/2018, and more recently this has also included Exoplanet science (13 papers to date). The latter field is expected to grow much more with the *Laser Frequency Comb* (LFC) shortly becoming available for calibrations of the HRS/HS mode.

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 still make studies more practical. We note that there has been a shift to using the RSS for high-speed work, instead of the traditional SALTICAM. This may change again in the future with a potential SALTICAM replacement, as it is the oldest of the SALT instruments.

4.1. SALT Publications

For the purposes of benchmarking SALT performance indicators and output, we briefly take a look at publication and citation statistics of papers based on SALT data. As it is now more than a decade since the start of normal science operations, bibliometrics, a common tool to measure productiveness of observatories, is becoming relevant. This analysis of the publications is presented in **Appendix E**, while below we summarise some of the main points and results.

Figure 2 below shows the total number of refereed papers published, per year, since the respective science operations began. The data are shown for all of the world's 8-10m class optical telescopes, and are normalised by the number of telescopes (i.e. accounting for e.g. *four* VLT units). As is seen, SALT is by and large following the general trend, and the annual paper production has increased steadily and now reached 60-70 papers by 2022. As explored more in the Appendix, a long-term expectation based on international trends regarding e.g. expected publications vs. observing programs executed may indicate that eventually the SALT paper rate could start slowly plateauing around the 90-110 per year mark.

Other factors going into productivity plots such as these that should be taken into account in a more detailed study and analysis, include e.g. the size of the contributing astronomical community, or resources available, or costs. Indeed, in Fig. 3, the publication counts are normalised by the telescope's construction and annual operation costs, and it is seen that SALT is actually an *extremely cost-effective* observatory in comparison to its peers.

Examining citations counts, a common proxy for the impact of a facility, is also possible since the baseline is now long enough. Looking at the SALT papers from 2013 (onward from which there are enough statistics) to 2019 (after which the citation counts are still ramping up), the typical *average* citation count per SALT paper per year is between 30 and 40. This, again, compares reasonably well with other large telescope facilities. Figure 4 below shows an analysis performed by the Gemini Observatory on the "mean citation impact" of papers based on data from selected major observatories, and confirms that SALT is following the general trend very well. Thus, considering the massively different sizes of some of the communities (such as the VLT and Keck user communities), as well as their respective resources, we conclude that the relevance of SALT as measured by citations has reached a healthy and respectable maturity. As is detailed in the Appendix, individual SALT papers with most citations include Supernova and Multi-Messenger astronomy related follow-up, together with some highly cited more "traditional" extragalactic and Galactic astronomy studies.

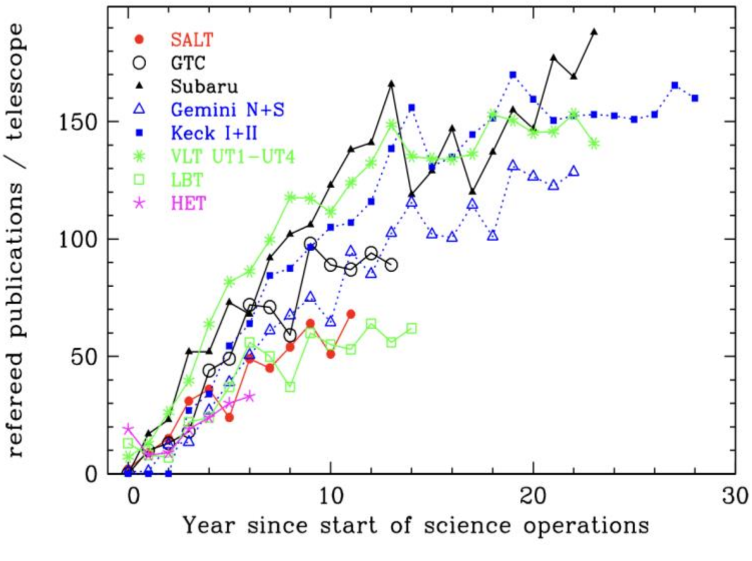

Figure 2. Refereed publications per telescope for 8-10m class optical observatories. SALT, in red, is seen to follow the broad general trend after the start of full science operations. (Note that the HET graph starts at its return to science operations after the telescope's full top-end redesign).

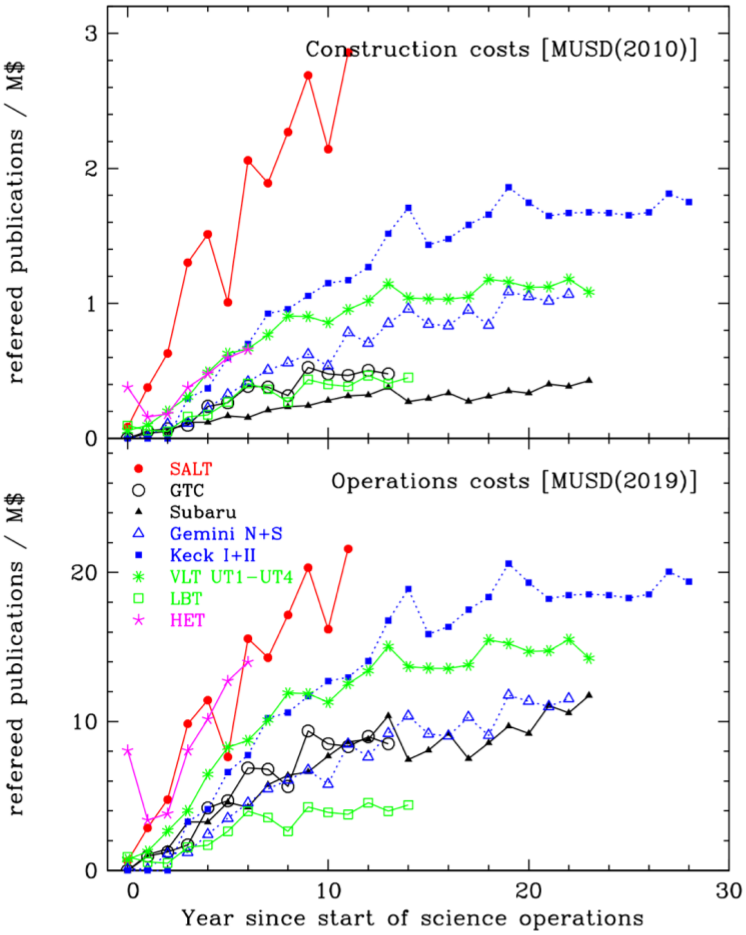

Figure 3. Paper counts as in Figure 2, but now normalised by the observatory construction and operations costs, respectively, highlighting the cost-effectiveness of SALT.

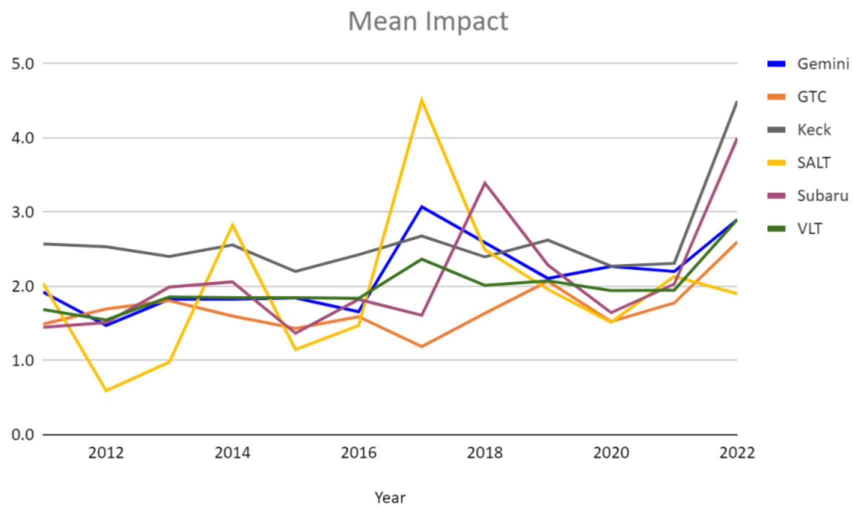

Figure 4. 'Mean impact' of large optical observatories based on citation counts of papers based on the facility. SALT is following the broad trend. The peak in 2017 is due to a single extremely highly cited paper on the electromagnetic follow-up of the gravitational wave event that year. Mean impact in this case means the average citation count in a given year normalised by the citation impact value of ApJ in that year. (The graph above hence means that large telescope data papers are on average 2-3 times more cited than overall ApJ papers; there may also be smaller implicit effects shaping the curves, depending on which journal, with varied citation impacts, the bulk of given facilities data is published in.) (Image courtesy of the Gemini librarian, Xiaoyu Zhang.)

As of December 2022, there were 452 refereed publications based on SALT observations in the literature, including seven in *Nature* or *Science*, and another seven in *Nature Astronomy*. Furthermore, there are another 34 refereed SALT publications that are classified as instrumentation related, or survey descriptions, and hence the total of refereed "SALT papers" is 486 currently. In addition to these, there are more than 130 SALT papers in the *SPIE* Astronomical Telescopes and Instrumentation conference series. Figure 5 shows the breakdown by fields of research in astronomy, represented in the 452 SALT "data papers". These statistics give an indication of successful SALT science thus far.

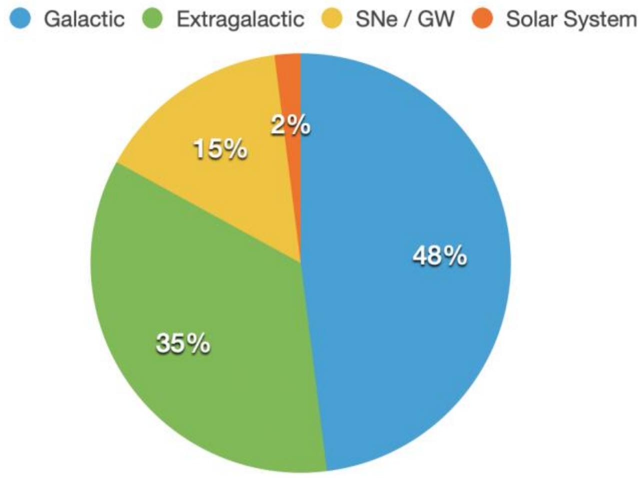

Figure 5. Breakdown of papers based on SALT data by science field. Note that we have classified Supernovae and gravitational wave follow-up separately from the broader ''extragalactic' category.

Finally, for strategic purposes, it is worth noting which type of programs are most efficient in publishing results. As elaborated in the Appendix, we show that e.g. DDT programs are more than twice more likely to produce a paper than "normal" programs, while e.g. actual *time* spent on ToO programs is nearly three times more efficient in producing a paper than the normal programs. Similarly, while the Transients LSP has used 8% of observing time on the telescope during its lifetime, the 60+ data papers ascribed to it represent approximately 20% of all SALT data papers during the same time period. Overall, we note that the fraction of ToO based papers has grown significantly over the past several years, signifying the continuing, and even growing, appeal of SALT for rapid-response observations.

Instrument statistics show that the RSS, and its long-slit mode in particular still remains SALT's workhorse instrument with more than 70% contribution to all-time papers. However, HRS has started to contribute much more significantly. The fraction of HRS papers has doubled since 2019, and quadrupled since 2017, which is attributable to the release of the HRS pipeline in 2017. The paper-rate of RSS and HRS is reflected in the usage, by time, of them as well, as seen in the further analysis of the instrument trends presented in the Appendix.

5. SALT Strategic Goals

The vision for future SALT Science is discussed next, starting from the highest level Strategic Goals. The following sections then move to motivations for, and directions of, short-to-medium term work, as well as specific directions of longer-term strategy, including a brief description of the strategic SALT science focus areas. These focus areas are naturally influenced by what the Consortium member community is interested in, as evidenced by the past and on-going science presented in the previous Section. At the same time, the Partnership must endeavour to constantly consult and understand its user community to be able to drive the development of the telescope's capabilities in directions that help satisfy the *future* requirements and vision of the users.

The overall high-level strategic goals of the SALT Consortium were formulated by the SALT team and the community, and then approved by the Board in 2018. These high-level Goals remain unchanged.

1. **Goal: 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. **Goal: 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. **Goal: 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.

Crucially, as much as SALT has demonstrated its scientific competitiveness since its launch, it is clear that it needs a *scientific & technological development plan* to keep it competitive in its chosen focus areas, and globally relevant as a major observatory, in the world arena of constantly developing technology and innovation.

6. SALT Short-Term Priorities

The SALT Operations Team *continually prioritises* projects and tasks to better serve the SALT user community. Projects are done to fix known issues on the telescope, in particular to improve, refurbish, and develop existing SALT instrumentation, and the telescope's operational efficiency, as well as add new capabilities for SALT in line with the strategic vision and focus areas. It is the team's responsibility to ensure he team makes sure that approved projects are efficiently carried out with the available resources. The SALT Scientific and Technical Committee (STC), led by the SALT Observatory Scientist, together with the SALT Operations Heads and the SAAO Director, oversee these activities.

Table D shown in the ***Appendix*** shows an example of on-going recent P0 and P1 high-priority projects at SALT, colour-coded with status in around mid-2023. Some of the high priority projects that specifically address improved capabilities and/or new modes, include the on-going **NIRWALS** commissioning, the **Laser Frequency Comb** installation for HRS, Slitmask I**FUs**, the **MaxE** project, as well as on-going **RSS Detector** replacement project, while the **RSS Optics** were just refurbished successfully in early 2023.

7. 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 has increased steadily reaching typically 60-70 refereed SALT-data based publications annually by 2022, broadly following other major observatories' trends when counted from start of science operations (see Section 4.1 and Appendix E).

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, and regular SALT science workshops are being arranged to facilitate more interaction among SALT users, and between users and the Operations team. A comprehensive SALT **top-end redesign** over the next years is also discussed, which could both open new options for new instruments and also significantly enhance the operational and maintenance efficiency of the current system.

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 the course for the telescope and the partnership.

In 2016, the Board adopted a basic fundamental principle:

- **SALT should continue operating largely as a general-purpose telescope doing PI-driven science**.

This was in contrast to an alternative option that SALT could focus largely on a single scientific experiment, along the lines of what, for example, HET has done with the HETDEX project. However, in parallel, the Board also decided that SALT would actively seek to design and execute *large scientific projects* (LSP). Indeed, as already noted in Section 4.1, a multi-partner LSP on the Transient Universe that has been running since 2017 has been very successful and productive in terms of publications. It should be of strategic importance for SALT to encourage more similar programs, but in different fields of astronomy, that have both wide and active participation across individual partners.

Following the strategic decision regarding PI-driven science, the details of future SALT science were actively discussed by the SALT community the following year, and the Board ratified the resulting recommendations in November 2017. Three *Science Focus Areas* were selected to pursue the Strategic *Goal 1* set above (see Section 5), while the importance of *instrumentation development*, *Goal 2* above, was stressed for the strategic sustainability of SALT. Decisions about next-generation instrumentation are to be in line with these fundamental drivers. The plan specified ambitious goals for transforming the telescope into a world-leader in carefully selected research domains. An example of the type of science that was 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.

Furthermore, while the SALT strategic plan benefits directly the full Partnership, it would also benefit South African science and technology communities and the knowledge economy in the country since the plan calls for determined development of new instrumentation. This will bring together expertise from within the SALT Partnership with the explicit purpose of developing in-house and South African high-tech capacity in support of the *Strategic Goal 3*.

Going forward, the strategy will involve new investments, while at the same time capitalising on SALT's existing strengths and new and future collaborations, with e.g. SKA and the Rubin Observatory/LSST, and also planning e.g. how the newest instrument NIRWALS can be used together with science coming out from the cutting-edge infrared facility in the world, the JWST.

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.

7.1. 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 Rubin Observatory, LSST-cadence time-domain studies, including sophisticated decision-making software and networking with other instruments. The 2017 LIGO gravitational wave event and the rapid electromagnetic follow-up performed at SALT and SAAO is an example of this science area, as is the very successful large Transient Universe program at SALT. MeerKAT, along with the MeerLICHT connection, already offers South Africa a globally-unique new window into this exciting field as well. In other words, this strategy positions SALT as a pivotal player in the multi-wavelength / multi-messenger astronomy era occasioned by the establishment of SKA, the Rubin Observatory, and other advanced and complementary global instruments.

- ***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 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 many of the largest international astronomy projects of decades past have been dominated by the drive to understand the early 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.

7.2. Roadmap to Next-Generation SALT Development

Following the determination of science focus areas, including the canvassing of the SALT community, a roadmap was sketched in 2018 to start addressing them, with both immediate and medium-term requirements and possibilities. In particular, the roadmap also considered which aspects could be fast-tracked while longer-term aspirations could still be left for a later phase. Figure 6 below summarises the overall plan as presented in 2018.

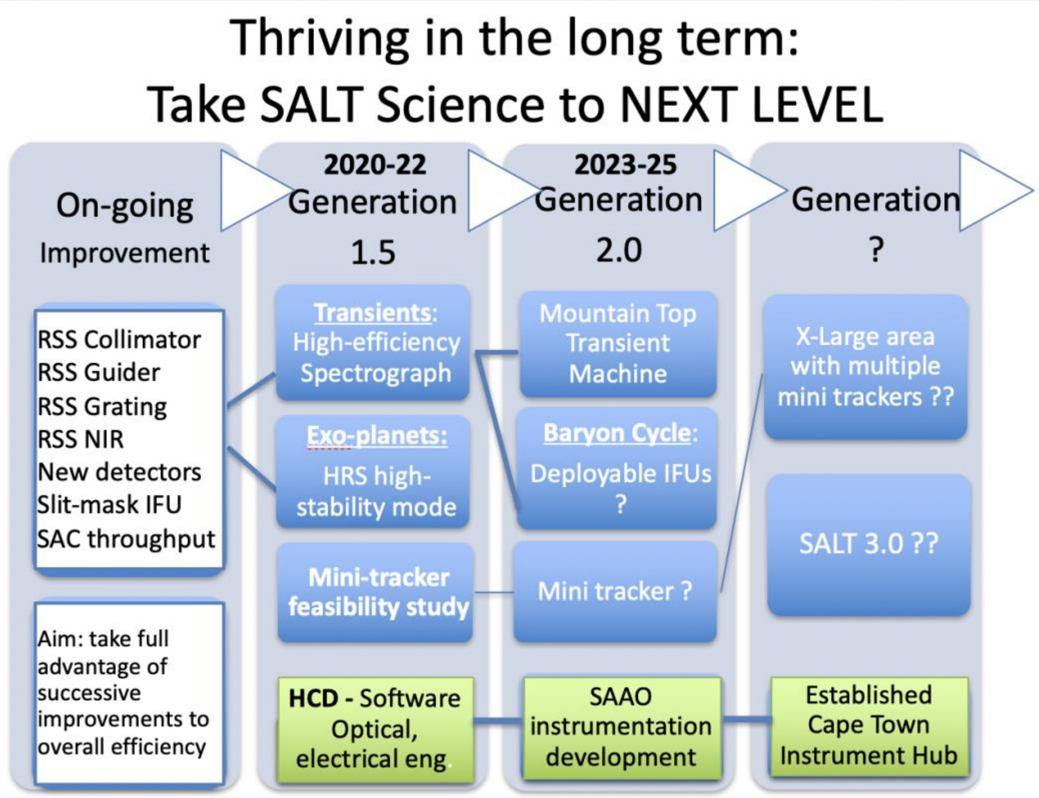

Figure 6. Plan for SALT Development as presented in mid-2018, including instrumentation and human capacity aspects, and options thereof. Currently, in early 2023, nearly all the items up to and including the Generation 1.5 step have been either completed, or are in progress, after successfully identifying and finding funding for them – see text for details.

It is instructive to reflect on the progress in the high-level plan of Fig. 6. Currently, in early 2023, most of the "on-going", as of 2018, projects have been completed, with only the SAC throughput project of those mentioned not yet addressed, and the Slit-mask IFU and Detectors projects on-going in advanced stages. All of the steps in the *Generation 1.5* section are in progress (see the separate Section 7.3 below for more details), with the mini-tracker feasibility study completed. Regarding the latter, it was decided in 2021 not to continue towards implementation of this quite revolutionary concept, at least not until a better science case is developed and a science champion in the form of a local PI is identified. Nevertheless, SALT is now approaching the Generation 2.0 stage, where decisions are required as to how exactly to move forward, and, importantly, on how to fund the developments.

7.3. SALT Generation 1.5 Project

Most of the "on-going improvement" projects listed in Fig. 6 above were already funded at the time of drafting of the plan, from either the Asset Renewal Fund, or the SALT Development Fund.

The *Gen 1.5* project (aka the *SII* project, see below), however, was new. The technological requirements were refined and defined after the selection of the science areas, the requirements were costed and prioritised, and then funding had to be sought. As the three SALT science focus areas were analysed, most relevant and appropriate astronomical instrumentation projects were defined to address them:

A. Develop a maximum-efficiency, single-object competitive spectrograph on SALT serving the *Transient science* domain. SAAO would design, develop, and build, in the new MaxE Project, such an instrument. It should be built quickly to overlap with the MeerKAT, and start operations with the globally transformative Rubin Observatory, and the Large Survey of Space and Time (LSST) survey, based in Chile, from 2025 onward.

B. Upgrade the existing SALT High Resolution Spectrograph (HRS) instrument to be capable of ultra-precise radial velocity planet detections, to serve the *Exoplanet science* aspirations. This should be achieved as soon as practically possible due to the many new and upcoming exo-planet related NASA and ESA projects.

C. Continue the optimisation of SALT to support Rubin Observatory / LSST-cadence *time-domain* studies, including next-generation sophisticated decision-making software and network SALT and other telescopes at the SAAO. This became known as the *Intelligent Observatory* (IO) project.

D. Develop, either by sourcing or building, or a mix, a fully-deployable integral field unit (IFU) spectrograph, capable of spatially-resolved spectroscopy over fields of view competitive with similar instruments at other international observatories, to serve the *Galaxy Evolution (Baryon Cycle)* science case. This instrument does not have a timescale defined for it at this stage.

After several discussions in South Africa the process culminated in an *Internal Memorandum of Agreement* between SAAO and SARAO, the two major players of the astronomical landscape in the country, for the establishment of the "*SALT Generation 1.5 Project*" to upgrade SALT capabilities for the 2020s; the project is often also referred to as the "***Strategic Instrumentation Initiative (SII)***". The *SII* packages the items **A** to **C** above into this single project/initiative, while it was decided that item **D**, the more complex larger format IFU spectrograph, will be deferred to a later Generation 2.0 phase. In the *SII* scheme, SARAO together with SAAO, jointly fund the project, using both direct project funding and in-kind contributions in terms of staff. The total *SII* budget over the duration of 5-6 years is approximately R70M.

Importantly, in addition to addressing the science focus areas through these specific technological developments and upgrades, a major incentive of the *SII* scheme is to develop rare-skills South African human capacity in high-tech SAAO-based instrumentation in the engineering and astronomy domains, including software development; this is reflected in Fig. 6 as the HCD aspects shown in green (see also Section 6.6).

Status in early 2023:

1. **MaxE,** for "Maximum Efficiency" project, evolved into building "*RSS-dual*", a new efficient mode and camera for the SALT/RSS spectrograph. It will perform *simultaneous* "red" and "blue" spectroscopy, i.e. observing the full optical spectral range with the spectral resolution required, in particular, for the identification of unknown Transient astronomical objects (R~800 in the blue, and R~2000 in the red). Work began in 2019, and the team is currently working towards a full system PDR, while e.g. the optics of the instrument have already passed this milestone. Commissioning of the instrument expected to begin in late 2024 or 2025, in time for the Large Survey of Space and Time (LSST).
2. **HRS / High-Stability (HS) Mode** – The inherent stability of the HRS instrument was studied carefully to verify which type of a calibration mode would be most useful to achieve radial velocity precisions required in exo-planet studies. In 2020, after demonstrating that 40 cm/s accuracy was in principle achievable with the system, and thus it would indeed be scientifically useful for SALT to acquire the most sensitive type of a calibrator, a *Laser Frequency Comb,* to aim perhaps for a ~1-5 m/s scale precision. The project is well under way, and the main components of the LFC have been purchased and have arrived in Sutherland, and installation is happening in 2023. The project also includes a new science-ready data pipeline development, which is well underway.
3. The **Intelligent Observatory** is a pilot study in the *SII* framework, while overall the IO is a longer-term overarching initiative at the SAAO, significantly enhancing the efficiency of service to the national and global community, SALT included. Within the pilot phase, the Lesedi telescope in Sutherland has been used to develop and test the IO concepts of *fully autonomous* operations. There have been numerous milestones reached in 2022/23,

including week-long operations without human intervention, including “listening” to international target data-stream triggers and their scheduling and execution, i.e. not merely following pre-defined scheduling as “normal” robotic observations usually do. The IO team is working towards utilising these capabilities on multiple SAAO telescopes and SALT, and networking them into a “single” unit that can also trigger each other.

4. While it was decided that the large-format deployable IFU was deferred until (at least) Generation 2.0 stage, there has been significant development on the IFU front nevertheless – however, this is not part of the SARAO/SAAO funded *SII* Project. As the first steps to start addressing the *Galaxy Evolution* science case, a new (and totally unique in the continental context) **Fibre Photonics Lab** has been established at the SAAO, mainly using the NRF SARChI funding. As the first product of the Lab, SALT is receiving optical IFU capabilities in the form of the “Slit-mask IFUs”, entirely locally built. Having been established and developed in the last 1-3 years the core optical engineering and opto-mechanical capabilities are now present at the SAAO, and SAAO is working on safe-guarding the long-term sustainability of these skills at the SAAO – indeed, the Lab received special funding from SALT in 2022, and the first two lab-specific personnel have been hired for this purpose.

7.4. 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 and pursue its long-term science goals and also to drive high-end skills development within the Partnership, and particularly in South Africa.

Becoming self-sufficient in terms of developing new instruments will require a new level of engagement. The SALT partnership hosts a wealth of instrumentation expertise, IUCAA and the University of Wisconsin in particular, 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.

The development and establishment of the Fibre Photonics Lab, as described above, is an example of the type of engagement and collaboration that is required, resulting in growth. And more generally, aggressively exploring new concepts will require iterative designing, prototyping and testing in all the major engineering disciplines associated with astronomical instrumentation, creating an ideal environment for student training and up-skilling of staff.

7.5. Funding of SALT Development

The SALT funding structure is based on an annual Operations Budget drawn from the Operations Levies of the Partners, whose contributions reflect their respective shareholding percentages. This Ops Budget covers salaries of the operations staff, all running costs, and maintenance for the upkeep of the telescope and science instruments. The Budget also covers ***Asset Renewal*** (AR), a comprehensive forward-looking plan that caters for the life-cycles and appropriate replacement timescales for all the technological sub-systems of SALT, as well as the supporting assets such as vehicles, machinery, and buildings. All the relevant work is broken into separate Projects that are planned, prioritised, and managed by the operations team. The largest AR project in a ten-year time horizon will likely be the replacement of the custom-built precision edge sensor technology and controllers of the SALT mirror alignment SAMS system, and also investigating how best to retain the capabilities of the Spherical Aberration Corrector (SAC). Another significant upgrade will be related to the SALT Tracker and Payload, i.e. a SALT top-end redesign project (whether this should be considered asset renewal, or ‘development’, may be asked however). The AR portion of the annual budget has been varying between 3-5% typically, which has been found to work well thus far. However, **given that the age of the telescope is now approaching two decades, it is likely that the asset renewal funds will need to increase in the coming years.**

Moreover, it is recognised that it is not enough to merely keep the current system in good running order, but also to develop new technology to address new questions. Funding for these types of projects is referred to as the ***Development Fund*** (DF) in the SALT funding structure, which requires contributions *over and above* the Ops Levies.

The (first) DF was closed in November 2017, with approximately 95% of the target value of R74M reached. The Board agreed that the outstanding balance would be funded by the relevant Partners returning shares to SALT. The originally agreed-upon DF is hence concluded, and most of the relevant funding has already been used for the successful primary mirror active alignment system (SAMS), the tracker upgrade project, RSS Doublet and Triplet optics refurbishment projects, or committed to on-going or near-future projects. The current balance stands at R39M which will be used for significant and necessary upgrade projects, many of which have already been approved in principle. We also note that the annual Operations budget includes contingency funds (typically 5%), and any unspent contingency funds, together with interest earned on invested funds, are used to supplement the DF.

The important aspect to note is that while many important upgrade projects are funded, 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, including securing funding for next-generation instrumentation needs, remains an extremely high priority for the Board.

It is noteworthy that the *SII* project was conceived in South Africa to bridge a gap in the clear need to keep SALT competitive in the 2020s, and to attract new partners with upgraded capabilities. This was done in the hope of jump-starting a second (future) Development Fund which is required to move towards the *2nd Generation* of instruments. Hence the name '*SALT Generation 1.5'* project, and the funding by SARAO for it may be considered NRF's contribution to that second DF. Scaled by the current shareholding and the initial NRF contribution, the other partners would ideally contribute another R180M or so, over a number of years. The Fund would be used for the 2nd generation instrumentation suite over ten years, commencing after completion of the SALT Generation 1.5 project. While not yet costed in detail, to build a large-format deployable IFU, for example, might still need another new 5-10% partner to join the consortium. A joining fee for a new 10% Partner would currently contribute approximately R130M, helping to bridge much of the gap in funding towards the bold SALT instrumentation aspirations.

According to this overall SALT Strategic Plan, as also indicated in Fig. 6, the 2nd Generation development (however funded), would utilise the SAAO-based instrumentation development group established and skilled during the first phases of this plan, i.e. the Gen 1.5 project. The assumption is that the SAAO core funding would allow for the retention of some or most of the staff and skills developed, thereby allowing a strengthened SAAO instrumentation group to tackle the larger future projects in service of SALT. This will also reduce the lead time for development and perhaps also allow SAAO to second personnel to SALT on a cost-recovery basis, or as an "in-kind" contribution to any Generation 2.0 instruments that the Board decides to pursue.

7.6. SALT and African Astronomy

SALT is the flagship project of the SAAO, and hence of all African astronomy in the optical and near-infrared wavelengths, due to SAAO being the National Facility in this regard, and also the continental hub. The success of building SALT, and operating it, paved the way for the much larger, and successful, South African SKA-bid. South Africa, as the largest SALT partner, the host, and the operator, plays a crucial role in the scientific and technical leadership for the telescope for mutual benefit.

This role in the SALT collaboration drives both multi-wavelength astronomy and astronomical instrumentation development in the country – indeed, both the chosen SALT Science Focus Areas and the high-level Strategic Goals intimately tie together with the Department of Science & Innovation approved *South African National Multi-Wavelength Astronomy Strategy*, as well as the SAAO Vision. The SALT (and SAAO) science focus areas in turn are globally relevant "mega-trend" topics in astronomy in this decade, meaning that the South African community can both stay relevant and attract even greater interest for the competitive facilities that the country is able to provide. Developments with and at SALT directly benefit the overall astronomical community also using the SKA precursor and high energy astrophysics platforms.

South Africa's participation in SALT generates world-class science and simultaneously cultivates young African astronomers who are comfortable working in the most modern astrophysical fields, employing cutting-edge technologies. Dozens of South African post-graduate students have used and/or been involved with SALT data for their work, and/or been directly supervised by SAAO/SALT based staff astronomers. There is budding interest for SALT usage from around Africa, in particular from a handful of new astronomy groups/departments in Rwanda, Uganda, Namibia, and Ethiopia, where in every case the key people in these departments have had their post-grad training in South Africa and/or collaborations and projects with SAAO/SALT. Together with the SAAO-hosted *African Astronomical Society* (AfAS), SALT Ops is constantly looking for ways to expand both the interest and the skill-sets of the African astronomical community via e.g. SALT data reduction workshops.

SALT also contributes significantly to science engagement and outreach, and to transformation within the country. This happens both through training, and also through the socio-economic benefits brought to the Sutherland community where SALT is based, e.g. through tourism (with SALT, the town has transformed into a tourist destination) and related employment, and also through direct interventions such as a Community Centre being operated in town, and SALT funding a full-time maths & science teacher in the local school system.

It is also instructive to consider how SALT has impacted SAAO – it has transformed SAAO during the project's lifetime. Nearly 40% of the total annual SAAO budget is actually "SALT", and a similar fraction of SAAO's scientists are employed using SALT funds. More than 80% of SAAO-based engineers are actually SALT personnel. It is clear that the world-class Observatory that SAAO is today would not have been possible without the flagship project that SALT is, a strategic partnership in an international endeavour that South Africa took the lead in. And on the other hand, the success of SALT would not have been possible without the dedicated support, both paid and otherwise, that the telescope gets from the SAAO as the host-organisation.

Furthermore, an overarching SAAO plan for this decade is a comprehensive goal to enhance *Instrumentation Development* resources and skills, with a specific goal to establish an **Astronomical Instrumentation Technology Hub**, ideally in collaboration with SARAO, and, crucially, to build a full pipeline of *training* around it. The motivation for this comes from the fact that in the international astronomical landscape, it is often those communities that are active in instrument development that are also at the forefront of scientific discoveries. Merely buying and using instrumentation will not raise the South African astronomical community to the highest level. Rather, to make full use of novel scientific ideas, it is important to truly understand both the potential and the implications of the newest technological innovations, and be involved in such R&D. This obviously is difficult if there is no such expertise in the country. Hence SAAO's goal is to aggressively pursue instrumentation development, which has to reflect also in personnel choices and training strategies. The SALT partnership, and more recently the *SII* project described in Section 6.3 together with SARAO engineers, has been an ideal nucleus with which to begin building this future. The SALT / NRF connection has also resulted in the establishment of the Fibre Photonics Lab described above, that is building the first SALT IFU instrument.

In addition to specific SALT instruments and instrument modes that the SII project builds and/or upgrades (the MaxE and LFC projects, as well as the Slit-mask IFUs), the Intelligent Observatory initiative seeks to revolutionise the way South African astronomy presents itself globally this decade, impacting both the SAAO and the wider South African astronomical community in the era of extremely massive data and rapid response requirements. Networking SALT and the SAAO telescopes into what will eventually be an autonomous single "machine", is a *game changer* for SAAO. This growth in capabilities and service will directly impact SALT as well.

Finally, SAAO not only hosts SALT, but also other continentally and globally significant astronomy organisations, the IAU Office of Astronomy for Development (OAD) and AfAS, as already mentioned. This results in putting SALT and its personnel naturally and seamlessly in contact with all major African development in astronomy, which is often seen in collaborative training workshops and other events whether locally or continentally, whether AfAS or OAD or SALT driven, or e.g. UK's Newton Fund and South African government funded DARA (Development in Africa with Radio Astronomy) Big Data program. These strong synergies also extend to the enhanced visibility SALT enjoys in international conferences (IAU, EAS, AAS, for example) where SALT, SAAO, OAD, AfAS, and the IAU General Assembly 2024, typically run coordinated and/or combined exhibition booths and ad campaigns (see Fig. 7 below for an example).

Figure 7. A picture from the Closing Ceremony of the European Astronomical Society's (EAS) large annual congress in 2023, in Krakow, Poland, where the African delegation had the opportunity to advertise the IAU-General Assembly 2024 in Cape Town. SALT constantly features very prominently as a successful flagship astronomy project on the continent.

8. SALT Five-Year Strategic Goals

Considering the SALT Strategic Goals from 2018, the Board-approved Science Focus Areas, instrumentation development projects, and the progress made on these during the past 3-5 years, this section lists re-evaluated, specific strategic goals for a five-year time-frame from 2023 onward.

The individual items/goals are grouped under five separate categories below. Furthermore, **Table 1** below presents more detail for each of the goals regarding timelines and the baselines.

A – Positioning SALT strategically in the global context

- Establish SALT as a world-leading Transient object follow-up machine in the 19 to 22 magnitude brightness range, in the era of Rubin Observatory / LSST, with the help of a completed *RSS-dual* mode instrument (MaxE), with a new monolithic RSS detector, and by effectively using autonomous observations developed by the IO project, i.e. artificial-intelligence-type algorithms, and networked facilities on the Sutherland observing plateau.
- Establish SALT as a key player in southern-hemisphere exoplanet work:
    - Securing ~1 m/s scale precision radial velocities with HRS and the new Laser Frequency Comb, ready for upcoming major missions such as the PLATO.
    - Attract more scientific expertise in the field to the SALT/SAAO team and the SALT partnership.
- Leverage the very dark skies of Sutherland for internationally competitive extragalactic 'Baryon Cycle' type science on SALT utilising in particular the imminent IFU capabilities, as well as considering 2nd generation instrumentation for this science focus. The SAC optics will need to be clean for best performance, and flat-fielding better understood.
- Build strong links with cutting-edge science projects starting in this time-frame, SKA and the Rubin Observatory in particular, and have SALT regularly contribute to MeerKAT Key Projects in the meantime.
- Continue expanding an active instrumentation development program based at SAAO, using both SALT and SAAO resources, as well as actively collaborating with SALT Partners in instrumentation development:
    - Rigorously continue developing the new Fibre Photonics Lab at the SAAO for SALT benefit, for both new instruments and for skills training.
    - Establish new formal skills-exchange and training programs between the SALT Partners to benefit all SALT instrumentation development, following earlier and on-going instrumentation collaboration such as that with UWisc, IUCAA, and Rutgers.

B – Acquisition of new instruments

- Make decisions concerning 2nd Generation instrumentation and major telescope upgrades:
    - The recommendation from the SALT community last time was for a deployable, at least 1 arcmin in field of view, IFU instrument: consider a *technical feasibility study* and *costing of a concept*.
    - If feasible and approved, fund and build the instrument on a time-scale that would deliver it to SALT by the end of the decade.
    - Call for, and consider, any other new suggestions for 2nd Gen instruments.

C – Enhancing scientific productivity

- Enhance scientific productivity through dedicated SALT software effort by having *all* observing modes supported by science grade data reduction and analysis packages.
- Enhance scientific productivity through a significantly upgraded user-friendly data Archive also with high-level science data products and extracted parameters (use the SDSS data archive as an example).
- Ensure SALT's data products are available to the wider community (once public) through enabling IVOA searches.

D – Upgrading systems

- Initiate a SALT Payload upgrade (aka a “top-end redesign”) feasibility study.
- Service the SAC mirrors.
- Decide on the best upgrade path for the SALTICAM replacement, and complete the project.
- Complete the RSS Vis Detector upgrade project, and continue developing all detectors on SALT instruments.

E – Maintaining financial stability

- Make decisions regarding a 2nd Development Fund, and fund-raise for it within the Partnership.
- Attract a new 10% level SALT partner, or a group of partners.
    - In the short term, make a practical plan/roadmap how to go about identifying potentially interested parties, and how to attract them.

Table 1. Individual 5-year strategic goals grouped under higher level headings.

	Baseline	Target	Timeline
A – Strategic positioning			
Transients	Efficient on-going LSP with current instruments	Added capability a monolithic RSS detector, with RSS Dual (MaxE), and with IO	2024 2025 2026
Exoplanets	Developing HRS/HS	Installed Laser Frequency Comb and science pipeline	2024
Baryon cycle	RSS long-slit and MOS programs (previously also FP)	Productive science done also with Slitmask IFU and NIRWALS; and potentially using a new Payload	2024/5 2027
Rubin Observatory and SKA links	LSST in-kind program; MeerKAT Key programs being observed	Productive LSST PIs using LSST data and SALT, using MaxE in particular; Coordinated SKA programs	2025 2028
SAAO-based Instrumentation	On-going Fibre Lab and Slitmask IFU development	Slitmask IFU installed; Established Lab for instrument building, training	2024 2026
Partnership instrumentation program	IDSAC, NIRWALS projects; ad hoc visits	Established training and exchange program with at least IUCAA	2025
B – Acquisition of new instruments			
Large-IFU feasibility study	Suggested instrument by community in 2017	Conduct feasibility/costing study	2024/5
Call for 2nd Gen instruments	Not done to date	Do formally, STC to manage	2024
C – Enhancing science productivity			
Science-ready pipelines	HRS pipeline exists	Add also all RSS modes and NIRWALS; Revamp HRS (incl.HS) pipeline	2024 2025
Enhanced higher-level data products available	Archive for primary-reduced data exists	SDSS-like user-friendly science data archive with products, parameters, etc.; SALT data available via IVOA searches	2026 2026
D – Upgrading systems			
SALT Payload upgrade	Dated and cumbersome system	Initiate feasibility study for “Top-end redesign”	2024
Service SAC (as part of a Payload upgrade, or utilising a separate scheme)	Scattered light in the SAC system	Decide what to do exactly; aiming for pristine SAC optics with regular servicing	2024 2025

SALTICAM replacement	Old Instrument, working, but with issues	Decide what to do exactly; complete upgrade using Development Fund	2024 2026
Instrument detectors	RSS Vis and Dual upgrades ongoing	Complete Vis/Dual projects; Plan also HRS detector upgrades, as well as NIRWALS	2024 2026 2027
E – Maintaining Financial stability			
2nd Development Fund	1st Dev Fund closed, NRF contributed to the 2nd DF through the SII project	Partnership to agree and raise funds for new DF	2025
Roadmap to new partners	Need new partners	Systematic plan to identify potential partners	2024
Attract new 10% partner	Need new partners	New partner or group of partners	2027

9. SALT Ten-Year Outlook

It is difficult to imagine all the ways in which the various extraordinary new facilities that are due to be online within the coming years (e.g. SKA, LSST, 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, and also by virtue of its unique geographic location in the global astronomy community. While the mini-tracker concept, which in principle could revolutionise the *area* on the sky where simultaneous large-telescope transient follow-up could be done, has been put on ice for the moment, the Intelligent Observatory initiative continues, and promises *very* rapid and efficient follow-up in general.

Exoplanet science will undoubtedly continue to astound us, particularly once the JWST truly settles in its groove in obtaining 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 various large exoplanet missions such as the future PLATO, and continue contributing to target lists for the JWST.

Although it may be 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.

10. Implementation Plan

An implementation plan pertaining to this Strategic Document will be presented separately. The SAAO Director, together with the SALT Operations team and the Scientific and Technical Committee, will make recommendations to the Board on the implementation road-map.

The current status of the Implementation steps following the 2018/9 goals and plan is also presented in a separate Board document.

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, 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.

Table A: The SALT Partnership (as at end of 2022)

PARTNER INSTITUTION	COUNTRY	SHARE (%)
National Research Foundation (NRF) [1]	South Africa	33.56 (51.88)
Rutgers University (RU)	USA	9.98
Centrum Astronomiczne im. M. Kopernika (CAMK)	Poland	9.67
Dartmouth College (DC)	USA	9.49
University of Wisconsin – Madison (UW)	USA	8.08
Inter-University Centre for Astronomy and Astrophysics (IUCAA)	India	6.90
UK SALT Consortium (UKSC) [2]	UK	2.26
American Museum of Natural History (AMNH)	USA	1.74

[1] *The formal share-holding of South Africa (NRF) is 33.56%. However, NRF currently has shares* ***on-loan****, after agreeing to cover the Operations Levies of several small partners that have left the Consortium over the years (Goettingen University, University of Canterbury, and University of North Carolina), as well as currently having partial shares of existing partner, UW and UKSC. This is why the share of SALT time for NRF is currently 51.88%.*

[2] *Consisting of University of Central Lancashire, Keele University, Armagh Observatory, University of Southampton, the Open University, and University of Nottingham (the latter, UN, is in the process selling shares to IUCAA, a transaction perhaps to finalised by the end of 2023).*

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 ~320nm and ~950nm, expanding to 1650nm with NIRWALS
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 [*update status for new 2023 situation*]
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 – Current (and near-future) Instrument Characteristics

RSS:	• Low to medium resolution spectroscopy • Observing modes: a. Long-slit spectroscopy b. Multi-object spectroscopy c. High time resolution spectroscopy d. Narrow-band imaging e. [Fabry-Pérot imaging spectroscopy currently on-hold] f. Optical IFU – due to be commissioned in 2024 • 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

	● Narrow band imaging (R~50) is available over the spectral range 430-890 nm ● Linear and circular polarimetric capabilities associated with each mode ● Optical IFU mode will provide 320-900nm coverage for spectral resolutions of 200-9000 using two fibre-bundles with fov's of 18x23 and 21x44 arcsec, and fibre sizes 0.9 and 1.8 arcsec, respectively
NIRWALS:	● Near-infrared Integral Field Unit (IFU) imaging spectroscopy – currently in on-sky commissioning ● NIR fibre-fed IFU provides 800-1650nm wavelength coverage with spectral resolution of 2000-5000, and 1.3 arcsec fibre size, over an 18x29 arcsec fov
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-scrambler and optional iodine cell or simultaneous ThAr calibration injection; a laser frequency comb and associated precision radial velocity data pipeline is under development, due to be commissioned in 2024
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

D – Recent and On-going Capability Developments

The following Table shows a Project Status Summary, as it stands in September 2023. The Table presents the highest P0 and P1 priority projects colour-coded w.r.t. the relevant progress at the time of reporting. The wide range of projects is aimed at improving, refurbishing, and developing existing SALT instrumentation and telescope & operational efficiency, as well as adding new capabilities for the use of the SALT user community.

NOT STARTED	STALLED	DRAGGING	PROGRESSING	CONVERGING	COMPLETE

P0 PROJECTS	RESOURCES	STATUS	TARGETED CAPABILITY
New RSS Collimator Doublet	The Pilot Group, Melanie, Nico	Doublet received from TPG, installed Mar 2023.	Enhanced science output (faint targets), higher observing efficiency.
New RSS Collimator Triplet	The Pilot Group, Melanie, Lisa	Triplet received from TPG, installed Mar 2023, RSS scattered light eliminated.	Enhanced science output (faint targets), higher observing efficiency.
New Web Manager	Christian, Astro Ops Software	Major update to the WM.	Enhanced user support.
New RSS Longslits	Tasheen, SALT Ops, SAAO Workshop	On-sky performance looks good, full set to be made now.	Higher observing efficiency.
Gen 1.5 – HRS-HS LFC	Lisa, Richard McCracken, Daniel Holdsworth, Wimpie	Phase I of installation completed in Aug 2023, Phase II to follow in Nov 2023	Extending science capabilities, enhanced science output.
PIPT Upgrade/API	Christian	API nearly complete, early testing in progress.	Enhanced user support.
NIR-SA (NIRWALS)	UW, SALT Ops, Moses	NIRWALS installed in 2022, science commissioning and pipeline development underway. New ADC and Calsys Phase I completed.	New science capability.
New RSS Detector	Ros, Kathryn, SAAO Instrumentation, IUCAA	Detailed design continuing. Controller configuration and testing in progress.	Enhanced science output, higher observing efficiency.
Calsys Phase II	SALT Ops, Mike Smith, Melanie	Mike Smith joined the team and is starting investigations.	Higher observing efficiency, extending science capabilities.

Gen 1.5 – RSS Dual (aka MaxE)	Roufurd, Janus, Deon, David Buckley	Optomechanical designs being completed, PDR to follow in 2024.	Extending science capabilities, enhanced science output, higher observing efficiency.
SALT Data Quality	Rudi, Enrico, Astro Ops	Ongoing improvements.	Enhanced science output.
Simulations from Queue Scheduler	Enrico, Lee, Astro Ops	Working on implementing semester simulations.	Enhanced operational efficiency, enhanced user support.
Structure + Dome Drive Replacement	Richard, Paul, Bryne	Obsolete and problematic systems, need to decide how best to proceed.	Enhanced operational stability/efficiency.
SALTICAM Replacement	SALT Ops, STC	Alternatives (including sCMOS) being considered.	Extending science capabilities, enhanced science output, higher observing efficiency.
SAC Recovery + Maintenance Plan	SALT Ops, STC	Key aspect of proposed new top end project.	Enhanced science output, higher observing efficiency.
Top End Redesign	STC, Deon, SALT Ops	Investigate how to modify the top end of the telescope to future-proof the system.	Extending science capabilities, enhanced science output, higher observing efficiency.
Tracker Controller Upgrade	Bryne	Investigations started.	Enhanced operational stability/efficiency, higher observing efficiency.

P1 PROJECTS	RESOURCES	STATUS	TARGETED CAPABILITY
Slit-mask IFUs	Sabyasachi, Matt	Delays due to workshop scheduling, but good progress.	New science capability.
Telescope Focus	Deon, Janus, Malcolm, Xola	Understanding the influence of segment piston, working on model to predict HRS focus.	Higher observing efficiency, enhanced operational stability.
Performance Monitoring Website	Xola, SALT Ops	Good plots to monitor pointing performance and acquisition overheads, more to follow.	Enhanced operational stability/efficiency.
SALT Acquisition Efficiency	Encarni, Malcolm, Software	Have contracted a software person to work on this.	Higher observing efficiency.
Louver Upgrade Study	Deon, Nico, Malcolm	Look into replacing the louvers to improve the way the dome is ventilated during night-time operations.	Improved IQ by removing internal seeing component

E – SALT Publications Analysis

It is now more than a decade since the start of normal science operations, and bibliometrics are hence becoming relevant, in contrast to e.g. measuring paper outputs within a few years of start of operations, which inevitably would look poor due to the time-lag between data acquisition and published work, not to mention citation counts which build up over time. See e.g. Crabtree (2018) for an example of a study focusing on observatories' output over 2012-2016: SALT is seen in very unflattering light therein, if the context of the difference between telescopes that had started recently, versus those that had been operating for decades is not recognised. In contrast, as is seen below, typical SALT metrics for papers now, in 2022/23, are more or less where one would expect them to be, when starting times of observatory operations are taken into account. Observatory performance indicators should *always* be compared as a function of time since the start of full science operations to be fair.

Figure 2 in Section 4.1. showed, first of all, the total number of refereed papers published, per year, since the respective science operations began. The data are shown for all of the world's 8-10m class optical telescopes, and are normalised by the number of telescopes (i.e. accounting for e.g. *two* Geminis, and *four* VLTs). It was seen that SALT is by and large following the general trend, it has increased steadily and reached 60-70 papers by 2022. In particular, comparisons with the Large Binocular Telescope (LBT) and the Gran Telescopio de Canarias (GTC) may be useful, since they started just a little before SALT, as well as comparing to Hobby Eberly Telescope (HET) because of the very similar telescope design (note that here we present the HET rates since their new top-end design, not the original telescope, which would have put the operations start 16 years earlier).

Other factors going into productivity plots that should be taken into account in a more detailed study and analysis include e.g. the size of the contributing astronomical community, and to a lesser degree also such details as the fraction of usable weather. Resources available, and costs, are also relevant. Hence, Figure 3 showed the same publications counts, but now normalised, separately, by the telescope's construction costs, and annual operation costs. Here it was seen that SALT is actually an extremely cost-effective observatory in comparison to its peers, in fact the most cost-effective telescope of its class in the world.

Where should SALT aim to be as far as publication numbers are concerned? One way of assessing this is simply looking at Fig. 2 – it is typical that facilities' productivity increases for a decade (or two at maximum) as, presumably, the user community learns how to use the available instruments effectively, after which the productivity starts to plateau. This has been noted by other bibliometric analyses. Looking at the trends of these similar aperture telescopes, one could aim to plateau to around 130 annual papers by, say, 15 years of operation. However, as mentioned earlier, the size of the contributing community may be a bottleneck as well, which is something we do not know yet.

Another way of assessing a "typical" data-paper production rate is to compare to the number of observing programs executed on the telescope. This would implicitly calibrate e.g. effects of average weather downtime at different locations. For example, an extensive study performed by ESO (Sterzik et al. 2016) on over 8000 VLT programs over a 16-year period revealed that, approximately, only 35% of all (normal) programs publish. On the other hand, those that do publish produce an average of 1.7 papers. Thus, in the case of SALT, if these VLT "normal program" (i.e. excluding DDTs, Large Programs, and Guaranteed Time Programs) results were to be taken as a long-term guideline, taking a typical number of about 70 individual programs per semester, or double that in a year, one might eventually be aiming at 80-90 papers per year, which is somewhat lower than the simplistic "plateau-comparison" of other major facilities suggested above.

We might, however, add another 10-15 papers to that eventual expected goal above based on *DDT* and Large Science Program (*LSP*) trends. An analysis at the end of 2022 made of all SALT programs found that the publication rate of "normal" programs was approximately 20%, in comparison to the 35% at VLT. (Note, however, that this SALT analysis included also recent programs, so the rate will be higher later since the lag between observations and publications is quite significant - typically 2-5 years as found by e.g. Crabtree 2016 and Sterzik et al. 2016, as well as an early SALT study by Schroeder et la. 2015.) At the same time, the DDT program publication rate was 44%, i.e. significantly higher. However, as there are only 7-10 DDT programs a year, the absolute impact is not significant. Conversely, a larger impact can be expected for LSPs, at least based on the single long-running one at SALT, which has produced roughly 10 papers per year. Hence, at this point, a goal should perhaps be set at some **100** SALT papers pa.

Conversely, if the productivity trend were to start plateauing below these ~100 p.a. values, we should attempt to understand reasons for it, and try and correct any limiting factors. Furthermore, production rates below 50% per program, while apparently universal, call for studies and surveys to understand the reasons, in case there would be any low-hanging fruit to release blockages (e.g. science pipelines, user support, or very specific data quality issues).

Citations to SALT data papers compared to other Observatories

Finally, we look at *citations* to the publications based on SALT data as a proxy for the impact, or relevance, of the telescope. Citations to papers published in a given year of course only become relevant 2-4 years after the publication year, since they grow as a paper ages (see e.g. ESO Publication Statistics[1] for an example). Looking at the SALT papers from 2013 (onward from which there are enough statistics) to 2019 (after which the citation counts are still ramping up), the typical *average* citation count per SALT paper per year is between 30 and 40. For two of those years the average number is much higher, around 80-90, due to single *extremely* highly-cited papers: the electromagnetic follow-up of the 2017 gravitational wave event in 2017, and another highly-cited SN paper in 2014. Excluding those two papers, the averages are similar to the other years, 35 in both those cases.

In more detail, Figure 3 in Section 4.1 already showed an analysis performed by the Gemini Observatory on the "mean citation impact" of papers based on data from selected major observatories. The impact was normalised to the annual ApJ impact parameter, showing how data papers typically are cited 2 to 3 times more than all ApJ refereed papers on average. SALT is clearly following the general trend. Considering the very different sizes of some of the communities (such as the VLT and Keck user communities), as well as their respective resources, we conclude that the relevance of SALT as measured by citations has reached a healthy and respectable maturity. Of course, there is still room for improvement in motivating the user community even more, but SALT is by no means an outlier anymore, like it appeared to still be in some bibliometric analyses, perhaps somewhat unfairly, 5-8 years ago (c.f. Crabtree 2018).

Science published in SALT data papers – trends

Currently (as of December 2022) there are 452 refereed publications based on SALT observations in the literature, including seven in *Nature* or *Science*, and another seven in *Nature Astronomy*.

Furthermore, there are another 34 refereed SALT publications that are classified as instrumentation related, or survey descriptions, and hence the total of refereed "SALT papers" is 486 currently.

It is noteworthy that, in addition to the above, there are more than 130 SALT papers in the *SPIE* Astronomical Telescopes and Instrumentation conference series, the world's premier conference on these topics. This highlights the *very* strong record of publishing technical developments at SALT.

Statistics regarding the fields of the SALT data publications give an indication of successful SALT science. The *Table* below shows statistics of the number of papers per topic, or category. We have included the ten gravitational wave follow-up papers in the Supernova category, which then represents the bulk of the extragalactic transient science. The percentages shown in the Table are similar if statistics are done on *programs* contributing to the papers.

[1] https://www.eso.org/sci/php/libraries/pubstats/

The largest field of SALT science has thus been Galactic astronomy, dominated by an assortment of variable stars, especially cataclysmic variables, symbiotic stars, white dwarfs and novae. Exoplanet papers (13 in this count) have started growing recently, as part of the wide Galactic category.

N = 452 refereed SALT *data* papers (12/2022)	
Galactic	48%
Extragalactic (excl SNe etc.)	35%
SNe / GW	15%
Solar System	2%
total	100%
Target-of-opportunity (ToO) [% of total N]	30%
More than 10 targets/observations [% of total N]	8%
RSS	71%
HRS	21%
SALTICAM	8%

Table E1. Breakdown of papers based on SALT data by science field, and the instrument used. In addition, the fraction of the papers that are from ToO proposals, and from proposals with more than ten targets, are also shown.

The extragalactic papers are roughly evenly divided between those studying the nearby Universe, and targets at higher redshifts. The former category mostly involves dwarf and early-type galaxies, and star-forming galaxies, while the latter is dominated by AGN/QSO studies, followed by galaxy clusters.

As mentioned above, transient science has been a very successful SALT science field. Supernova follow-up has been a successful field, contributing 13% of SALT data papers, with another 2% coming from GW papers, only since 2017. This category of course has made a *very* large impact when considering citations.

ToO observations in general have thus far generated nearly a third of all data papers, significantly more than their share of actual observing time, which is 9% over a 10-year period. Similarly, there are over 60 SALT data papers based on data taken as part of the Transients *Large Science Program*, i.e. approximately 20% of all SALT papers in the relevant time-frame come from this single program, while the corresponding time fraction used on the program is 8% in this same period.

As far as citations go, apart from the most cited gravitational wave 2017-event paper, many of the most-cited SALT papers are SDSS SN survey related analyses, and other extragalactic papers, both of the transient type and more traditional galaxy/cosmology works. Strictly considering the top ten cited SALT *data* papers to date, three are related to SALT follow-up of the gravitational wave event, while another one is also an extragalactic “multi-messenger” paper, publishing follow-up of a neutrino-detection of a blazar. Two of the ten are more traditional Galactic astronomy works, and another one is in the field of galaxy evolution / cosmology, while the rest, three, are all Supernova related data-papers.

Instrument statistics show that the RSS, and its long-slit mode in particular (see the Table below showing statistics of *programs* having published data), still remains SALT's workhorse instrument with more than 70% contribution to all-time papers. However, HRS has started to contribute much more significantly, as seen if Fig.7. showing the historical trend of the split of SALT papers broken down by the used instrument. The significant increase of HRS papers can be attributed to the release of the HRS pipeline in 2017, increasing the efficiency of publishing data from the instrument. Indeed, over the past 3-5 years, HRS papers have contributed to 30-40% of annual data papers, which in fact is similar to the split in time-usage on the telescope between the two instruments (see Fig.8) indicating that there is no significant difference between the productivity of the instruments, and/or the communities using them.

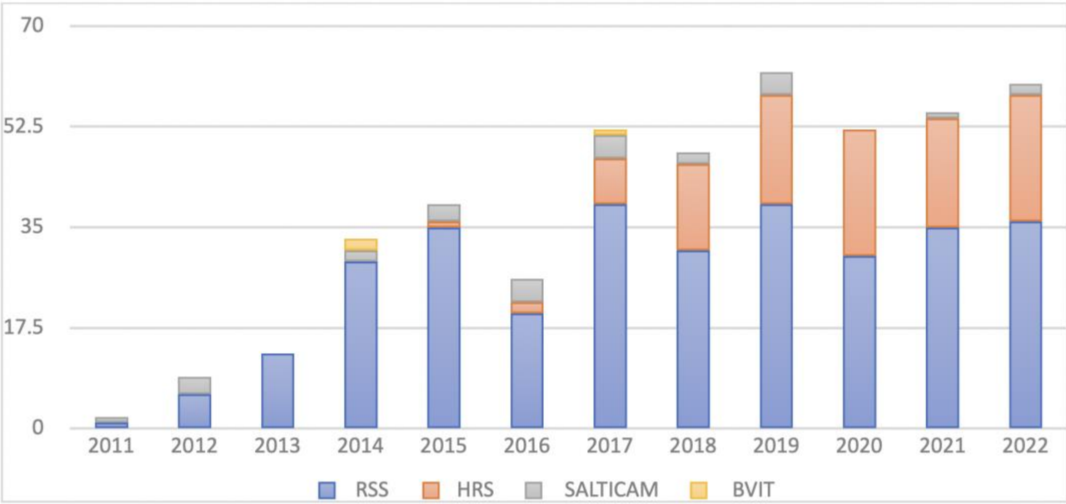

Figure 7. Historical split of SALT papers per year broken down by instrument used.

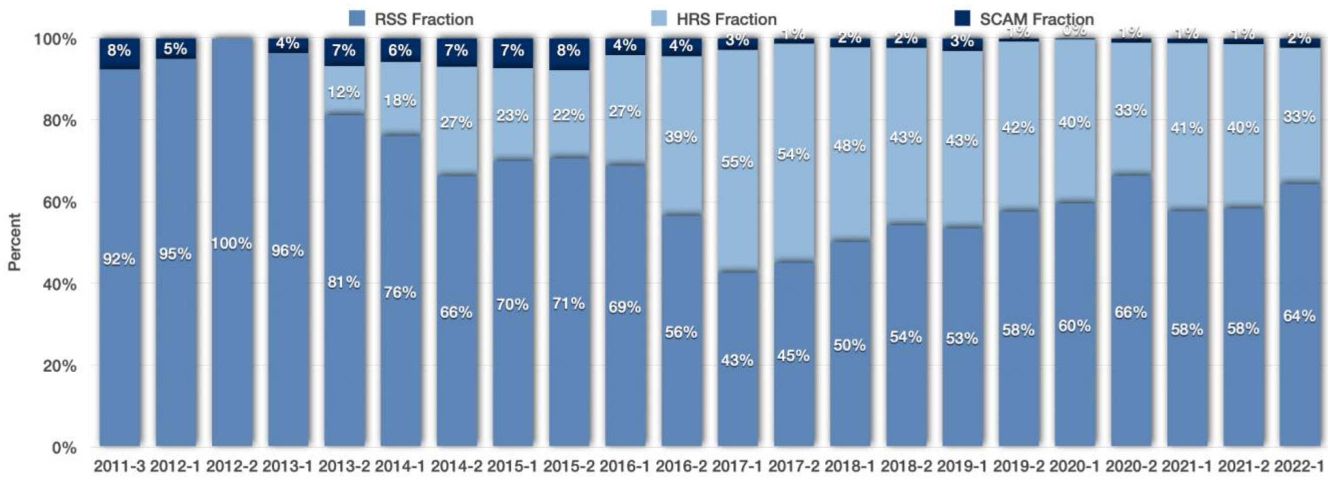

Figure 8. Historical split of time-usage on the telescope per semester broken down by instrument used.

It is interesting to also consider other changes, or similarities, in the publication statistics over the past years. When compared to the situation in 2018/2019, with approximately half the current number of papers, the fractional split across the major Science areas has essentially not changed at all. However, the fraction of ToO-based papers has grown quite significantly from 18% to 30%, signifying the continuing, and even growing, relevance and appeal of SALT (as well as the interest of the SALT community of course) for rapid-response observations. Consequently, the fraction of larger published programs, i.e. papers with more than 10 targets published/analysed in a single paper, has decreased somewhat (from 14% to 8%). This is contrary to the expectation five years ago of more long-term programs getting done and published over time – while this has happened as well, it is overshadowed by the even larger increase in the ToO science where results based on single, or small number of, targets are often published.

Another interesting change in trends relates to SALTICAM papers. While the overall cumulative fraction of these imaging papers has not changed much since 2018 (from 10% to 8%), it is clearly decreasing as the typical annual fractions of SALTICAM papers has been 4-6% over the past five years. On the other hand, typical SALTICAM usage of the time on the telescope over this period is approximately only 2%, so it is still an *efficient* mode time-wise. However, overall, it is noteworthy that there has been a trend of decreasing usage of SALTICAM *high time resolution* mode and papers. This is likely to various technical difficulties of the instrument for this mode (such as lack of guiding, or efficient focus control, as well as some detector noise issues) - hence, there has actually been a shift by users to rather utilise RSS for SALT high time resolution observations recently.

N = 970 *programs* contributing to the SALT data publications above (12/2022)		
RSS	68%	
Long-slit		93%
Multi-object		4%
Fabry-Perot		2%
Imaging		1%
SALTICAM	12%	
High time resolution		27%
HRS	19%	
LR		24%
MR		53%
HR		20%
HS		2%
BVIT	1%	

Table E2. Breakdown of SALT programs that have been included in publications, by instrument and instrument mode.

F – References

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G – List of Acronyms [update]

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