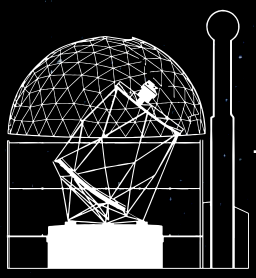


ANNUAL REPORT

SOUTHERN AFRICAN LARGE TELESCOPE

2021

S·A·L·T

IN MEMORIAM: VASILII VASILIEVICH GVARAMADZE

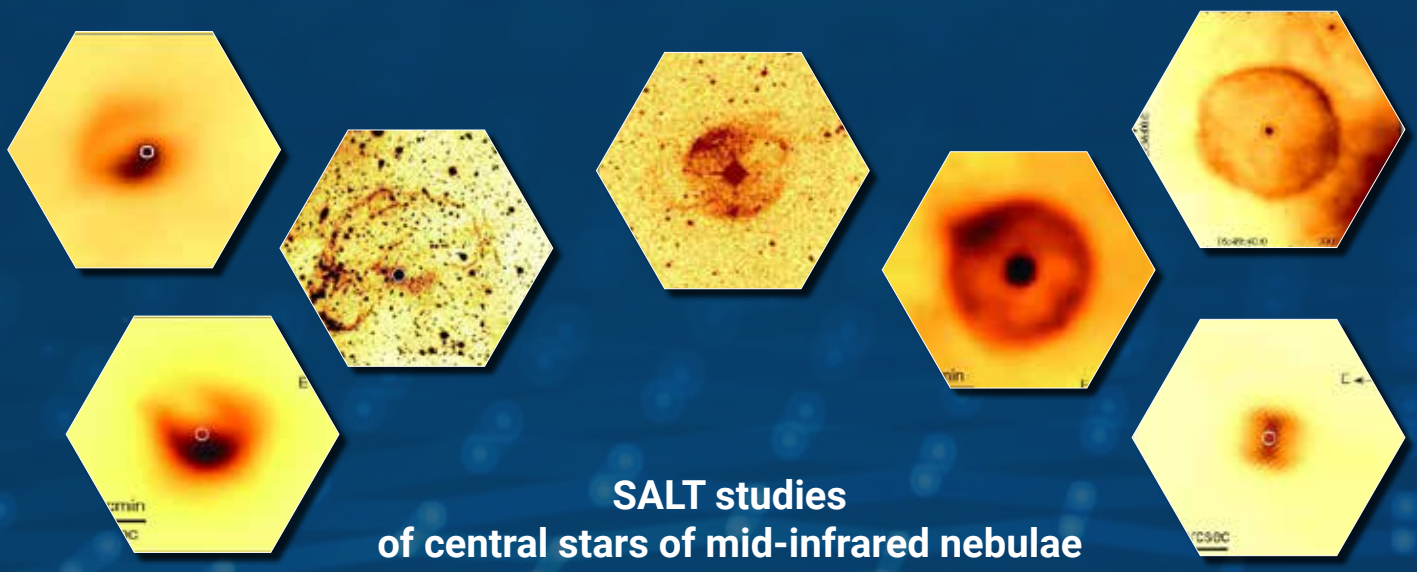
It is with great sadness that we announce the passing of Vasilii Vasilievich Gvaramadze from the Sternberg Astronomical Institute in Moscow at the age of 61. He was the most prolific first author of SALT publications with 15 first author papers and five more that he has co-authored. Many of these were described in SALT Annual Report issues, with his last paper reported in the current one. His main interest was nebulae around massive stars in the late stages of evolution, for which SALT is the ideal telescope. He closely worked with one of the SALT Astronomers, Alexei Kniazev.

Biography

Vasilii Vasilievich Gvaramadze was born on 9 July 1960 in Tbilisi (Georgia) and graduated from the Physics department of the Tbilisi State University. After graduation, he joined the Plasma Astrophysics department of Abastumani Astrophysical Observatory as a theorist. His early career research on plasma physics and magneto-hydrodynamics allowed him to develop a deep understanding of astrophysical flows. After several postdoc positions in Bulgaria, Italy and Germany, he came to work at the Sternberg Astronomical Institute of the Moscow State University towards the late 1990s. He started as a theorist, but in the middle 2000s, Vasilii started mining archives of infrared space telescopes, which contain so much valuable data that the teams of these telescopes do not have the time to analyse them all. Vasilii developed a uniquely successful strategy to identify massive stars in the late stages of evolution based on their unusual nebulae (that is, dusty envelopes that are resolved on *Spitzer* and *WISE* images), which often turned out to be key objects for advancing our

In 2018, Vasilii visited Eva Grebel at the Astronomisches Rechen-Institut in Heidelberg. The photo was taken by his long-time collaborator Alexei Kniazev from SAAO one evening in a restaurant.

Examples of various shapes of MIR nebulae



SALT studies of central stars of mid-infrared nebulae

Mass-loss from massive stars, along with the effects of stellar rotation, magnetic fields and binarity, are the origin of circum- and interstellar nebulae of various shapes and scales. The formation of coherent (observable) nebulae around the majority of stars, however, is hampered by the effect of stellar winds from other massive stars in the vicinity, because most (if not all) of these stars form in star clusters. Thus, to produce observable nebulae, (massive) stars should escape from their birth clusters through either supernova explosions in binary systems or dynamical encounters with other (massive) stars.

The ejected, so-called runaway stars constitute about 20% of all OB stars. A wind bubble produced by a runaway main-sequence OB star rapidly becomes elongated and transforms into a bow shock (an arc-like structure ahead of the star) if the star is moving supersonically with respect to the local ISM. A runaway OB star, however, can produce a short-lived (~4 yr) circular shell during the advanced stages of evolution if it is surrounded by

understanding of their evolution. His organisational skills immediately showed up: for every unique massive star he could gather an effective team of specialised observers, theoreticians and simulators to reveal the details of its evolution from the observational signatures. The originality and impact of his work allowed him to obtain data with the most advanced ground and space based telescopes, and to publish his work over the last fifteen years in almost sixty papers in the highest quality journals, including a first author paper in Nature. In 2020, he was nominated to the Lomonosov Scientific Prize of the MSU and presented his series of works “Discovery and investigation of extremely rare stars”.

Based on archival data and on follow-up spectral observations, initiated by him at the large telescopes SALT and the Big Azimuthal Telescope (BTA) in the Caucasus Mountains, his discoveries include post-main sequence runaway stars, four ‘true’ luminous blue variables (LBV) stars and about two dozen candidate LBV stars, blue supergiants with circumstellar envelopes, the product of the merger of two massive white dwarfs, and pre- and post-supernova stars — including a WO-type Wolf-Rayet star which appears to be both.

Vasilii was a very demanding collaborator and scientist. In his private life, he was very interested in collecting photos of old Tbilisi, Borjomi, Abastumani etc. He accumulated over 1000 photos, sometimes paying high prices for a photo.

Vasilii Vasilievich Gvaramadze passed away at the age of 61 on 2 September 2021 at the peak of his career. The death of such an outstanding and extremely productive scientist in his very creative prime is a great loss. His ground-breaking interpretations of the massive stars and nebulae will keep inspiring many of us.

a dense material comoving with the star, i.e., the dense matter shed during the red supergiant phase, and if it is massive enough to evolve afterwards into a Wolf-Rayet star. The circular nebulae can also be formed as the result of eruptive mass ejection during the luminous blue variable, or LBV, phase.

The circumstellar nebulae and bow shocks are known to be sources of infrared (IR) emission and can be detected with modern IR telescopes. Searches for compact nebulae and bow shocks using data from the *Spitzer Space Telescope* and the *Wide-field Infrared Survey Explorer* (*WISE*) resulted in the discovery of hundreds of such objects. Vasilii Gvaramadze conducted a systematic search of *Spitzer* and *WISE* archives and initiated the creation of a catalogue of such found infrared nebulae, published in 2010. Follow-up spectroscopy of stars associated with these IR nebulae and bow shocks with SALT have led to the discovery of some dozen massive stars at various evolutionary stages, of which the most common and interesting are the LBV candidates. From 2010 on, using SALT and SAAO’s smaller telescopes, Gvaramadze together with Alexei Kniazev from SALT/SAAO and their co-authors carried out spectroscopic and photometric monitoring of about a dozen newly identified candidate LBVs to search for possible spectral and photometric variability, and, where possible, to prove their true LBV nature. This allowed him and his co-authors to add four new members to the class of Galactic *bona fide* LBVs, bringing the number of these very rare stars to eighteen, and doubling the number of previously known Galactic candidate LBVs. The discovery of new LBVs and the modeling of their spectra are of great importance for understanding their evolutionary status and their connection to other massive transient stars, as well as for unveiling the driving mechanisms of the LBV phenomenon, which are still poorly understood. The study of the central stars of the infrared shells showed that massive stars can produce compact circumstellar nebulae while they are still on the main sequence or shortly after they left it, and that, most likely, the formation of these nebulae is related to the binarity of their central stars. The obtained results have important consequences for understanding the LBV phenomenon as well as the mechanisms of formation of circumstellar shells.

As a by-product, SALT spectroscopy revealed that several of the detected nebulae were created in the course of evolution of low-mass stars with unique development: a rare WN-type central star of a planetary nebula, a new member to the small group of barium stars with circumstellar nebulae, a new member of the rare group of H-poor planetary nebulae. Moreover, one of the nebulae (detected around the high-mass X-ray binary SXP 1323) turned out to be a supernova remnant.

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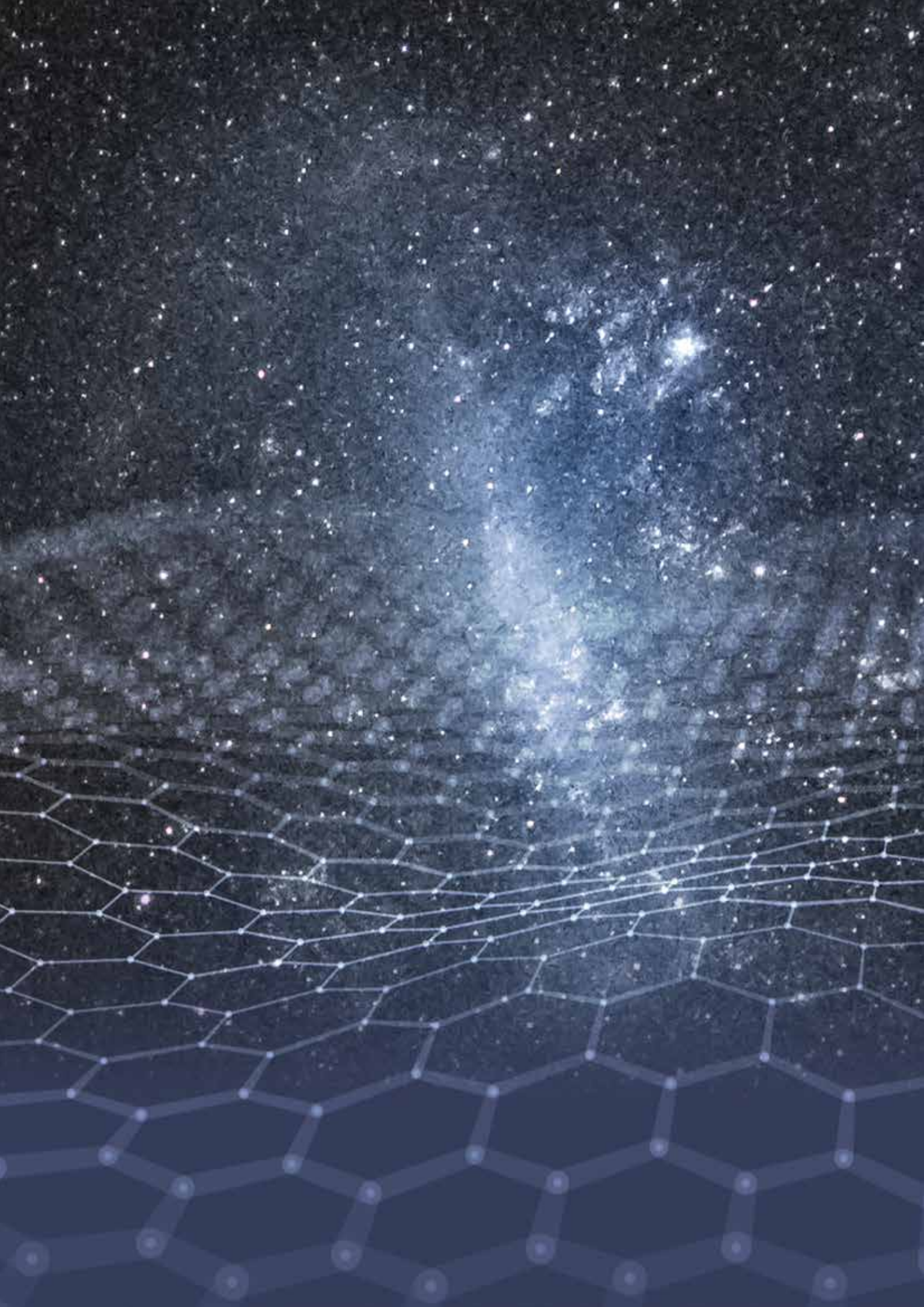


ABOUT SALT

The Board of the Southern African Large Telescope (SALT) is proud to present its Annual Performance Report for the period 1 January 2021 to 31 December 2021. This report offers an overview of the activities and performance of SALT, highlights a selection of SALT research projects, and introduces the SALT partner institutions/consortia.

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 metres in diameter, consisting of 91 individual 1-m hexagonal mirrors. It is the non-identical twin of the Hobby–Eberly Telescope (HET) located at McDonald Observatory in West Texas (USA). The light gathered by SALT's huge primary 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 owned by the SALT Foundation, a private company registered in South Africa. The shareholders of this company include universities, institutions and science funding agencies from Africa, India, Europe and North America. The South African National Research Foundation (RSA) is the major shareholder with a ~52 percent stake. Other large shareholders are the University of Wisconsin–Madison (UW), the Nicolaus Copernicus Astronomical Centre of the Polish Academy of Sciences (POL), Dartmouth College (DC) and Rutgers University (RU). Smaller shareholders include the Indian Inter–University Centre for Astronomy and Astrophysics in India (IUCAA), the American Museum of Natural History (AMNH) and the UK SALT Consortium (UKSC), with the latter representing the Universities of Central Lancashire, Keele, Nottingham, Southampton, the Open University and the Armagh Observatory. The size of the shareholding of each partner determines the access to the telescope that they enjoy. The HET Consortium, although not a shareholder, received ten percent of the telescope time for the first ten years of operation, in return for providing all of the designs and plans from the HET, as well as assistance during the construction of SALT. Three of the original shareholders, Göttingen University (Germany), the University of Canterbury (New Zealand) and the University of North Carolina (USA), left the SALT Foundation. The SALT Foundation is currently looking for new shareholders.

SALT is located at the observing site of the South African Astronomical Observatory (SAAO), near the small Karoo town of Sutherland, about 370 km northeast of Cape Town. This site has been host to a number of other smaller telescopes since the early 1970s, and benefits from its location in a semi-desert region with clear, dark skies. The quality of this site for optical astronomy is preserved by South African legislation.

VISION AND MISSION

Vision

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

Mission

Lead the advancement and development of optical astronomy on the African continent and inspire and educate new generations of scientists and engineers worldwide.

Provide a world-class large telescope research facility cost-effectively to astronomers in an international community.

Strategic objectives of SALT

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. Which 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

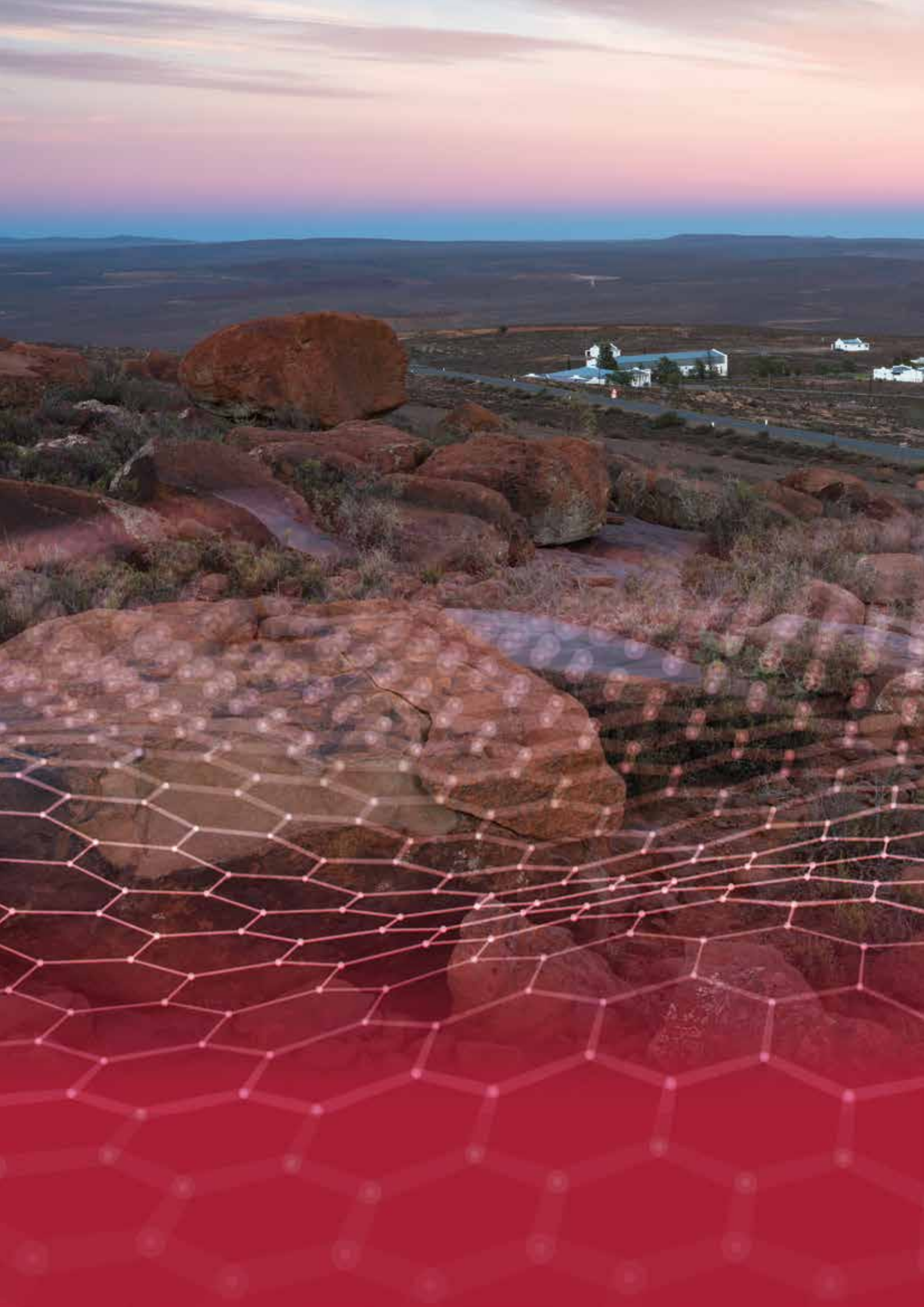
Pursue instrumentation development

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, through outreach to undergraduates, schools and the general public; to train graduate students; to have a special focus on developing and leading professional astronomy and high-tech astronomical instrumentation on the African continent; to promote 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.



CHAIRMAN'S REPORT

2021 was an extraordinarily difficult year worldwide, and neither South Africa nor SALT were spared the challenges and problems posed by COVID-19. Great effort went into successfully keeping SALT operating remotely, and I want to express the Board's appreciation for the hard work that kept excellent data rolling in despite the pandemic.

Amongst the highlights of 2021 were a badly needed shutdown during October to make specific measurements needed in preparation for receiving new hardware (such as the near-infrared spectrograph and the replacement RSS collimator lens groups), as well as replacing the payload cooling system and modifying the slitmask mechanism to accommodate new, thicker masks (that will include the slitmask IFUs currently under development in Cape Town). All these tasks were completed on schedule and the telescope was back online on 28 October.

Resignations and retirements brought about acute staff shortages, which were challenging to fill during the pandemic. But aggressive and determined recruiting filled almost all vacancies with highly qualified candidates by the end of 2021.

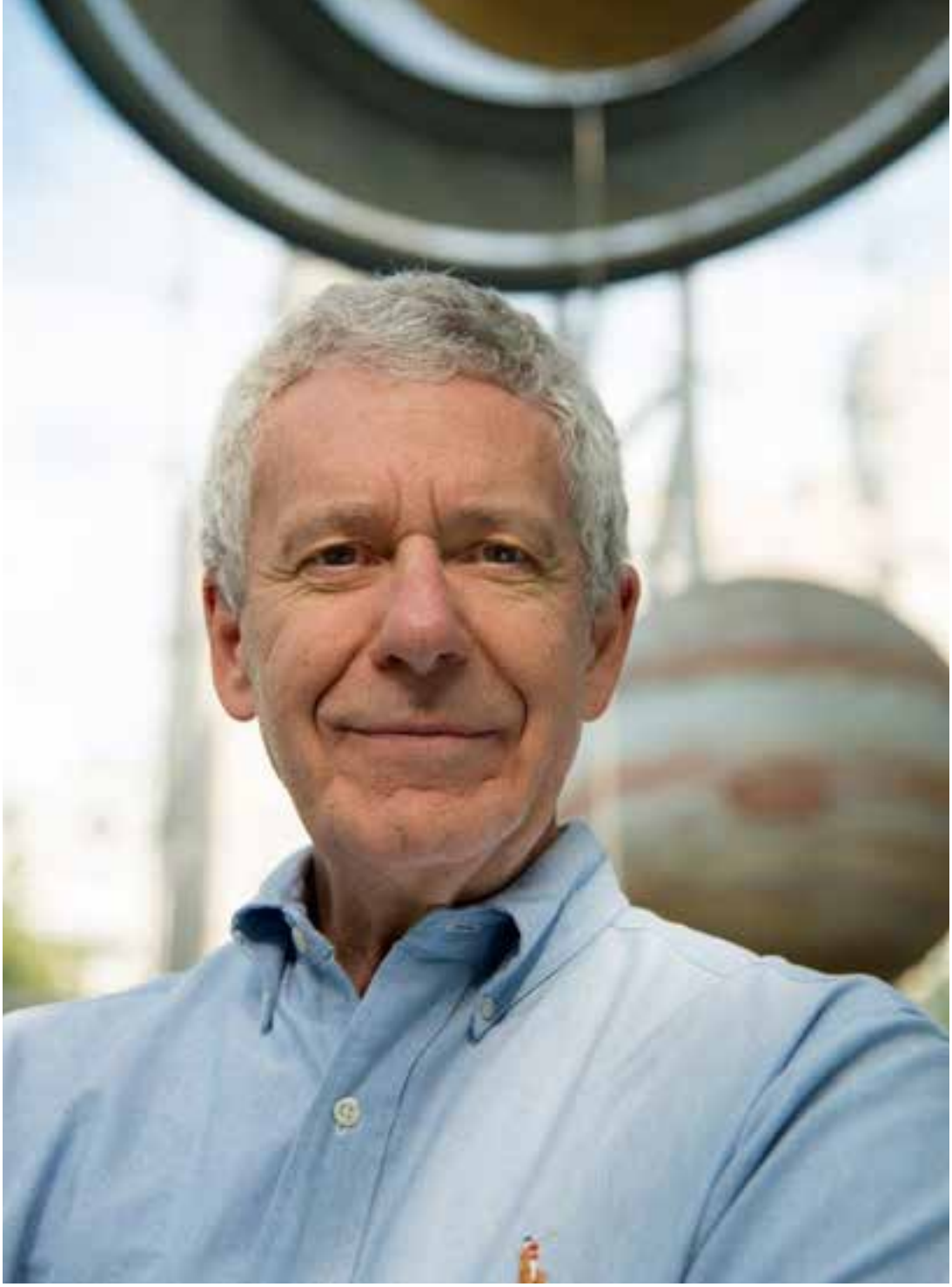
Extensive testing of the High Resolution Spectrograph demonstrated that it is capable of metre-per-second radial velocity stability, and the Board has accepted the recommendation of the Scientific and Technical Committee to add a Laser Frequency Comb to HRS to support precision radial velocity science. An order was placed with Heriot-Watt University for the comb development, with integration and commissioning anticipated in early 2023. A data reduction pipeline for the instrument's high-stability mode was also funded and is underway.

As part of a long-term upgrade of the spectrographic capabilities of SALT, a 700 lines/mm grating that will provide wavelength coverage of the full visible range in a single exposure was ordered. This new grating has now been delivered and will be installed in early 2022.

Construction of the long anticipated Near-Infrared spectrograph was completed at the University of Wisconsin in 2021. The instrument will be shipped to South Africa in early 2022, with installation and commissioning to follow in early through mid-2022.

A two-year study of the feasibility of adding mini-trackers to SALT concluded that there was no obvious 'show-stopper', and a preliminary design demonstrated how they could operate. The cost of such a system is larger than anticipated though, and the Board opted to halt further development until a broader review of all next-generation instruments is carried out.

On a different note, given the immense success of the previous SALT—Stobie PhD programme, funding has now been made available to restart the scholarships and introduce visits for South African students and postdoctoral fellows to spend time at SALT partner institutes. A pre-call was announced towards the end of 2021, with placements expected to begin as soon as the situation with the COVID-19 pandemic allows. Related to this, discussions around teacher training, placements and exchanges with other SALT partners are underway.



In November 2021 the board decided to include two additional board members from South Africa, providing further opportunities to develop leadership expertise and to continue to drive optical astronomy research and build the community across the country.

I'll conclude on a personal note. After three terms, and nine immensely satisfying years, I'm gratefully handing over the SALT Board Chair to Brian Chaboyer of Dartmouth College. Due to the enormous dedication and hard work of its staff, and the steadfast support of its Board members, SALT is vastly more capable today than it was nine years ago. I know that under Brian's leadership those capabilities will continue to grow, and that SALT will continue to flourish.

Prof. Michael Shara
Chairperson, SALT Board

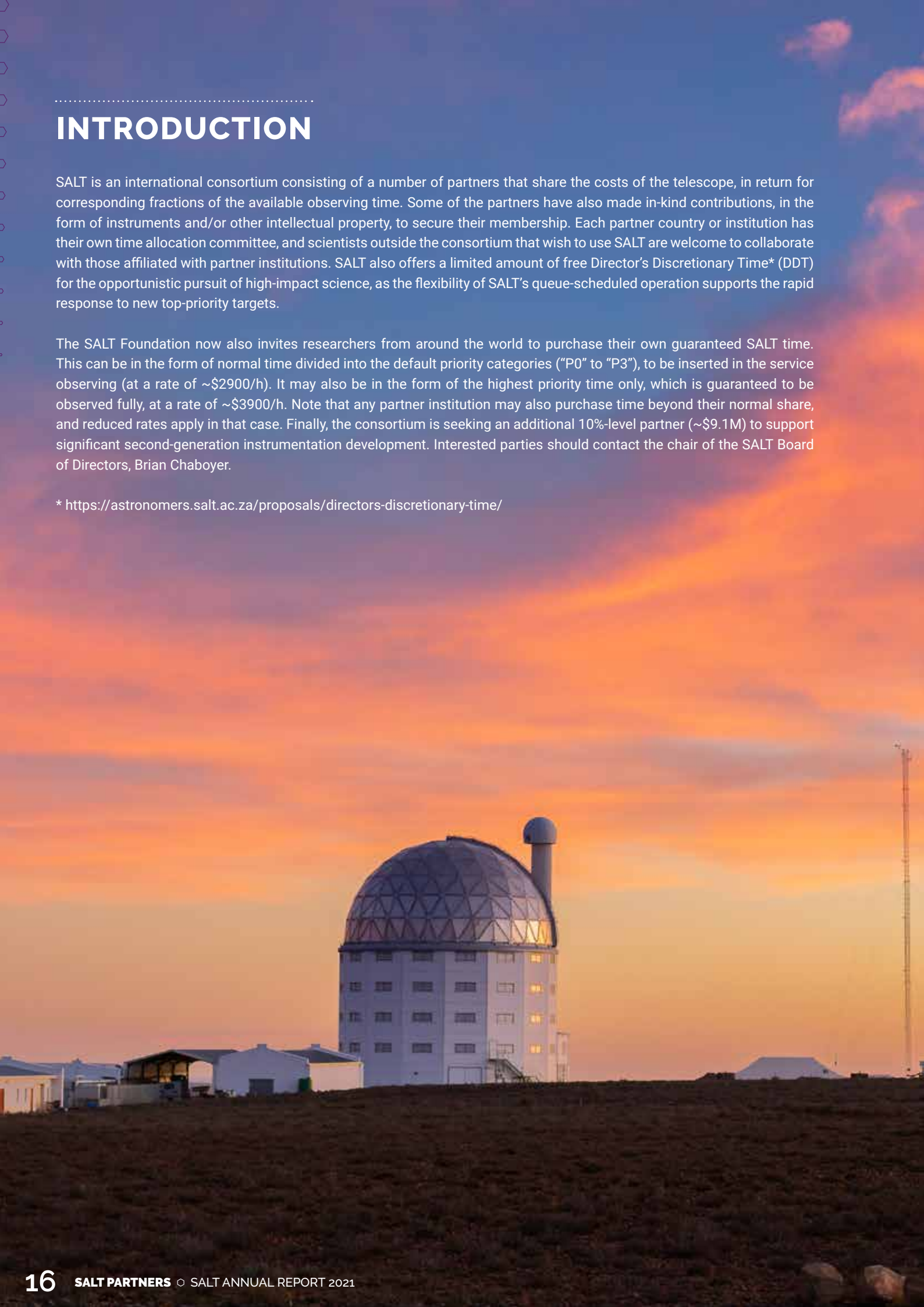
PARTNERS

INTRODUCTION

SALT is an international consortium consisting of a number of partners that share the costs of the telescope, in return for corresponding fractions of the available observing time. Some of the partners have also made in-kind contributions, in the form of instruments and/or other intellectual property, to secure their membership. Each partner country or institution has their own time allocation committee, and scientists outside the consortium that wish to use SALT are welcome to collaborate with those affiliated with partner institutions. SALT also offers a limited amount of free Director's Discretionary Time* (DDT) for the opportunistic pursuit of high-impact science, as the flexibility of SALT's queue-scheduled operation supports the rapid response to new top-priority targets.

The SALT Foundation now also invites researchers from around the world to purchase their own guaranteed SALT time. This can be in the form of normal time divided into the default priority categories ("P0" to "P3"), to be inserted in the service observing (at a rate of ~$2900/h). It may also be in the form of the highest priority time only, which is guaranteed to be observed fully, at a rate of ~$3900/h. Note that any partner institution may also purchase time beyond their normal share, and reduced rates apply in that case. Finally, the consortium is seeking an additional 10%-level partner (~$9.1M) to support significant second-generation instrumentation development. Interested parties should contact the chair of the SALT Board of Directors, Brian Chaboyer.

* https://astronomers.salt.ac.za/proposals/directors-discretionary-time/



REPUBLIC OF SOUTH AFRICA

South Africa's National Research Foundation (NRF) is the majority shareholder in SALT, with approximately a one-half share. The South African Astronomical Observatory (SAAO), contracted to host and operate SALT, is also one of the NRF's several national facilities. As the intermediary agency between the policies and strategies of the government of South Africa and the country's research institutions, the NRF's mandate is to promote and support research through funding, human resource development and the provision of the necessary facilities, in order to facilitate the creation of knowledge, innovation and development in all fields of science and technology (including indigenous knowledge), and to thereby contribute to improving the quality of life of all South Africans. The country's considerable investment in astronomy, both in optical and radio, is due in no small part to this field's extraordinary potential to capture the imagination and hence to encourage the brightest young minds to pursue scientific and technical qualifications.

SALT is located at the Sutherland site of the SAAO in the Karoo desert (about 370 km from Cape Town), making it one of the darkest observing sites in the world. SAAO hosts all the SALT Astronomers, responsible for liaising with PIs and making the observations, as well as all the technical and support staff associated with SALT. The Observatory's mechanical and electronics departments at the SAAO headquarters in Cape Town include large workshops and a dedicated CCD lab. SALTICAM and the RSS detector packages, as well as the fibre-instrument feed and various auto-guiders for the SALT instruments, were designed and built here. The maintenance and servicing of all instruments and telescope sub-systems are done in Sutherland by the Technical Operations team.

One of SALT's strategic objectives is Human Capital Development which is particularly important for South Africa and, even more so, for the African continent. Thus the SALT Collateral Benefits Programme (SCBP) was established during the construction of SALT and the objectives of this programme were clearly directed at the benefits derived by society from building this large telescope. The SCBP is mainly directed at schools but also includes outreach to the general public.

South Africa's astronomical community has grown significantly since SALT was built, with SALT and later the SKA/MeerKAT initiatives spurring much of this growth. The entire South African community has access to SALT, and scientists from national research facilities and universities across the country use SALT regularly. There are now over two hundred PhD astronomers at institutes around the country and students at all levels of study. Students are actively encouraged to participate in SALT projects and to propose for time on SALT. The recent decision to have two additional board members from South Africa will provide further opportunities to develop leadership expertise and to continue to drive optical astronomy research.

South African researchers are active across a wide range of the multi-wavelength astronomy domain. In particular, the strategic vision for SALT, developed by the South African community in 2017, identified two main focus areas for future development, which tie in closely with both MeerKAT, the country's precursor to the SKA, and local high-energy astrophysics research. These are transient science (a range of highly energetic time-dependent phenomena) and galaxy evolution (particularly understanding the fuelling of star formation and recycling of gas in the baryon cycle). Over the past year, research in both these areas has continued to strengthen, e.g., with dedicated, multi-semester programmes on SALT. Exoplanet research and building instrumentation capacity have also been highlighted as growth points for the future, resulting in the current improvements of the high-stability mode of the High Resolution Spectrograph and a project to develop a laser frequency comb.

SALT Board members:
Shazrene Mohamed, SAAO/SALT
Fulufhelo Nelwamondo, NRF

RUTGERS UNIVERSITY (USA)

Rutgers, the State University of New Jersey, is a large public research university in the United States. Originally chartered as Queen's College in 1766 during the colonial era, in 1825 it was renamed Rutgers College after a wealthy benefactor. Rutgers became the New Jersey land-grant institution in 1864 and in the mid-20th century, it was designated the State University of New Jersey by the state legislature. Rutgers University has expanded far beyond its modest colonial roots and now includes campuses in Newark and Camden as well as the flagship campus in New Brunswick. Across the state, more than 8000 Rutgers faculty instruct over 49,000 undergraduate as well as 19,000 graduate students. There are more than 150 undergraduate majors and 200 graduate programs.

Astronomy was part of the curriculum at Rutgers since its earliest days. The current Department of Physics and Astronomy at Rutgers–New Brunswick traces its origins to the late 19th century. Significant expansion in the astronomy program began in the 1990s with the addition of a number of research-active astronomers and an increase in the number of graduate students. At the end of the decade, Rutgers joined the SALT consortium. In 2021, the astronomy group comprised nine faculty, five emeritus faculty, four postdoctoral associates (including an Einstein Fellow), and 27 graduate students.

Rutgers' astronomers, led by T. Williams, participated in the design, development and fabrication of the Robert Stobie Spectrograph (RSS) and led the effort to build the Fabry–Pérot Imaging Spectrophotometer subsystem. Williams and his colleagues used this instrument to carry out the RSS Imaging spectroscopy Nearby Galaxies Survey (RINGS) of nearby, normal galaxies to characterise their structure using measurements of Hα velocity fields.

S. Jha uses SALT/RSS to study supernova explosions, observing mostly type Ia, or thermonuclear, supernovae to investigate their nature and, more broadly, to answer key questions in SN Ia cosmology. Jha has been measuring binary orbital parameters of a sample of candidate white dwarf binaries with the HRS and has used RSS long-slit spectroscopy to observe a sample of *Gaia* hypervelocity stars.

The main focus of J.P. Hughes' current research is the astrophysics of clusters of galaxies. Current student P. Doze is leading a multiwavelength study of a massive ACT cluster. In collaboration with colleagues at UKZN and elsewhere in South Africa, Hughes is studying the brightest cluster galaxies in massive clusters detected by the Advanced Atacama Cosmology Telescope (AdvACT). The goal is to trace the evolution of AGN feedback (both radio and quasar mode), stellar populations, and the growth of central galaxies in clusters over a 3.4 Gyr time period ($0.3 < z < 0.8$). Hughes also has an on-going SALT project for confirmation and redshift measurement of Planck cluster candidates.

A. Baker is involved in two large SALT collaborations: the "SALT Gravitational Lensing Legacy Survey" targets sub-mm-band sources from the Herschel space mission that are likely high-redshift ($z \sim 2 - 4$), gravitationally-lensed star-forming galaxies. The second project, "Preparing for LADUMA: SALT Redshift Measurements", aims at obtaining redshifts of galaxies in the LADUMA field to allow stacking of 21-cm H I spectra. Baker is Co-PI of the LADUMA radio survey with the South African MeerKAT array to study the evolution of neutral gas in galaxies over cosmic time.

Other SALT efforts at Rutgers include RSS long-slit spectroscopy of low surface brightness dwarf galaxies from the Satellites Around Galactic Analogs (SAGA) Survey (led by Y. Mao). Graduate student J. Hay is obtaining multi-epoch RSS and HRS spectra of microlensing events to probe the properties of the lenses of these events. E. Gawiser is working with a group of undergraduate students to observe low redshift ($z < 0.4$) [O II]-emitting galaxies from HETDEX, thereby revealing key properties of these star-forming galaxies. G. Telford and K. McQuinn are using SALT to observe a single massive star in a relatively nearby metal-poor galaxy. The RSS spectrum will determine accurate stellar parameters required for stellar atmosphere modeling of the star's HST/COS spectrum.

SALT Board member: Jack Hughes

The Physics & Astronomy department building at Rutgers–New Brunswick.

POLAND

Poland is a country with a long astronomical tradition. For example, Nicolaus Copernicus (1473–1543) was the creator of the heliocentric system, and Johannes Hevelius (1611–1687) was the founder of lunar topography. After World War II, Polish astronomy started to slowly build up its resources but it was only after the communist regime fell in 1989 that Poland could join ESO, ESA and other European and International astronomical organisations. Currently, about 250 astronomers are employed in six separate university institutes and two institutes of the Polish Academy of Sciences (PAS). Some of them partnered to form the Polish SALT Foundation which has a 10% share in the construction and running costs of SALT. The Nicolaus Copernicus Center (CAMK) is the Polish coordinator for the project. Marek Sarna of CAMK is Poland's Board director and has been highly active in the Board and other SALT committees. Joanna Mikołajewska is a member of the STC, being highly involved in this and other SALT committees. There are five main SALT partner institutions in Poland.

The **Nicolaus Copernicus Astronomical Center** (CAMK, or NCAC in English) of the PAS is the leading astronomical institute in Poland. It is located in Warsaw and was established in 1978. At present, 57 scientists are working at CAMK along with 35 PhD students. Astronomers at CAMK are involved in a number of major international observational projects (e.g., CTA, *Herschel*, SALT/HRS), and are actively collaborating with scientists all over the world. Collaborations on SALT science include SAAO and AMNH. The main SALT research interests are: the search for symbiotic stars in the Milky Way and the Magellanic Clouds and the study of individual systems; novae; post AGB binaries and dark matter studies using spectroscopic long term monitoring of selected quasars. J. Mikołajewska leads SALT/HRS monitoring of Magellanic symbiotic stars and Galactic recurrent novae where the focus is the determination of the first-ever spectroscopic orbits to measure masses of both components. B. Czerny from the Center for Theoretical Physics PAS leads long term monitoring of broad emission lines coming from AGNs.

The **Astronomical Observatory of the Jagiellonian University** is a part of the Faculty of Physics, Astronomy and Applied Computer Science of the Jagiellonian University. The Observatory was founded in 1792 and comprises a number of small radio and optical telescopes that are located at Fort Skała on the outskirts of Kraków. The Observatory is involved in exploiting large facilities such as H.E.S.S., CTA and SALT and runs one of the LOFAR telescope stations, playing an important and active role in the European LOFAR collaboration. The main scientific programs that use SALT data are studies of giant-size radio galaxies, accretion discs in AGNs using Doppler tomography and timing analysis of their multi-wavelength light curves.

The **Institute of Astronomy of the Nicolaus Copernicus University** in Toruń is located in Piwnice village, 15 km north of Toruń, and is home to a VLBI station and a few optical instruments. The optical telescopes are used mainly for student training and modest research projects. SALT researchers here are interested in symbiotic stars and novae as well as PNe.

Founded in 1919, the **Institute Astronomical Observatory (IAO) of Adam Mickiewicz University** runs a Global Astrophysical Telescope System (GATS) consisting of two robotic instruments (in Poland and in Arizona) used for photometry and spectroscopy. The third node — a cluster of 0.7-m and 0.3-m telescopes for space debris tracking — is under construction. IAO research topics include dynamics of artificial satellites and space debris, studies of Small Solar System Objects, stellar astrophysics, dynamics of star clusters, radio and IR observations of gas and dust in galaxies. IAO uses SALT for photometric and spectroscopic observations of asteroids.

The Astronomical Institute of the **Wrocław University** is located in the eastern part of Wrocław. Research concentrates on the investigation of solar activity and on pulsating stars (using asteroseismology). Observations are conducted with a coronagraph located near Wrocław and with SALT (among others), respectively. Satellite observations also play an important role in these investigations.

SALT Board member:
Marek Sarna, CAMK

DARTMOUTH COLLEGE (USA)

Founded in 1769, Dartmouth College is one of the leading liberal arts universities in the United States. Dartmouth has forged a singular identity for combining its deep commitment to outstanding undergraduate liberal arts and graduate education with distinguished research and scholarship in the Arts & Sciences, and its three leading professional schools: the Geisel School of Medicine, the Thayer School of Engineering, and the Tuck School of Business. Dartmouth College educates the most promising students (approximately 4300 undergraduates and 2000 graduate students) and prepares them for a lifetime of learning and of responsible leadership, through a faculty dedicated to teaching and the creation of knowledge.

Astronomy has a long history at Dartmouth, with the Shattuck Observatory (built in 1853) being the oldest scientific building on campus. The first photograph of a solar prominence was obtained by the Shattuck Observatory (in 1870).

Today, the astronomy group at Dartmouth is housed within the Department of Physics and Astronomy and has a 25% share in the MDM observatory (consisting of a 2.4-m and 1.3-m telescope in Kitt Peak, Arizona, USA) in addition to its ~10% investment in SALT. Astronomers at Dartmouth have a broad range of research interests and have used SALT to study supernovae, active galactic nuclei and metal-poor stars, among other projects. Currently, the astronomy group consists of four faculty members, three post-doctoral fellows and about ten graduate students.

SALT Board member (new chair):
Brian Chaboyer

Astronomy group photo taken in front of the Shattuck Observatory on campus.

The astronomy department group on top of their building.

UNIVERSITY OF WISCONSIN–MADISON (USA)

The University of Wisconsin–Madison is a public, land-grant institution that offers a complete spectrum of studies through 13 schools and colleges. With more than 43,000 students from every U.S. state and 121 countries, UW–Madison is the flagship campus of Wisconsin's state university system.

UW–Madison is a formidable research engine, ranking sixth among U.S. universities as measured by dollars spent on research. Faculty, staff, and students are motivated by a tradition known as the Wisconsin Idea that the boundaries of the university are the boundaries of the state and beyond.

One of two doctorate-granting universities in the University of Wisconsin System, UW–Madison has the specific mission of providing "a learning environment in which faculty, staff and students can discover, examine critically, preserve and transmit the knowledge, wisdom and values that will help ensure the survival of this and future generations and improve the quality of life for all."

UW–Madison joined the SALT partnership, contributing both to the construction as well as designing and building the Prime Focus Imaging Spectrograph since renamed the Robert Stobie Spectrograph. Wisconsin is now building a near-infrared spectrograph for SALT in its Washburn Laboratory. Wisconsin astronomers use SALT to understand the kinematics and distribution of ionised gas in and around galaxies, redshift surveys to measure the distribution of mass in galaxy clusters, surveys of galaxies at intermediate and high redshifts, as well as high-resolution studies of stellar variability.

SALT Board member:
Matthew Bershady

INTER-UNIVERSITY CENTRE FOR ASTRONOMY & ASTROPHYSICS (INDIA)

The Inter-University Centre for Astronomy & Astrophysics (IUCAA) was established in 1988 by the University Grants Commission of India in Pune. The main objectives of IUCAA are to provide a centre of excellence within the university sector for teaching, research and development in astronomy and astrophysics, as well as to promote nucleation and growth of active groups in these areas in colleges and universities. Besides conducting a vigorous research programme of its own, workers from Indian universities, teachers and students are enabled to visit IUCAA for any length of time to participate in research and to execute developmental projects. IUCAA also actively collaborates with universities in initiating and strengthening teaching and research in Astronomy & Astrophysics in the university system.

Research interests of IUCAA members and associates include (i) gravitation, cosmology, large scale structures in the Universe, gravitational wave physics and data analysis; (ii) cosmic microwave background theory and data analysis, cosmic magnetic fields; (iii) galaxies, quasars, quasar absorption lines, intergalactic and interstellar matter; (iv) X-ray binaries, accretion disc theory, radio and X-ray pulsars, gamma-ray bursts; (v) solar physics, stellar physics, stellar spectral libraries, machine learning; (vi) observations in optical, radio and X-ray bands, astronomical instrumentation and (viii) data-driven astronomy, virtual observatory. IUCAA runs a 2-m telescope at Girawali to support various observational projects. Members of IUCAA are actively involved in various national large science projects such as the Indian participation in TMT, SKA and LIGO–INDIA etc., and IUCAA has a 7% share in SALT. It is utilised by IUCAA members to identify and study extragalactic sources (large scale outflow, quasars, radio galaxies and field galaxies producing absorption lines in quasar spectra), high-resolution spectroscopy of stars and coordinated observations of time-varying sources.

IUCAA's technical contribution to SALT is the SIDECAR Drive Electronics Controller (ISDEC) which is used as the control and data acquisition system for the H2RG detector in the new NIR spectrograph.

During the last couple of years, IUCAA added about five new faculty covering a wide range of A&A topics and Gravitational wave experiments, the latest being Sowgat Muzahid who works on quasar spectroscopy. Two faculty members, Joydeep Bagchi and Varun Sahni, have retired in 2021. Starting in the academic year 2021, IUCAA has a masters programme on A&A at Pune university (Savitribai Phule Pune University).

SALT Board member:
Somak Raychaudhury

THE AMERICAN MUSEUM OF NATURAL HISTORY (USA)

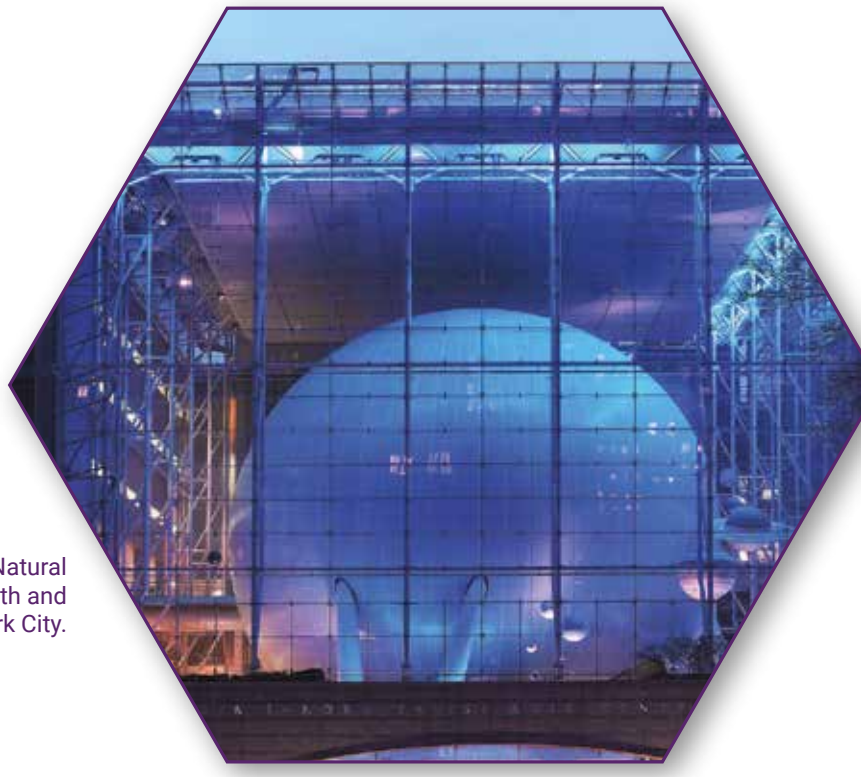
The American Museum of Natural History (AMNH) is one of the world's preeminent scientific and cultural institutions. Since its founding in 1869, the Museum has advanced its global mission to discover, interpret, and disseminate information about human cultures, the natural world, and the Universe through a wide-ranging program of scientific research, education, and exhibition. With 200 active researchers, including curator/professors, postdoctoral fellows, PhD and Masters degree students as well as research associates and assistants, AMNH is the only institution in North America that is both a research university and a museum, hosting over five million visitors each year.

Astronomy has been part of AMNH since the opening of the Hayden Planetarium, partly funded by philanthropist Charles Hayden, in 1934. The completely rebuilt Planetarium, opened in 1999, is a 30-m diameter sphere inside an eight story-high glass cube, which houses the Star Theater. The theatre uses high-resolution full-dome video to project space shows based on scientific visualisation of current astrophysical data. A customised Zeiss Star Projector system replicates an accurate night sky as seen from Earth. The AMNH Astrophysics research department is responsible for the content of space shows, for conducting research in astrophysics, and for training graduate students and postdoctoral fellows.

AMNH became a member of SALT in 2008 on the basis of a gift from the late Paul Newman. AMNH astrophysicist Michael Shara became Chairman of the SALT Board in 2012 and served in that position until 2021. Shara uses SALT to study cataclysmic binary stars — novae, the stars that give rise to them, and the ways that they hide from astronomers during the millennia between eruptions. He is also interested in mass transfer in such binaries that spins up the black hole progenitors — O stars in O+Wolf-Rayet star binaries — to high speeds.

In collaboration with Shara, PhD student Laura Rogers (University of Cambridge) continues to use SALT/HRS to characterise white dwarfs heavily polluted with metals, probably via accretion of asteroids and dust. AMNH Postdoctoral Fellow Sam Grunblatt has initiated an HRS study of hot, southern exoplanet candidates identified with *TESS*. The first radial velocity detection of a planetary orbit with SALT/HRS has now been accepted for publication in 2022, and SALT/HRS is now being used to confirm a second planetary signal from this survey. Once this planet is confirmed it will be added to a catalogue paper of planets transiting evolved stars which is currently in preparation.

SALT Board member (past chair):
Michael Shara



The American Museum of Natural History's Rose Center for Earth and Space in New York City.

UK SALT CONSORTIUM

An early and enthusiastic supporter of the SALT project, the UK's consortium (UKSC) consists of six astronomy groups, all of whom have had a long-standing involvement with astronomers in South Africa (SA), including providing support for visiting graduate students and postdocs to SA. Furthermore, UKSC has successfully hosted a half-dozen SALT—Stobie scholarships, greatly enhancing the production of SA astronomy PhDs. From 2018 – 2020, the consortium was able to use its "Global Challenges" research funding to support SA post-docs to visit the UK for extended periods. UKSC have a wide range of SALT science interests and are involved as collaborators in a number of major SALT science projects, in particular playing a leading role in the X-ray binaries component of the SALT Transients Large Programme. The following institutions form the UKSC.

SALT scientists at the **University of Central Lancashire** (UCLan) include G. Bromage, A. Sansom, D. Kurtz and D. Holdsworth. Bromage was UKSC's previous Board director and has also been highly active in other SALT committees (e.g., BEC, SSWG), and continues as a member of FAC. UCLan has made extensive contributions to the SALT Collateral Benefits Programme (SCBP), has hosted successful SALT Stobie scholarships, and has provided UCLan's distance learning university-level Astronomy courses (at discounted rates) for SALT engineers, operators and other staff since SALT began operating, as well as supporting visiting graduate students. Their SALT science interests involve collaborations within UKSC (with Keele and Armagh) and with SA, in particular with NWU and SAAO.

At the **Open University**, science interests range from the "Dispersed Matter Planet Project" (C. Haswell), which has identified a key population of rocky exoplanets orbiting bright nearby stars and studied dust from catastrophically disintegrating planets (such as Kepler 1502b), to studies of variable star populations and unique individual variables from SuperWASP (A. Norton, M. Lohr). Norton has recently focussed on following up a set of close-contact red giant eclipsing binary candidates which may be red nova progenitors. S. Serjeant, S. Urquhart and L. Marchetti (UCT) coordinate the "SALT Gravitational Lensing Legacy Program" to pioneer a major new strong gravitational lens selection method, combining *Herschel Space Observatory* wide-area sub-mm observations with multi-wavelength ancillary data, generating the largest (> 500) sample to date of homogeneously selected lens candidates and obtaining SALT spectroscopy for most of them. These data will be used in conjunction with Urquhart's recent results, the Bright Extragalactic ALMA Redshift Survey (BEARS), identifying redshifts of bright gravitationally-lensed galaxies from the *Herschel* ATLAS.

SALT science at **Armagh Observatory & Planetarium** focuses on stellar remnants, massive stars, ultra-compact binary systems, and solar-system science, with extensive effort on stellar pulsations and abundance analyses using SALT's RSS and HRS. They have collaborations within UKSC and with SA (SAAO, UCT and UWC). People involved at Armagh are S. Jeffery, M. Burton, G. Ramsay, J. Vink, G. Doyle as well as M. Sarzi, who has taken on the role of representing Armagh on UKSC and looks forward to using the NIR integral-field spectrograph. AOP is now also the UKSC administrating institution.

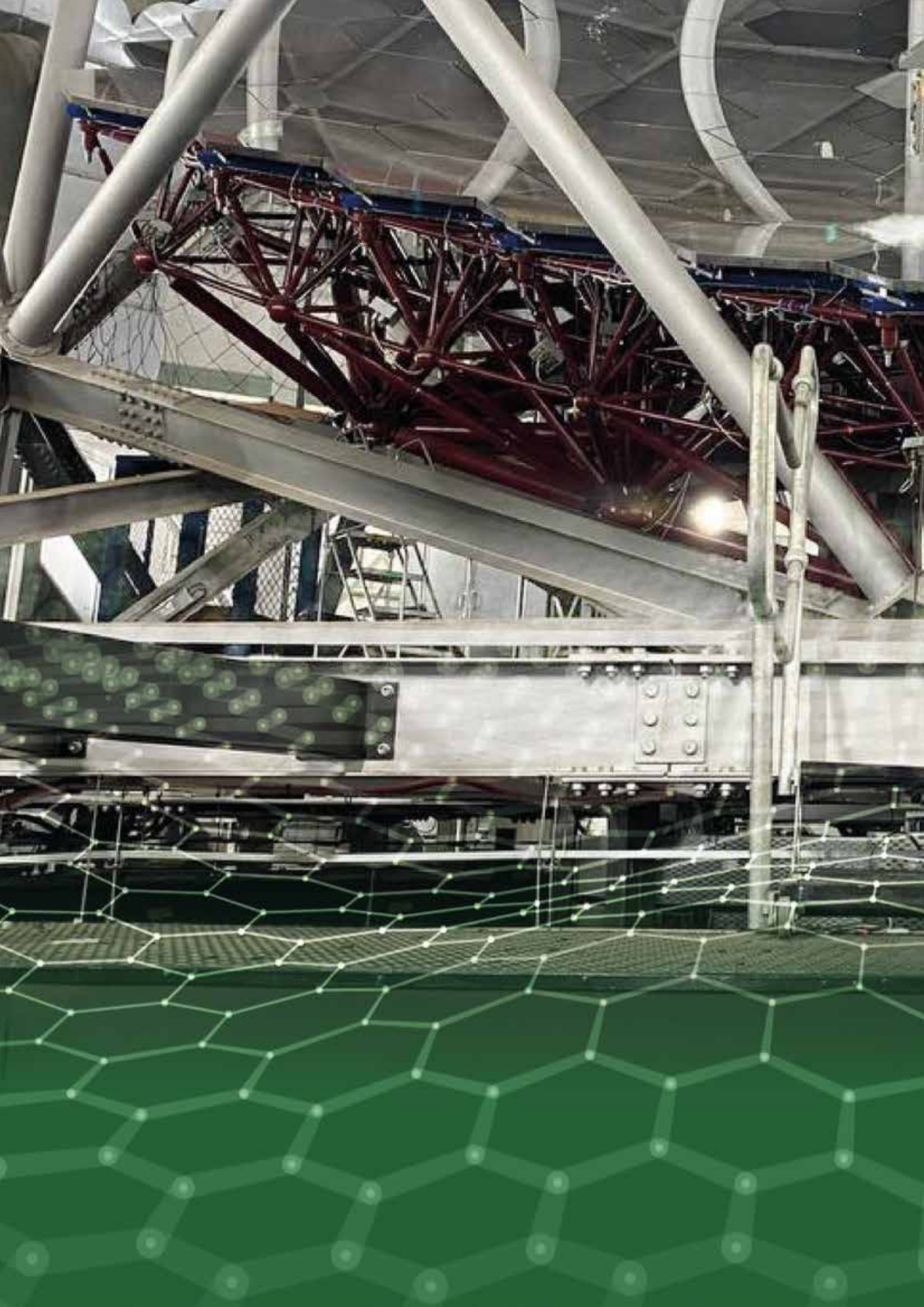
At **Keele University**, J. van Loon's interests in SALT have been to exploit the RSS Fabry–Pérot mode to map emission as well as absorption features in nearby galaxies, and long-slit spectroscopy of various types of stars but mostly a series of AGN. This work is generally done as part of PhD projects including students from underprivileged countries. It has featured in press releases and in a science-art outreach project at Sutherland's Highschool.

The **University of Nottingham** has had significant involvement in SALT administration (UKSC Board director for four years and Chair of the FAC for three years), as well as funding a post-doc (six months) and two graduate students (two months each) to work on technical and software development for SALT in its early years. Following P. Sarre's recent retirement, Nottingham has now handed over UKSC administration to Armagh, and they no longer have any involvement in SALT observations.

The photo was taken at the UKSC management committee meeting in Keele in November 2017.

P. Charles from the **University of Southampton** (current UKSC Board director for SALT) was SAAO Director for seven years and, together with many of the Southampton Astronomy Group, is actively involved in the SA-led "SALT Large Science Programme Observing the Transient Universe". Southampton's interests focus on black-hole, neutron star and white dwarf X-ray binaries, usually in association with other ground-based (e.g., ASASSN, OGLE, MASTER) and space-based (e.g., *Swift*, *MAXI*, *Astrosat*) facilities, frequently arranging for simultaneous or contemporaneous observing. The *Astrosat* observations include another major SALT partner, India. M. Sullivan is involved in SN–cosmology studies, which is part of the SALT long-term programme on supernovae. SALT is also used for rapid follow-up spectroscopy of outbursting X-ray sources in the SMC arising from the ongoing *Swift's* S–CUBED monitoring (M. Coe). Also interested in SALT science are C. Knigge, D. Altamirano, T. Bird, P. Gandhi and M. Middleton.

SALT Board member:
Phil Charles, University of Southampton



SCIENCE HIGHLIGHTS

SCIENCE HIGHLIGHTS
Extragalactic astronomy

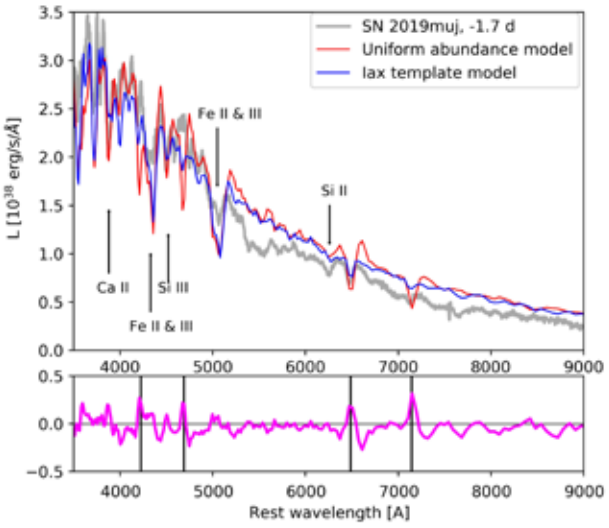
SALT observes a type Iax supernova that bridges the luminosity gap of the class

SNe Iax are supernovae originating from the thermonuclear explosions of CO white dwarfs (WD). It is still an open question, though, whether a single explosion scenario, like pure deflagration, could explain the observed diversity of these objects. The peak absolute magnitudes of SNe Iax cover a wide range between −14.0 and −18.4 mag, from the extremely faint SNe 2008ha to the nearly normal Ia-bright SN 2012Z. The expansion velocities also have a very diverse nature, showing a photospheric velocity of 2000 – 9000 km/s at the moment of maximum light, which is significantly lower than that of SNe Ia (typically > 10 000 km/s).

Despite the intensive search for these objects, only ~70 of SNe Iax have ever been discovered, with the majority being too faint to be subject of follow-up campaigns. Most of the best-studied cases belong to the relatively luminous part of the subclass, while only a few represent the extremely faint end of SNe Iax. However, objects between the two extremities, i.e., with peak absolute magnitude between −15 and −17 mag in *V*-band, have been missing so far from the literature, probably because of observational bias. SN 2019muj bridges this luminosity gap, as it is the first moderately luminous SN Iax with well-covered pre-maximum epochs, detailed spectroscopic follow-up, and a relatively well-constrained distance. Thus, the analysis of SN 2019muj allows a unique opportunity to link the two extremes of the subclass and to test whether SNe Iax indeed share a common origin.

Due to the uniqueness of SN 2019muj, an intensive spectroscopic follow-up was started by several collaborations and observatories. Besides Las Campanas Observatory, Las Cumbres Observatory and ESO NTT, SALT also took part in the campaign, supplying five optical spectra between 8 and 60 days after the explosion. The RSS provided high-quality data between 3500 Å and 9300 Å, which were fit by the TARDIS spectral synthesis code. The fitting aimed to test the previously constrained chemical abundance structure proposed for SNe Iax and estimated the physical properties of the ejecta, e.g., photospheric velocity, luminosity, and density profile. Moreover, the spectra were compared to those of extremely faint as well as luminous SNe Iax obtained at the same epochs. Based on the comparisons of the observables, SN 2019muj shows a better match with the more luminous SNe Iax before the moment of maximum light, and with the extremely faint ones at the post-maximum epochs, making it a truly transitional object.

Barna, B., et al. 2021/02,
MNRAS 501, 1078: SN 2019muj - a well-observed Type Iax supernova that bridges the luminosity gap of the class



CAPTION:

Observed RSS spectrum of SN 2019muj obtained 1.7 d before maximum light (or 8.5 d after explosion; grey), the TARDIS synthetic spectrum assuming the abundance template from previous work (blue), and the impact of assuming uniform abundances based on the low-luminous pure deflagration model (red). The purple residuals show the difference between the two synthetic spectra. Vertical lines indicate the absorption minima of the [C II] lines.

Lyman-α emission from an optically faint powerful radio galaxy at *z* = 3.1

Shukla, G., et al. 2021/03,
MNRAS 501, 5362:
Lyman-α emission from a *WISE*-selected optically faint powerful radio galaxy M151304.72-252439.7 at z = 3.132

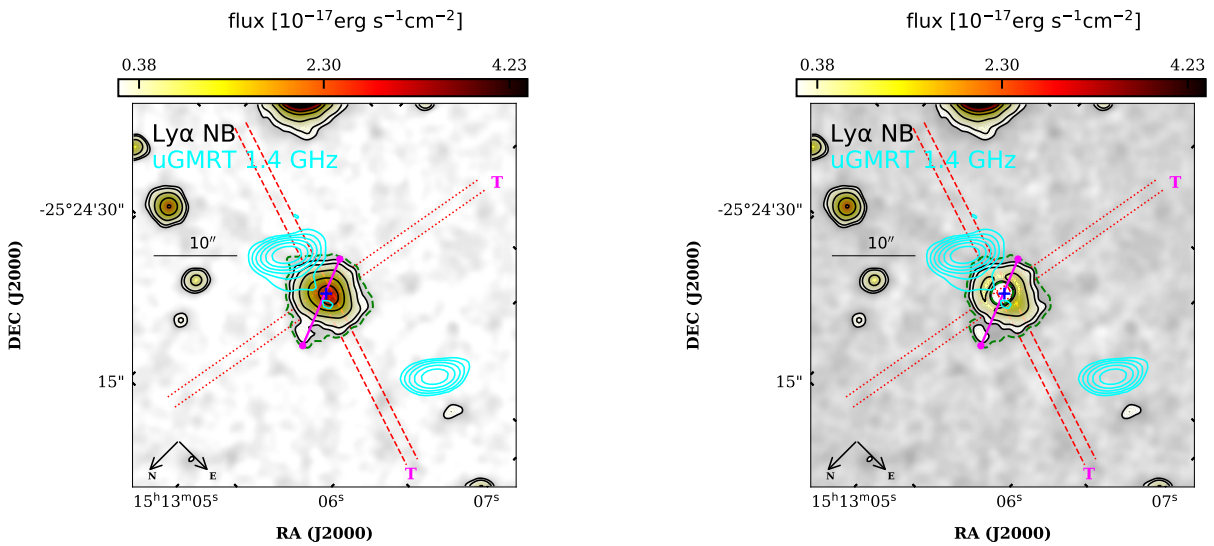
PhD student Gitika Shukla from IUCAA and collaborators study the spatial distribution of extended Lyα emission around radio-loud quasars (RLQs) and its connection with AGN optical/radio properties in a dust-unbiased sample of AGNs, using long-slit spectroscopy and narrow-band imaging from SALT. Such a study can provide vital clues on various feedback processes that drive star formation and AGN activities in high-*z* galaxies. This project is the second dedicated study of extended Lyα emission around RLQs in the literature.

SALT/RSS was used along with spectroscopy from the Nordic Optical Telescope (NOT) to confirm the nature and measure the redshifts of a subset of radio bright southern AGN candidates selected using *WISE* MIR-colours. These form part of the sample for the MeerKAT Absorption Line Survey (MALS), an ongoing large radio survey using the South African SKA-precursor MeerKAT, which has led to 250 spectroscopic identifications with a median redshift of z = 1.8. Shukla selected a subset of AGNs from this MALS-SALT-NOT sample with $z > 2.7$ to search for the presence of extended Lyα emission. One of the objects in this sample (M1513−2524, z = 3.312) is particularly interesting since it is the largest radio source in the sample, its radio power and Lyα luminosity ((6.80 ± 0.08) × 10^{44} erg/s) are among the highest known and, moreover, associated Lyα absorption was detected around this source, a configuration that is very rare. The double-lobed radio emission has an extent of 184 kpc, but the radio core, i.e., emission associated with the AGN itself, is barely detected.

The SALT/RSS spectrum revealed Lyα, [N V], [C IV] and [He II] emission lines with a very weak continuum. Shukla identified two spatial components: a compact component with a high velocity dispersion (~1500 km/s) and an extended component with a low velocity dispersion (700 – 1000 km/s). The emission line ratios are consistent with the compact component being in photoionisation equilibrium with an AGN. She also detected spatially extended associated Lyα absorption, which is blue-shifted by 250 – 400 km/s with respect to the Lyα peak. The probability of Lyα absorption detection in such large radio sources is low (~10%). Follow-up deep integral field spectroscopy is essential for probing this interesting source and its surroundings in more detail.

CAPTION:

Lyα emission observed in the narrow-band image around M1513−2524 (right image: after subtracting the contribution from the central source). The images are smoothed (Gaussian kernel of FWHM = 1.2"). Flux levels are given as values per pixel. Cyan: uGMRT Band-5 radio contours at 1.6 × (-1, 1, 2, 4, 8, 16, 32, 64, ..) mJy/beam; dashed green contour: 3σ level (1.06 × 10^{-18} erg/s/cm^2); black contours at (1.6, 2.5, 5.5, 11 and 20)×10^{-18} erg/s/cm^2; blue plus: position of the *WISE* source; pink line: maximum extent of the Lyα emission at the 3σ flux level; red lines: directions of the slit (dashed: PA = 72°, dotted: 350°).



eROSITA and SALT witness the awakening of two massive black holes

Arcodia, R., et al. 2021/04, Nature 592, 704: X-ray quasi-periodic eruptions from two previously quiescent galaxies

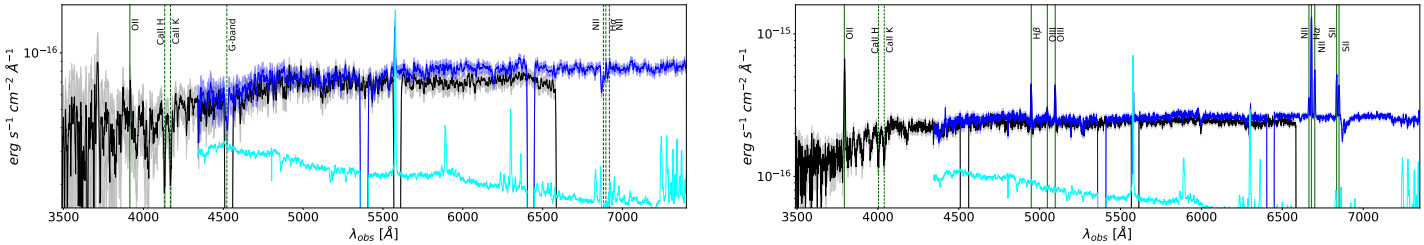
Quasi-Periodic Eruptions (QPEs) are extreme high-amplitude bursts of X-ray radiation recurring every few hours and originating near the central supermassive black holes in galactic nuclei. It is currently unknown what triggers these events, how long they last and how they are connected to the physical properties of the inner accretion flow. Before the launch of *eROSITA* (the primary instrument on-board the *Russian-German Spectrum-Roentgen-Gamma* (*SRG*) mission) only two such sources were known. It is of particular interest that they were observed in low-mass galaxies, therefore providing a new channel through which the black holes at their centres are activated. Using data from the ongoing *eROSITA* all-sky surveys, scientists at the Max Planck Institute for Extraterrestrial Physics, led by PhD student Riccardo Arcodia, have found two more. Both the new sources show high-amplitude X-ray variability within only a few hours, which was confirmed by follow-up observations with the *XMM-Newton* and *NICER* X-ray satellites: peak-to-peak separation of the X-ray outbursts are about 18.5 hours for one QPE and only about 2.4 hours for the other.

Since the two galaxies were spectroscopically unknown before, SALT observations were scheduled by David Buckley (SAAO) as part of the Large Science Programme on transients. Contrary to the two previously known objects, the host galaxies of these new QPE sources do not show any signs of previous black hole activity, indicating that a pre-existing accretion flow typical of active nuclei is not required to trigger these events. Furthermore, one galaxy has been classified as passive from the absence of any significant emission line, the other shows very strong and narrow emission lines indicating that star forming processes are the dominant ionisation mechanism. Both galaxies are fairly close-by at z = 0.0505 and 0.0175.

Scientists currently do not know what causes these bursts. Periods, amplitudes and profiles of the newly discovered QPEs are inconsistent with current models that invoke radiation-pressure driven accretion disc instabilities. Instead, these eruptions might be triggered by the presence of a second orbiting object, whose mass has to be much smaller than that of the central massive black hole (for instance, of the order of the mass of a star or a white dwarf) and which might be partially disrupted by the huge tidal forces close to the black hole at each passage. This scenario could make QPEs a viable candidate for the electromagnetic counterparts of the so-called extreme mass ratio in spirals, making them observable via both electromagnetic and gravitational wave signals, thus opening up new possibilities for the future of multi-messenger astrophysics and cosmology.

CAPTION:

SALT optical spectra (black and blue) of the two inactive galaxies (with the sky spectrum in cyan). The absence of any emission lines in the spectrum of the first galaxy (left) easily classifies it as passive, while for the second (right), narrow lines indicate ionisation from star formation.



SALT investigates a supernova remnant associated with a Be X-ray binary

Gvaramadze, V. V., et al. 2021/05, MNRAS 503, 3856: SALT observations of the supernova remnant MCSNR J0127-7332 and its associated Be X-ray binary SXP 1062 in the SMC

CAPTION:

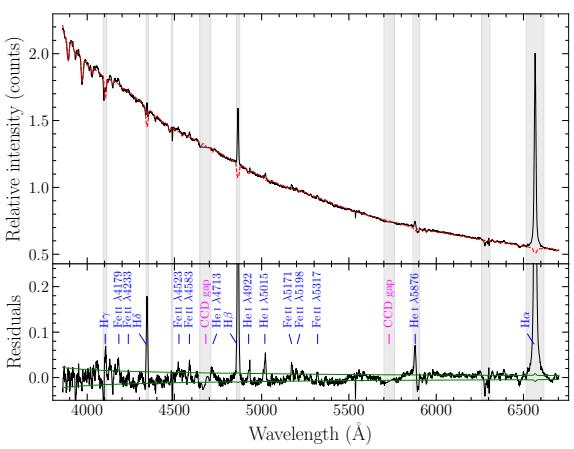
LEFT: Results of modeling a spectrum of the central star. Top: comparison of the observed spectrum (solid black line) with the best-fitting model (red dashed line). Grey vertical areas: spectral regions excluded from the spectral fit (contaminated by emission from the circumstellar disc). Bottom: difference between the observed and model spectrum with 1σ errors (green). Weak emission lines became more noticeable after the model subtraction. Positions of identified emission lines and CCD gaps are indicated.

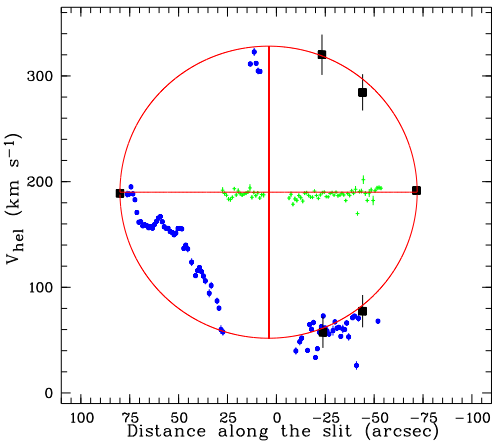
RIGHT: Hα heliocentric radial velocity distribution along the slits. Black squares and blue dots: heliocentric radial velocity of the shell measured at several positions along two slit orientations, respectively. Crosses: heliocentric radial velocity of the background Hα emission of ~188 ± 6 km/s.

A binary system surviving a supernova (SN) explosion of one of its components could evolve into an X-ray binary in which the compact stellar remnant (neutron star or black hole) accretes material from the normal (massive or low-mass) star. The typical time-scale of ~10^6 – 10^8 yr for the formation of X-ray binaries containing neutron stars is one to three orders of magnitude longer than the time-scale of ~10^5 yr for the visibility of supernova remnants (SNRs), suggesting that no such X-ray binary should be detected within an SNR. However, several neutron star X-ray binaries (XRBs) were found to be associated with SNRs, which challenges the traditional view on the formation time-scales for these objects and is still waiting to be explained.

Vasilii Gvaramadze (SAI, Moscow) and Alexei Kniazev (SAAO/SALT) with their collaborators obtained SALT/RSS observations of MCSNR J0127−7332, an SNR in the SMC, and of the mass donor star of its associated BeXRB SXP 1062. The long-slit SALT spectroscopy of the SNR shell allowed them to measure an expansion velocity of ~140 km/s for the SNR, which is typical of SNRs in the radiative 'snow-plough' phase. A comparison of the line ratios in the spectrum of the SNR shell with the library of line intensities for shock models showed that the observed line ratios taken together did not fit any model. The authors suggest that these ratios can be explained if the local ISM is ionised by the central star and/or by OB stars in the vicinity of the SNR. To reconcile the co-existence of the slowly expanding optical shell of the SNR and the soft X-ray emission within it, the SN explosion could have occurred within a cavity that was evacuated by the wind of the SN progenitor star and which, at the moment of the SN explosion, was surrounded by a massive shell (more than 50 times more massive than the SN ejecta). This proposal implies an age of the SNR of ≤ 10,000 yr.

RSS Spectroscopic observations of the central star have revealed that the equivalent width (EW) of the Hα emission line decreased by about 40% in ~130 d after the periastron passage of the neutron star and then almost returned to its original value in the next ~100 d. These changes in the EW are accompanied by other changes in the spectral appearance of the Be star: the spectrum obtained shortly after the periastron showed a noticeable emission line of [He II] λ4686, which disappeared in the next two weeks or so. The authors interpret these changes as the result of the interaction of the neutron star with the circumstellar disc, which leads to a temporary disturbance and heating of the disc. They also found an indication that the neutron star orbits the central star in a highly eccentric orbit, but additional high-resolution spectra covering all orbital phases of the binary system are needed to confirm this.





An unusual BeXRB pulsar in the LMC

A research team around Helena Treiber (Amherst College) reports on the results of *eROSITA* and *NICER* observations of the June 2020 outburst of the Be/X-ray binary pulsar RX J0529.8—6556 in the LMC, along with the analysis of archival X-ray and optical data from this source. There are two anomalous features in the system's behaviour. First, the pulse profile observed by *NICER* during maximum luminosity is similar to that observed by *XMM-Newton* in 2000, despite the fact that the X-ray luminosity was different by two orders of magnitude. In contrast, a modest decrease in luminosity in the 2020 observations generated a significant change in pulse profile. Secondly, the historical optical outbursts are not strictly periodic, as would be expected if the outbursts were triggered by periastron passage, as is generally assumed. The optical peaks are also not coincident with the X-ray outbursts. This all suggests a misalignment of the Be star disc and the orbital plane, which might cause changes in the timing of the passage of the neutron star through the disc as it precesses.

Treiber, H., et al. 2021/06,
MNRAS 503, 6187: RX J0529.8-6556: a BeXRB pulsar with an evolving optical period and out of phase X-ray outbursts

A Be/neutron star system in the SMC

Swift J004929.5—733107 is an X-ray source in the SMC that has been reported several times, but the optical counterpart has been unclear due to source confusion in a crowded region. Malcolm Coe from Southampton and his collaborators used data obtained from the S-CUBED project to show that the X-ray position is inconsistent with the previously suggested counterpart [MA93] 302; instead, a previously unclassified object has all the indications of being a newly identified Be star exhibiting strong Hα emission. Significant I-band variability suggests that it is a Be type star with a large circumstellar disc. Optical monitoring by the OGLE project reveals a periodic modulation at a period of 413 d, probably the binary period of the system. A SALT optical spectrum shows strong Balmer emission and supports a proposed spectral classification of B1-3 III-IVe. The X-ray flux corresponds to a luminosity ~10^{35} erg/s. All of these observational facts indicate that this a Be star/neutron star X-ray binary (BeXRB) in the SMC, albeit one with an unusually long binary period at the limits of the P_{spin} – P_{orb} correlation ("Corbet Diagram").

Coe, M. J., et al. 2021/06,
MNRAS 504, 1398:
The Be/neutron star system Swift J004929.5-733107 in the Small Magellanic Cloud-X-ray characteristics and optical counterpart candidates

SALT reveals correlated time variability of multicomponent high-velocity outflows in a quasar

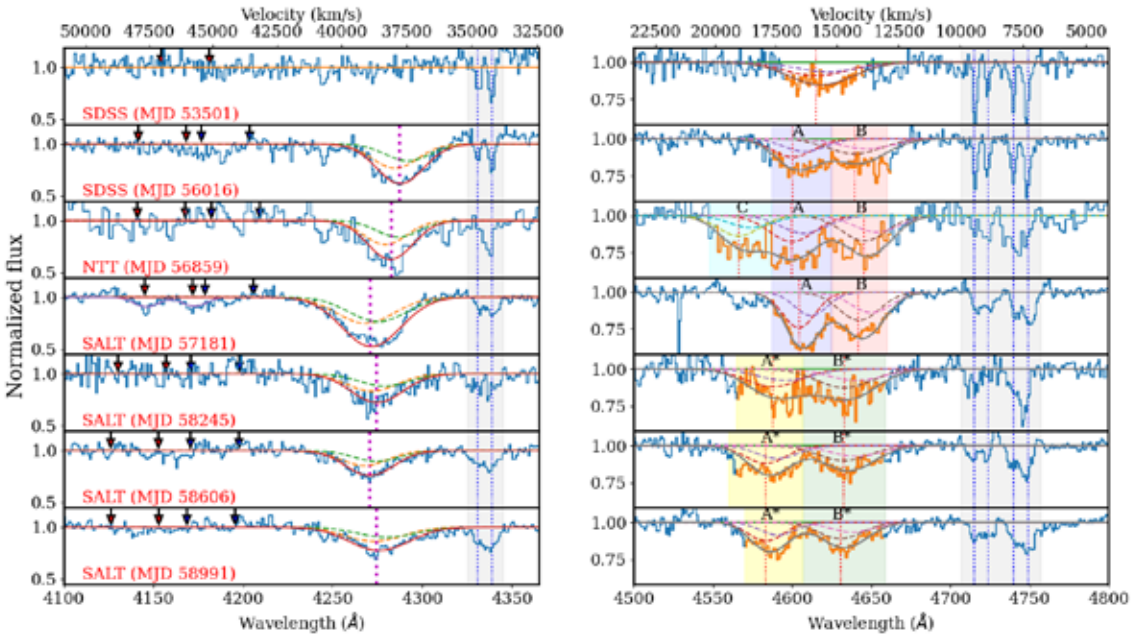
Aromal, P., et al. 2021/07, MNRAS 504, 5975: Correlated time variability of multicomponent high-velocity outflows in J162122.54+075808.4

PhD student P. Aromal from IUCAA and collaborators have been working on a research project on time variability of broad absorption lines (BAL), selecting spectra of 63 quasars from SDSS DR15, which show BALs at outflow velocities greater than 15,000 km/s (ultra-fast outflows or UFOs) and which are observable with SALT. UFOs are interesting since the observed large velocities can be attributed to the fact that these outflows originate very close to the central AGN engine and hence are expected to show larger variability, emergence and acceleration in the BAL profiles. This variability study can help to constrain various physical properties of the UFO BAL absorbers and to check if these properties statistically correlate with the quasars properties themselves. In addition, by probing the energetics and location of UFOs, their effect on the host galaxy environment through AGN feedback mechanisms can be studied in detail.

As part of this project, Aromal has analysed the peculiar BAL quasar J162122.54+075808.4. The data show the emergence of a BAL component with UFO velocities (37,500 km/s) followed by a kinematic shift in the BAL profile, implying acceleration along the line of sight. Another, previously known, BAL at comparatively lower velocities (at 15,400 km/s still satisfying the definition of UFOs) also shows high variability. Interestingly, the variability of these two distinct BAL components are highly correlated. Photo-ionsiation and disc wind models give an idea about the density and location of the outflowing gas but a simple ionisation change or a velocity law cannot fully explain the observed BAL variability. Aromal and his collaborators conclude that the observation of non-monotonic changes in the acceleration and the lack of restoration of the absorption profile can be reconciled by the presence of density and velocity fluctuations in the disc winds.

CAPTION:

Normalised spectra showing the time evolution of the two [C IV] BALs (left: high-vel; right: low-vel). The relative velocity scale with respect to the systemic redshift (z_{em} = 2.13945) is given at the top. The absorption profiles are fitted with Gaussian components (red and gray solid lines). A, B and C indicate locations of components of the low-vel BAL. Dashed lines: centers of individual Gaussian components contributing to the best fit. Dotted lines: intervening absorption lines. Arrows: expected positions of the [SiIV] absorption lines associated with the [C IV] components identified in the low-vel BAL.



A survey of mid-IR selected, powerful radio-bright AGNs at 0 < *z* < 5

The MeerKAT Absorption Line Survey (MALS; PIs Neeraj Gupta and Raghunathan Srianand from IUCAA) is one of ten large surveys being carried out with the MeerKAT radio telescope in South Africa. The main goal of the project is to better characterise the evolution of cold atomic and molecular gas in galaxies at 0 < *z* < 2. Over the period 2014 – 2017, the MALS team carried out an ambitious spectroscopic survey using SALT (180 hrs) and the Nordic Optical Telescope (NOT; 6 nights) to build a purely infrared-selected sample of radio-loud quasars (RLQs) at *z* > 1.5 and to define the MALS footprint.

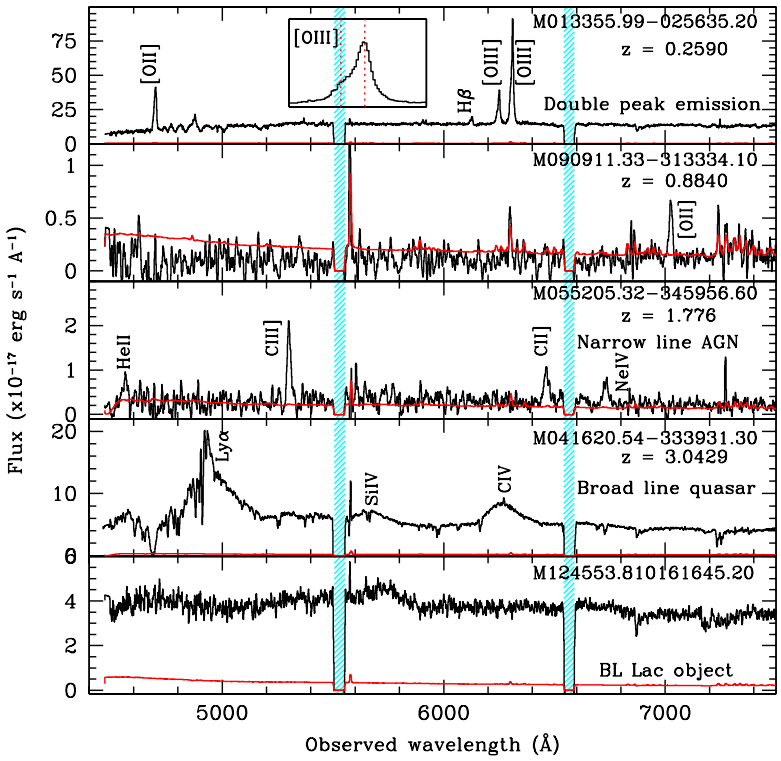
The SALT-NOT sample is optically fainter compared to the quasars used to search for high HI column density (damped Lyman-α, DLA) absorbers in the past. The detection of five intervening (redshift path ~9.3) and two proximate DLAs from the subset survey is slightly excessive compared to the statistics based on optically selected quasars. This hints towards the presence of dusty AGN that may have been missed in optically selected samples of AGN. The follow-up blind search for radio absorption lines using the upgraded Giant Metrewave Telescope (uGMRT) has allowed first constraints on the cross-section of HI and OH absorption lines at *z* > 2. The SALT-NOT survey is leading to various multi-wavelength follow-up observations using MeerKAT, uGMRT, VLT, VLBA, and VLA to address fundamental issues related to AGN and cold gas evolution.

All the spectra from the survey will be shared with the community through https://mals.iucaa.in/ and a MALS data release is scheduled in 2022. The MALS footprint is a major objective of the SALT-NOT survey.

Gupta, N., et al. 2021/08, ApJS 255, 28: Evolution of Cold Gas at 2 < z < 5: A Blind Search for H I and OH Absorption Lines toward Mid-infrared Color-selected Radio-loud AGN

CAPTION:

SALT spectra of five representative AGNs from the survey. Different emission lines based on which the redshift was determined are identified. Error spectra are shown in red. Hashed regions mark CCD gaps. Inset in the top panel is the double peak [O III] λ5007 profile. In the bottom panel an example of an AGN without detectable emission lines is shown.



Spectropolarimetry and photometry of the early afterglow of GRB 191221B

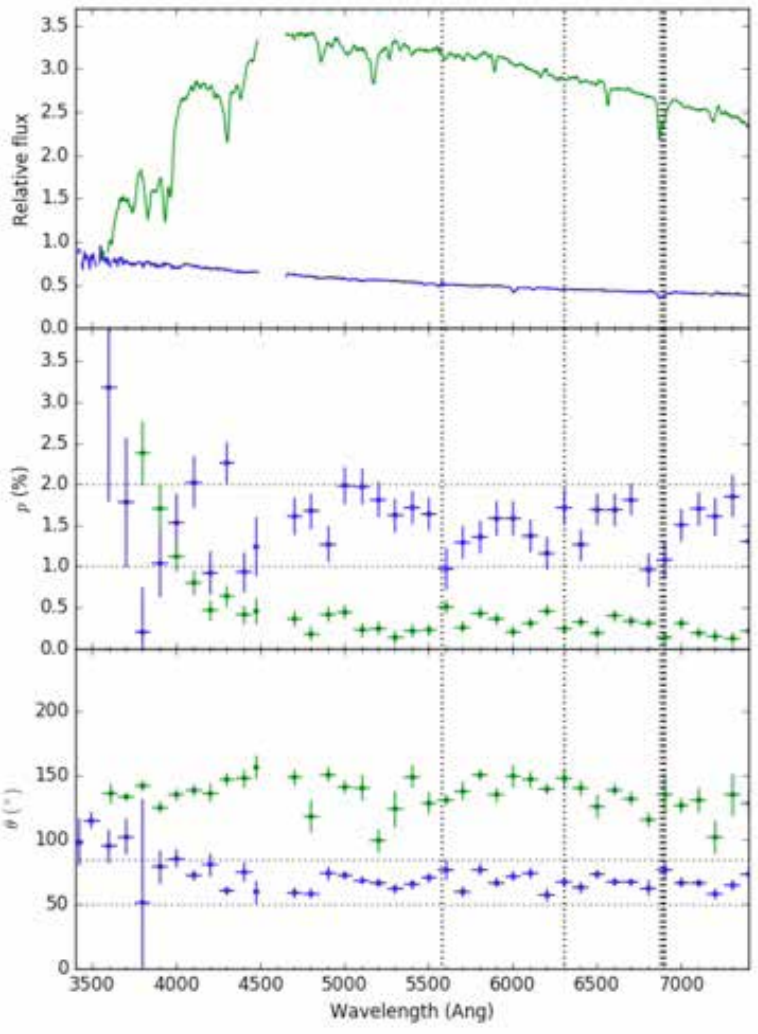
Buckley, D. A. H., et al. 2021/09, MNRAS 506, 4621: Spectropolarimetry and photometry of the early afterglow of the gamma-ray burst GRB 191221B

Gamma-ray bursts (GRB) are the most luminous sources of gamma-rays in the Universe; they are either the results of the collapse of massive stars at the end of their life or of a merger of compact objects. Polarimetry is a remote sensing technique which is highly sensitive to the asymmetry of a radiative source or of the medium between the source and the observer. As such, it may be used to characterise the rapidly expanding ejecta of a GRB, in particular when they collide with the surrounding medium. SALT/RSS is one of a few polarimeters capable of obtaining useful data from faint sources.

Using SALT/RSS and VLT/FORS2, a large international team led by David Buckley (SAAO) has obtained spectropolarimetry of the afterglow of one of these GRBs, namely GRB 191221B, about 3 h and 10 h after the burst, as well as photometric monitoring data from two telescopes of the MASTER Global Robotic Network. The data were interpreted in terms of slow-cooling synchroton emission. The linear polarisation at ~1.5%, measured during a period when the brightness had plateaued, showed little change some seven hours later when GRB 191221B was on the decline (p = 1.2%). Such a low-level polarisation is expected for the late afterglow, when the emission is dominated by the forward shock with a randomly oriented magnetic field configuration.

CAPTION:

SALT/RSS spectropolarimetry of GRB 191221B (blue) and the nearby bright field star (green), where p & θ were determined after binning the data to 100 Å. Telluric lines are indicated with thick black dotted lines. There are no data from ~4500 – 4650 Å due to a chip gap in the CCD mosaic.



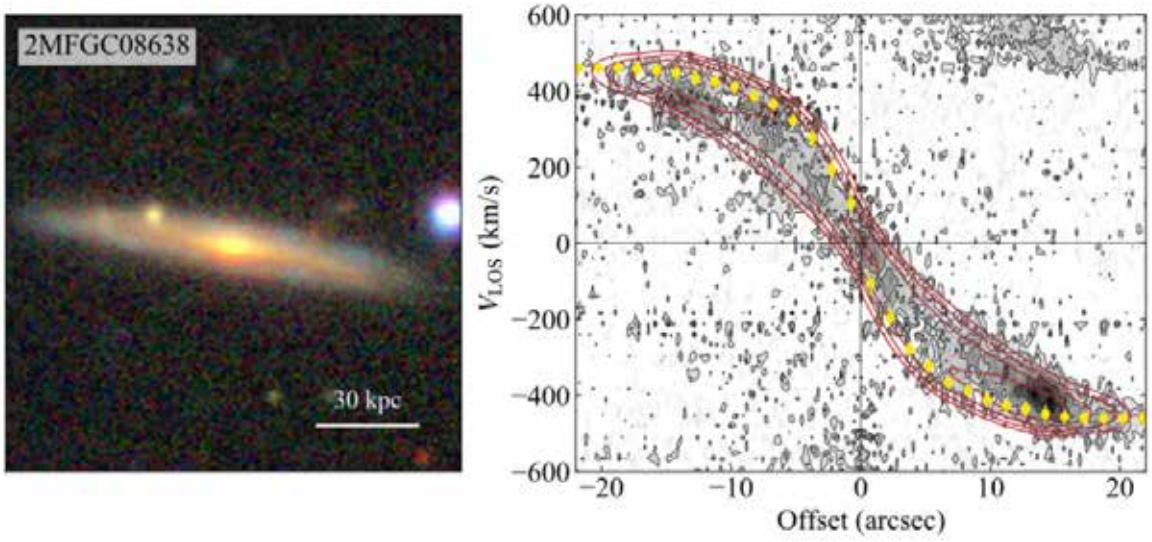
Rotation curves and scaling relations of super-spiral galaxies

Di Teodoro, E. M., et al. 2021/11, MNRAS 507, 5820:
Rotation curves and scaling relations of extremely massive spiral galaxies

Super-luminous spiral galaxies are an extreme and rare population of disc galaxies, having gigantic star-forming discs with stellar masses up to 10 times larger than our own galaxy, the Milky Way. Systems with similar masses are usually ellipticals, that is, galaxies that have no gas and have stopped forming new stars. In contrast, super-spirals appear to have so far avoided quenching of star formation and dramatic morphological transformations while conspicuously growing in mass. Understanding how these objects have preserved their star-forming discs for so long can give us valuable information on how galaxies assemble their mass.

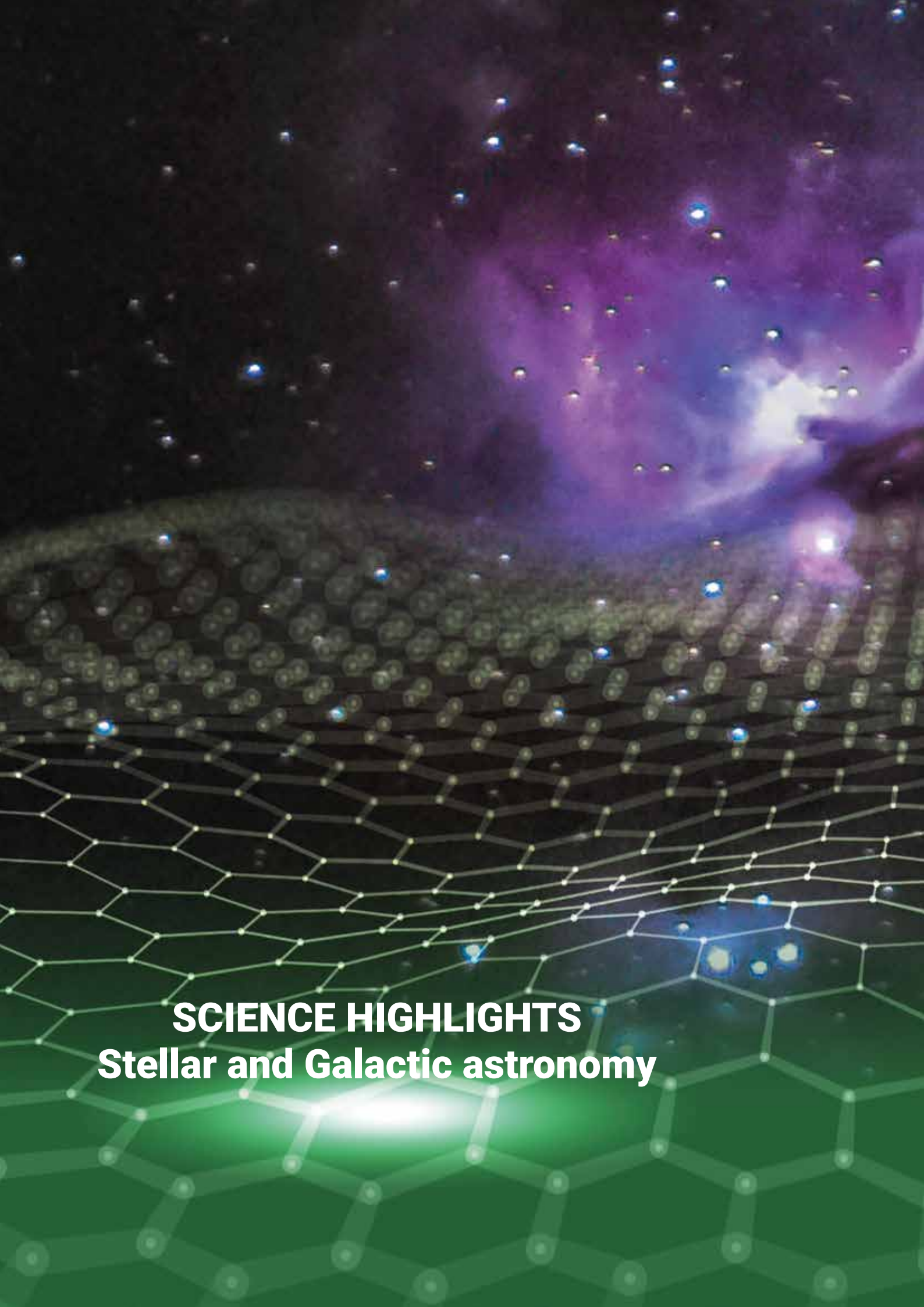
Since galaxy kinematics and scaling relations are classical and powerful tools to study the internal structure of galaxies and to constrain theoretical models of galaxy evolution, Enrico Di Teodoro and his co-authors decided to use SALT/RSS to investigate the kinematics and scaling relations of a sample of nearly 50 extremely massive spiral galaxies. The high resolution and high efficiency of SALT/RSS allowed them to observe in detail such a large sample of galaxies within reasonable integration times. In particular, they observed some of the strongest emission lines from the ionised gas, Hα and [N II], across each galaxy's major axis.

Di Teodoro and his team used these new SALT data to derive accurate rotation curves and to place these galaxies on the two most important scaling relations: the Tully—Fisher relation between a galaxy's velocity and its visible mass and the Fall relation between stellar mass and specific angular momentum. The authors found that the rotation curves of these systems are very similar to those of less massive discs, reaching a flat part in the outer regions, although with rotation velocities significantly higher than those of normal spirals. In contrast with previous results based on preliminary data, they also determined that these monster galaxies lie on the regular Tully—Fisher and Fall relations. These results show that these rare, giant spiral galaxies are scaled up versions of less massive discs, implying that they must have had a very similar evolutionary history. Unlike the majority of massive galaxies in the Universe, super-spirals must have somehow avoided disruptive events like major mergers and AGN feedback, which are capable of transforming their disc-like morphology and of moving them off the scaling relations, and instead must have simply continued to assemble their stellar mass through secular evolution and minor mergers.



CAPTION:

An example of a super-spiral galaxy with a stellar mass 10x and a stellar disc 5× larger than the Milky Way. Left: composite image of the galaxy in the *g-r-z* filters from the DESI Legacy surveys. Right: long-slit SALT data of the Hα emission line (grey scale), highlighting the galaxy's rotation reaching ~450 km/s. The best-fit kinematic model and rotation curves are shown in red contours and yellow dots, respectively.



SCIENCE HIGHLIGHTS
Stellar and Galactic astronomy

SALT survey of helium-rich hot subdwarfs

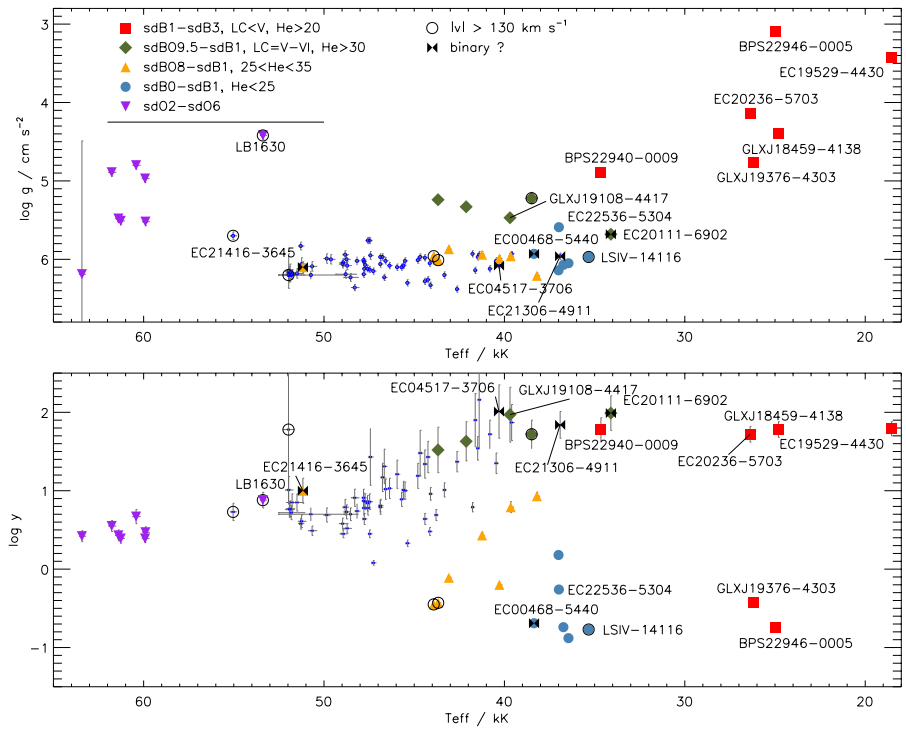
Jeffery, C. S., et al., E. 2021/02, MNRAS 501, 623: The SALT survey of helium-rich hot subdwarfs: methods, classification, and coarse analysis

Hot subdwarfs are blue stars of spectral types O and B. They are less luminous than hydrogen-burning main-sequence stars, and generally have between one third and one times solar masses. In a late phase of evolution, the majority (~90%) are probably the remains of red giant stars, which have been stripped to leave a helium-burning star with a thin hydrogen surface layer. The remainder (~10%) have hydrogen-deficient surfaces, and their origins appear to be different and diverse, including remnants of white dwarfs which have reignited helium, either in the core or in a shell. They also include the products of double white dwarf mergers. Some are nitrogen-rich, some are carbon-rich. A few are binaries. Being very rare, unravelling their histories is hampered by sparse data. Simon Jeffery from Armagh Observatory and his team designed a SALT survey to increase the sample of well-studied helium-rich subdwarfs by classifying their spectra and measuring their surface properties, reporting here on the coarse properties of 100 subdwarfs.

Several discoveries made during the survey have already been reported, including the first new extreme helium star discovered for nearly 40 years (GALEX J184559.8−413827) and the extremely lead-rich intermediate helium subdwarf EC 22536−5304. The distribution of the sample in terms of spectral type, surface gravity (log g) and surface helium fraction (log y = log (n_{He}/n_H)) is illustrated in the figure. Evidence that some might be binaries, either because their absorption lines are unusually broad or because their radial velocity is unusually large, is indicated in the figure. Extreme helium stars (red squares) lie at the top right of both panels, extreme subdwarf O stars (violet triangles) to the extreme left. Low-gravity subdwarfs (green diamonds) and intermediate helium subdwarfs (blue circles, yellow triangles) are also highlighted. The SALT survey continues, with analysis of low-resolution data for a further 100 stars and fine analyses for a significant subsample advancing well.

CAPTION:

The distribution in effective temperature (T_{eff}) – surface gravity (log g) (top) and effective temperature – surface hydrogen (log y = log (n_{He}/n_H)) (bottom) for helium-rich subdwarfs measured from SALT spectroscopy. The grey error bars associated with each datum are formal errors.



Three very young planets orbiting a 120 Myr-old star

Newton, E. R., et al. 2021/02, AJ 161, 65: TESS Hunt for Young and Maturing Exoplanets (THYME). IV. Three Small Planets Orbiting a 120 Myr Old Star in the Pisces-Eridanus Stream

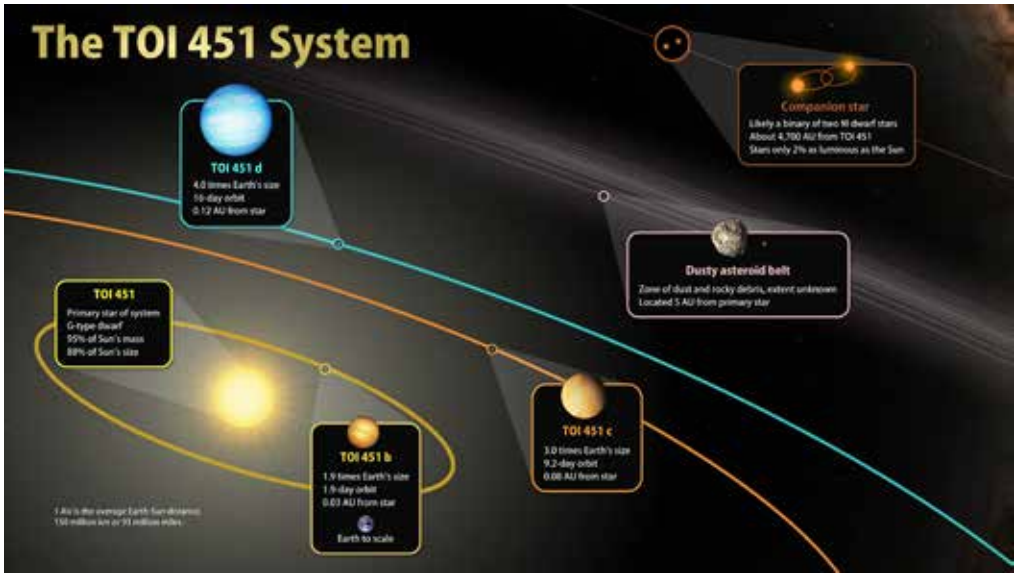
At ages of tens to hundreds of million years, young exoplanets are still undergoing the atmospheric and dynamical evolution that shape planetary systems. The *TESS* Hunt for Young and Maturing Planets (THYME) collaboration is leading a search for young, transiting exoplanets using data from NASA's *TESS* mission. Planets in young clusters provide a special opportunity because the age of the planet is known through its association with the cluster. Recent discoveries in the field of stellar astrophysics provided a new opportunity for this search: data from *Gaia* and *TESS* revealed a new stellar association, dubbed Pisces-Eridanis, which is only 120 Myr old and only 130 parsecs away.

TESS Object of Interest (TOI) 451 was an otherwise anonymous candidate planetary system identified by the *TESS* team. But when the Pisces-Eridanis stream was discovered, the THYME collaboration realised that TOI 451 is a member of this new association. This meant that the star and any orbiting planets (if confirmed as *bona fide* planets) are only 120 Myr old. One of the important ways of making sure a planet is real is by obtaining radial velocity measurements. The idea is not to detect the radial velocity signature of the planet itself but rather to use the radial velocities to rule out non-planetary companions (stars or brown dwarfs). SALT's southern location, ability to obtain data over a span of a weeks to months, and the high resolution of SALT'S HRS, make it ideally suited to this purpose.

The team led by Elisabeth Newton from Dartmouth College obtained six spectra of the TOI 451 host star with SALT/HRS. Using these spectra in combination with imaging data, the team statistically ruled out non-planetary companions at the orbital periods of the three planets and thus confirmed TOI 451 as a *bona fide* planetary system. Analysis of *TESS*, *Spitzer*, and ground-based photometry revealed three planets in the TOI 451 system, ranging from 2 – 4 Earth radii and with orbital periods from 1.9 – 16 days. A *WISE* infrared excess indicates the presence of a cool debris disk, and *Gaia* astrometry shows a distant, co-moving stellar companion TOI 451 B (itself likely composed of two M dwarfs). The host star itself is found to be very close to Sun-like; and using its kinematics, its lithium abundance, and the rotation and UV excesses of both TOI 451 and TOI 451 B, the authors show that the system is part of the Pisces-Eridanus stream and confirm its age to be only 120 Myr. Future observations with *HST*, *JWST*, and ground-based telescopes will allow learning about the atmospheres of these young planets.

CAPTION:

A sketch of the main features of TOI 451, a triple-planet system located 400 light-years away in the constellation Eridanus. -- Credit: NASA's Goddard Space Flight Center



Kinematics and the period—luminosity—metallicity relations of RR Lyrae stars

Muhie, T. D., et al. 2021/04, MNRAS 502, 4074: Kinematics and multiband period-luminosity-metallicity relation of RR Lyrae stars via statistical parallax

RR Lyrae (RRL) type variables are low mass stars that have evolved off the main sequence when their core hydrogen is exhausted. They occupy a fairly narrow strip in the Hertzsprung—Russell diagram at the intersection of the pulsating-star instability strip and the horizontal branch once their mean effective temperature reaches ~6000 – 7500 K, making them old, low-mass, yellow or white giants in the core helium burning stage. They were once stars with similar or slightly lower mass than the Sun, around 0.8 $M_{\odot}$, and belong to the Population II stars. They are radially pulsating, A – F type stars with periods of 0.2 – 1.2 d. Due to these properties, they can serve as distance indicators as well as kinematics and metallicity tracers of old populations.

Most of the RRL are classified into three main types according to the mode in which they pulsate radially: fundamental-mode RRab stars, first-overtone RRc stars and double-mode RRd stars. They are easily identified by their periods and characteristic light curve shapes. Like other pulsating stars they follow a period—luminosity—metallicity (PLZ) relation in any given passband. RRLs can be used as standard candles because of these LZ and PLZ relations. The near- or mid-infrared (NIR or MIR) PLZ relations are more preferable than the visual M_V – [Fe/H] relation, because they are less dependent on interstellar extinction, metallicity and evolution effects.

Tesfaye Dagne Muhie (Entoto Observatory, Ethiopia) and his colleagues from SAI/Moscow and SAAO/SALT report on results from photometric and statistical-parallax analyses of a sample of 850 field RRL variables. The largest part of the spectral data (448 RRLs) were taken as part of the MAGIC project (the Milky wAy Galaxy wIth SALT speCtroscopy) conducted by co-author Alexei Kniazev (SAAO/SALT) with SALT, leading to the currently largest homogeneous sample of RRLs.

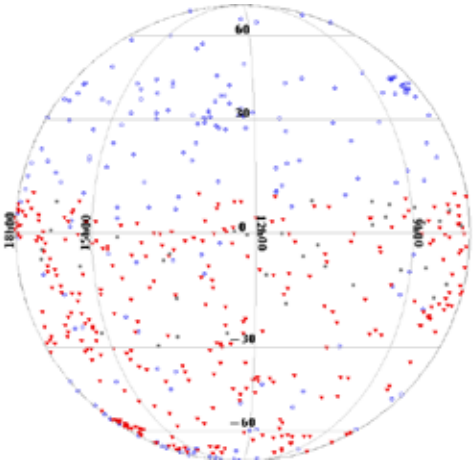
The kinematical results of the analysis indicate that the mean rotational velocity of the halo and disc RRLs in the solar neighborhood are 23 ± 17 km/s and 196 ± 16 km/s, respectively, with respect to the inertial Galactic Centre reference. Moreover, the velocity dispersions for both halo and disc RRL population are non-isotropic ($\sigma V_R > \sigma V_\phi > \sigma V_\Theta$) in the solar neighbourhood. These results are in good agreement with previous statistical-parallax studies but with higher accuracy: the uncertainty of RRLs distances could be reduced down to ~4.5%. These kinematic results represent the current best estimates of these kinds of studies and are at the same time quite consistent with those obtained using other techniques.

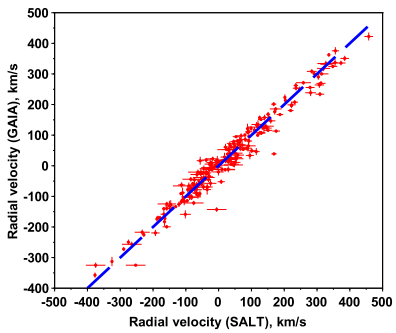
The calibrated PLZ and LZ relations are used to estimate the Galactic Centre distance and the distance modulus of the LMC, which are found to be 7.99 ± 0.49 kpc and 18.46 ± 0.09 mag, respectively. These results are also in excellent agreement with published work based on statistical-parallax analysis, but are considerably more accurate and precise than these. The zero-points of the calibrated PLZ and LZ relations are also consistent with current results found by other techniques and yield an LMC distance modulus that is within 0.04 mag of the current most precise estimate.

CAPTION:

TOP: Sky distribution of the 850 RRLs. Red triangles: new RRLs from SALT observations; blue circles: RRLs from the literature; grey circles: 40 RRLs with both spectroscopic data serving as a test sample.

BOTTOM: Comparison between SALT measured radial velocities with their available Gaia DR2 data. The dashed line has slope one and goes through the origin.





SALT reveals a very massive white dwarf in the nova V3890 Sagittarii

Mikołajewska, J., et al. 2021/06,
MNRAS 504, 2122:
The symbiotic recurrent nova V3890 Sgr: binary parameters and pre-outburst activity

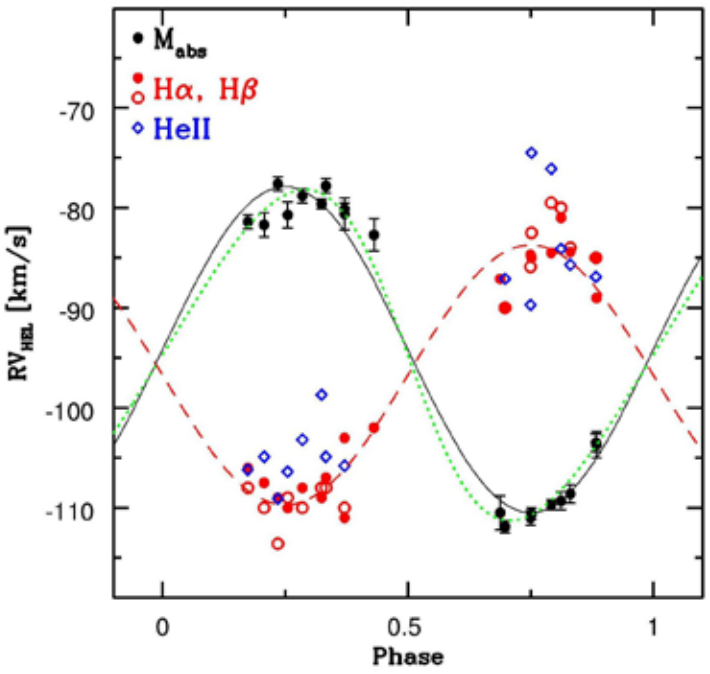
Recurrent novae (RNe) are novae with two or more thermonuclear explosions recorded. They should contain massive white dwarfs (WDs) that accrete at very high rates to build critical-mass envelopes quickly enough to erupt so frequently. Those with evolved giant donors, called symbiotic recurrent novae, with their massive WDs and high accretion rates, are promising candidates for the SN Ia via single-degenerate (SD) channel, provided that they contain carbon—oxygen (CO) WDs which can grow secularly in mass to approach the Chandrasekhar limit and ignite carbon burning to produce a SN Ia. Recent theoretical simulations show that the SD symbiotic channel could produce SNe Ia with intermediate and old ages, contributing up to 5% of all SN Ia in the Galaxy.

The team led by Joanna Mikołajewska (Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences) has recently combined optical photometry and high-resolution SALT spectra of the symbiotic RN V3890 Sgr at quiescence and determined the orbital period to be 747.6 days. The double-line spectroscopic orbits indicate that the component masses are $M_{WD} \approx 1.35\ M_{\odot}$ and $M_g \approx 1.05\ M_{\odot}$. The orbit inclination is ~ 67°– 69°. The red giant is filling (or nearly filling) its Roche lobe, and the distance d ≈ 9 kpc set by its Roche lobe radius is consistent with that resulting from the giant's pulsation period. The outburst magnitude of V3890 Sgr is then very similar to those of RNe in the Large Magellanic Cloud.

V3890 Sgr shows remarkable photometric and spectroscopic activity between the nova eruptions on timescales of years. The active source has a double-temperature structure which has been associated with the presence of an accretion disc. The activity would then be caused by changes in the accretion rate. The team also provides evidence that V3890 Sgr contains a CO WD accreting at a high rate: a few × 10^{-8}–$10^{-7}\ M_{\odot}$/yr. The WD is growing in mass, and should give rise to a SN Ia within ≲10^6 yr, that is, the expected lifetime of the red giant.

CAPTION:

SALT/HRS radial velocity curves phased with the orbital period and orbital solutions (circular) for the M giant absorption lines (black) and the WD traced by broad emission line wings (red and blue). The green dotted line represents the best elliptical fit to the M-giant's absorption lines.



SALT's HRS supplies metallicities for 49 RR Lyrae variables

Gilligan, C. K., et al. 2021/06, MNRAS 503, 4719: Metallicities from high-resolution spectra of 49 RR Lyrae variables

The precise value of H_0 is currently under debate, with late-time and early-time measurements disagreeing at a 4.4σ level (late-time measurements refer to measuring H_0 locally, e.g., using Cepheids as a first step; early-time measurements are usually based upon the Cosmic Microwave Background). To determine if the cosmic distance ladder's underlying methods are somehow not correct, we need an independent method of recalibrating the distance ladder. RR Lyrae variables, for example, can be used instead of Cepheid variables for the first rung of the ladder.

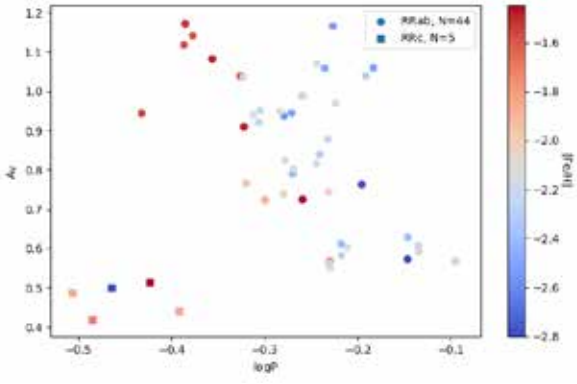
Christina Gilligan from Dartmouth College and her co-authors examined 58 RR Lyrae stars with SALT/HRS, hoping to attain accurate metallicities. Having all of the stars' spectra taken with the same instrument decreases issues with calibration between instruments, leading to a homogeneous dataset and to reducing errors in the final period—luminosity—metallicity (PLZ) relationships. All of the target stars were drawn from the *Gaia* DR2 catalogue, having positive parallaxes and uncertainties less than 10%. Due to the short exposure times (required by the relatively short periods of RR Lyraes), Gilligan did not conduct a line-by-line abundance analysis for each of the stars. Metallicities were instead measured using synthetic spectral analysis. She would create a model atmosphere with a set of input stellar parameters (temperature, pressure, microturbulent velocity, and [Fe/H]). Then she compared the SALT spectra to the synthetic spectra, adjusting the stellar parameters in an iterative fashion until a global minimum in χ^2 was found. For 11 of the RR Lyraes, the χ^2 values only created a shallow minimum, making it impossible to determine an accurate metallicity for these stars. These stars were removed from the final sample of RR Lyrae stars.

In the end, metallicities for 58 RR Lyraes were obtained using this method, 49 of which did not previously have metallicities determined using high-resolution spectrographs. This dataset is also one of the largest, homogeneous datasets of metallicities in RR Lyraes, and the team hopes to make it even larger with the help of SALT in the future. By combining the new 49 RR Lyrae metallicities with 109 previously determined metallicities obtained with high-resolution spectroscopy, the authors were able to construct new PLZ relationships for the *WISE* bands *W1* and *W2*. The team's PLZ relationships have smaller uncertainties than any previous observational determinations of the RR Lyrae PLZ relations in the mid-IR.

In the future, the team hopes to combine these metallicity measurements with IRSF lightcurves obtained by them to produce NIR PLZ relationships for RR Lyraes. In addition, there are nearly 150 more RR Lyraes with more than 20 epochs of IRSF data which do not yet have metallicities from SALT. Both of these efforts will bring the team one step closer to solving the Hubble tension. Moreover, future observations with *JWST* will completely change the picture since it will be possible to get infrared lightcurves of RR Lyrae, potentially even in some nearby local group galaxies.

CAPTION:

Bailey diagram for the 49 RR Lyrae stars with new metallicities. The colours of the points correspond to the metallicity found with SALT. The shapes indicate if the star is RRab (fundamental-mode) or RRc (first-overtone).



EC 22536–5304: a lead-rich and metal-poor long-period binary

Dorsch, M., et al. 2021/09,
A&A 653, A120:
EC 22536–5304: a lead-rich and
metal-poor long-period binary

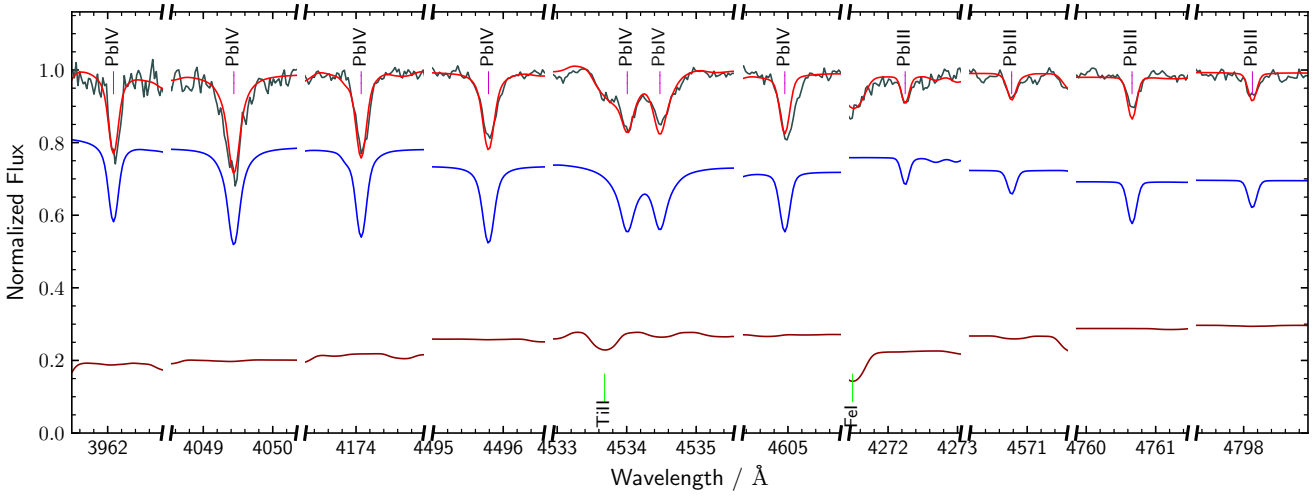
Among the hot subdwarf stars exists a small subclass of stars with effective temperature and helium abundances between the cooler helium-poor B-type subdwarfs and those of the hotter helium-rich O subdwarfs. Recently, several members of this small population have been found to be extremely enriched in heavy elements such as strontium, yttrium, zirconium, or lead. These again fall into two groups: the hotter being lead-rich and the cooler being zirconium-rich.

EC 22536–5304 was identified as a helium-rich subdwarf in the Edinburgh Cape Survey. SALT/HRS spectroscopy demonstrated it to be an intermediate helium-rich subdwarf with prominent lines of triply-ionised lead, making it one of these extremely rare 'heavy-metal' subdwarfs. Given the difficulty of accounting for the formation of heavy-metal subdwarfs, Matti Dorsch and his collaborators decided to obtain additional SALT/HRS observations to follow-up the question of whether EC 22536–5304 could be a binary.

Whilst the 2020 spectra revealed that EC 22536–5304 could not be a short-period binary, the spectrum of a faint F-type companion was detected in the co-added high signal-to-noise spectrum. Combined with other archival observations, radial-velocity measurements indicated a long orbital period of 457 days (which was confirmed with new SALT observations in 2021), and masses of 0.4 and 0.84 solar masses for the hot and cool components, respectively. The metallicity of the companion is some 1% that of the Sun, making the very high lead abundances observed in the hot subdwarf (+6.3 dex relative to solar and probably +8.2 dex or 160 million times overabundant relative to its companion) even more remarkable. The results for the orbital period, mass ratio, and metallicity are consistent with the system being formed through stable Roche lobe overflow.

CAPTION:

Very strong lead lines in the HRS spectrum of EC 22536–5304 (grey). The combined model spectrum (red) is the sum of the contributions of the sdOB (blue) and F-type star (dark red).



SALT finds giant flares at high-latitudes on fully convective stars

Cool stars produce intense flares that indicate strong stellar magnetic fields and shape the environments of exoplanets in their orbits. However, the mechanism that produces the magnetic field that drives these flares is poorly understood. A key hindrance to understanding this mechanism is the difficulty of measuring the small-scale surface magnetic field of these stars.

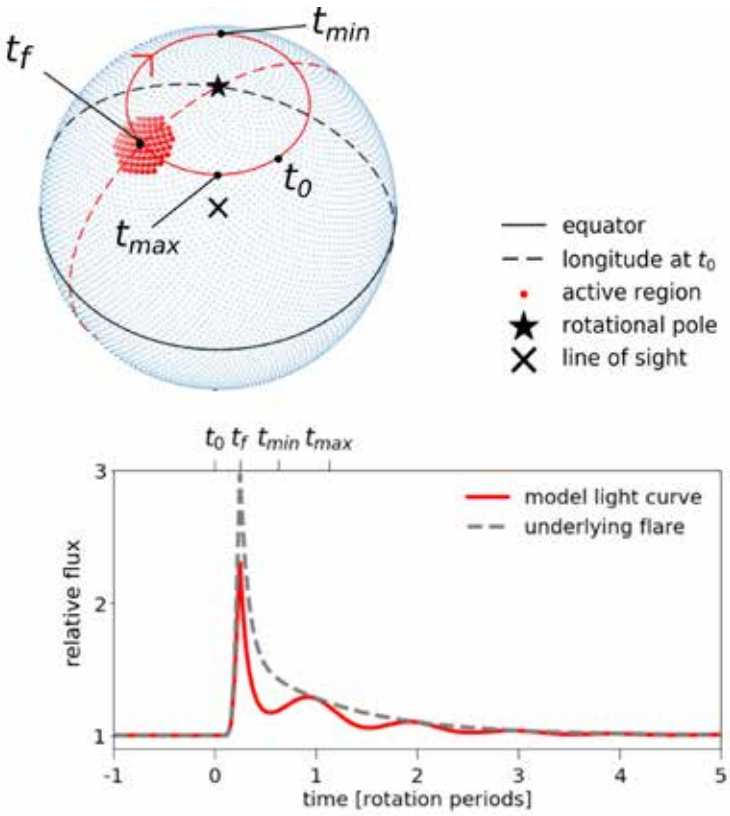
In a systematic analysis of fully convective stars observed with *TESS*, Ekaterina Ilin from the Leibniz Institute for Astrophysics Potsdam and her colleagues detected four stars that displayed giant flares, which were modulated in brightness by the stars' rapid rotations. The exceptional morphology of the modulation — an oscillation in the flare light curve in phase with rotation — encodes information about the latitude of the small-scale magnetic region that produced the flare. However, the information on latitude is degenerate with the inclination of the stellar rotation axis. Using *v* sin *i* measurements obtained from high-resolution SALT spectra of these stars, the authors could break this degeneracy, and directly localise these flares between 55° and 81° latitude on the stellar surface — far higher than on the Sun, where they typically occur below 30°.

Such high latitudes imply that strong, dynamic magnetic fields tend to emerge close to the rotational poles for rapidly rotating, fully convective stars, which is an important prediction of stellar magnetic field models that has, so far, been difficult to test systematically. Moreover, planets that orbit these stars may be exposed to different amounts of radiation and particles depending on the tilt of their orbital plane with respect to the stellar rotation axis.

Ilin, E., et al. 2021/10, MNRAS 507, 1723: Giant white-light flares on fully convective stars occur at high latitudes

CAPTION:

Direct flare localisation from optical light curves. The flare flux (grey dashed line) is modulated (red line) as the flaring region (red dots) rotates in and out of view (t_0 -> t_f -> t_{min} -> t_{max}) on the stellar surface (blue sphere). The latitude can be inferred unambiguously if the stellar inclination axis is known.



A very large and near-by supernova remnant at high Galactic latitude

Fesen, R. A., et al. 2021/10,
ApJ 920, 90: Far-UV and Optical Emissions from Three Very Large Supernova Remnants Located at Unusually High Galactic Latitudes

There are currently about 300 confirmed supernova remnants (SNRs) in the Milky Way, mostly discovered via their non-thermal radio emission. They are typically less than a degree in angular size and more than one kpc distant. Very large SNRs with angular dimensions greater than a few degrees are quite rare, as are remnants located more than ten degrees off the Galactic plane or lying closer than 500 pc away. A huge 20° × 26° optical emission nebula called Antlia was discovered in 2002 through low-resolution all-sky Hα images (l = 275.5, b = +18.4). Because of coincident soft X-ray emission detected by the German *ROSAT* satellite, it was proposed to be an unusually large and very old SNR of the order of one million years. However, due to its location near the even larger Gum Nebula (diameter = 35°) plus its location extending almost 20° above the Galactic plane, a SNR nature of Antlia was generally viewed as doubtful and consequently gained little follow-up attention.

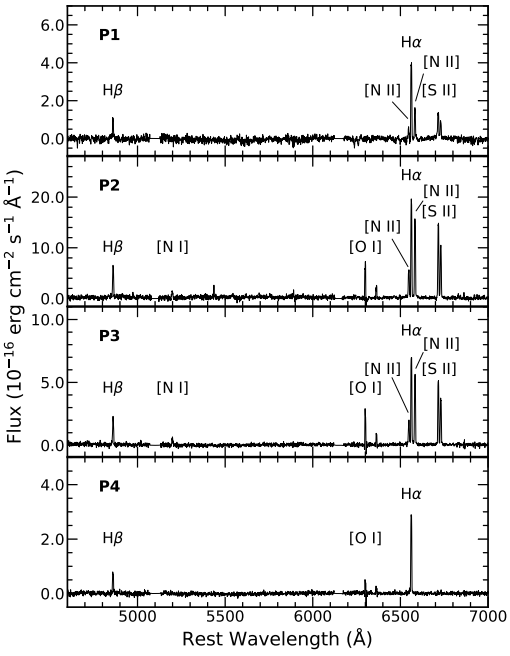
Using far-UV (FUV) images taken with the *GALEX* satellite, Rob Fesen (Dartmouth College) began a study of the Antlia nebula in 2019 together with collaborators at Harvard and Purdue universities plus several amateur astronomers who were able to obtain very wide-field Hα images via remotely controlled observatories located in the US, France, Germany, and New Zealand. This project uncovered several FUV filaments coincident with numerous faint, thin Hα filaments associated with the Antlia nebula suggestive of interstellar shocks like those seen in Galactic SNRs. These detections subsequently led Fesen and Katie Weil (Purdue University) to obtain SALT/RSS spectra of several Antlia filaments. These data revealed line emissions consistent with shocks, making it clear that the Antlia nebula is a *bona fide* SNR. The SALT spectra indicate the remnant's expansion velocity to be around 75 – 150 km/s, pointing to a much younger remnant of ~75,000 years rather than the earlier suspected 1.0 – 1.2 million years.

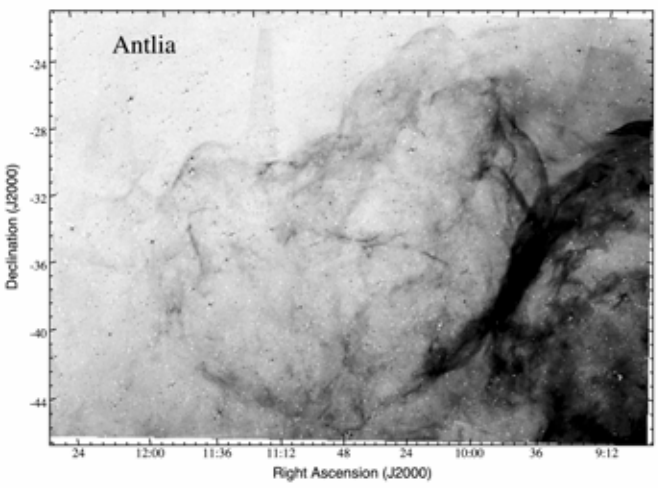
Fesen and collaborators also found that the Antlia nebula is not just located near the Gum Nebula but has actually collided with it. This discovery allowed them to estimate its distance to be similar to that of the Gum Nebula, namely around 300 pc, leading to a physical size of the Antila nebula of roughly 100 pc. Thus, despite its enormous apparent size and expansion well off the Galactic plane and into the Milky Way's outer halo, the Antlia Nebula is now the largest confirmed Galactic SNR as well as one of the nearest to us.

CAPTION:

LEFT: Low-resolution SALT/RSS spectra of four filaments in the Antlia supernova remnant. The spectra of P1 – P3 exhibit strong [S II] line emission characteristic of shocks, while the spectrum of P4 shows a hydrogen Balmer dominated spectrum indicating a high-velocity shock moving through a low-density interstellar medium.

RIGHT: A continuum subtracted, deep Hα image of the Antlia Nebula showing it to span ~20° × 26° in angular size.





V838 Monocerotis: remnant of a binary merger in a triple system

Kamiński, T., et al. 2021/11, A&A 655, A32: V838 Monocerotis as seen by ALMA: A remnant of a binary merger in a triple system

V838 Monocerotis (V838 Mon) is a red nova whose eruption in 2002 sparked anew the debate on whether binaries composed of normal stars, such as pairs of main sequence stars, can be observed during the process of collision and coalescence. In subsequent years, a large body of evidence was collected to demonstrate that indeed stellar mergers can happen before our eyes and their optical manifestations are eruptive events known today as (luminous) red novae. Red nova outbursts are typically more luminous than classical novae but less luminous than supernovae. They are believed to be more frequent than supernovae, with two bright events per decade per galaxy. A lot of effort has been invested in trying to understand why normal stars merge and what are the physical processes driving binaries into a collision. V838 Mon remains the prototypical object of the class and its post-outburst evolution is studied closely. Many observations during and after the outburst have been obtained at SAAO (e.g., by Lisa Crause).

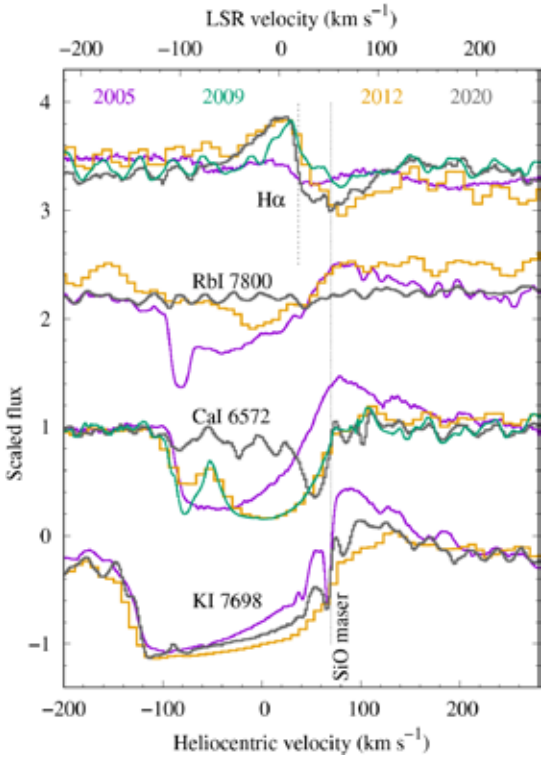
In 2019, V838 Mon was observed with the ALMA interferometer at its longest baselines, providing Tomek Kamiński from Poland and his team with the most detailed maps of the merger remnant to date. The observations show that before the merger, V838 Mon was a triple hierarchical system. The inner binary, which coalesced in 2002, was composed of a main-sequence B3 star of ~8 $M_\odot$ and a protostar of a much lower mass (~0.4 $M_\odot$). The outer companion is also a B3 main-sequence star. ALMA maps showed for the first time the location of the latter with respect to the coalesced binary. Its orbit is very wide, at least 250 AU (the orbital period is longer than 1000 years), though that could have something to do with the collision if the orbit is elliptical. The ALMA maps show complex interaction of merger ejecta with the companion, including a shock region where the ejecta changes its chemical composition.

ALMA observations were supplemented by SALT/HRS spectra in December 2020 as a DDT project. While ALMA maps show the distribution of ejecta projected on the sky, SALT spectra showed the material along the line of sight toward the stellar remnant of the merger. Both molecules and atomic matter are seen in the SALT spectra, providing information about the radial structure of the material. In addition to the merger ejecta seen at high velocities, the spectra display features which arise in the wind of the star produced in the merger. The wind is very similar to those often seen around red supergiants with heavy mass loss. The (possibly unprecedented) combination of ALMA and SALT data thus gives the most comprehensive view on the remnant, some 17 years after the merger.

An artistic animation of the expanding nebula can be found at https://youtu.be/9Wb4bUqt7dY.

CAPTION:

Temporal changes in selected atomic line profiles of V838 Mon. Purple: Keck/HIRES (2005), green: VLT/UVES (2009), orange: VLT/X-shooter (2012), grey: SALT/HRS (2020). The spectra were arbitrarily scaled to show changes in the four labeled atomic lines. The vertical lines mark the velocity of the SiO maser (or the supposed stellar systemic velocity; 54 km/s LSR or 71 km/s in the heliocentric frame) and the position of the turnover in the inverse P-Cyg profile of Hα (37 km/s heliocentric).



A new intermediate polar cataclysmic variable

Gorgone, N. M., et al. 2021/12, ApJ 923, 243: Swift/XRT Deep Galactic Plane Survey Discovery of a New Intermediate Polar Cataclysmic Variable, Swift J183920.1-045350

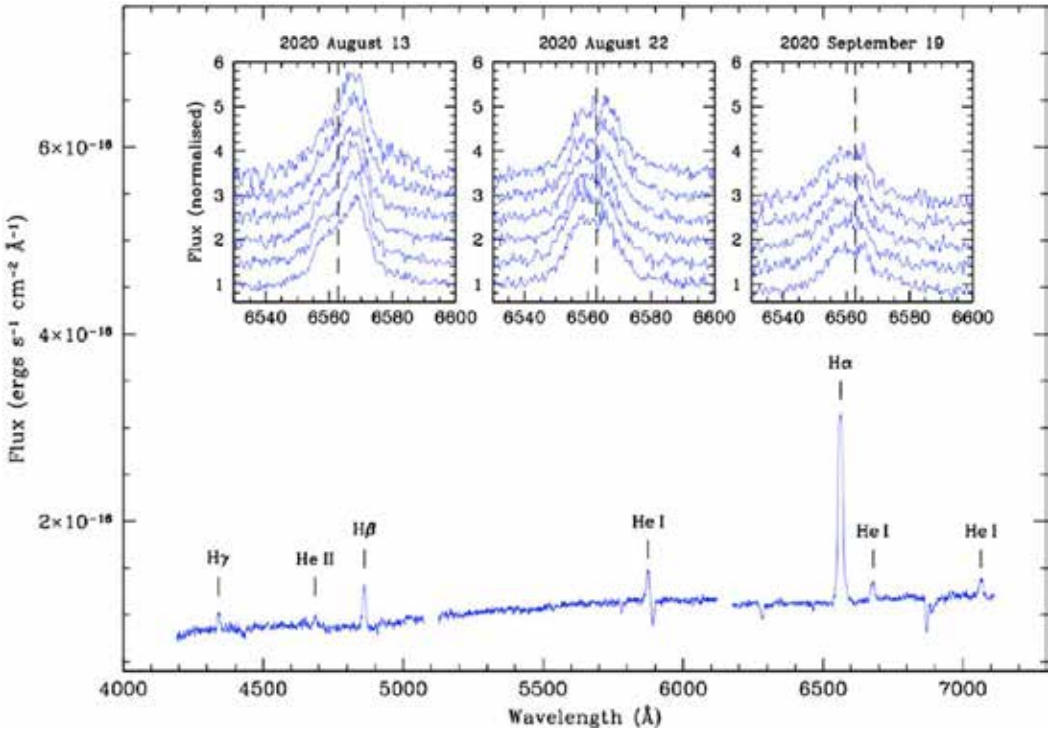
Cataclysmic variables (CVs) are binary systems where a white dwarf (WD) accrets material from a companion. An accretion disc can form if the magnetic field of the WD is sufficiently small (nonmagnetic CVs). While at high magnetic field strengths no accretion disc can form (polar systems), the intermediate polars (IPs) show discs disrupted by the magnetic field.

Nicholas Gorgone (George Washington University) and his team now report on a *Swift/XRT* Deep Galactic Plane Survey discovery and multiwavelength follow-up observations of a new intermediate polar (IP) cataclysmic variable, Swift J183920.1-045350. A 449.7 s spin period was found in X-ray data from *XMM-Newton* and *NuSTAR*, accompanied by a 459.9 s optical period that is most likely the synodic, or beat period, produced from a 5.6 hr orbital period. The X-ray pulse fraction of the source decreases with increasing energy while the X-ray spectra are consistent with the presence of an Fe emission line complex, with both local and interstellar absorption. Follow-up SALT/RSS optical spectra reveal strong emission lines of Balmer hydrogen and helium, including high-excitation lines that are common in magnetic CVs. The source properties are thus typical of known IPs, with the exception of its estimated distance of $2.26^{+1.93}_{-0.83}$ kpc, which is larger than typical, extending the reach of the CV population in our Galaxy.

The authors conclude that deep X-ray surveys of the Galactic plane in combination with multi-wavelength follow-up observations will detect IPs far away from the Solar neighborhood in a systematic manner, an important step to directly study the Galactic distribution of CVs.

CAPTION:

Averaged SALT/RSS spectrum with main emission lines labeled. The insets show the varying Hα emission line profiles as observed at higher spectral resolution; each sequence shows a series of consecutive 500 s spectra. The vertical dashed lines indicate the rest wavelength of Hα.



The binary central star of the bipolar pre-planetary nebula V510 Puppis

Manick, R., et al. 2021/12, MNRAS 508, 2226: The binary central star of the bipolar pre-planetary nebula IRAS 08005-2356 (V510 Pup)

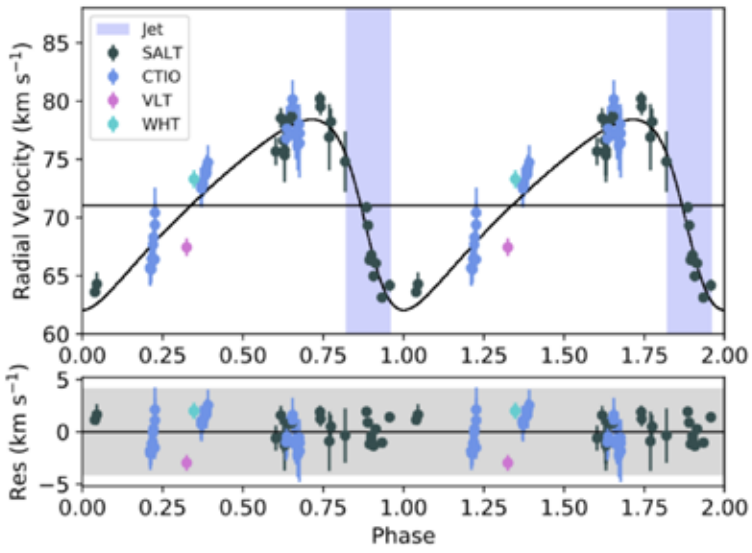
Current models predict that binary interactions are a major ingredient for the formation of bipolar structures among pre-planetary nebulae (PPNe). Despite years of radial velocity monitoring, there is a paucity of known binaries amongst PPNe. Arguably the only two known binaries in PPNe are The Red Rectangle and HD 101584. As part of a wider program to find binaries among PPNe, Rajeev Manick from SAAO and his co-authors monitored the bipolar PPN IRAS 08005–2356 aka V510 Pup using SALT/HRS. They also used archival data from the Small and Medium Aperture Research Telescope System 1.5-m telescope at the Cerro Tololo Inter-American Observatory. Another two Echelle spectra were obtained from the William Herschel Telescope and the Very Large Telescope, respectively.

The observations proved the binary nature of the central star of the PPN. With an orbital period of 2654 ± 124 d, this is currently the longest measured orbital period within a PPN. The authors fit the RV orbit with an eccentricity of 0.36 ± 0.05. Adopting a primary mass of 0.57 ± 0.1 $M_{\odot}$, they derive a companion mass of 0.63 ± 0.13 $M_{\odot}$. They also find evidence of high velocity outflows (jets) in the Hα profiles which are highly dependent on the orbital phase: they are likely being launched by the companion and only appear when the latter is located between the observer and the evolved star. These results suggest that binary interaction plays a key role in producing bipolar systems like V510 Pup. The jets may be supplying the primary force in shaping the surrounding nebula into a bipolar structure.

Although previous studies showed that measured orbits among PPNe are rare, this analysis of V510 Pup suggests there may be more binaries to be found among such systems. High-resolution spectroscopic monitoring surveys on large telescopes have the potential to detect the orbits of such long period systems, and PPNe with long-period light variations are among the most likely binary candidates. Finding more binaries among PPNe will help bridge important gaps in our understanding of binary evolution among evolved stars. Accordingly, the authors launched a new programme at SALT to monitor several more PPNe in the south, which display likely signatures of binarity, with the aim to place important statistical constraints on their orbital distribution.

CAPTION:

Top panel: A Keplerian model (black curve) is fit with an eccentricity of 0.36 ± 0.05. The blue shaded region indicates the phase range where the jets appear. Bottom panel: Residuals to the fit with the grey shaded region representing a standard deviation of 3σ.



SCIENCE HIGHLIGHTS
Ongoing research

A number of exciting SALT science projects are either close to being published or are longer-term projects that may lead to publications on selected objects of interest, awaiting completion of the final science goals. The following section gives an overview of a small selection of these.

Over the two semesters in 2021 (2020-2 and 2021-1), a total of 123 proposals were accepted by the various TACs. Eight of these were **DDT proposals**, receiving a total of 70 kiloseconds of observing time. All but one were completed by the end of the year (observations of the one are to be repeated since the observing conditions had not been met). Three of these projects are mentioned below, and one already has a paper published in 2021 (see previous section). While 80 proposals were normal **science proposals** (SCI), there were 33 **multi-semester proposals** (MLT), with 16 newly submitted and 17 carried over from previous semesters (some starting as early as 2018-1). To date, there have been only two **Large Science Proposals** (LSPs), one of which was completed in 2020-2.

The longest-lasting LSP on SALT is dedicated to "Observing the Transient Universe" and is led by David Buckley at SAAO. SALT is the ideal telescope for such a transient follow-up project: its queue scheduling provides the rapid response required (within days, or even hours) and having the full suite of instruments available at all times allows the observer to quickly switch between them, depending on the science requirements. Targets for the programme are chosen by request form a collaborator. Priorities are determined through discussion as well as the nature of the transient. For example, fast transients like GRBs need "P0", as do time critical objects. Occasionally competing targets within the programme are decided on by the PI. The programme, which started in the second semester of 2016, was renewed twice: in the semesters 2018-2 and 2021-2. The 2021-2 programme involves even more international co-investigators than before, namely 68, including 13 postdocs or early career researchers and 18 postgraduates students, and five SALT partners: RSA, POL, UKSC, IUCAA and UW. Observations for the year 2021 comprised 151 successfully completed observations, totalling ~350 kiloseconds. A total of 32 observation attempts were aborted or rejected due to unacceptable observing conditions or technical issues. About 100 different targets were observed covering the following classes and percentages of time allocated:

Optical transients from Gaia, ASASSN, OGLE, including microlensing events and nuclear transients: 22.1%
Low Mass X-ray binaries and related objects: 15.9%
Cataclysmic Variables and related objects: 14.8%
AGN, tidal disruption events, mostly from *eROSITA* alerts: 11.4%
Novae, recurrent novae: 10.1%
Blazars: 7.5%
Be X-ray binaries: 7.4%
MeerKAT radio transients: 5.6%
GRBs and gamma ray binaries: 2.8%
Unidentified X-ray sources: 2.2%

The scientific progress, counted as published refereed papers, reached 37 by the end of 2021, with six publications in 2021 and several in press, accepted or submitted. Data from the project are also regularly presented at conferences and in Astronomer Telegrams. Remarkable highlights of the last year include press releases on a warped disc in a black hole low-mass X-ray binary (led by Jessymol Thomas from SAAO, see below) and the awakening of two massive black holes (led by PhD Riccardo Arcodia from MPE, see previous section).

Observations for the second LSP, "BEAMS (*Brightest cluster galaxy evolution with ACT, MeerKAT, and SALT*)", led by Matt Hilton from UKZN, were completed in 2021. Brightest cluster galaxies (BCGs) are the most massive galaxies in the Universe and are found in special environments: the centres of galaxy clusters, which are in turn the most massive gravitationally bound structures in the Universe. In fact, clusters are so massive that they have 'atmospheres' of hot (10 – 100 million Kelvin) gas, which are detectable at X-ray and millimetre wavelengths. The project's goal is to observe around 150 BCGs in galaxy clusters detected by the Atacama Cosmology Telescope (ACT) through the Sunyaev–Zel'dovich (SZ) effect. The target clusters cover the redshift range $0.3 < z < 0.7$, which corresponds to a 3.4 Gyr time period. The aim is to measure the growth of BCGs over time through cannibalism of their neighbours and the evolution of their stellar populations, as well as to study the evolution of their star formation activity and the impact of the supermassive black holes that they host on the

surrounding cluster environment. This requires the combination of ACT and SALT data together with MeerKAT radio observations. By the end of the observing programme, a total of 95 targets out of the goal of 150 were observed (63%), and have been processed using the RSSMOSPipeline package. For a spectrum to be usable, it must be possible to measure the BCG redshift from it, which was possible for 81/95 observing blocks (85%; this number may improve with further processing effort). A total of 145 secure redshifts have been measured, since some fields contained multiple galaxies in the slit. Preliminary findings indicate that only 4/81 BCGs with usable data (5%) show evidence of [O II] 3737 emission and are potentially AGNs. The rest of the BCG sample is quiescent, with luminous red galaxy type spectra. Work is underway at Northwest University on stacking spectra in redshift bins, and fitting them with stellar population models. Some of the spectroscopic redshifts measured by BEAMS are included in the ACT DR5 cluster catalogue published in 2021. Details on the project can be found at https://astro.ukzn.ac.za/~beams/.

Drew Chojnowski and his collaborators obtained SALT/HRS data using a DDT proposal on "Confirming the rigidly rotating magnetosphere in Trumpler 16-26". Five years ago, a team involved in APOGEE, one of the SDSS III programmes, announced the discovery of the rigidly rotating magnetosphere (RRM) stars HD345439 and HD23478. NIR spectra of these objects revealed an emission-line behaviour identical to that previously discovered in the helium-strong star σ Ori E, which has an extremely strong magnetic field and rotates fast. The discovery of a new rigidly rotating magnetosphere star, Trumpler 16-26 in the η Carinae region, was recently made known to Ewa Niemczura and her team by their collaborator Drew Chojnowski, who observed prominent Brackett series emission lines with a characteristic double-horned profile in the H-band spectrum of this star. As such massive early B-type stars with strong magnetic fields and very fast rotation are extremely rare, they proposed to use FORS2 spectropolarimetry to characterise the magnetic field topology of this new RRM star and to obtain UVES spectral coverage to fully characterise its atmosphere. Through the DDT proposal, the team expected that at a rotation period of about 24 hours, substantial variability will be seen in exposures separated by 2 – 4 hours. The primary goal of these observations was to sample the spectroscopic variability across the apparent photometric rotation period and to either confirm that it is the actual rotation period or else to constrain the actual rotation period.

Danny Lennon from IAC in Spain obtained observations through a DDT proposal (PI Itu Monageng). The Be-type source NGC2004#115 in the Large Magellanic Cloud was previously characterised as a short period (2.9 d) eccentric binary that exhibited almost stationary Hα emission. While it was suspected that the emission originated from a possible accretion disc around a black hole, this conclusion was based on only two epochs of Hα spectroscopy. The DDT proposal aimed to improve the phase coverage of the Hα velocities but resulted in the surprising discovery that the system is in fact a triple system, while the Hα emission has almost vanished. The orbit of the inner binary of this system is now determined to be almost circular and, assuming the inner primary (also a B-type star) is synchronised, that is, tidal forces have fixed the rotational periods of the two stars to be equal to the orbital period, this leads to the possibility that the secondary is a ~25 solar mass black hole.

Together with their team, **Richard Monier** and **Ewa Niemczura** (Wrocław University) are working on a long-term programme called "Searching for new chemically peculiar stars in the southern hemisphere". The region of the main sequence centered on early A to late B stars represents an ideal laboratory to study a wide variety of physical processes that are at work in most stellar types. These processes include radiation-driven diffusion, differential gravitational settling, and magnetic fields. While their observable manifestation is particularly prominent in tepid stars, some or all of them play a significant role in the physics, formation, and evolution of most stars. Among the tepid stars, one can find chemically peculiar objects that have characteristic surface abundance patterns, strength and structure of the magnetic field, rotation, and multiplicity. For instance, the classical magnetic BpSi stars and the HgMn stars result from different formation and evolution scenarios. Their study allows insight into the above-mentioned physical processes. The researchers have been granted MLT time to obtain spectroscopic observations of late B stars from the southern hemisphere to search for such peculiar objects. The analysis of SALT/HRS spectra will allow the team to determine atmospheric parameters, chemical abundances, and to study processes in the atmospheres of these stars.

Ewa Niemczura and her student **Natalia Posiek** from the Wrocław University are working on a publication concerning Am stars with spectra obtained by SALT, which is part of the MLT project on "Chemically peculiar Am stars observed by the *TESS* satellite on the southern sky". The detailed analysis of these spectra will allow the determination of atmospheric parameters, chemical composition, and projected rotational velocities of the proposed targets. They will also identify double-lined spectroscopic binaries in the sample. This information is necessary to fully understand the *TESS* observations of these stars. The precise photometric time series gathered by *TESS* will help to answer several questions regarding the incidence of pulsations in Am stars, dependence of pulsation characteristics on atmospheric parameters, chemical abundances, and projected rotational velocities. Moreover, the analysis of the *TESS* photometric data, supplemented with the results of spectroscopic analysis, are the necessary ingredients for stellar seismology, the only method that allows probing of the inner structure of a star.

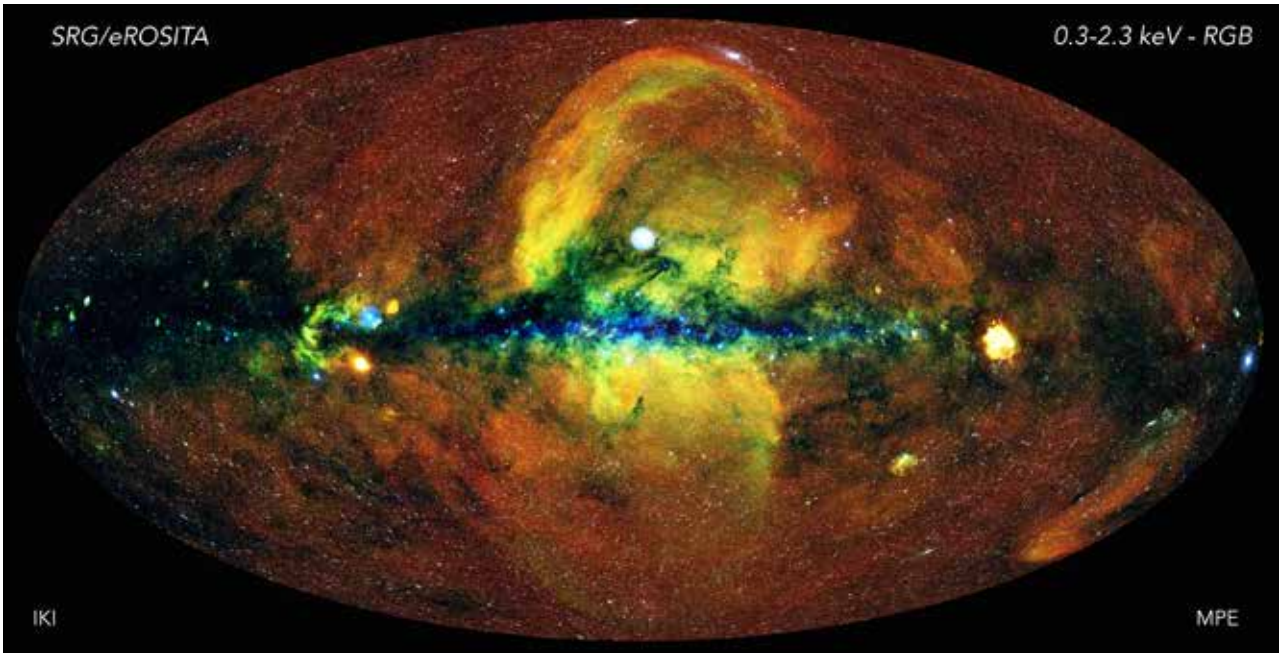
Rahul Jayaraman (MIT), **Swetlana Hubrig** (AIP), **Daniel Holdsworth** (UCLan) and collaborators are using *TESS* and SALT to detect and characterise certain properties of rigidly rotating magnetospheric (RRM) stars. RRM stars are a subclass of main-sequence B stars in which rapid rotation and a strong magnetic field combine to form a centrifugally supported magnetosphere with rotationally modulated hydrogen line emission. Few such stars are known, and discovering them via *TESS* and/or spectropolarimetric observations requires significant effort. However, identifying and characterising these stars is important, as they can shed light on many questions about stellar evolution, including the effects of magnetic fields on stellar rotation. HD 135348 is a B star in the southern hemisphere that was observed at two-minute cadence in *TESS* Sector 38; the photometric data enabled the team to derive a rotational period of 2.06 d. Since this was the first use of *TESS* data to photometrically detect a candidate RRM star (thus resulting in a high impact science result, which could not wait for the usual proposal cycle), the team submitted a DDT proposal to obtain spectropolarimetric observations using SALT/RSS. These data allowed the team to measure the longitudinal magnetic field and they concluded that this star possesses a centrifugal magnetosphere. Moreover, given its similarity to the star HD 66765 — which was found to have weak Hα emission — the researchers argue that this star is a strong candidate to have an RRM. In the future, they hope to identify RRM stars in *TESS* using machine learning.

SALT/*eROSITA* collaboration

Axel Schwope from AIP (Germany) reports on a very fruitful collaboration between SALT and *eROSITA* (extended Roentgen Survey with an Imaging Telescope Array). *eROSITA* is a soft X-ray survey instrument, the main instrument on the Russian-German *Spektrum-Roentgen-Gamma* mission (*SRG*). Since December 2019, it continuously surveys the X-ray sky in the passband 0.2 – 10 keV. Every half a year, a complete map of the whole sky is generated with unprecedented sensitivity. These sky surveys allow time-domain astronomy on various timescales: between surveys (6 month), between scans within a survey (4 hours) and even within a scan (CCD frame time 50 msec). Taking advantage of the complementing capabilities of *eROSITA* and SALT, a Memorandum of Understanding (MoU) between the *eROSITA* consortium and the SALT transient survey team (PI David Buckley, SAAO) was signed that allows *eROSITA* scientists to request SALT follow-up for transient phenomena discovered with *eROSITA*. By the end of 2021, more than 70 SALT observations were triggered, of which more than 60 led to successful spectroscopic follow-up observations. Targets were AGN ignition and shutdown events, quasi-periodic eruptions in AGNs, possible tidal disruption events, and cataclysmic events in close interacting binaries. The highly successful collaboration is planned to be continued until the *eROSITA* surveys come to an end (December 2023). Papers were published in Nature and in A&A as a special issue, presenting first results of the *SRG* mission (the A&A issue is expected to be published in early 2022).

CAPTION:

***eROSITA* sky map of diffuse X-ray emission without the several million point sources. Colours correspond to X-ray hardness: soft X-ray emission appears red, hard X-ray emission blue. The Galactic plane appears mainly blue because of the pronounced absorption of soft (red) X-rays in the plane by interstellar matter. The red glow away from the plane depicts hot gas in the Local Bubble.**



SALT defines the footprint of the MeerKAT Absorption Line Survey

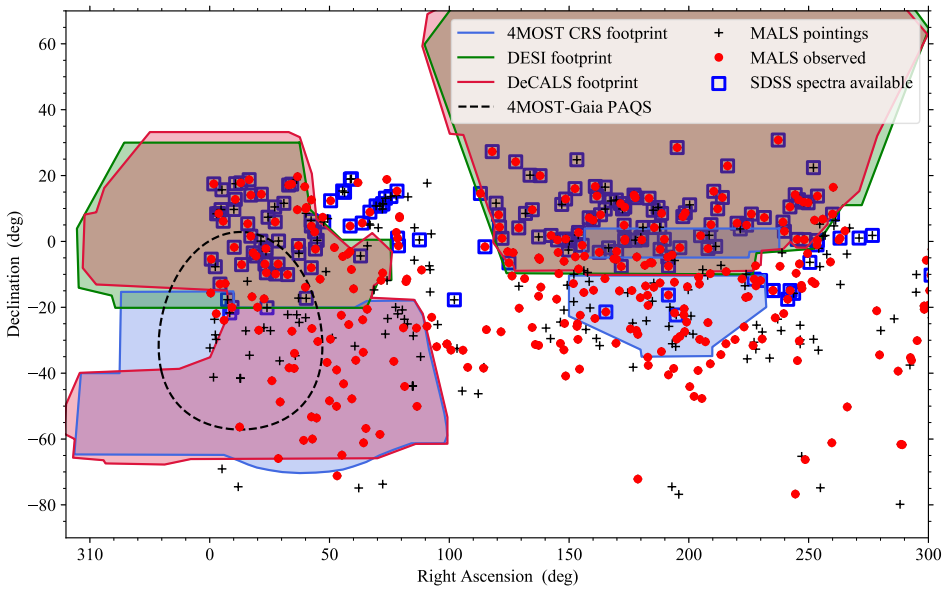
The MeerKAT Absorption Line Survey (MALS) is carrying out the most sensitive blind HI 21-cm and OH 18-cm absorption line survey to date using the radio telescope MeerKAT, a precursor of the Square Kilometer Array (SKA) to be built partly in South Africa. Each MALS pointing is centered on a high-*z* radio source brighter than 200 mJy at ~1 GHz. To obtain a list of appropriate targets, Neeraj Gupta, co-PI of MALS, has led an MLT project with SALT (from 2014 — 2017), resulting in a dust-unbiased sample of radio bright AGNs in the southern hemisphere.

For this project, the team developed a novel technique based purely on *WISE* mid-infrared colours to select the candidates. While the 180 hours SALT observing time was shared by IUCAA, RU and RSA, the project also included six observing nights with the Nordic Optical Telescope (NOT) on La Palma to cover the northern part. A total of 303 new AGNs were identified, representing the most luminous and powerful AGNs in the universe. The sample consists of 250 AGNs showing emission lines (median z = 1.8), 26 with no emission lines, and 27 without optical counterparts, covering an AGN parameter space which is underrepresented even in the SDSS. In addition to providing ideal targets for the MeerKAT survey, these observations provide an unbiased sample of radio-loud quasars for systematically addressing issues linking the evolution of AGNs to dust obscuration, black hole growth and host galaxy properties.

The SALT project is leading to several papers and follow-up programmes with NTT, VLBI and VLT. Two of the papers appeared in 2021, and two more are at the refereeing stage. They include exciting discoveries like the extended Lyα halos associated with powerful AGN by PhD student Gitika Shukla (supervisor: R. Srianand) and the discovery of the most powerful radio bright AGN in the Universe at z > 5. All the spectra obtained through this SALT project will be publicly released in 2022 through https://mals.iucaa.in/.

CAPTION:

MALS footprint as based on the SALT and NOT surveys.



RS Ophiuchi: a well-known recurrent nova in a symbiotic binary system

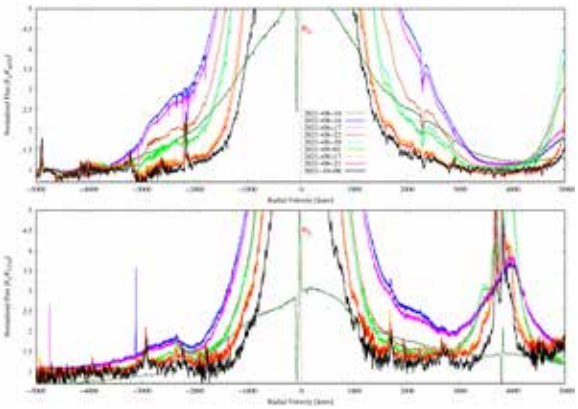
Classical and recurrent novae are binary systems hosting a white dwarf, and their outbursts are attributed to a thermonuclear runaway (TNR) on the surface of the white dwarf that is accreting material from its binary companion. The designation 'recurrent' implies that the outburst is observed more than once over human life timescales, although all novae are thought to be recurrent on longer, secular timescales that can greatly vary, depending on the mass accretion rate and the white dwarf mass. The more massive the white dwarf is, the smaller its radius, so the accumulated material is more degenerate and is ignited with lower accreted mass. Thus, the frequently erupting recurrent novae host rather massive white dwarfs. RS Oph is also a symbiotic system, that is, a system with a giant companion, specifically an M0-2 III mass donor, with a 453.6 day orbital period. Compelling evidence indicates that the white dwarf is very massive, in the 1.2 – 1.4 solar mass range, and that it is a carbon-oxygen white dwarf that may one day undergo a complete thermonuclear explosion (a type Ia supernova). The effective temperature estimated in the supersoft X-ray phase in 2006 was about 800,000 K, which is indicative of a mass of at least 1.2 solar masses. This implies that it must have grown in mass and not have ejected all the accreted material, since the largest mass of newly formed white dwarfs is below 1.2 even for very low metallicity. This has spurred much interest in the possibility that RS Oph is a type Ia supernova progenitor. As such, each single eruption is observed with great interest, searching for evidence that may indicate that somewhat less material is ejected from one outburst to the next, and that the white dwarf may be retaining part of the accreted envelope.

RS Oph appeared in outburst again on 9 August 2021 at a visual magnitude of 4.8. Immediately afterwards, the nova was also detected at gamma-ray energies with *Fermi*-LAT and H.E.S.S., and in hard X-rays with *MAXI* and *INTEGRAL*. The AAVSO optical light curve of RS Oph in different bands, from B to I, appeared extremely similar to the optical light curve of the 2006 outburst. In the X-rays, the evolution was instead quite different, with a more variable and shorter period of luminous supersoft X-rays due to the central source, apparently indicating a smaller accreted envelope and more variable absorption due to more turbulent phenomena in the collision with previous ejecta and with the red giant's wind.

This 7th outburst of RS Oph gave the team around Marina Orio and Ken Nordsiek from UW as well as Joanna Mikołajewska (CAMK, Poland) the rare possibility to compare the development of the outburst with the previous one, making use of high timing and spectral resolution in different wavelengths. As part of the multi-institution, multi-semester transients' programme led by David Buckley (SAAO), the team obtained nine optical spectra at different outburst phases during the two months following the first observation on 10 August, both with HRS and RSS. In addition, they performed four spectropolarimetric observations. The data are still being analysed, but a few important facts have emerged, and undoubtedly this bulk of data is revealing several interesting facts. In the first week, the prominent emission lines in the spectrum had had a full width at half maximum of 2900 km/s with blue-shifted P-Cyg components that disappeared within a few days, while two weeks post-maximum they showed an acceleration up to 4700 km/s. The team also measured satellite components in Hα and Hβ, suggesting a bipolar outflow as observed in the radio in 2006. The spectropolarimetry data show a clear continuum intrinsic polarisation, likely due to electron scattering, starting at about 1.5% at PA = 90° and decreasing by a factor of two over a month. The lines are mostly unpolarised but with intrinsic polarisation effects in the wings.

CAPTION:

The evolution of the Hα and Hβ emission lines and their wings that trace the changes in the outflowing material.



A young stellar quadruple with non-coplanar orbits

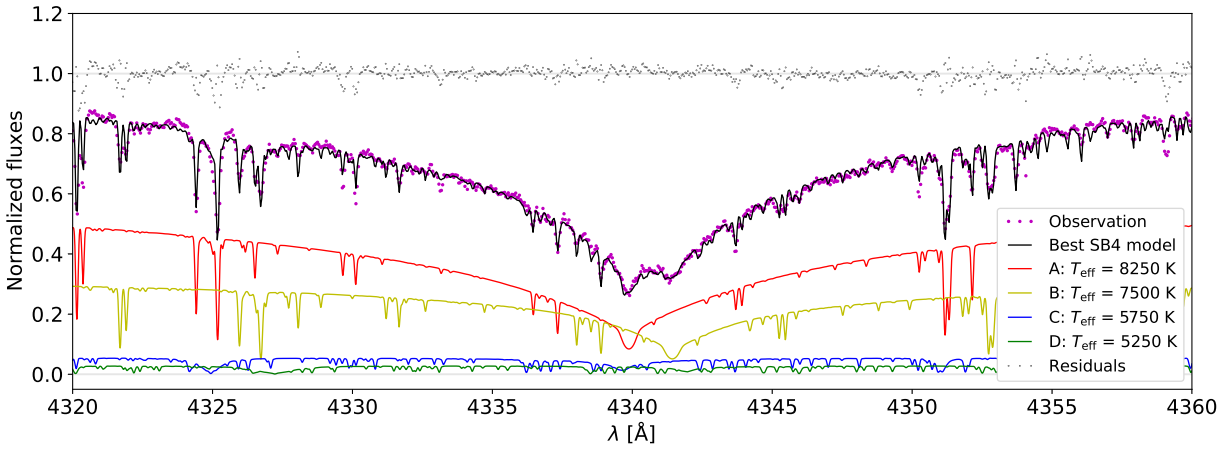
Merle, T., et al. 2021/06, Proceedings of the Annual meeting of the French Society of Astronomy and Astrophysics (Brussels, Belgium): A young stellar quadruple with non-coplanar orbits

Stars form in clusters and associations; some of the multiple systems born in such environments will remain gravitationally bound for their entire life. Multiplicity is thus an inherent property of stellar populations. Recent large spectroscopic surveys have harvested many spectroscopic multiple systems with two and three components, but those with four components (SB4) remain comparatively rare. At the Annual Meeting of the French Society of Astronomy and Astrophysics in June 2021, Thibault Merle from the University at Brussels, Belgium, reported on the preliminary properties of the first SB4 found within a cluster: HD 74438 is located in the close-by young open cluster IC 2391. It is also the youngest (43 My) SB4 discovered so far. Identified in the context of the *Gaia*-ESO Survey, this system benefited from SALT/HRS and UCMJO/HERCULES spectroscopic follow-up as well as archival observations from ESO. Merle showed that the system consists of a 2+2 bound hierarchical stellar system, i.e., two SB2 bound gravitationally. He presented the derived orbital and astrophysical parameters for the two inner pairs, which led to the discovery that their orbits are non-coplanar. The outer pair is characterised by a preliminary orbit of 6 yr with an eccentricity of 0.5. The non-coplanarity of the two inner pairs sheds light on secular evolution of quadruple systems that can lead to merger end-points of stellar evolution in multiples.

Stars in multiple systems may follow a complex evolution involving mass transfer and collisions, leading to mergers that are possible progenitors of type Ia SNe. The progenitors of such explosions are still highly debated. While binaries have received much attention so far, higher-order stellar systems show a wide variety of interactions especially in tight systems. Merle reports now that the HD 74438 appears to be a possible progenitor of a sub-Chandrasekhar type Ia supernova (SN) through white dwarf mergers. This specific type of SN Ia better accounts for the chemical evolution of iron-peak elements in the Galaxy.

CAPTION:

Display of the observed composite spectrum (magenta dots), taken with SALT/HRS, when the four components were well separated and resolvable. The best fitted SB4 composite model is shown in black and the residuals in grey, shifted around *y* = 1 for clarity. The individual spectra are also shown and colour-coded as given in the legend; they give an idea of the contribution of each component to the total flux.



The first ever discovery of a warp disc in a black hole low-mass X-ray binary

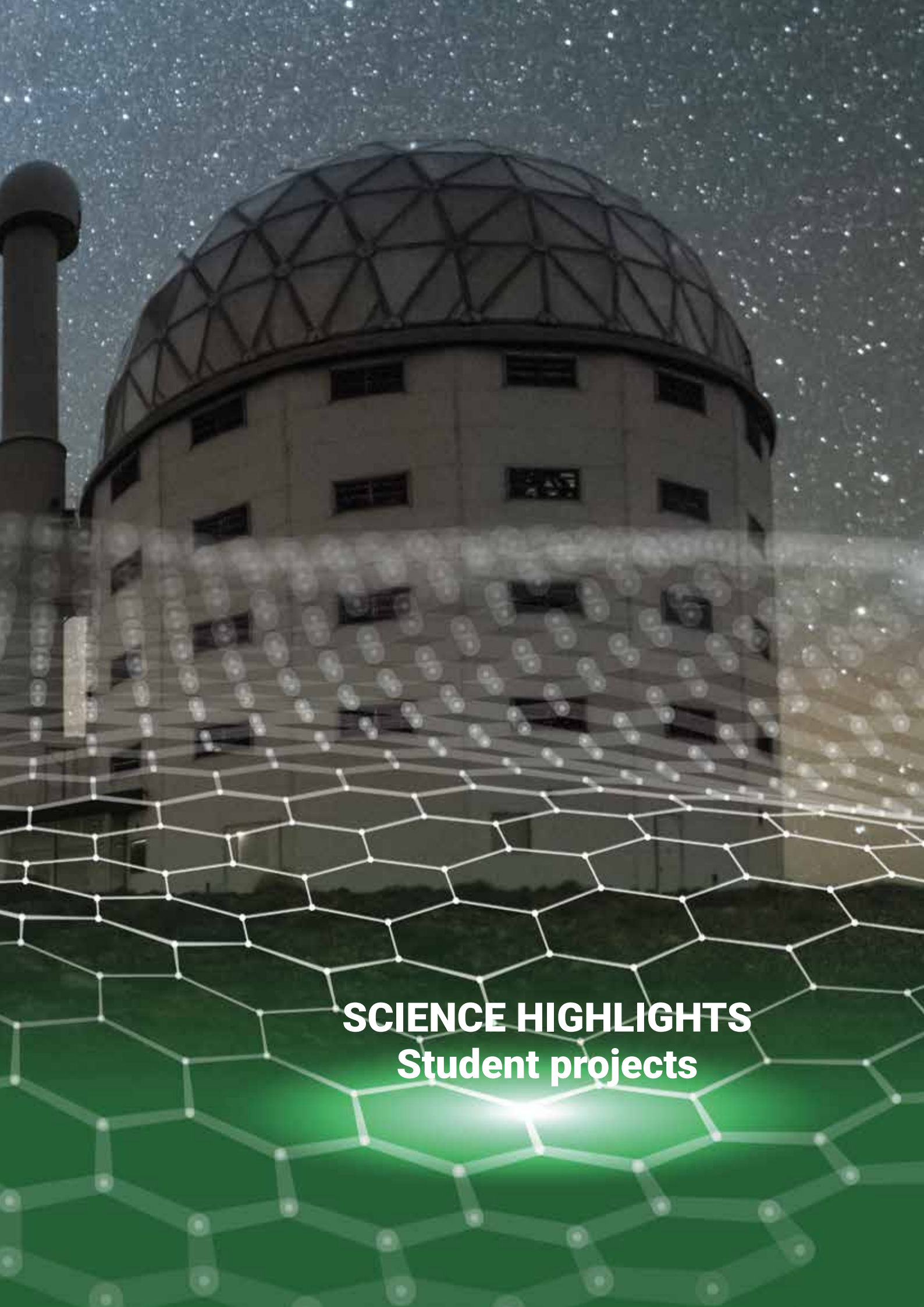
Thomas, J., et al. 2021/01, 43rd COSPAR Scientific Assembly (Sydney, Australia): Orbital and superorbital variability of the new black hole LMXB MAXI J 1820+070 during the 2018 outburst

The black hole X-ray transient MAXI J1820+070 (or ASSASN-18ey), discovered in March 2018, was one of the optically brightest low mass X-ray binaries (LMXB) ever seen. It led to the most complete and detailed optical outburst light curve of a black hole X-ray transient to date. Multi-wavelength observations of MAXI J1820+070 were undertaken with a number of telescopes from the time of its discovery. At the 43rd COSPAR Scientific Assembly, held virtually in January 2021, Jessymol Thomas from SAAO reported on the results from optical monitoring of MAXI J1820+070 with the SAAO's 1-m telescope, SALT (SALTICAM as well as imaging with the RSS) and by the American Association of Variable Star Observers (AAVSO) over the period of its outburst from March to October 2018. High-speed photometry revealed quasi-periodic oscillations (QPOs) of the source in the frequency range of ~0.04 – 0.3 Hz, and the optical light curve, combined with X-ray and radio light curves, allowed the team to study the major geometric changes the source had undergone during the outburst. The detailed temporal analysis revealed the presence of remarkably high amplitude (>0.5 mag) modulations, which evolved from the superhump (16.87 h) period towards the presumed orbital (16.45 h) period. The analysis further confirmed that MAXI J1820+070 exhibited disc precession with a period of 27.548 days. Since the meeting, Thomas together with her collaborators Phil Charles (U Southampton), David Buckley (SAAO) and many others, finalised the analysis of the data, leading to a major discovery reported in a press release in October 2021: the first ever discovery of a warped disc in a black hole LMXB and the first truly simultaneous observations of X-ray and optical QPOs from such an object.

Their conclusions regarding the large amplitude modulation on the superhump period are: (i) the amplitude is too large to be explained via an area-variation effect in an eccentric, precessing disc; (ii) the modulation can not be due to an X-ray variation, as no X-ray modulation is present on any of the observed optical periodicities; (iii) the variations in the light curves show clearly that it cannot be explained as X-ray heating of the inner face of the donor. The team's interpretation of the modulation is an irradiation-driven warping of the outer disc, which is tilted towards the observer and thereby provides a sufficiently large disc area. This also requires a raised, hard X-ray emitting source that is associated with the outflow and base of the jet as it approaches the end of the hard state. The team further postulates a precessing jet model that explains that the optical and X-ray QPOs must be produced in regions physically very close to each other (within ~0.1 lightseconds), which is implied by the close synchronisation of the two wavelength regimes.

CAPTION:

An artist's impression of the black hole system MAXI J1820+070 with the warped accretion disc and jets, based on observed characteristics. – Credit: John Paice



SCIENCE HIGHLIGHTS
Student projects

In compliance with SALT's strategic objective of Human Capital Development, a large number of projects involve students or are initiated by students. Some examples of student projects are presented here. Projects with refereed publications in 2021 can be found in the research section.

Rutgers student **Peter Doze** is leading a multiwavelength study of the massive cluster ACT-CL J0034.4+0225. The study provides strong evidence of the cluster undergoing a major merger that is being viewed close to the time of closest approach. SALT/RSS spectroscopy, obtained by collaborators at the University of KwaZulu-Natal, has resulted in redshift measurements of 52 cluster members which are being used to constrain merger properties.

Labanya Guha is a PhD student at IUCAA and is working on identifying galaxies responsible for ultra strong [Mg II] absorbers. This work mainly focuses on identifying galaxies responsible for strong (rest equivalent width > 3 Å) [Mg II] absorbers at $0.4 < z < 0.8$. A complete sample of such absorbers in the southern sky has been compiled and a systematic survey using RSS long-slit spectroscopy is underway. The first phase of the survey, host galaxy observations of all the 26 absorbers in the sample, is complete. The basic properties of the galaxies are derived and compared with the properties of the absorption lines seen in the quasar spectra. This has already increased the number of known host galaxies of such absorbers by a factor of five. Sixty percent of the second phase (search for host galaxies at $0.6 < z < 0.8$) is also completed and SALT time has been allocated to complete this survey. This project will produce the by far biggest complete sample of host galaxies of ultra strong [Mg II] absorbers to date.

PhD student **P. Aromal** from IUCAA is studying time variability of a complete sample of ultra fast outflows (UFOs) in high-*z* quasars. Aromal has monitored 65 UFOs in the southern sky, identified in SDSS, over the past five years with SALT. This is by far the largest UFO sample monitored over a period of more than 20 years (starting from SDSS epochs) with good cadence. The data reveal spectacular variability signatures and, interestingly, most of the sources in the sample show BAL variability more frequently compared to the general BAL quasar population. Currently, Aromal is quantifying these signatures using statistical measures and exploring their correlations with the properties of quasars such as black hole mass, Eddington ratio, bolometric luminosity, dust reddening etc. The team is planning SALT follow-up observations to study the short-time scale variability as well.

Gitika Shukla, PhD student at IUCAA, has made use of a SALT/RSS spectroscopic survey of all the 23 quasars at $2.7 < z < 3.3$, identified in the MALS-SALT survey (PI R. Srianand). The main goal of her project is to map the extended Lyα emission from these powerful radio-loud AGNs (RLQs) that are brighter than 200 mJy at 1.4 GHz and are selected on the basis of mid-infrared colours, i.e., unbiased by the presence of dust. There are seven confirmed and five tentative detections of diffuse Lyα emission in the sample. Based on this, Gitika explores in detail the relationship between the properties of diffuse Lyα emission and various quasar properties. She finds a strong dependence of the Lyα halo detection rate on extent of the radio source, spectral luminosity of RLQs at 420 MHz and presence of associated [C IV] absorption and nuclear [He II] emission line equivalent widths. The FWHM of diffuse Lyα emission in the case of confirmed detections appears to be much higher. This sample is the second largest sample of RLQs being studied for the presence of diffuse Lyα emission and fills in a redshift gap between previous such studies.

Natalia Posiek is Master student at Wrocław University and works on "Chemically peculiar Am stars in *TESS* and SALT observations" under Ewa Niemczura. The project concerns metallic Am stars observed by *TESS*. Natalia is working on the SALT/HRS follow-up spectra: So far, all spectra were prepared for the analysis (normalised) and the spectral classification is finished. Currently, she is using Balmer and metal lines to determine atmospheric parameters of stars and their chemical composition.

Students working with Eric Gawiser at Rutgers University are leading an ongoing project using RSS+MOS to study [O II]-emitting galaxies discovered by the Hobby Eberly Telescope Dark Energy eXperiment (HETDEX). The observations use the PG3000, PG2300, and PG0900 gratings to obtain simultaneous spectra of roughly a dozen emission-line galaxy targets, with the higher resolution gratings sufficient to resolve the [O II] doublet, while the PG0900 provides broad coverage redwards of the initial HETDEX spectral range of 350 – 550nm. Science goals include measuring the electron density, ionisation parameter, dust reddening, and metallicity of these galaxies' ISM, along with their star formation rates and velocity dispersions. Rutgers undergraduate **Elisabeth Turrner** completed her Senior Honors Thesis on "SALT Multi-Object Spectroscopy of HETDEX [O II] Emitting Galaxies" by designing and analysing this survey in April 2021 and is now in a PhD programme at Tufts University. Rutgers undergraduate **George Kharchilava** is leading the subsequent data analysis and recently presented a talk at a meeting of the American Physical Society.

Spectropolarimetry of gamma-ray active and quiescent blazars with SALT

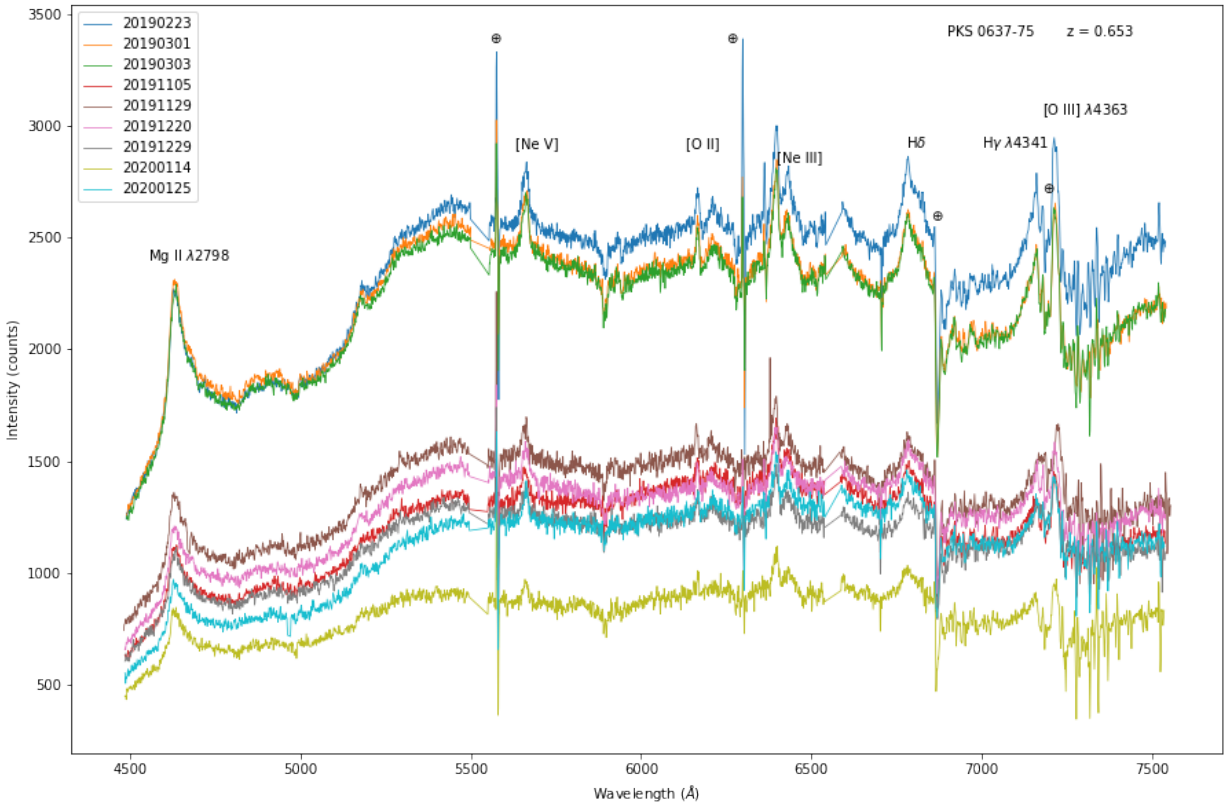
Stephanie A. Podjed from Dartmouth College (Supervisor Jedidah Isler) is working on blazars for her PhD project. Broad line regions (BLR) of blazars have generally been modeled as a thin spherical shell approximately 0.1 pc from the central engine. Recent temporally resolved multiwavelength studies suggest a more complex and dynamic BLR structure may be required to fit the observational data. Stephanie used SALT/RSS to obtain spectropolarimetric observations of seven gamma-ray flaring and quiescent blazars to monitor changes in optical linear polarisation percentage and position angle, as well as emission line equivalent width, with the aim to constrain BLR kinematics.

At the AAS 237 in January 2021, she presented one of her targets, PKS 0637-75, for which she obtained approximately bi-weekly medium resolution (R ~ 2000) optical spectropolarimetric data. The conference helped her to learn more about the BLR and see if she could determine which type of models more accurately describe the inner-parsec region of blazars. Stephanie approaches the data in a different way to determine if the jet itself and/or orientation effects play a role in continuum and broad line polarisation amounts as compared to what is to be expected from type 1 quasars.

Podjed, S. & Isler, J., 2021/01, Bulletin of the AAS, 53-1, id. 138.06: Spectropolarimetry of Gamma-Ray Active and Quiescent Blazars with SALT

CAPTION:

Non-normalised RSS spectra of FSRQ PKS 0637-75. The preliminary study concentrated on the region around [Mg II] λ2798, the full spectral range will be used in future analyses.



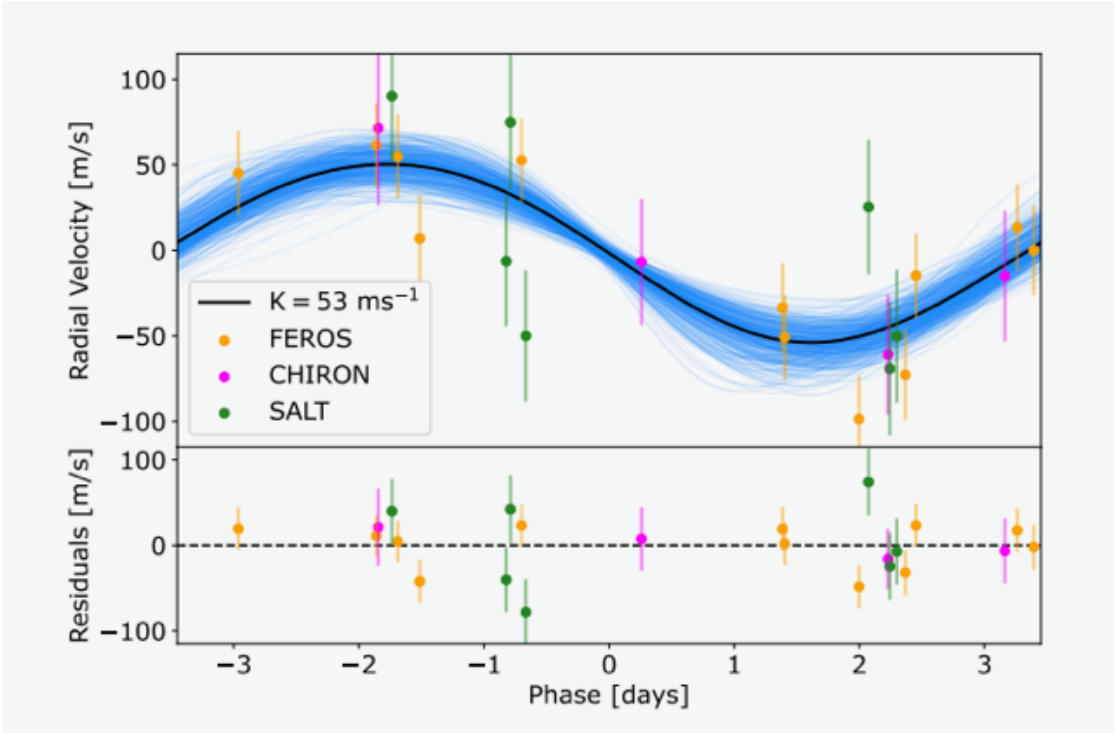
First radial velocity detection of a planetary orbit with SALT/HRS

Nicholas Saunders, University of Hawaii and AMNH, USA, MSc 2021

At the University of Hawaii, MSc students are required to perform two year-long research projects. Nicholas Saunders' first project was to confirm a hot Jupiter candidate that his supervisor, Sam Grunblatt from AMNH together with his team, had found around an evolved star with NASA's *TESS* telescope using multiple ground-based facilities. Nick reprocessed the light curve from *TESS*, calculating a more accurate radius for the planet, and then combined radial velocities from FEROS, CHIRON, and SALT/HRS to calculate a planet mass and orbital eccentricity for this system. He found that this planet was approximately the size of Jupiter (1.0 +/- 0.05 R_{jup} and 0.65 +/- 0.16 M_{jup}) and thus is not inflated, even though the incident flux on this planet is much higher than would be needed to inflate this planet. This could be telling us something interesting about the inflation of hot Jupiters: it is possible that the relation between incident flux and planet radius breaks down for post-main-sequence systems, because the incident flux on the planet is changing much more rapidly than it would change on the main sequence. The research group is now working on measuring masses for more of these *TESS* candidate evolved hot Jupiters with SALT and other telescopes to see if this trend is consistent for a population of planets.

CAPTION:

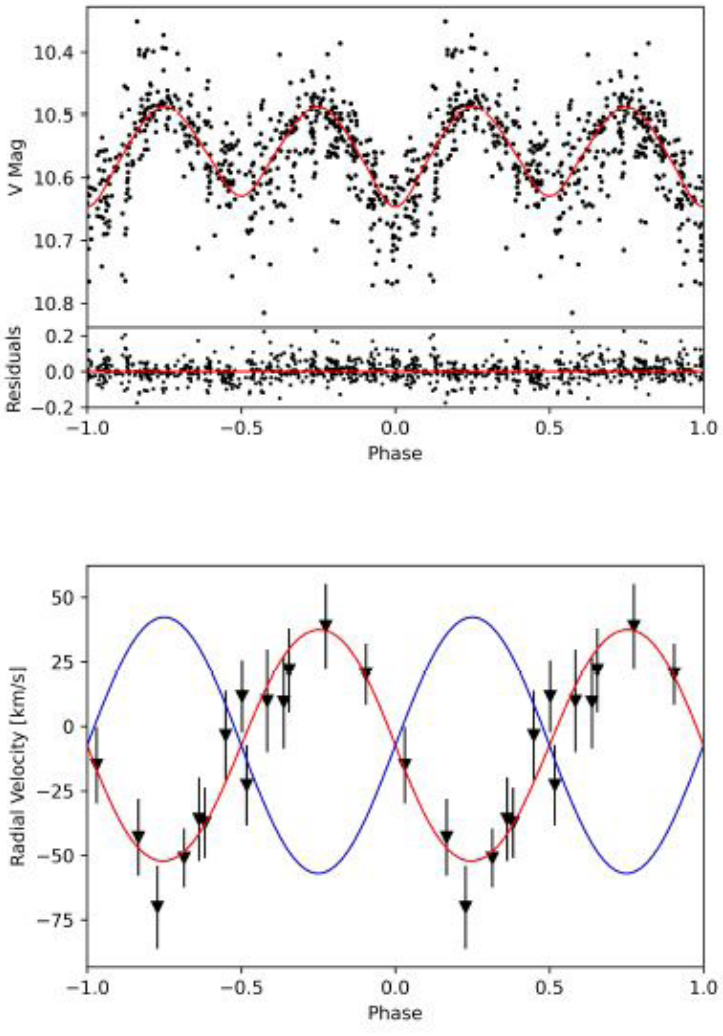
Phase-folded radial velocities with the residuals after subtracting the median radial velocity model from the data shown at the bottom. The solid black line shows the best fit to the radial velocity. The blue lines each represent a single realisation of the model drawn from the sampled posterior distribution.



Variable stars in the SuperWASP all-sky survey

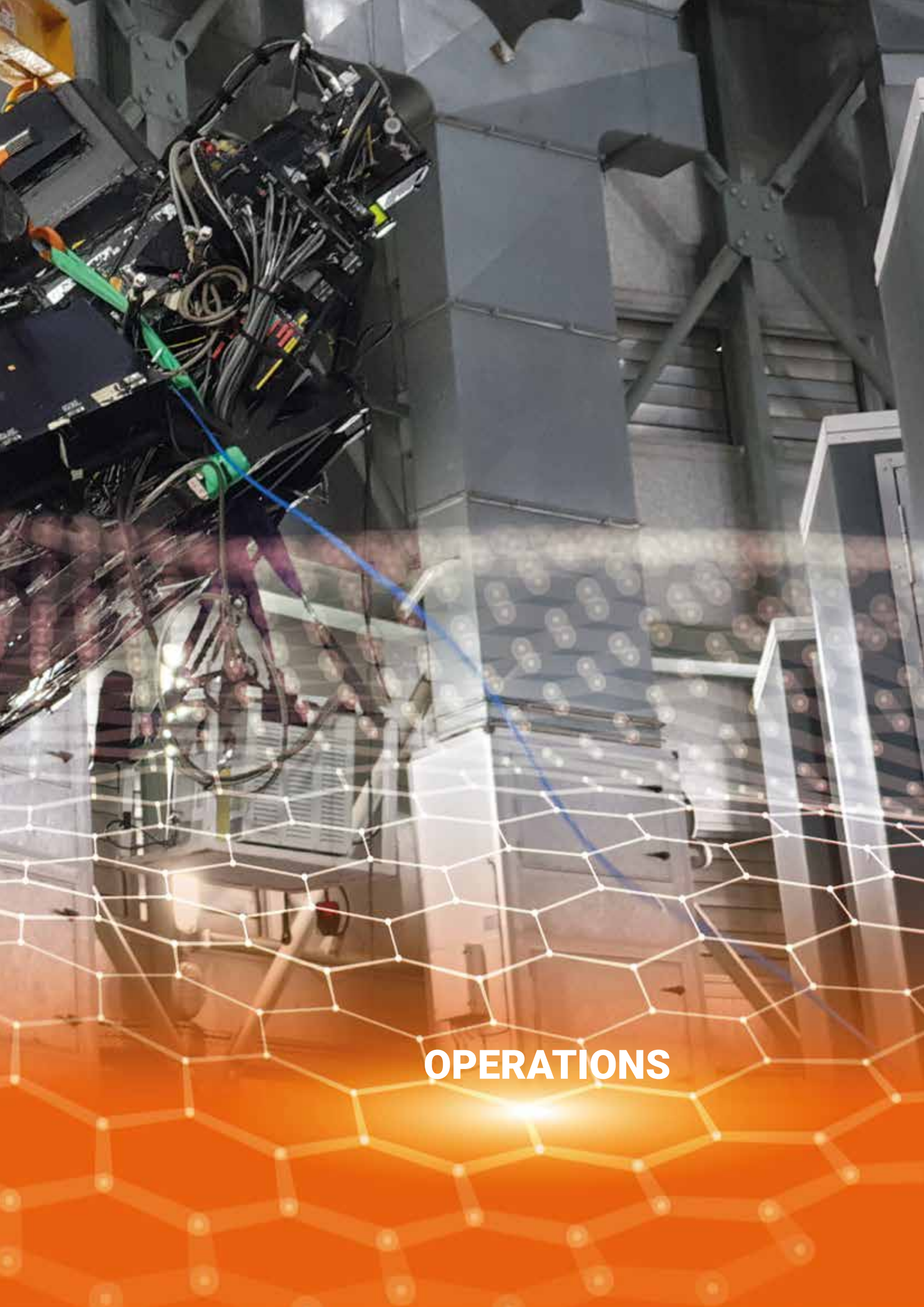
Heidi Thiemann, Open University, UKSC, Ph.D., 2021

Initially, a single candidate near-contact eclipsing binary in a long period (~40 d) orbit was serendipitously discovered in an analysis of SuperWASP photometric light curves. It was postulated that the system comprised a red giant component and hence could be a progenitor of the rare red novae events. Subsequently, about two dozen similar candidates were identified photometrically from the SuperWASP and ASAS-SN archives. The systems were followed up with multi-colour photometric observations using the Open University's robotic telescope (northern hemisphere) and Las Cumbres Observatory (southern hemisphere). Spectroscopic observations were largely obtained with the Liverpool Telescope (northern hemisphere) and with SALT and the South African 74-inch telescope (southern hemisphere), allowing radial velocity curves to be constructed. PhD student Heidi Thiemann, under the supervision of Andrew Norton, fed the observational data directly into component modeling and evolutionary modeling, confirming that approximately half of the candidates were indeed near-contact red giant binaries. Component masses of ~0.3 – 3 $M_{\odot}$, semi-major axes of ~13 – 70 $R_{\odot}$, temperatures of ~3600 – 5600 K, and radii of 3 – 25 $R_{\odot}$ were determined. Heidi concluded that for such unusual binaries to form, they must have evolved from detached binaries with mass ratios close to one and are on the brink of experiencing a rapid inspiralling event, which will likely occur within a few thousand to a few million years. It is, however, uncertain whether the death of near contact red giant eclipsing binaries will form white dwarf binaries, red novae, or something else entirely.



CAPTION:

The system J183357 with a period of 8.72 d. TOP: SuperWASP V-band phase-folded light curve fitted with PHOEBE model. BOTTOM: Radial velocity curve fitted with PHOEBE model.



OPERATIONS

OPERATIONS
Astronomy operations

Like the rest of the world, South Africa endured multiple COVID-19 waves during 2021. As a consequence, SALT observations have continued mostly remotely, with only occasional presence at the telescope by the SALT Astronomer and/or the SALT Operator. As in 2020, the network between Cape Town and Sutherland suffered multiple breakages this year, but since the SAAO IT department set up a new backup link via GSM in May (after a few-month extended proof-of-concept testing period), SALT observations have been subject to fewer disruptions than last year.

Several extra engagements have taken place during the year: In addition to our fortnightly meetings with the NIR project team at the University of Wisconsin, they also joined us for some online observing demonstrations, we traded 'show-and-tell' sessions with the Hobby-Eberly Telescope team, and we also hosted a SALT community-wide discussion about science with mini-trackers, which led to an updated “MT science potential” document.

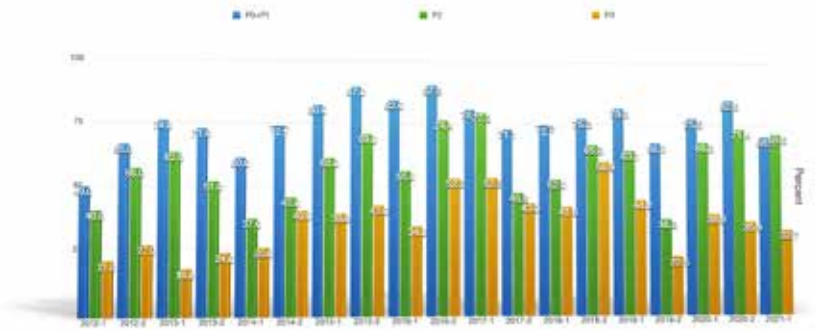
The telescope also underwent a shutdown during October: a full shutdown from the 11th to the 20th, then HRS and SALTICAM back on the telescope from the 20th, and RSS re-installed on the 28th.

Semester statistics

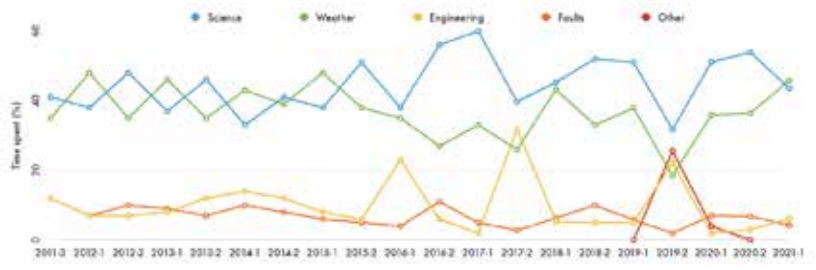
Our completion levels recovered in semester 2020-2 with good statistics. Unfortunately, semester 2021-1 was negatively affected by the much needed shutdown being scheduled right at the end of the semester, which stopped us from completing high priority targets that were only accessible at the end of the semester. In addition, since August the weather was the worst since 2015, allowing very little time for science.

The impact of the combination of adverse weather and the additional engineering time resulting from a shutdown is clearly visible in the time usage per semester, where the science time has dropped significantly for semester 2021-1. Please note that we used “other” in red to indicate the time lost due to the COVID-19 lockdown, which occurred across two semesters in 2020.

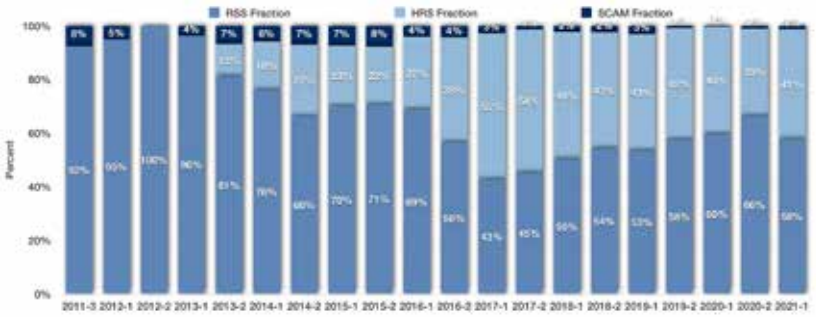
In terms of instrument usage, RSS continues to be our main workhorse instrument, dominating our very best conditions (dark, clear, good seeing nights). HRS, on the other hand, is our main instrument for bright nights and worse seeing conditions.



Completeness per priority in percent.



SALT time usage per semester.

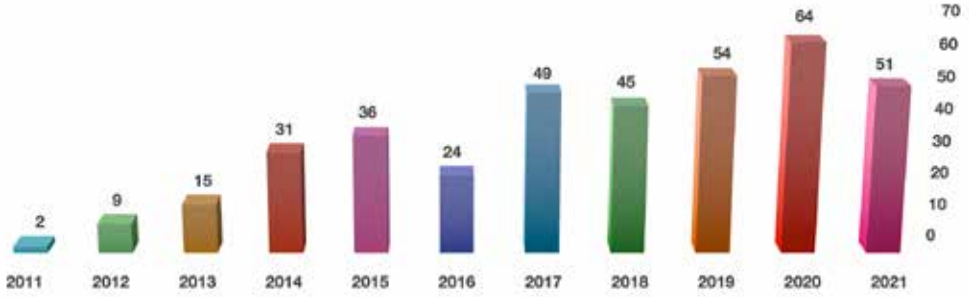


SALT instrument usage per semester.

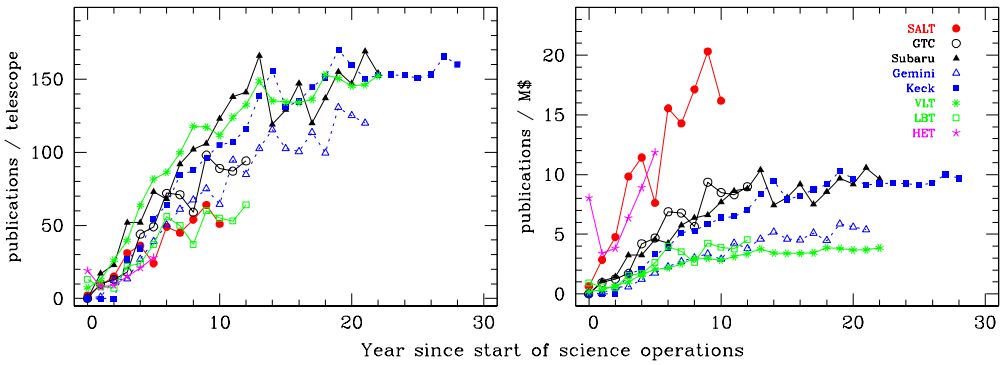
Publication statistics

While 2020 saw a record-breaking 64 refereed SALT publications, 2021 yielded only 51. Such yearly fluctuations are not unexpected though and SALT's publication growth remains comparable to that of other similarly-sized telescopes around the world, while the operations cost per paper clearly illustrates the excellent value delivered by the telescope. As usual, the publications were fairly evenly split between extragalactic science (19) and Galactic science (21), with eight more papers on supernovae and two on exoplanets.

RSS continues to be our main source of publications, though HRS contributions have been steadily increasing over the last few years. SALTICAM's lack of guidance and difficulty with maintaining focus has made it less attractive to our users, resulting in no publications in the last two years. Although the pointing and focus of the telescope received dedicated attention during 2021 and are now the best they have been in many years, the remaining issues with SALTICAM are significant enough that we do not expect a notable increase in this instrument's usage.



Refereed publications based on SALT science data and including instrument-related publications, from the start of science operations in 2011.



Refereed publications since the start of science operations for various major telescopes. Left: publications per year and per telescope; right: publications per year and per operations costs in million US Dollars.

Instrument usage in SALT publications.

User support

The pipeline launched in 2020 has been in regular operation and is working well, as is the new quick-look software, which we use at the telescope to check on data quality. To improve our efficiency at the telescope, we have also developed a new queue-scheduler, which came into operation in October. This queue-scheduler is now the basis for a new semester simulator that we are working on, which will be used to study the observing queue and the various parameters that we use to determine it, in order to find ways to improve our efficiency and completion statistics.

The AstroOps team is also developing a new internal website dedicated to data quality and telescope performance metrics, part of which will be made available to users in the future.

In terms of support for the users, the team has mainly focused on developing a new, much faster Web Manager, which will be released in early-mid 2022.

While preparing the SDA and PIPT for the new NIR instrument, the opportunity was used to drop version numbers from the XML element namespaces, facilitating programmatic access to proposals in the long run.

Personnel

After 16 years of heroic service to SALT, Fred Marang stepped down at the end of February and Xola Ndaliso took over as a SALT Operator on 1 March.

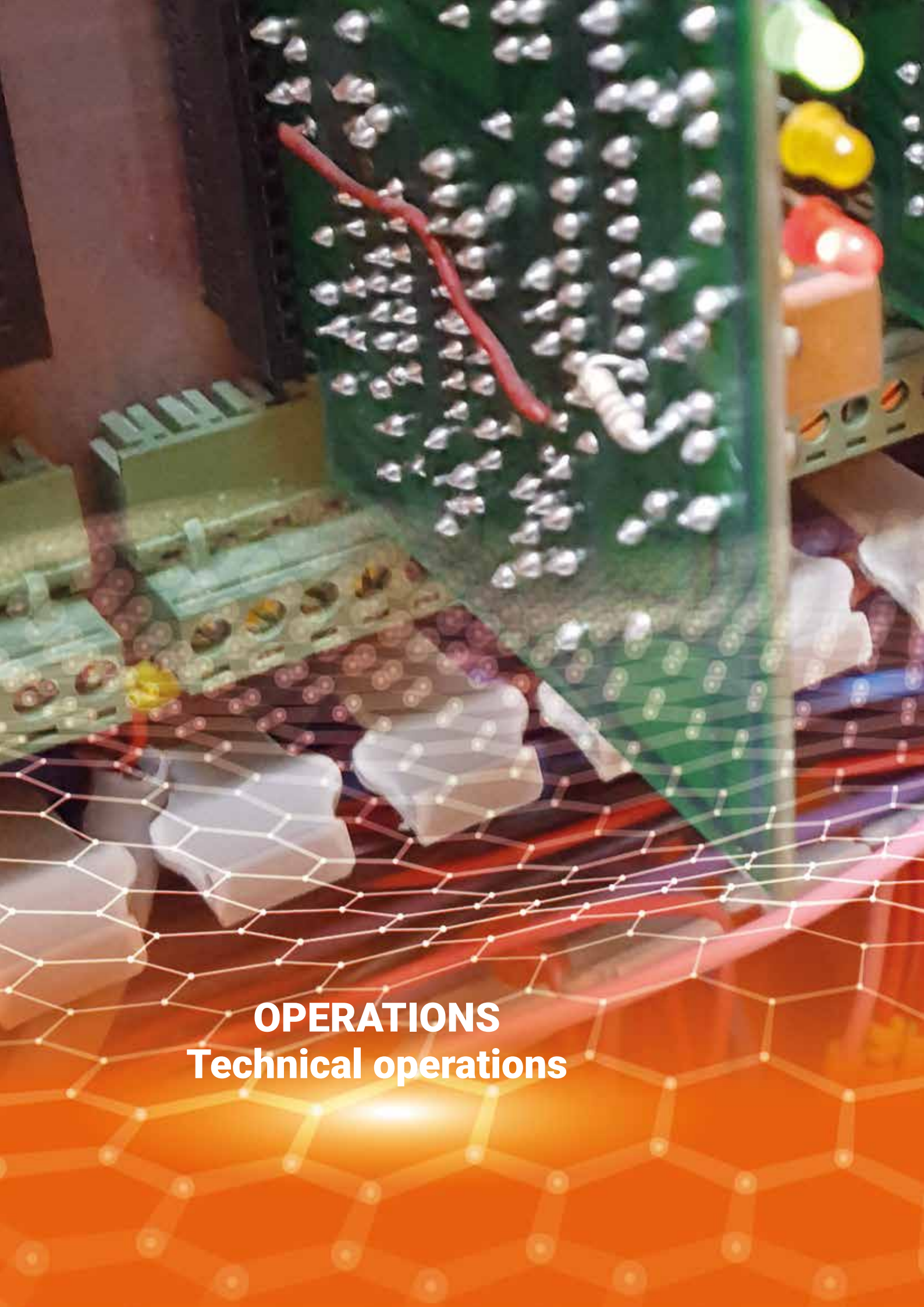
We had to say farewell to Lonwabo Zaula, who left SAAO at the end of March after completing his two-year DSI-NRF internship.

Solohery Randriamampandry became a new SALT Astronomer on 1 April. Unfortunately, his home country Madagascar went into COVID-19 lockdown just before his scheduled arrival, so he worked remotely until he could travel to South Africa on 1 June.

Elizabeth Naluminsa, having accepted her position as a dedicated SALT Fabry–Pérot postdoc in May 2020, finally received her work permit and was able to join the SALT team on 1 June 2021.

Chaka Mofokeng became a new SALT AstroOps software developer on 1 June.

Anja Schröder re-joined the team in August 2021 to work on the publication of the SALT Newsletters and Annual Reports.



OPERATIONS
Technical operations

For the semesters 2020-2 and 2021-1, the telescope's engineering downtime increased to 6%, which is largely attributed to the long shutdown. Downtime due to faults, which had been significant in 2020 due to vandalism of the fibre communication link between Sutherland and Cape Town, has decreased. While the installation of a backup fibre link on a separate route had to wait for early 2022, the interim solution, an LTE backup link, is good enough for remote observing operations and has already led to a significant decrease in downtime. While SALT has adapted to working around the COVID-19 pandemic, we have had challenges with suppliers both locally and abroad. Microchip shortages and manufacturing delays have influenced delivery of various projects and tasks.

October 2021 saw another successful shutdown to perform various tasks such as conducting rho rotational tests for the new NIR instrument, installing a new RSS letterbox to cater for the new IFU mask and long slits, collimation inspection and tests for the new RSS doublet and triplet, and some minor maintenance tasks and tests. The next shutdown is being planned for around July 2022 to install the new RSS doublet and triplet. The long awaited 700 lines/mm RSS grating, which arrived at the end of November 2021, was tested and is currently being planned for science operations in 2022-1.

The new RSS VIS and Red detector project continues with the PDR held in July 2021 and the CDR expected in mid-2022. The RSS Dual (MaxE) project has suffered a setback with the resignation of our Engineering Specialist Ockert Strydom. A short- and long-term solution of hiring specialists for this project is being implemented, together with a skills transfer plan. The RSS doublet is one of the projects that played an important role in skills development by taking on this task inhouse. After some lessons learned during previous attempts, great progress was made in understanding the characteristics and process of bonding large optical elements. The new structure and dome controller (SDC) upgrade to replace the obsolete PC and motion cards with a PLC is in full swing and is set to be completed in the first quarter of 2022. The NIR has gained momentum in 2021 with delivery of the instrument expected in the first quarter of 2022 and on-sky commissioning expected in mid-2022. The mirror coating plant controller was upgraded by replacing the problematic and obsolete PC and interface cards with a new Siemens PLC configuration. The coating plant can now also operate in automatic mode, which eliminates the need for continuous supervision and manual intervention during the mirror coating process.

TechOps has also made giant strides in working more closely with AstroOps and the STC to improve the science efficiency of the telescope. This was by way of adapting existing systems to better incorporate user requirements, as well as in efforts to enhance existing instruments and in the development of new systems.

Screenshot of the old (left) and new (right) HMI for the mirror coating plant.

Personnel

Three staff members resigned in 2021 with one staff member already replaced, while two new people joined the team:

Adelaide Malan left in January, and Jonathan Pieterse joined us as the new Procurement and Admin Officer on 1 October.

Dillon Klaasen joined the team in March 2021 and has been actively involved in aspects of the RSS Dual project, as well as assisting on NIR-SA related tasks.

We sadly had to say goodbye to Software Engineer Stephen Hulme who left at the end of April to pursue new challenges in the private sector. Interviews for his replacement and an additional Software Engineer position were concluded at the end of 2021, with offers being made to potential candidates.

Our long-term Engineering Specialist, Ockert Strydom, resigned in July 2021. We were not able to fill Ockert's position during the latter part of 2021, but the new Senior Mechanical Engineer, Tasheen Naicker, will start in February 2022.

Upskilling of staff remains a high priority, especially in opto-mechanical engineering. The short- to long-term plan involves training by specialists in this field and is set to start in February 2022. Training will be provided to various staff within the SALT TechOps and SAAO Instrumentation team. Other training opportunities were also identified for 2022, while some staff are furthering their engineering studies part-time.

Health and safety

All staff remain in good health with no serious injuries during this reporting period. We have been fortunate enough that COVID-19 has not affected our team in any way. The staff in Sutherland remains at risk of infection due to on-site work required at the telescope, but all safety protocols are in place to minimise this risk. Since there are no fire brigade services in Sutherland, it was decided to install a fire hose reel system around the perimeter of the SALT building. All personnel were trained in the usage of this system.

OPERATIONS
Instrument news

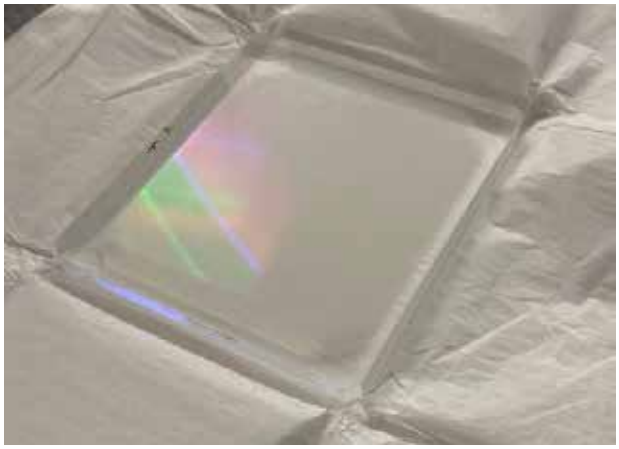
SALT shutdown

The 2021 SALT shutdown began on 11 October, with the AstroOps team having already run the necessary baseline tests during the previous week. The whole telescope was offline until 20 October, at which point it went back on-sky with SALTICAM and HRS. Work on RSS continued on the ground for a further week before recommissioning tests could be done on 28 October and the telescope returned to full operation. Numerous tasks were successfully completed during the shutdown, several of which involved making specific mechanical and optical measurements needed for future instruments and developments (such as the NIR spectrograph and the new red arm for RSS). With the instruments and some of the other large sub-systems on the ground, the TechOps team was also able to carry out much-needed maintenance and replace aging hardware, such as the cooling system within the payload's rotating structure. The RSS interventions included installing the new "letterbox" that will accommodate the slitmask IFUs (being developed at SAAO in Cape Town), and preparation for the 2022 installation of elements of the RSS Big 5, such as the new 700 lines/mm grating and the replacement collimator lens groups (the triplet and doublet). Aside from the many technical tasks successfully completed during the shutdown, it was also an excellent team-building exercise for SALT Ops, with each person contributing their unique skills and experience to this important endeavour.

RSS Big 5 projects

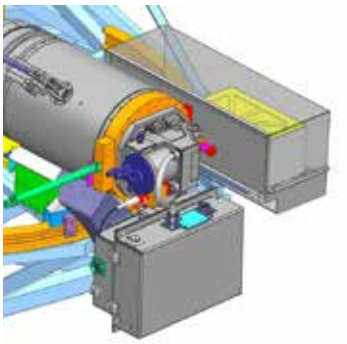
The top priority RSS upgrade project, dubbed the "RSS Big 5", consists of the following elements: new long-slits with a new focal plane letterbox that the slit in use gets inserted into, a new 700 l/mm grating, a new collimator doublet, a new collimator triplet and a new detector package (see below for more information). A successful preliminary design review for the detector replacement project was held in July, the integration and characterisation of the new collimator triplet was completed by "The Pilot Group" (in California) in November, and we were excited to get to test the new 700 l/mm VPH grating on-sky at the start of December. The new collimator doublet has presented various challenges as the thin elastomeric bonds have proven unstable under thermal cycling tests in the lab. Work is underway to adapt the cell design and prepare the lenses and new cells for integration in 2022. The new RSS long-slits have also presented challenges as vendors failed to meet the tight tolerances on the glass slit blades. Subsequent discussions have yielded new ways to simplify the manufacturing process, while still being able to meet the relevant science-driven requirements. Since the Ops team will need to focus on getting the telescope ready for the new NIR Spectrograph that will be arriving in early 2022, the installation of the replacement collimator lens groups (the doublet and triplet) will likely be delayed until mid-2022. The new long-slits will go into service whenever they become available, since the new focal plane letterbox (designed to accommodate the new thicker masks) was installed during the October shutdown. The 700 l/mm grating will be commissioned in early 2022 and made available to users soon after that, while the new RSS detector system will likely only be installed in 2023.

The new RSS collimator triplet in the lab at "The Pilot Group" in California.



The new 700 l/mm VPH grating for the RSS being unwrapped in the lab.

RSS detector upgrade project

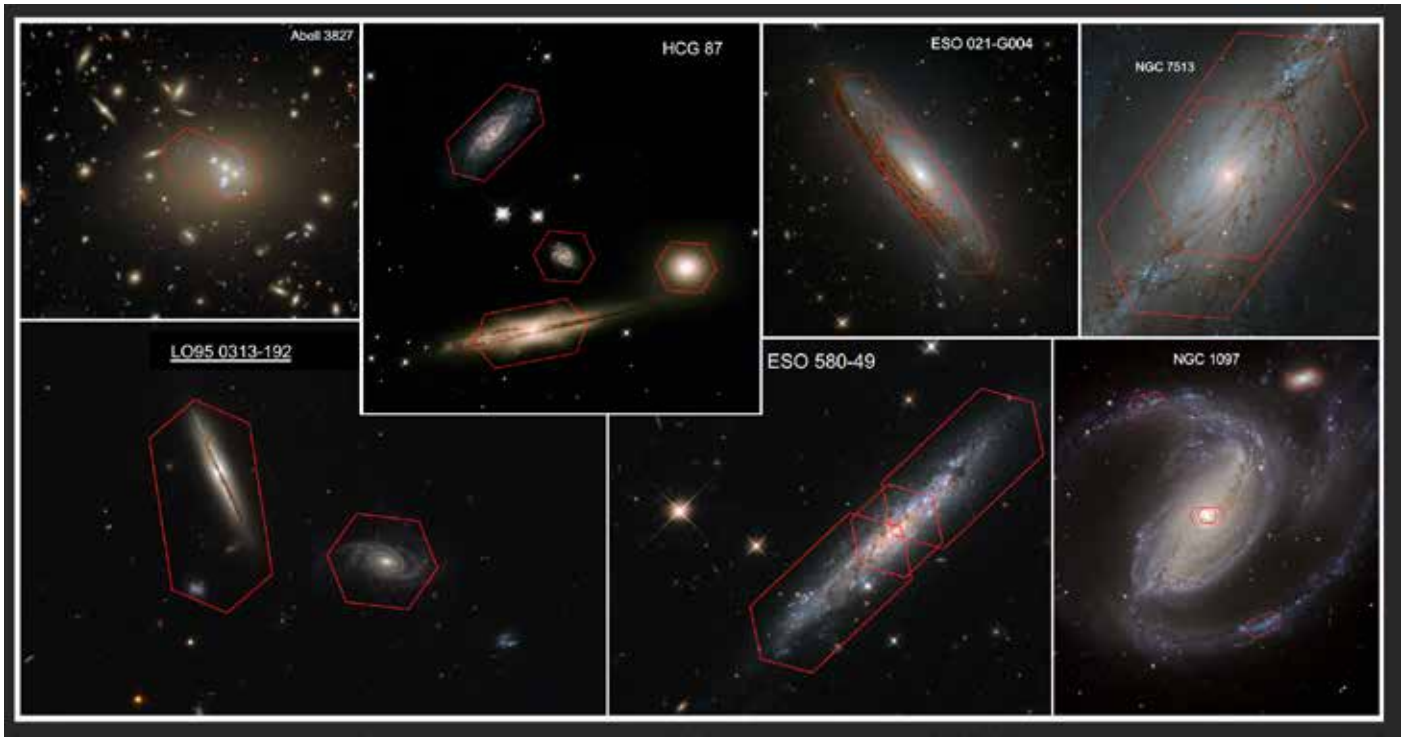


The new RSS detector shown on the end of the RSS camera barrel. The large enclosure underneath is a concept for mounting the CCD controller.

The long-slit spectrograph RSS is the workhorse instrument on SALT, with multiple modes from regular long-slit to narrow-band imaging, multi-object spectroscopy, imaging, spectro-polarimetry and Fabry–Pérot imaging spectroscopy. The RSS was re-installed on SALT in 2011 and has been a mainstay of regular science operations since then. Ten years later, the detector package, made up of a mosaic of three CCDs and an SDSU controller, now poses a risk due to the controller being obsolete and spares no longer being available. This prompted a project to upgrade the controller and replace the CCDs with a monolithic chip to improve science performance. A new 6K × 6K CCD has been procured from Teledyne e2v. This chip will have higher quantum efficiency and better fringe-suppression in the red than the current system.

The new detector package is being designed and built by a SALT/SAAO engineering and astronomy collaboration. The preliminary design was presented to the community in July 2021, and valuable feedback was received. Many of the issues raised will be passed on to the RSS Dual preliminary design review, since the new RSS Red Arm will use a nearly identical detector package (see the section on MaxE). Work on the two detectors is progressing in tandem. The project continues to source long-lead and high-risk items, with a view to doing early development and characterisation work on this hardware to have greater certainty on the presented design. Much work has gone into the overall layout of the system on RSS, with the latest working concept shown in the figure.

Slitmask integral field units for the RSS



Montage of HST images with the RSS IFUs overlaid (in red) to give an idea of coverage on galaxy cluster cores, groups, and individual galaxies.

Two fibre integral field units (IFUs) are being built in the SAAO fibre-lab for the Robert Stobie Spectrograph's visible arm and the future red arm. They will become available some time in 2022.

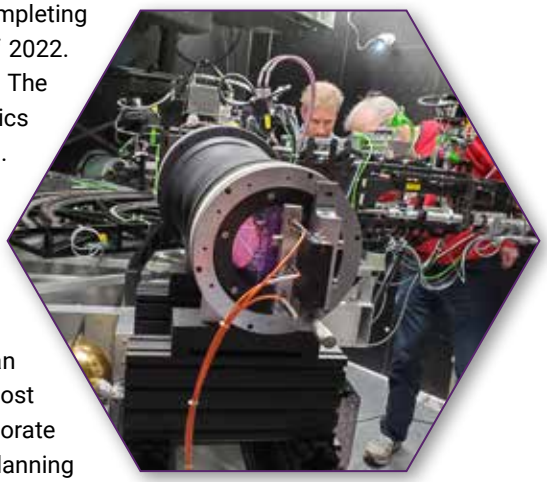
The smaller, 200 micron fibre IFU has 309 x 0.9 arcsec diameter spatial elements covering an elongated hexagonal footprint of 18 x 23 arcsec. The larger, 400 micron fibre IFU has 178 x 1.8 arcsec diameter spatial elements covering an on-sky area of 21 x 44 arcsec. In both cases there are two groups of 13 fibres offset by roughly 50 arcsec on either side of the primary array to sample sky. From the user/observer's perspective, these IFUs can be used with any grating and camera angle, yielding spectral resolutions comparable to 0.9 and 1.8 arcsec slit-widths. The IFUs have a fill-factor of roughly 60%. With a 3-point dither pattern the spatial coverage can be made truly integral.

The IFUs work as follows: Each sits in its own slitmask cassette and is referred to as a slitmask IFU (SMI). These are inserted in the same fashion as the existing long-slit cassettes at the SALT focal plane. Prismatic fold mirrors direct the focal plane into the fibre IFU and then back into the RSS collimator after the fibres are routed 180° within the cassette and formatted into a pseudo-slit. Fold-prisms ensure that the spectrograph collimator continues to see the same focal plane.

In 2021, we have designed and procured the fold prisms, procured fibre for the first two IFUs, and designed and fabricated the first mechanical cassette. During the recently completed SALT shutdown, the SMI exterior mechanical cassette was tested on the RSS cartridge-elevator-letterbox mechanism to ensure mechanical integrity and the longevity of the optical surfaces. The fibre polishing station has been assembled and single-fibre cables of 200 and 400 microns are polished with satisfactory end finish. Using the SAAO fibre-lab state-of-the-art optical metrology and characterisation system, we found that the polished fibres are introducing marginal focal ratio degradation due to the additional bending inside the cassette. The scheme for interior fibre routing and polishing is being tested through a prototype that was developed using a 3D printer. Testing of the delicate bonding process of fold-prisms into their mechanical structures is currently being performed to confirm the choice of glue and its application method. 2D and 1D fibre array holder fabrication awaits tolerance testing to be performed on fixtures which are currently being fabricated. Over the coming semester, we plan to obtain all the fabricated parts before polishing and characterising all the fibres, including the prism assembly for both SMIs, simultaneously.

NIR instrument

The NIR instrument team in Wisconsin has made excellent progress towards completing the spectrograph, and the plan is to ship it to South Africa during the first quarter of 2022. The commissioning process will be split into three distinct campaigns during 2022. The first two will involve the assembly of the thermal enclosure, the structure and the optics (ending with first-light), while the third phase will centre on the on-sky commissioning. Meanwhile, work continues apace at SALT to get all of the relevant telescope sub-systems ready to receive this exciting new instrument. The main tasks on the to-do list include replacing the original atmospheric dispersion compensator (ADC) to allow for the transmission of NIR light, modifying the existing fibre instrument feed (FIF) to accommodate the NIR IFU and sky bundles, augmenting the telescope's calibration system to allow it to serve the NIR wavelength range, and upgrading the clean air and refrigeration infrastructure at SALT to support the NIR needs. Lastly, the most diverse and demanding task is that of developing all of the software required to incorporate the instrument into the broader SALT ecosystem. This ranges from the observation planning tools, through the instrument control system and extends to the final science data pipeline.



Equipping the HRS for exoplanet science

In our quest to equip the HRS for exoplanet research, we have explored the potential of using an iodine gas absorption cell, and then characterised the intrinsic stability of the spectrograph. Given the instrument stability that was demonstrated, it was decided in 2020 that SALT would pursue the development of a bespoke laser frequency comb (LFC) to improve HRS's wavelength calibration, and invest in a custom data pipeline to support precision radial velocity (PRV) science.

The initial wavelength range of the comb will be limited to the spectrograph's red channel (550 – 890 nm), but the modular design of the LFC electronics will allow for subsequent additions to fill in parts of the blue channel's wavelength range (370 – 550 nm). The comb will also include a spectral flattening module and the comb light will be delivered to the instrument's high-stability bench via a single-mode fibre, allowing it to be injected into either the object or calibration fibres, or into both simultaneously for testing purposes.

The LFC hardware is being designed and will be integrated and commissioned by members of the Ultrafast Optics group at Heriot-Watt University (in Scotland), the team that we worked with in 2016 during a field trial of an experimental LFC at SALT. A key decision was taken in 2021 to reduce cost and risk, and to enhance the value of this exciting collaboration: all of the LFC components will be ordered and shipped directly to SALT. Instead of building the comb in their lab in Edinburgh and then shipping it to the telescope, the LFC team will travel to South Africa for several weeks in early 2023 to do the integration and commissioning at SALT. This is a brilliant opportunity for Observatory staff as we will be able to contribute to, and directly participate in, this highly specialised project. The SAAO mechanical workshop will also be responsible for machining various components for the comb and local electronics staff will be building power supplies and the like for the LFC.

PRV pipelines are notoriously demanding and so we are collaborating closely with one of the world leaders in this field, Arpita Roy (now at the Space Telescope Science Institute in Baltimore) to build a data pipeline for the HRS high-stability mode and its LFC. A key challenge for the project was to identify someone to take on this daunting task and we are delighted to have secured 80% of the time of a veteran HRS user (Daniel Holdsworth at UCLan, one of the UKSC institutions) for a two-year period. The data reduction and PRV pipeline development will follow a phased approach and will draw heavily on expertise available within the growing PRV community that Arpita is central to.

After countless iterations, the contracts for the comb and pipeline development have been drawn up and some of the long lead items have already been ordered and delivered to SALT. Among those is the 1 GHz titanium-sapphire femtosecond laser system that will form the heart of LFC.

The MaxE project (RSS Dual)

The MaxE project aims to upgrade the current RSS instrument ("RSS VIS") by adding a second channel, the Red arm (630 – 900 nm). This extra channel will provide R~2000 resolution in the red and therefore allow the mode known as RSS Dual to simultaneously access the full optical range at higher resolution than RSS VIS currently can. This upgrade will enhance the capability of SALT to perform transient identification spectroscopy and hence support the SALT community's transient science goals. The work involves the development of a deployable fold mirror/dichroic mechanism which will provide the choice between the VIS and Dual modes. The Red arm includes a new red fold mirror, collimator doublet, grating and camera optics, as well as a cryogenic detector, control electronics and user interfacing software.

During 2021, the project made significant technical progress on the design. A key achievement was the agreement on the system requirements. These are technical requirements derived from the stakeholder requirements (made up of the science, astronomy operations and technical operations requirements) that describe the RSS Dual in precise, technical language, which engineers can use to design, build and verify the instrument. On the science front, John Menzies from SAAO assisted the project with a signal-to-noise simulator, which simulates the integrated performance and also forms the basis of the observation planning tool to be developed later in the project.

The project suffered a setback with the resignation of Ockert Strydom in July 2021, who was leading the opto-mechanical and structural design efforts. We have not been able to fill Ockert's position since he left, with a resulting slip in the preliminary design review schedule. There are now firm plans in place for the resourcing of this work, starting from January 2022. Currently, the MaxE team is working towards the preliminary design review.

Opto-mechanics, structure and optics

An external review with the aim of confirming the readiness for optical blank procurement was concluded favourably in November. Ordering of these long-lead time glass blanks is planned for early 2022, pending the final confirmation on the manufacturability of the main optical elements from vendors. Figure 1 shows the optical layout of the Red doublet and camera and outlines the materials and dimensions of the optical elements to be figured from the blanks. The optical integration and alignment plan was matured and confirmed that these lenses can be successfully mounted and aligned to within tolerances, given the opto-mechanical design.

Severin Azankpo from SARAO developed a finite element model of the RSS structure, which was used to evaluate the expected deflection at various rho angles (0°, 15°, 90°, 270°, and 345°). Figure 2 shows such a deformation plot for rho = 0°, showing where the greatest deflection is experienced on the structure in this configuration. The results have been further processed to determine how the relative angle between various optical elements (e.g., the collimator barrel and the VIS camera barrel) changes through flexure as the rho angle changes. The deflection analysis serves as a baseline against which the effect of adding the Red arm to the structure can be determined. With the delay in the opto-mechanical and Red structure design, however, the finite element analysis was limited to the baseline 'as-is' model until the Red structural design can be matured.

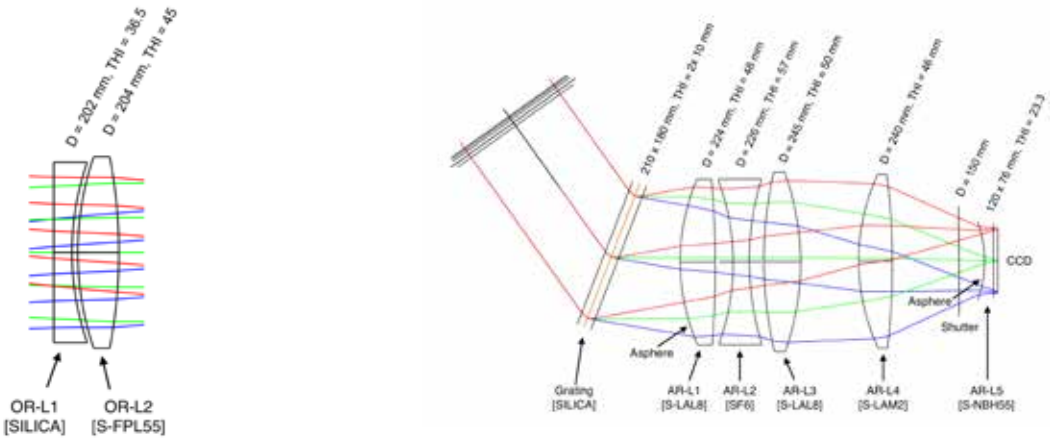


Figure 1: Optical layout of the Red collimator doublet (left) and camera (right).

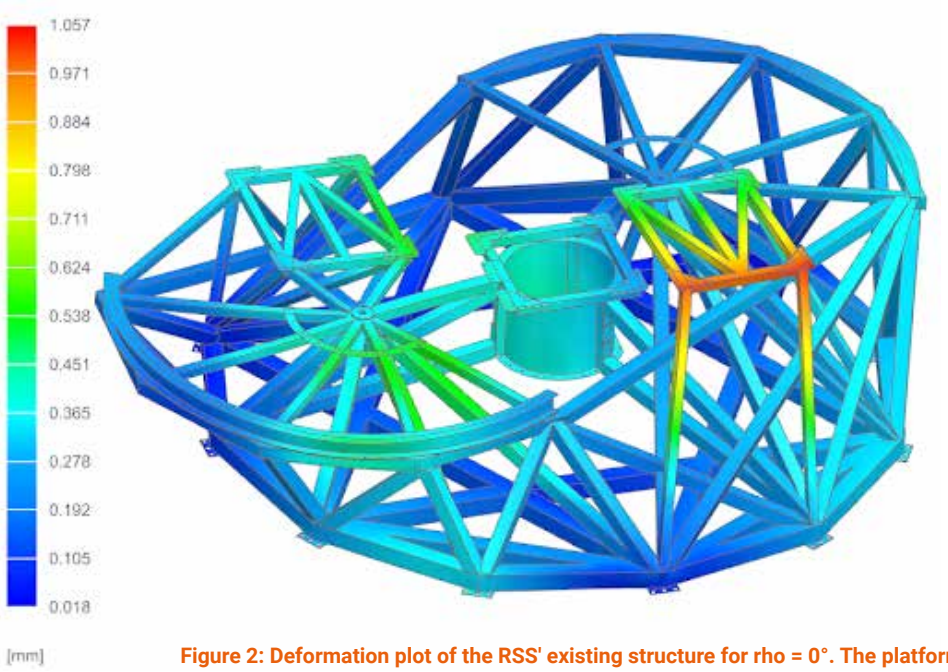


Figure 2: Deformation plot of the RSS' existing structure for rho = 0°. The platform on the right, which houses the VIS electronics cabinet, shows a maximum deflection of just over 1 mm in this orientation.

Red detector

The detector team has commissioned a test cryostat to house the large format 6K × 6K CCDs that are to be used in the RSS Red and upgraded VIS cryostats. This led to tests of various physical design concepts, as well as further development on the IDSAC (https://arxiv.org/abs/1807.05528) controller integration on a representative electrical sample CCD at temperature, without having the final science cryostat design in place. The detector cryostat design is close to its final form, with practical commonalities between Red and VIS to reduce spares inventory and to optimise the design effort. An assembly and alignment strategy has been determined to ensure the required tolerances are achieved on integration. As the IDSAC controller functions are different to the SDSU controllers that have been used on RSS to date, development of a new cryostat thermal control scheme using a PLC was necessary. A number of options have been conceptualised and test versions will be manufactured during the early part of 2022 to verify the suitability and performance of each. Collaboration with the IDSAC developers is ongoing to determine the performance of the system with the intended large format CCDs. Field experience is being gained on the IDSAC performance during the commissioning of the Sibonise camera installed at the SAAO Lesedi telescope.

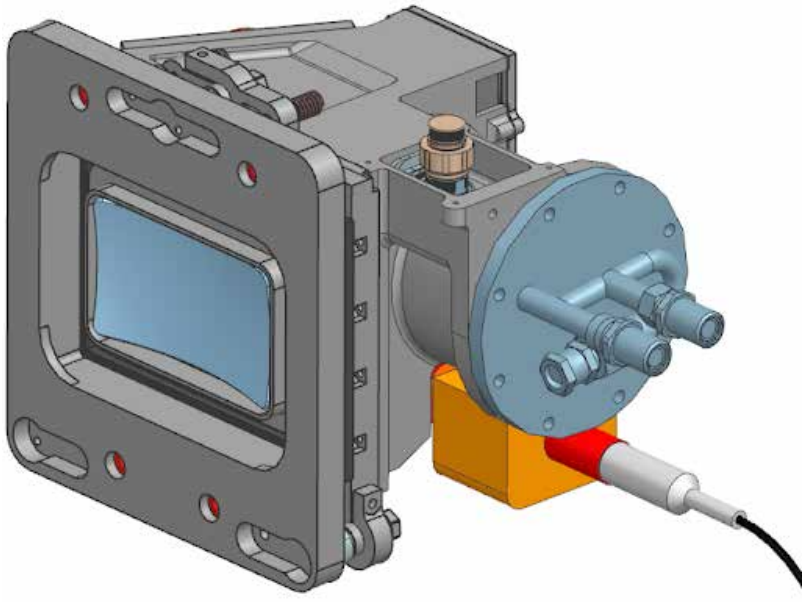


Figure 3: View of the Red cryostat module.

Mini-trackers

By taking advantage of the SALT's spherical primary mirror's large uncorrected field of view, a mini-tracker (MT), with its own optical corrector, would enable the telescope to acquire and independently observe more than one astronomical object at a time, including objects widely separated from the main SALT target under observation. Thus, the addition of up to four MTs to the telescope would in effect create multiple four-to-six-meter class telescopes using SALT's 10-meter diameter primary mirror. Each MT would be able to provide spectroscopic follow up for the current and future large astronomical surveys (e.g., MeerKAT, Gaia, LSST, SKA, etc).

The MT concept was introduced in a 2018 SPIE paper and, following a proposal presented to the SALT Board in November 2019, a feasibility study was conducted in which the basic elements of the MT project, including a broad science case, were explored. The study determined that the MT concept was viable, and the results of the study were presented in a formal report to the Board in July 2020. A preliminary concept design phase was then approved and funded by the Board, and this phase was completed in 2021.

The design phase study included development of a novel optical design for the mini spherical aberration corrector, preliminary mechanical designs for the telescope interface and the MTs themselves, and simulation tools to calculate the effective illumination of each MT for a selected target. A detailed project management plan and documentation framework were created as well, including a prototype development path, a project cost estimate, and a schedule to completion. What remains unclear, however, is whether there is a compelling enough science case to justify pursuing this radical technological development. In the absence of the necessary scientific drivers, this project will remain on ice.

Table 2 East pointing track at declination 0

Azimuth	SAC		MSAC		MT	Equivalent Telescope diameter for the MSAC
	DEC	Observing Range X-Axis	DEC	Tilt to SAC X-Axis		
East	0	6° TO -6°	-4.2	-6	Q-1	
			-11	-8	Q-2	
			5.7	8	Q-3	
			11	8	Q-4	

A sample of the results from the MT illumination simulator, showing the beam footprints for the four MTs, overlaid on the dark blue pupil for a target being observed with the main corrector.

OPERATIONS
Software updates

Significant effort is required to change the existing RSS detector (PDET) software to support the **new detector controller** of the RSS VIS upgrade project. An interim solution that supports full-frame mode has been developed, where the existing PDET code is re-used while communicating with a remote detector system. This reduces risk while a re-design of the detector software is underway. One notable issue that was resolved over the year is the periodic **ELS data engine** crashing issue. Upon investigation, communication with the mirror alignment subsystem turned out to be the culprit, as this system is the last still making use of the NI DataSocket protocol for its communication. Implementing a DataSocket-to-NATS bridge for this system solved the issue.To optimise time spent maintaining existing software, and therefore freeing up more time for developing new software solutions, a **standard architecture and template** for future applications was developed. Adopting this approach will reduce the amount of time required to familiarise oneself with a system before making required changes, as well as reduce the learning curve for new staff. The template modularises functionality using a well-defined hierarchical architecture. Sharing work is also easier with this approach as each module can be handed out as a stand-alone work package, with its own test code. This framework is being used to develop the NIR instrument control (NCON) software for NIR. Additionally, upgrade work on the telescope control system continues to prepare for NIR instrument support.

Structure and dome controller upgrade

Progress is being made on the SDC upgrade. A programmable logic controller (PLC) has been added to interface between the Main software application and the hardware. The Main application has been moved to a virtual machine, and will communicate with the PLC via the OPC Unified Architecture (OPC UA) communication protocol. Some of the functions that are currently performed in the Main application have also been moved to the PLC. Development continues on the Main application and the PLC software.

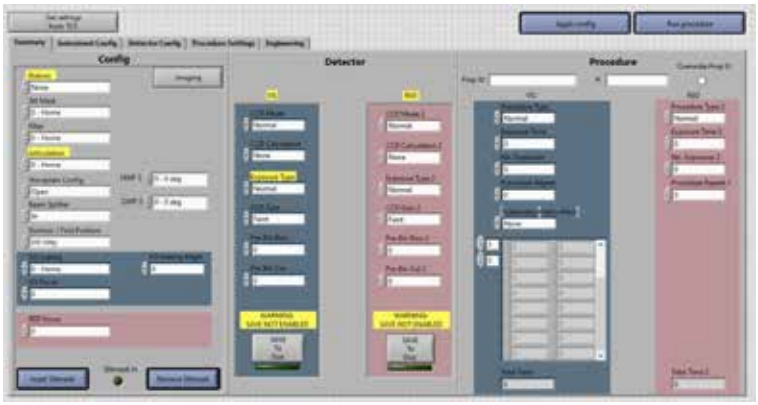
Accommodating the NIR instrument

In order to accommodate the NIR instrument and support the new wavelength range of the instrument, optical and mechanical changes have to be made to the ADC, pupil mask and the moving baffle sub-systems. The control software and electronics of these subsystems need to be updated to support these changes. An engineering change request (ECR) for the software and electronic design has been filed and accepted. The new design documents for these systems are currently being finalised for review.

In preparation for the various user-facing software changes required by the arrival of the NIR, the necessary tables for the SALT Science Database and the XML for defining NIR observations in the Principal Investigator Proposal Tool (PIPT) were designed. Work on the Phase 2 forms for NIR setups in the PIPT and on the code for mapping NIR requests to the Science Database have started and progressed well.

Control system for MaxE

The control subsystem design has made great strides since Dillon Klaasen joined the project team in March 2021. A key element of the control design is the RSS Human Machine Interface (HMI) or operator interface, which requires an upgrade to incorporate the RSS Dual functionality. For those familiar with the existing system, this upgrade will supersede the current PCON HMI being used. The MaxE team worked with the AstroOps team in designing the interface. The design is similar to the current PCON interface, but includes elements that will communicate with RedCON, the control system for the red portion of the MaxE instrument. A summary of the different tabs of the HMI can be found at https://bit.ly/RSS_HMI. As an example, the figure shows the new "Summary" tab displaying all the current settings for both VIS and Red. The "Get settings from TCS" button allows the user to populate the relevant fields with data from TCS instead of having to release control and the request control again.



The new "Summary" tab for RSS Dual. A yellow background indicates differences between the current instrument settings and the fields displayed on the HMI.

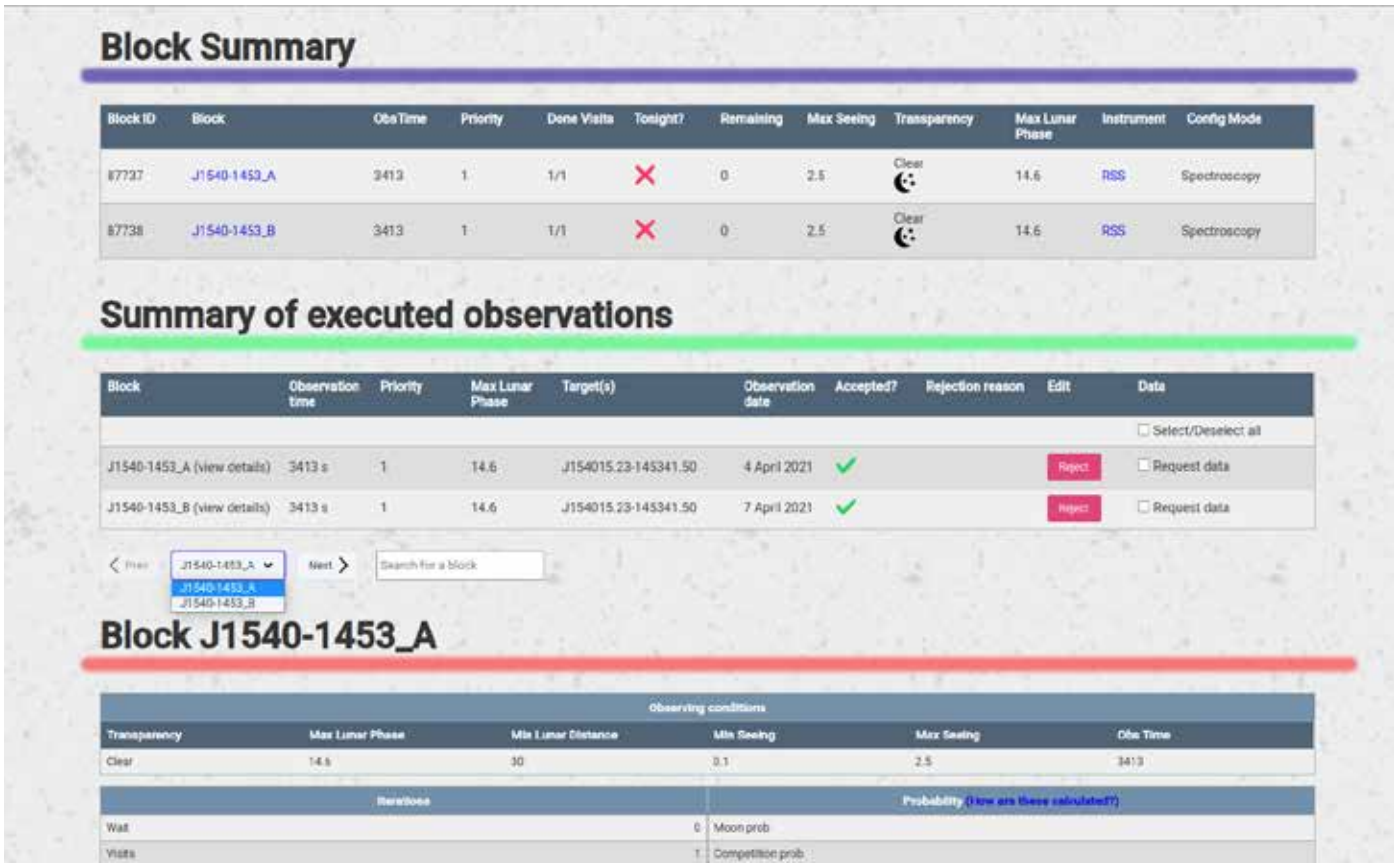
Web Manager

When the Web Manager was designed more than a decade ago, the use case for SALT was mostly proposals with a handful of blocks. However, in recent years there has been a marked shift to proposals with dozens or even hundreds of targets, which incur severe performance issues in the Web Manager. In addition, the Web Manager was written in PHP, whereas given the skillset of astronomers and software developers at SALT today, a Python-based app would make more sense.

It was therefore decided to completely rewrite the Web Manager, making use of the technological advances over the last years. The idea was not to reinvent the wheel and come up with a completely new workflow, but rather to make the existing one more user-friendly. Most notably, the new Web Manager shows full block details for one block at a time, which speeds up page load by an order of magnitude for large proposals.

The backend and frontend of the new Web Manager are completely separated from each other. The former is realised with Python (using the FastAPI web framework), the latter with Angular. The backend will also expose a public REST API, which means that anything you can do in the Web Manager, you will also be able to achieve programmatically, including submitting proposals, checking observations made and changing a block status. An important consideration behind this API is to ensure compatibility with the Astronomical Event Observatory Network (AEON).

The new Web Manager will be rolled out incrementally over the first half of 2022. As SAAO has been mandated to provide an aggregate breakdown of the SALT users by various statistics, a form for collecting these was added to the existing Web Manager towards the end of 2021.



View of the new Web Manager.

OUTREACH & EDUCATION

OUTREACH & EDUCATION
SALT Collateral
Benefits Programme

The SALT Collateral Benefits Programme (SCBP) was established during the construction of SALT, with the objectives of this programme being clearly directed at the benefits derived by society from building this large telescope. Its focus points are education in mathematics, science, engineering and technology; science communication and awareness; socio-economic development, and public engagement. Today, the SCBP activities are run by the SAAO science engagement personnel.

In 2021, the SCBP team continued to communicate the beauty, relevance and power of astronomy despite the disruptive and restrictive nature of the COVID-19 pandemic and associated protocols. A total of 3534 people were reached and engaged through a number of programmes as follows: girls focused programmes, school outreach, astronomy debate, astronomy quiz, astronomy competitions for teachers, learners and Sutherland youth, teacher based workshops, Sutherland Site Tours, Indigenous Astronomy programmes, production and dissemination of a gravitational documentary and production of a new SAAO career brochure.

Teacher training, support and development

Online teacher training workshop

A three-day teacher-training workshop was organized jointly with the KwaZulu Natal provincial education department. A total of 74 participants completed the programme. The aim of the programme was to support the teaching of the "Earth and Beyond" theme of the Natural Science curriculum, to expose teachers to new creative and engaging pedagogical approaches and to share resources and references, which teachers can use in the classroom. SCBP staff are convinced that empowering teachers will improve classroom practice and ultimately improve the performance of learners in science and mathematics.

Learners activities

In a bid to further extend our footprint in the Northern Cape Province, a massive outreach programme was implemented in the town of Port Nolloth, where 944 learners participated. This included presentations, hands-on activities such as telescope building, solar system scaling and phases of the moon, as well as evening star gazing using our Dobsonian telescopes. Namaqua High, Port Nolloth Primary and High School participated in the outreach programme.

Curriculum aligned activities were organized and implemented at Pinelands North Primary and Rhenish Primary school in Stellenbosch. These activities included presentations, Stellarium demonstrations and hands-on activities such as telescoping building and phases of the moon. The head of SALT AstroOps, Dr Encarni Romero Colmenero, presented to girl learners at the Wynberg Girls School in Wynberg. A further 185 learners participated in activities at Spine Road and Elsies River High schools.

Laboratory programme with ASSET

SCBP has been collaborating with the Association for Educational Transformation (ASSET), a laboratory assistance programme. The aim of the programme is to support the completion of the prescribed curriculum linked to science experiments. Since many of the schools still lack some of the laboratory apparatuses, SCBP also provided alternatives, mostly kitchen-based products that can be used to complete the experiments. This also encourages the learners to repeat the experiments at home. A total of 64 learners participated in this programme.

Astronomy debate

A new programme based on astronomy debate was successfully designed and implemented. The aim of the programme is to empower high school science learners in the art of debating and logical argumentation; it further seeks to encourage critical reading, research and writing in science. It also intends to encourage collaborative working among students and creates opportunities for postgraduate students to act as coaches for learners, while scientists act as judges. The inaugural debate on 9 September was between Elsies River High and Cape Science Academy with the topic "Is the colonisation of Mars a good idea?". The Cape Town Science Centre hosted the event with the judging panel and invited guests joining in by Zoom. Four learners from each school participated in the debate, taking turns to speak. The Cape Science Academy argued for, and Elsies River High was the opposition. The learners were well prepared and argued convincingly. The judges were carefully selected: Jim Adams is a retired scientist and engineer from NASA, Dr Martin Snow is a solar physicist and SARChI at SANSA, and Dr Sthabile Kolwa is an astronomer and lecturer at the University of Johannesburg. The judges selected Elsies River as the winner, who received a trophy engraved with "Astronomy and Space Debate". In addition, each student received the very latest scientific calculator. With the success of the pilot debate, the intention is to extend it to more high schools in Cape Town and the Karoo Hoogland.

Astro Quiz

Like every year, we extend our thanks to the pioneering work done by SALT software developer Dr Christian Hettlage, who again assisted SCBP staff to to implement an online version of the astronomy quiz for grade 7 learners in the Western and Northern Cape. The coding was further elaborated this year, and the astronomy quiz was implemented online nationally. Learners from all the provinces were able to participate, even while the fourth wave of the COVID-19 pandemic raged through South Africa.

Career-based activities

Girl-focused event

Thanks to SAASTA funding, a girl-focused learner event was organised at Touws River High school, where 20 learners participated. The presentations and follow-up deliberations were based on career information, inspiration to continue with science and technology and sharing of relevant resources. The audience also had an opportunity to engage with female scientists drawn from fields in astronomy, data science, etymology, chemistry and food technology. A hybrid format, which consisted of a combination of in-person and Zoom-based participation, was adopted and the events were shared live on social media, which allowed for anyone interested in the event to participate. It was quite pleasing to note that the event also drew the interest of a few boys who requested to be part of the event as they were interested in these careers.

Career brochure and Job Shadow programme

Since learners could no longer come on site due to the restrictive measures for the pandemic, the Job Shadow programme's manager, Ms Natalie Jones, looked for ways of taking the programme to the learners and thus developed the concept of an SAAO online careers brochure. SAAO staff from the various divisions (astronomy, engineering, information technology, administration, finance, public relations and human resources) answered eleven questions that were based on past experiences with Job Shadow learners. With an emphasis on encouraging the learners into their field of expertise, SAAO staff members now highlight hard facts about their tertiary education and experiences, as well as specific details around their career. The brochure now provides all the relevant information and responds to all questions usually asked by high school learners in their quest to choose their own career path.

The brochure is colourful, vibrant, easy to read and addresses learners in grades 10, 11 and 12. Even beyond the pandemic, it will play a critical role in the dissemination of the much needed career information, and in conjunction with on-site visits it can serve to enhance, reach, inform, advise and encourage. While the in-person programme can only cater for about 30 learners per year, the online brochure will reach many more learners. The brochure has been well received and is very popular among learners as well as teachers. It can be found at https://www.saao.ac.za/opportunities/saao-careers-brochure/.

Activities for the public

Gravitational waves documentary

Thanks to SAASTA for funding as part of the National Science Week, a 45-minute long documentary celebrating the detection of a source of gravitational waves by SALT. This was done using a combination of graphics and interviews with Prof. Petri Väisänen, Dr David Buckley, Prof. Bruce Basset, Dr Ramotholo Sefako, Dr Itumeleng Monageng, Dr Naomi Titus and Dr Nicolas Erasmus. The documentary will be made available on the SAAO and SALT websites.

Competitions

Three competitions, initiated towards the end of 2020 as part of the SAAO bicentenary celebrations, were concluded in 2021. These were an art competition for the foundation phase learners, a teachers competition and a Sutherland Tourism youth competition. A total of 2556 entries were received for the astronomy art competition; winners were selected and have received their prizes. Five teachers have won laptops from the teachers' competition. Three members of the Sutherland community have won a R10 000 prize and two R5000 runner-up prizes. Working with the SA Tourism Board and the Northern Cape Department of Tourism, we aim to assist the winners in establishing their own tour guiding companies.

Cultural astronomy project

Three cultural astronomy events, focused on stimulating interest in astronomy using storytelling, poetry, dance and music, were implemented in Hammersdale and Durban jointly with South Africa's national literacy laureate and world acclaimed story teller, Dr Gcina Mhlophe. Gcina combined her storytelling ability with music and dance to narrate some stories based on stars and drawn from indigenous cultures of South Africa. A third event focused on astronomy and space careers and involved members of the Department of Science and Innovation, SARAO and SAAO, who shared info on astronomy as a science and career related topic, while Dr Mhlophe performed between the various presentations. The cultural astronomy project is an ongoing project, which has so far included collection and documentation of indigenous astronomy knowledge and heritage, production of an indigenous astronomy video and creation of indigenous star lore posters.

In addition, a webinar on communicating astronomy using indigenous languages was held and Sibusio Biyela, a world acclaimed science journalist and employee of Science Link, presented to our post-graduates and scientists.

Sutherland activities

Our very first in-person tour (since lockdown) was undertaken on 3 November 2021, when 24 grade 9 learners from Sutherland High school visited the Sutherland facilities. This was followed by two more tours in early December (with 23 learners from grades 9, 10 and 11).

Sutherland tours

The Sutherland based tours remain popular, 2331 people visited the Observatory in 2021. We have had to suspend all tours with the commencement of the fourth wave, with no tours from late December 2021 until the end of February 2022. Even when we were open, we had to reduce the group sizes of both the day and night tours to 17 and 15 per tour, respectively, to comply with the COVID-19 prevention protocols. With a number of restrictions removed and a critical number of the population vaccinated, we are slowly seeing everything returning to normal, and we will soon be able to host larger groups on our site again.

A new math and science teacher for Sutherland schools

Thanks to the SALT Board for the support and funding, we have been able to employ Mr Thabo Banda to teach mathematics at both the Roggeveld and Sutherland High Schools. He is also helping with the co-curricular and extra curricular mathematics and science programmes. This will go a long way in retaining and improving the performance of Sutherland learners. He has adapted to his new post and is committed to contribute towards improving the teaching of mathematics and science in the area.

Word of Gratitude and acknowledgement

2021 has been a tough year for science engagement and outreach programmes due to all the restrictions. We have, however, successfully implemented a number of programmes, and 2022 will be a productive year again. Our thanks go to the SAAO director and management for all the support, advice and guidance and we also thank the SALT partners and the Board for all the collaborations and the support.

SCBP HIGHLIGHT: THE SUTHERLAND COMMUNITY CENTRE

The Community Development centre in Sutherland serves as a beacon of hope and is a site of community development and engagement. Originally, the Community Centre building had belonged to the unemployed people of Sutherland. In 2011, it was handed over to SAAO (and thus the SCBP) by the Sutherland Stakeholders Forum. The SCBP transformed the building through various repairs, painting and restructuring into the current centre, with the following background situation in mind. At that time, the town had a high unemployment rate, peaking at about 75% with the majority being school leavers. Sutherland also had problems with teenage pregnancy, substance abuse, alcoholism and fetal alcohol syndrome. While most pastimes included sports and church activities, many regular visits to locals "shebeens" were noticed. There were no after school programmes to engage the learners, and some learners that were part of big families had no space for studying at home due to overcrowding and lack of relevant resources. It was also noted that access to government department services were located in areas away from Sutherland.

The centre seeks to provide safe space, a place to study, and free access to the internet. In addition, it is a site of development and empowerment as SCBP invites government departments, non-governmental and non-profit organisations to facilitate workshops and provide services. The centre today has 26 computers and 100 work cubicles. The free internet access has become vital for learners and students doing research or completing projects for their studies, and the cubicles are a perfect space for studying. Furthermore, those looking for jobs or business opportunities also profit from the free internet. Thanks to the Sutherland Literacy Project, there are over 300 books on self-development, sport, business and school curriculum related topics. Finally, there is space for young children, offering various toys and kiddies books.

Some of the most successful programmes linked to the community centre include the following.
The Sutherland Reflections programme. Artists Marcus Neustetter and Bronwyn Lace conducted several development activities in Sutherland in partnership with the SCBP. These included the following:

- Art workshops for children;
- Kite building and flying;
- Interviews with older Sutherland residents about traditional astronomy knowledge;
- Development of the Sutherland planetary highway;
- Expansion of the Sutherland Arts and Craft programme;
- Improvement of the play park in Sutherland;
- Development of community-relevant art;
- Coordination of the Ou Lokasie project, which took residents back to pre-democracy locations and recorded their experiences;
- Art installation at the Observatory Visitor Centre
- Bridging the divide between the Observatory and the poorer community of Sutherland.

The success of the Sutherland Reflections programme led to two further projects. Firstly, a film based on the relationship between astronomy, the stars and the people of Sutherland with a number of residents featured in the film. It is titled ´My room in the corner of the Universe". Secondly, the construction of the Sutherland People Dome located on the SAAO site just underneath the plateau that hosts the modern telescopes. It is a symbolic dome acknowledging the excellent and healthy relationship between the community of Sutherland and the Observatory.

Computer based training. Prior to the pandemic, computer based support was continuously provided at the centre, which included creating social media profiles and training on Microsoft products such as Word, Excel and PowerPoint. A collaboration with the IAU OAD provided training in website development and programming for the youth and business owners, e.g., to publicise astro tourism.

Social development programmes. Sutherland faces many social challenges. The SCBP staff in collaboration with Love Life (an NGO working in AIDS awareness and prevention) ran workshops to raise awareness about AIDS and to change sexual behaviours. A programme on fetal alcohol syndrome sought to change the attitude of women towards alcohol while pregnant. Each year (except for 2020 and 2021), SCBP participates in Mandela Day celebrations and hosts an elderly Christmas Dinner for the pensioners of Sutherland.

Educational programmes. Mathematics, science and technology resources, e-books, programmes and software have been installed on the computers to help learners and students with their studies. Working with staff from the Las Cumbres Observatory, learners from Roggeveld Primary and Sutherland High School use the Las Cumbres telescope for observing. Learners also collaborated with the University of Bristol (UK) with the Milky Way as topic. The youth of Sutherland were given an opportunity to do artisan training funded fully by SARAO. We are currently hosting five tourism interns.

In the past few years, the centre hosted a number of youth interns or volunteers, who have assisted with the centre and obtained jobs with the experience they gained: Chante Visser is currently working for the Wind Farms as PRO; Jan De Wee works locally at Karoo Hoogland Municipality; Patrick Van Wyk has been absorbed into SAAO staff as a tour guide; Jean Bernado now works for SAAO IT; Delshia Kamfer (obtained a job at the West Coast); Aisha De Lange has worked at the Planetarium and is currently studying; George Willemse is environmental officer at the local municipality; Percival Van Wyk is self-employed.

OUTREACH & EDUCATION
SALT partner outreach programmes

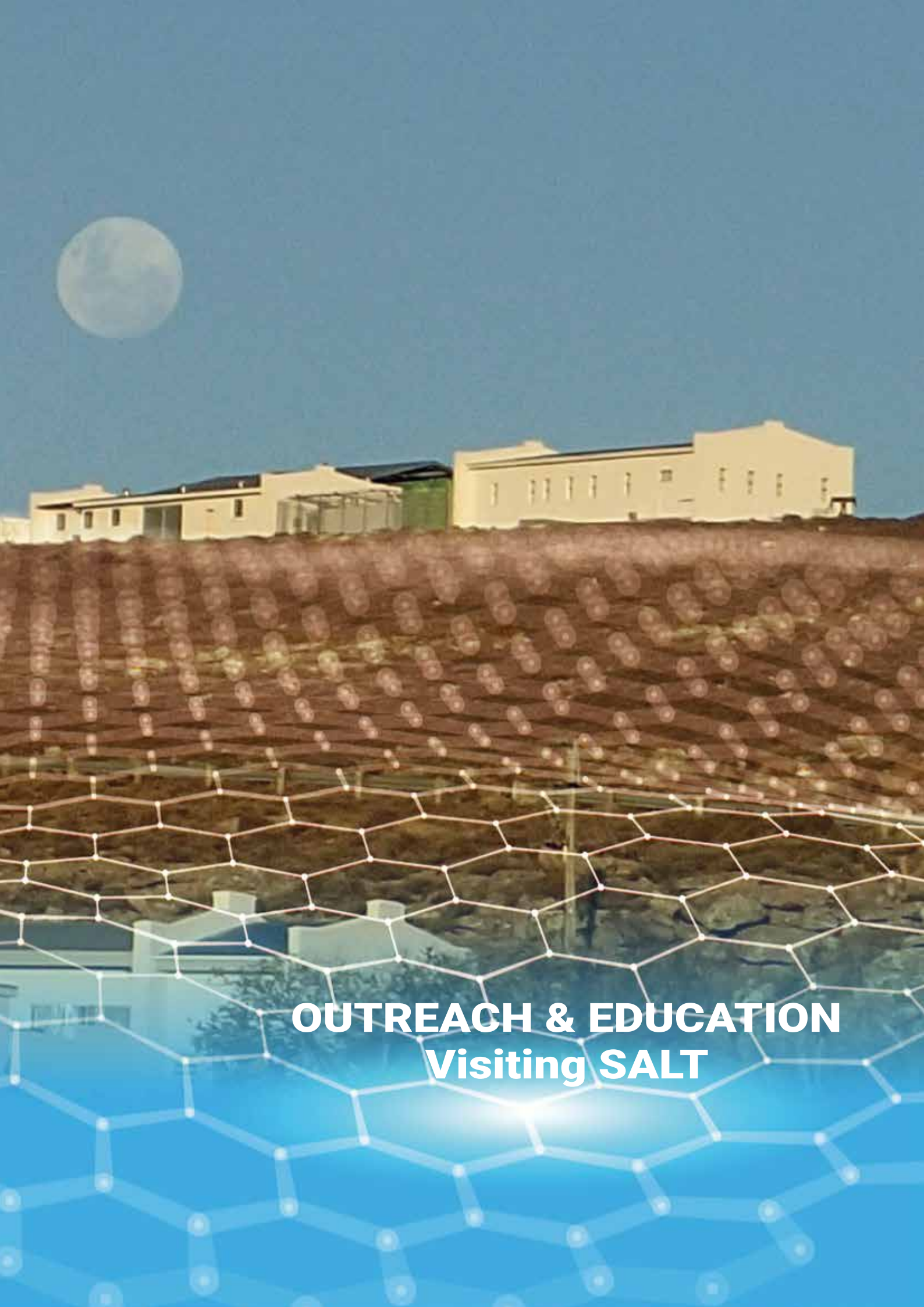
STOBIE–SALT SCHOLARSHIP – NEXT GENERATION

As part of a broader SALT Collateral Benefits Plan, the Stobie–SALT scholarship initiative (2003 – 2013) was aimed at training the next generation of astronomers to make use of SALT and other optical astronomy facilities in SA and beyond. In partnership with SALT consortium institutions, SA students had the opportunity to undertake doctoral studies in astronomy at Rutgers University (RU), Dartmouth College (DC) and the University of Wisconsin (UW) in the USA, as well as at Southampton University and the University of Central Lancashire in the UK (UKSC). The programme has resulted in major benefits for both SA and the participating institutions: ten students were trained, the majority are now in senior leadership positions in astronomy (many on a national and international level), training students in their own groups and continuing to work with astronomers in their doctoral institutions. For the international partners, the programme has indeed forged stronger ties and highly productive collaborations with astronomers in SA.

To ensure maximum benefit from the continued investment in SALT for astronomy and its broader impact on areas such as technology, engineering, data science, the NRF has provided R1 Million to re-launch the SALT scholarships programme, extending it to include research visits for students as well as postdoctoral fellows and early career researchers from SA to spend time at SALT partner institutes. There will be two or three application rounds per year. First, potential hosts at SALT partner institutions can submit a short description of possible projects and research areas. The list of possible projects will then be sent out to SA students and postdocs, and interested candidates can contact potential hosts and submit their applications for funding.

The focus of the projects will be on SALT and SALT-related projects including instrumentation, activities linked to the Vera C. Rubin Observatory, optical-radio synergies, theory/computation and/or data science. Proposals should also include specific outcomes like academic degree, publication(s), skills transfer, or new collaborations. More information can be found via the SALT homepage.

Previous SALT–Stobie scholars: Retha Pretorius (SAAO), Elmé Breedt (University of Cambridge), Vanessa McBride (SAAO) and Tana Joseph (University of Amsterdam).



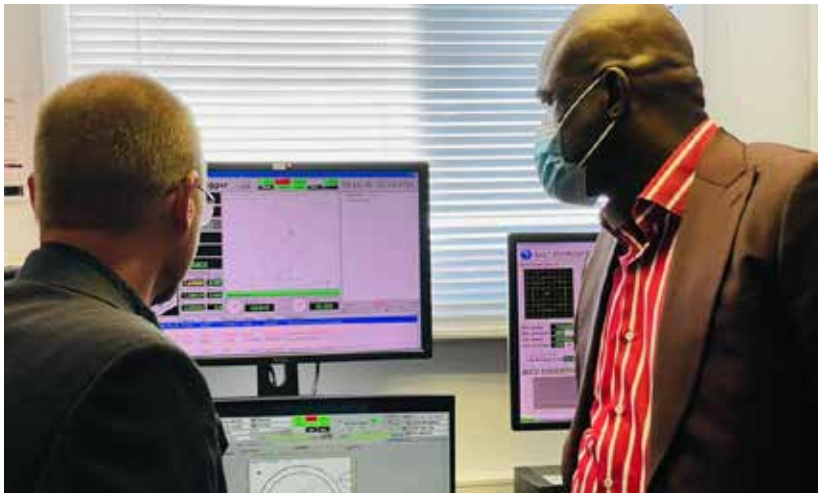
OUTREACH & EDUCATION
Visiting SALT

DELEGATIONS AND OFFICIAL VISITS

24 — 25 March

Dr Zamani Saul	Northern Cape Premier
Ms Bronwyn Thomas-Abrahams	Senior Manager: Media Liaison, Northern Cape Provincial Government
Mr Takalani Nemaungani	Director: Global Projects at DSI
Mr Daniel Mokhohlane	Deputy Director: Cyber Infrastructure at DSI
Ms Tebogo Mashile	Astronomy Policy Researcher at SARAO
Mr Paki Monyobo	Project Manager at Northern Cape Department of Education
Dr Clifford Nxomani	Deputy CEO: National Research Infrastructure Platforms
Prof. Petri Väisänen	Director of SAAO
Mr Anthony Mietas	SCBP manager

The Northern Cape Premier, Dr Zamani Saul and his delegation visited the Sutherland Observatory and SALT on 24 and 25 March, where they spent the night of the 24th at the SAAO Hostel. The purpose of the visit was for Dr Saul to receive a briefing on the facilities and their various activities, and to showcase the astronomical exhibitions and telescopes. After a tour of SALT, given by SAAO director Petri Väisänen, the delegation had the opportunity to enjoy the pristine dark skies of the Northern Cape with some stargazing during the evening. The next day they visited the rest of the Observatory. The Premier concluded his visit with meetings at the Sutherland Community Development Centre, as well as schools in Sutherland, accompanied by senior officials from the Department of Education. The visit was well received by the delegation, who have expressed their appreciation towards all involved in making this a memorable visit.



Petri Väisänen (left) and Zamani Saul (right) in the SALT control room.

The Northern Cape Premier at the Sutherland Community Centre.

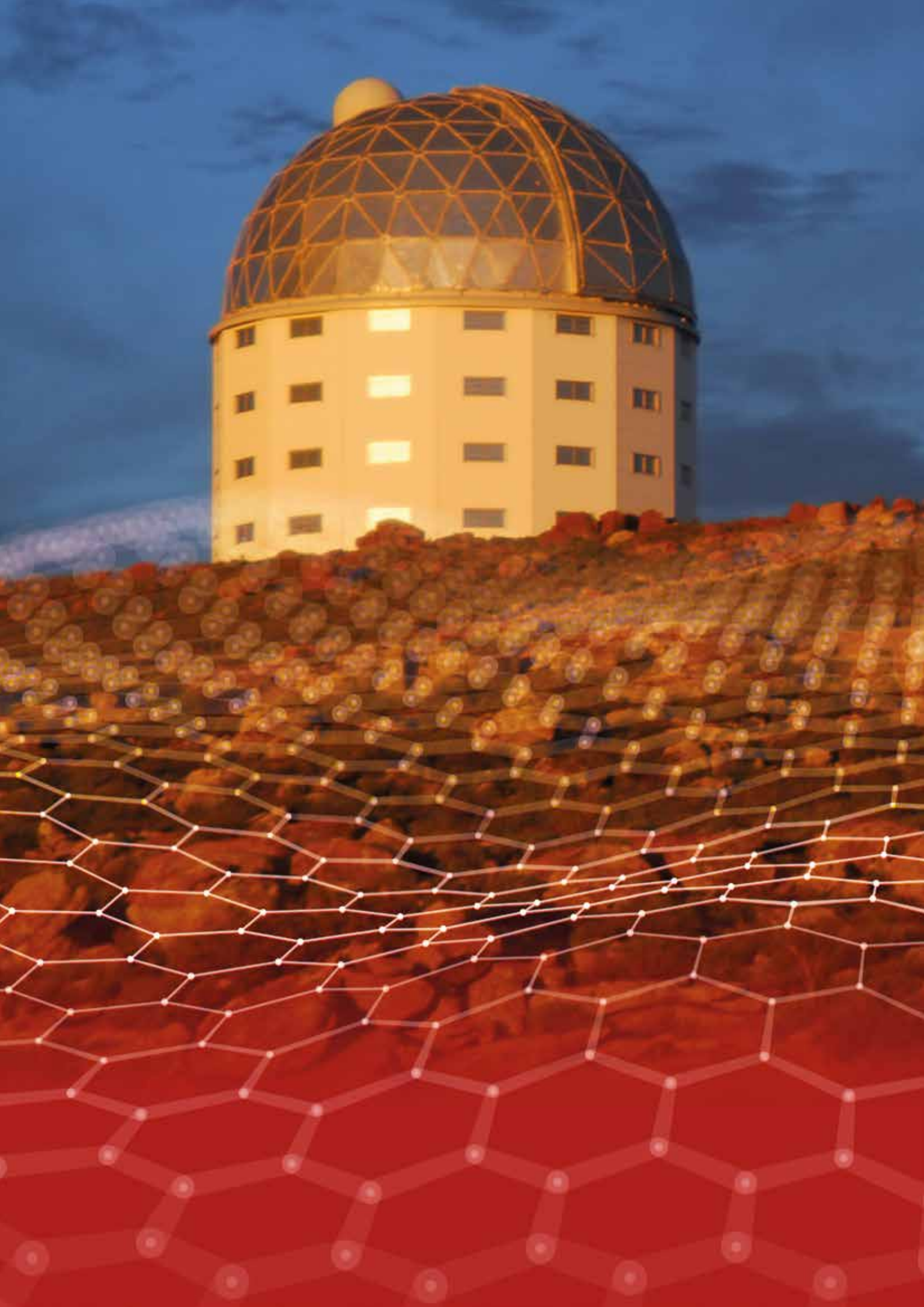
MEDIA VISITS TO SALT

September 2021 — Insider SA: Seeing stars with Grant Hinds and Ambel Barnard

The Insider SA is a serial lifestyle show on South Africa's SABC3 TV station. It portrays the stories of interesting people and businesses, aiming to inspire South Africans to live better, to make better choices and to create meaningful experiences. The show challenges the way people consume and encourages local talent. "Whether it be food, art, design, technology, fashion, artisans and entrepreneurs — The Insider SA features stories with a strong focus on sustainability, innovation, collaboration and community."

Each episode focuses on a different theme, and on 29 and 30 August, The Insider SA with the presenters Grant Hinds and Ambel Barnard visited the observatory at Sutherland and SALT. Daniel Cunnama, SAAO's Science Engagement Astronomer, gave them a private tour and invited them to some star gazing, enjoying the famous dark skies of Sutherland. The episode was broadcasted on 20 September. It can also be viewed at https://theinsidersa.co.za/explore-sutherland-with-grant-hinds-and-ambel-barnard/

The Insider SA visits SALT. – Credit: Insider SA/Janik Alheit



CORPORATE GOVERNANCE

The affairs of the SALT Foundation are regulated by the Shareholders' Agreement, signed at the formation of the Company. In terms of this agreement, the Company is controlled by a Board of Directors comprising two members from the National Research Foundation and one member from each of the remaining partner institutions. The Directors are elected at the Annual General Meeting of the Company and serve for a period of three years, following which they may be re-elected. All Board members are independent, Non-Executive Directors.

In this reporting period, the Board comprised of the following members:

Prof. Michael Shara (Chair until Nov/2021)
American Museum of Natural History, USA

Prof. Matthew Bershady
University of Wisconsin–Madison, USA

Prof. Brian Chaboyer (Chair since Nov/2021)
Dartmouth College, USA

Prof. Phil Charles
United Kingdom SALT Consortium, UK

Prof. John P. Hughes
Rutgers University, USA

Prof. Shazrene Mohamed
National Research Foundation, South Africa

Dr Fulufhelo Nelwamondo (Appointed 01/04/2021)
National Research Foundation, South Africa

Prof. Somak Raychaudhury
Inter–University Centre for Astronomy & Astrophysics, India

Prof. Marek Sarna
Nicolaus Copernicus Astronomical Centre, Poland

Other officers of the Company include Mrs Lizette Labuschagne (Chief Financial Officer, Company Secretary and Business Manager).

The Board meets twice a year, usually in May and November. The SAAO Director and senior staff involved in the operation of the telescope also attend the Board meetings.

Operations contract

SALT is operated on behalf of the SALT Foundation by SAAO and managed by the SAAO Director, Prof. Petri Väisänen. With the exception of Mrs Lizette Labuschagne, the staff who carry out the day-to-day operational activities are SAAO employees. Engineering operations are managed by the SALT Operations Manager, Mr Paul Rabe, while Dr Encarni Romero Colmenero heads the Astronomy Operations team. The operations plan and budget are presented by the SAAO Director at the November Board meeting for the following financial year.

The Board Executive Committee (BEC)

The Board has delegated authority to the Board Executive Committee (BEC) to manage the Company during the period between Board meetings. The BEC meets once or twice between Board meetings and receives reports on the operations and development of the telescope from the SAAO Director and other senior staff with the relevant responsibilities. The BEC comprises five Board members. In this reporting period, they were: Prof. Mike Shara (Chair), Prof. Brian Chaboyer, Prof. Phil Charles, Prof. Jack Hughes and Prof. Somak Raychaudhury.

The Finance and Audit Committee (FAC)

Although the full Board takes responsibility for the Annual Financial Statements of the Company, the Board has appointed a Finance and Audit Committee (FAC) to interrogate the management of the financial affairs of the Company at a detailed level. This committee meets at least twice a year, shortly before Board meetings, and presents a report at the Board meeting. In this reporting period, the members of the FAC were: Prof. Jack Hughes (Chair), Prof. Gordon Bromage, Dr Matt Bershady and Mrs Kate Soule.

Scientific and Technical Committee (STC)

The Scientific and Technical Committee (STC) was established in November 2018, as per recommendations arising from the SALT External Review. The fundamental purpose of this committee is to improve all levels of technical and scientific communication within the SALT collaboration, with the explicit goal of increasing the scientific productivity of the telescope. The SALT Observatory Scientist is a member of the committee. The STC reports to the SALT Board via the chair of the committee. In this reporting period, the members are: Prof. Paul Groot, Prof. Matt Bershady, Dr Hermine Schnetler, Mr John Booth, Prof. Joanna Mikołajewska, Dr David Buckley, Prof. Raghunathan Srianand and Dr Lisa Crause (Chair).

Technical Operations Team 2021

Paul Rabe (Head)
Richard Banda
Janus Brink
Keith Browne
Bryne Chipembe
Alrin Christians
Willa de Water
Timothy Fransman
Denville Gibbons
Johan Hendricks
Stephen Hulme*
Nicolaas Jacobs
Sunnyboy Kabini
Dillon Klaasen*
Anthony Koeslag
Jonathan Love
Deneys Maartens
Thabelo Makananise
Adelaide Malan*
Jonathan Pieterse*
Melanie Saayman
Etienne Simon
Ockert Strydom*
Nicolaas van der Merwe
Eben Wild

Corporate Governance Team 2021

Lizette Labuschagne
Surayda Moosa

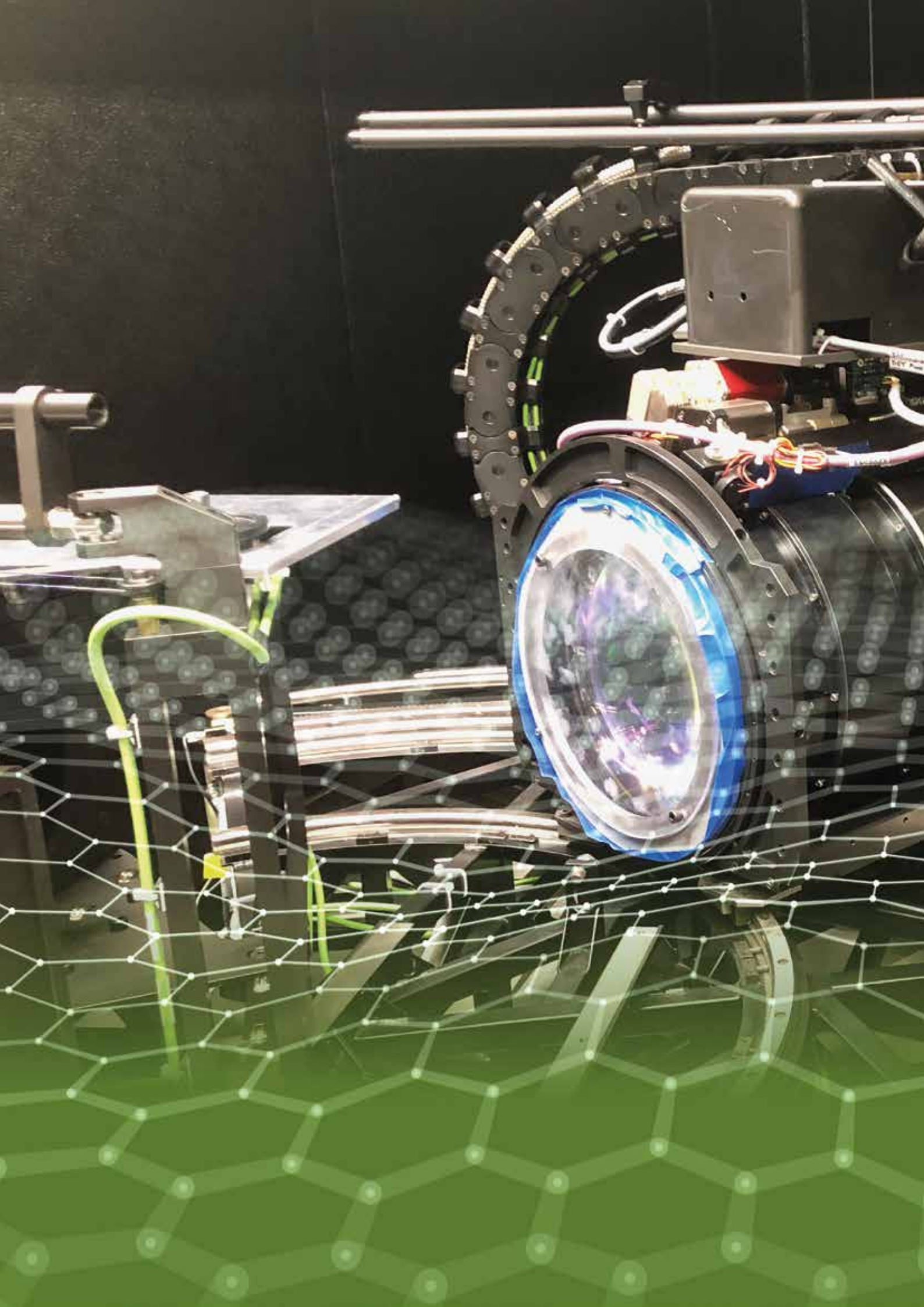
Astronomy Operations Team 2021

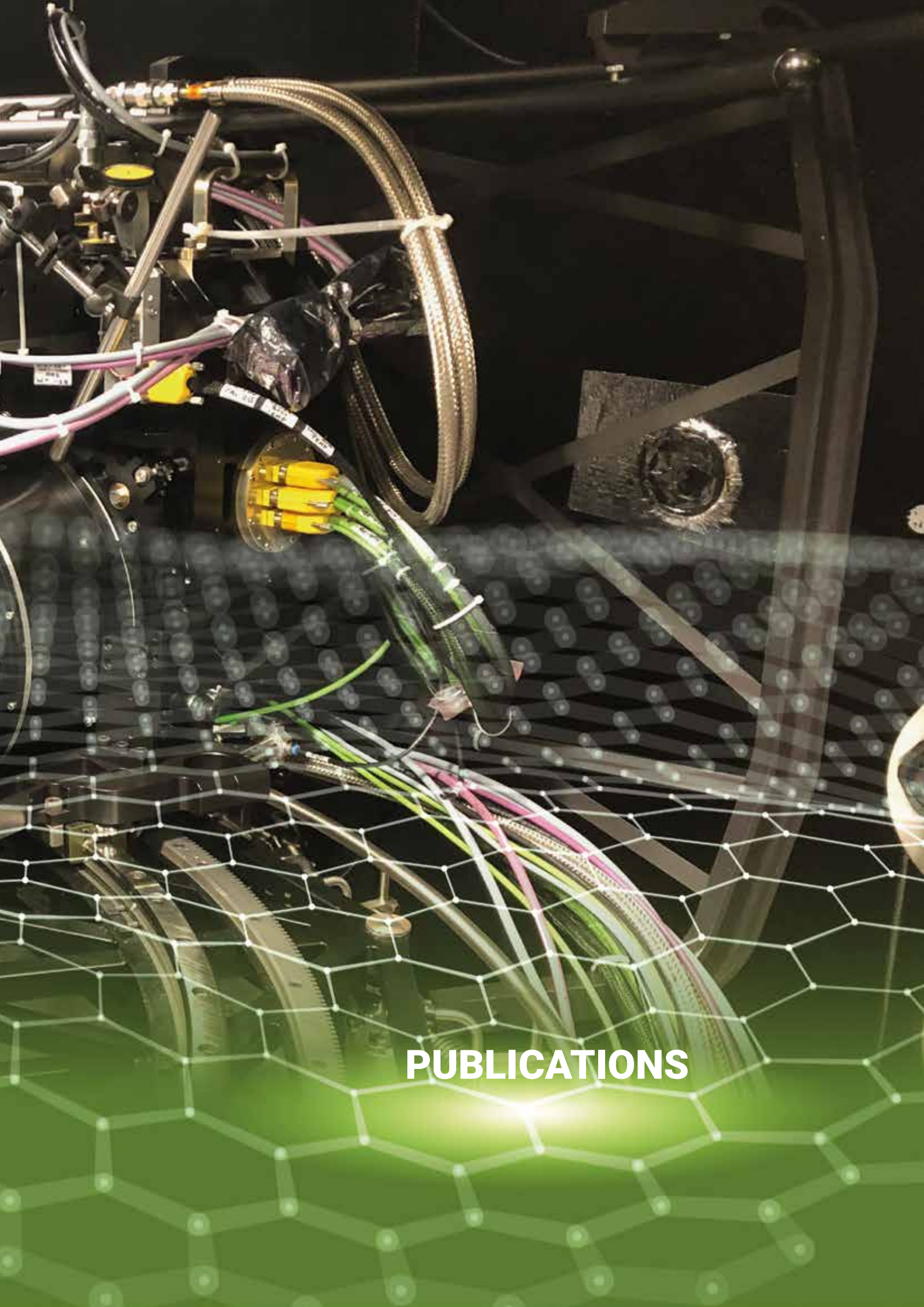
Encarni Romero Colmenero (Head)
Danièl Groenewald
Christian Hettlage
Alexei Kniazev
Thea Koen
Enrico Kotze
Rudi Kuhn
Nhlavutelo Macebele
Fred Marang*
Chaka Mofokeng*
Moses Mogotsi
Elizabeth Naluminsa*
Xola Ndaliso*
Solohery Randriamampandry*
Anja Schröder*
Rosalind Skelton
Lee Townsend
Veronica van Wyk
Lonwabo Zaula*

SALT Observatory Scientist 2021

Lisa Crause

** part-time and/or part of the year*





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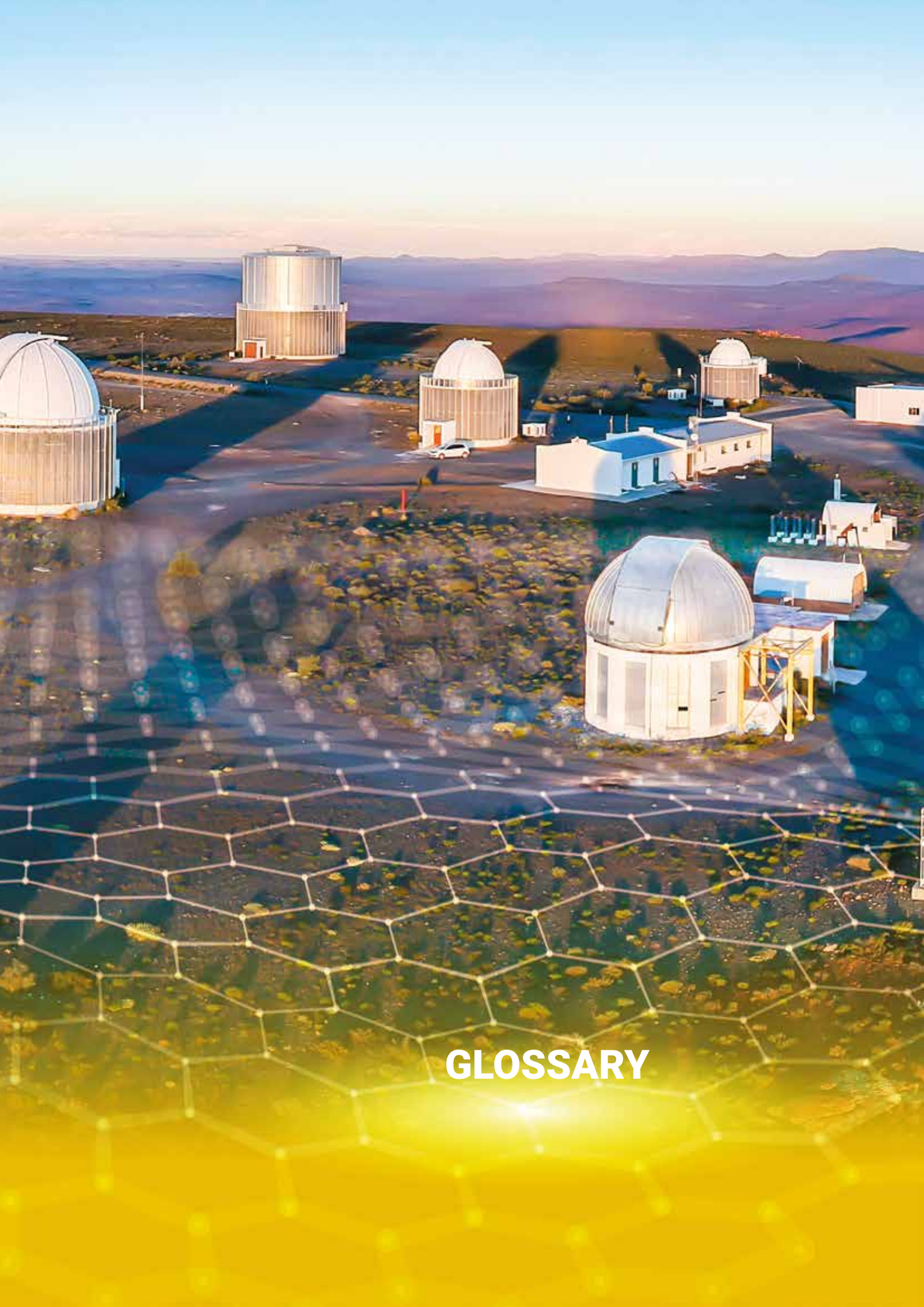

GLOSSARY

GLOSSARY & ACRONYMS

1D, 2D, 3D	one, two, three dimensional
2dFS	2 degree field survey of the SMC (object name prefix)
A&A	astronomy & astrophysics
AAS	American Astronomical Society
AAVSO	American Association of Variable Star Observers
ACT	Atacama Cosmology Telescope
AD	Anno Domini
ADC	atmospheric dispersion compensator
AdvACT	Advanced Atacama Cosmology Telescope
AEON	Astronomical Event Observatory Network
AGB	asymptotic giant branch
AGN	active galactic nucleus
AIDS	Acquired Immune Deficiency Syndrome
AIP	Leibniz Institute for Astrophysics Potsdam
ALMA	Atacama Large Millimeter/submillimeter Array
AMNH	American Museum of Natural History
AOP	Armagh Observatory & Planetarium
API	application programming interface
APOLLO	Automated Pipeline for sOlar-Like Oscillators (software)
ASASSN	All Sky Automated Survey for SuperNovae
ASSET	Association in Educational Transformation
ATLAS	Asteroid Terrestrial-impact Last Alert System
BAL	broad absorption line
BCG	brightest cluster galaxy
BEAMS	Brightest cluster galaxy Evolution with ACT, MeerKAT, and SALT
BEARS	Bright Extragalactic ALMA Redshift Survey
BEC	board executive committee
BLR	broad line region
BRICS	Brazil, Russia, India, China, and South Africa
BTA	Big Azimuthal Telescope
CAMK	Nicolaus Copernicus Astronomical Center
CCD	charge-coupled device
CDR	critical design review
CEO	Chief Executive Officer
CHIRON	a fiber-fed high-resolution échelle spectrometer
CL	cluster
CNSS	Caltech-NRAO Stripe 82 Survey
CO	Carbon–Oxygen
Co–PI	co–principal investigator
COS	Cosmic Origins Spectrograph
COSPAR	Committee on Space Research
COVID-19	coronavirus disease 2019
CPD	Cape observatory, photographic Durchmusterung
CTA	Cherenkov Telescope Array
CV	cataclysmic variable star
DC	Dartmouth College
DDT	director's discretionary time
DESI	Dark Energy Spectroscopic Instrument
DLA	damped Lyman α systems
DR	data release
DSI	Department of Science and Innovation
EC	Edinburgh-Cape survey
ECR	engineering change request
EGRET	Energetic Gamma Ray Experiment Telescope
ELS	event logging system
eRASSt	eROSITA all-sky survey transient source
eROSITA	extended ROentgen Survey with an Imaging Telescope Array
ESA	European Space Agency
ESO	European Southern Observatories
EW	equivalent width
FAC	finance & audit committee
Fermi-LAT	Fermi Large Area Telescope collaboration
FEROS	Fiber-fed Extended Range Optical Spectrograph
FIF	fibre instrument feed
FLAMES	Fibre Large Array Multi Element Spectrograph
FORS2	FOcal Reducer/ low dispersion Spectrograph 2
FP	Fabry–Pérot
FSRQ	flat-spectrum radio quasar
FUV	far ultraviolet
FWHM	full width half maximum
GALEX	Galaxy Evolution Explorer (UV space telescope)
GATS	Global Astrophysical Telescope System
GRB	gamma-ray burst
GSM	Global System for Mobile communications
GTC	Gran Telescopio Canarias
H2RG	HAWAII–2RG detector
HD	Henry Draper catalogue
HE	Hamburg–ESO survey
HERCULES	High Efficiency and Resolution Canterbury University Large Echelle Spectrograph
H.E.S.S.	High Energy Stereoscopic System
HET	Hobby–Eberly Telescope
HETDEX	HET Dark Energy eXperiment
HIRES	High Resolution Echelle Spectrometer
HMI	human machine interface
HRS	high-resolution spectrograph
HS	high-stability
HST	Hubble Space Telescope

IAC	Instituto de Astrofísica de Canarias
IAO	Institute Astronomical Observatory
IAU	International Astronomical Union
IC	Index Catalogue
IDSAC	IUCAA digital sampler array controller
IFU	integral field unit
IGR	INTEGRAL gamma-ray source
INTEGRAL	International Gamma-Ray Astrophysics Laboratory
IP	intermediate polar
IR	infrared
IRAS	Infrared Astronomical Satellite
IRSF	InfraRed Survey Facility
ISDEC	IUCAA SIDECAR drive electronics controller
ISI	international scientific indexing
ISM	interstellar medium
IT	information technology
IUCAA	Inter–University Centre for Astronomy & Astrophysics
JWST	James Webb Space Telescope
KAT	Karoo Array Telescope
LADUMA	Looking At the Distant Universe with the MeerKAT Array
LBT	Large Binocular Telescope
LBV	luminous blue variable
LFC	laser frequency comb
LIGO	Laser Interferometer Gravitational wave Observatory
LMC	Large Magellanic Cloud
LMXB	low-mass X-ray binary
LOFAR	LOw Frequency ARray
LOSVD	line-of-sight velocity distribution
LSP	SALT large science programme
LSR	local standard of rest
LSST	Large Synoptic Survey Telescope
LTE	long term evolution
Ly	Lyman (hydrogen spectral series)
LZ	luminosity-metallicity relation
M	MALS source
MA93	Meyssonnier + Azzopardi, 1993 (source name prefix)
MAGIC	Major Atmospheric Gamma-Ray Imaging Cherenkov Telescopes
MAGIC	Milky wAy Galaxy wIth SALT speCtroscopy
MALS	MeerKAT Absorption Line Survey
MASTER	Mobile Astronomical System of the TElescope–Robots network
MaxE	Maximum Efficiency spectrograph
MAXI	Monitor of All-sky X-ray Image
MCSNR	Magellanic Cloud SNR
MDM	Michigan–Dartmouth–MIT Observatory
MIR	mid-infrared
MIPS	Multiband Imaging Photometer for Spitzer
MIT	Massachusetts Institute of Technology
MLT	SALT multi-semester proposal
MN	MIPS 24μm nebula
MOS	multi-object spectrograph
MoU	memorandum of understanding
MPE	Max Planck Institute for Extraterrestrial Physics
MSc	master of science
MSU	Moscow State University
MT	mini tracker
NASA	National Aeronautics and Space Administration
NATS	an open-source messaging protocol
NCAC	Nicolaus Copernicus Astronomical Center
NCON	NIR instrument control
NGC	New General Catalog
NGO	Non-Governmental Organisation
NI	National Instruments
NICER	Neutron Star Interior Composition Explorer
NIR	near-infrared
NOT	Nordic Optical Telescope (Roque de los Muchachos Observatory, La Palma)
NRF	National Research Foundation
NTT	New Technology Telescope (ESO)
NuSTAR	Nuclear Spectroscopic Telescope ARray
NWU	North–West University
OAD	Office of Astronomy for Development
OGLE	Optical Gravitational Lensing Experiment
OPC	open platform communications (PLC protocol)
OTN	optical transient network
P0 … P4	priority 0 – 4
PA	position angle
PanSTARRS	Panoramic Survey Telescope And Rapid Response System
PAS	Polish Academy of Sciences
PASIPHAE	Polar-Areas Stellar-Imaging in Polarization High-Accuracy Experiment
PC	personal computer
PCON	PFIS (now RSS) controller
PDET	PFIS (now RSS) detector
PDR	preliminary design review
PFIS	Prime Focus Imaging Spectrograph (now RSS)
PhD	doctor philosophiae
PHOEBE	PHysics Of Eclipsing BinariEs (software tool to model eclipsing binary stars)
PHP	general-purpose scripting language
PI	principal investigator
PIPT	Principal Investigator Proposal Tool
PKS	Parkes radio telescope
PLC	programmable logic controller
PLZ	period-luminosity-metallicity relation
PN	planetary nebula
PNV	possible nova (object name prefix)

GLOSSARY & ACRONYMS

continued

POL	Poland
PPN	pre-planetary nebula
PRO	public relations officer
PRV	precision radial velocity
PSR	pulsar (object name prefix)
QPE	quasi-periodic eruptions
QPO	quasi-periodic oscillations
RedCON	RSS Red arm instrument control
REST	Representational State Transfer (API)
RINGS	RSS Imaging spectroscopy Nearby Galaxies Survey
RLQ	radio-loud quasar
RN	recurrent nova
ROSAT	Röntgensatellit
RRL	RR Lyrae star
RRM	rigidly rotating magnetospheric star
RSA	Republic of South Africa
RSS	Robert Stobie Spectrograph
RV	radial velocity
RU	Rutgers University
RX	ROSAT source
SA	South Africa
SAAO	South African Astronomical Observatory
SAASTA	South African Agency for Science and Technology Advancement
SABC3	South African Broadcasting Corporation 3
SAGA	Satellites Around Galactic Analogs
SAI	Sternberg Astronomical Institute
SALT	Southern African Large Telescope
SALT3	Spectral Adaptive LightcurveTemplate v3 (SN lightcurve fitting package)
SALTICAM	SALT Imaging CAMera
SANSA	South African National Space Agency
SARAO	South African Radio Astronomy Observatory
SARChI	South African Research Chairs Initiative
SB2, SB4	stellar binary/quadruple system
SCBP	SALT Collateral Benefits Programme
SCI	SALT science proposal
S–CUBED	Swift SMC Survey
SD	single degenerate (SN type Ia model)
sd	subdwarf
SDA	SALT data archive
SDC	structure and dome controller
SDSS	Sloan digital sky survey
SDSU	San Diego State University
SIDECAR	system image, digitising, enhancing, controlling, and retrieving
Sk	Sanduleak
SKA	Square Kilometre Array
SMC	Small Magellanic Cloud
SMI	slitmask IFU
SN	supernova
SNR	supernova remnant
SRG	Spektrum-Röntgen-Gamma satellite
SSWG	SALT science working group
STC	scientific and technical committee
SuperWASP	Super Wide Angle Search for Planets
SXP	SMC X-ray pulsar (object name prefix)
TAC	time allocation committee
TARDIS	Tomographic Absorption Reconstruction and Density Inference Scheme
TCS	telescope control system
TESS	Transiting Exoplanet Survey Satellite
THYME	TESS Hunt for Young and Maturing Exoplanets
TMT	Thirty Meter Telescope
TNR	thermonuclear runaway
TOI	TESS Object of Interest
TYC	Tycho mission (object name prefix)
U	university
UA	unified architecture
UCLan	University of Central Lancashire
UCMJO	University of Canterbury Mount John Observatory
UCT	University of Cape Town
UFO	ultra-fast outflows (of BALs in AGNs)
uGMRT	upgraded Giant Metre-wave Radio Telescope
UKSC	United Kingdom SALT Consortium
UKZN	University of KwaZulu-Natal
UNC	University of North Carolina – Chapel Hill
UV	ultraviolet
UVES	Ultraviolet and Visual Echelle Spectrograph
UW	University of Wisconsin–Madison
UWC	University of the Western Cape
VERITAS	Very Energetic Radiation Imaging Telescope Array System
VIS	visible
VLA	Very Large Array
VLBA	very long base-line array
VLBI	very long baseline interferometry
VLT	Very Large Telescope
VPH	volume phase holographic
WALOP	Wide-Area Linear Optical Polarimeter
WD	white dwarf
WISE	Wide-field Infrared Survey Explorer
WO	type of Wolf–Rayet stars with dominating oxygen lines
WR	Wolf–Rayet
XML	Extensible Markup Language
XMM	XMM–Newton observatory
XMMU	unique XMM source
XRB	X-ray binary
XRT	X-Ray Telescope

The SALT consortium is seeking an additional 10%-level partner (~$9.1M) to support significant second-generation instrumentation development. Interested parties should contact the chair of the SALT Board of Directors, Brian Chaboyer*.

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