

ANNUAL REPORT

SOUTHERN AFRICAN LARGE TELESCOPE

Background image: SALTICAM composite image of the Eagle Nebula, made from separate images captured with i' band, g' band, and Hα narrowband filters on the same night, prior to the NIRWALS observation.
Credit: Moses Mogotsi

First Light for SALT's new instrument NIRWALS

The evening of 7 July 2022, SALT celebrated First-Light of the NIRWALS instrument. It is the first new instrument since the HRS was installed in 2013. NIRWALS is a standalone integral field spectrograph, fed by a fibre bundle that resides inside a cold enclosure in the spectrometer room, next to the HRS enclosure. It was developed and built by the Washburn Astronomical Laboratories of the University of Wisconsin-Madison's Astronomy Department, with Marsha Wolf (UW) as the PI. It is going to be a great addition to the existing suite of instruments and will extend SALT's capabilities into the near-infrared (NIR).

Science driver

NIRWALS will paint a clearer picture of if and how AGN have regulated the star formation histories of galaxies. While the optical spectra using RSS-VIS give information on the star formation histories of the galaxies and the ionisation state of the gas (indicating the presence of an AGN and its extent), the NIR spectra will give information on shocks in the gas from AGN outflows, past supernovae, and the very youngest stellar populations. The combined data will answer questions on where and when stars formed in a galaxy, where AGNs ionise the gas, if and where there were outflows from the AGN, and where star formation was shut down in the galaxies (*e.g.*, was it along the AGN outflows?). Furthermore, NIRWALS will allow the comparison of light signals from galaxies at high redshifts to galaxies nearby that have been observed with RSS-VIS. And since NIR wavelengths can easily penetrate dust, NIRWALS can be used to study dusty star-forming galaxies. The IFU is necessary to isolate the different galaxy components and get simultaneous spectra of the different regions, including the faint outer parts for which SALT's large aperture is particularly suited.

Specifications

NIRWALS provides medium resolution spectroscopy at R = 2000 – 5000 over the wavelength range of 800 – 1700 nm. Its integral field unit (IFU) is an elongated hexagonal bundle of 212 fibres, each of which subtends 1.3 arcsec on the sky, approximately matching the median site seeing. The IFU's on-sky dimensions of 29 x 18 arcsec are ideally suited for resolving nearby galaxies. A separate 36-fibre bundle simultaneously samples the sky. It can be adjusted to distances ranging from 45 – 145 arcsec from the object IFU, with a gimbaled jaw in the fibre Instrument Feed (FIF) that maintains telecentricity and common field angles for the object and sky bundles. Sky fibres are interleaved with object fibres along the 8-arcmin long spectrograph slit for optimising sky subtraction. The spectrograph is cooled to −40° C in an enclosure beneath the telescope, with the cryogenic dewar inside this enclosure operating at 120 K via a separate closed-cycle cooler. The spectrograph uses volume phase holographic gratings with an articulated camera, similar to RSS, for setup versatility. The spectrograph has been fully tested in the laboratory at the University of Wisconsin and is currently being commissioned on SALT.

Wavelength coverage	800 – 1700 nm
Spectral resolution (R)	2000 – 5000
Peak predicted throughput	0.40
Number of fibres in IFU	212
IFU field of view on-sky	18 x 29 arcsec
Fibre size on-sky	1.33 arcsec
Number of fibres in sky bundle	36
Sky bundle field of view on-sky	4 x 29 arcsec
Adjustable sky bundle distance from IFU	45 – 145 arcsec

7 July 2022 — A diary by Marsha Wolf

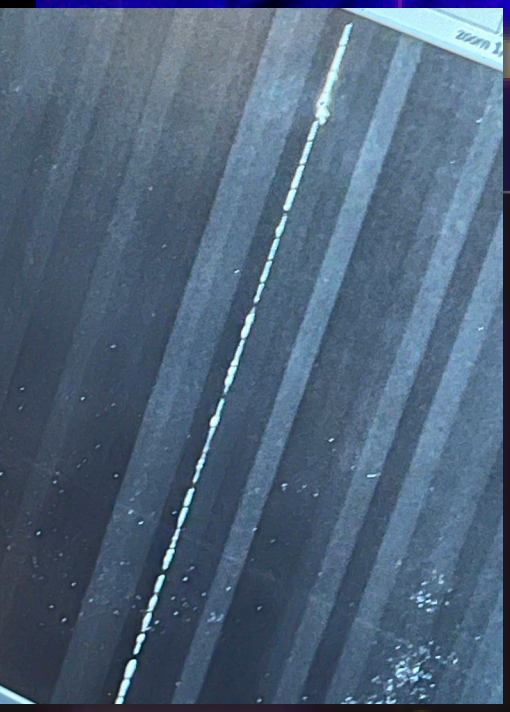
In the evening of 7 July 2022 the weather looked better than on the previous night (when we had first calsys light). The SALT Tech Ops team was feverishly trying to get the FIF guider fixed up, since it suddenly started misbehaving ahead of the big occasion. They also wanted to get the new calsys hardware installed this evening, plus the primary mirror was due for an alignment. But since it's the NIR team's last night here until October, we decided to grab what we could: run without the guider (we can choose brighter targets to knock the exposure times down), give up on the new calsys for now (the current calsys will suffice for tonight) and we can align the mirror after getting starlight through the instrument!

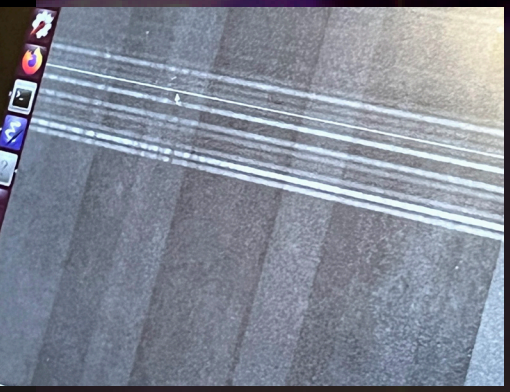
So, the first task on-sky was to verify the telescope pointing and the positioning of an object on our fibre bundle. We picked a bright star for the first test, HD 189140, a 6th magnitude M-type star. The centre fibres in our bundle are mapped to the edges of the spectrograph slit, meaning that if the star did land near the centre, fibres toward the edges of our image should light up. Indeed, this is exactly what we saw! I couldn't believe that it actually worked. My engineer, Mike Smith, shared the reaction. As silly as it sounds, this was the most exciting moment of the night for me.There were about 15 people in the telescope control room … people came out of the woodwork for this momentous occasion. Observers from other telescopes on the mountain were there. A group of visiting students was there. Some of the SALT technical operations staff who maintain the telescope were there. They had logged many long-hour days helping us prepare for this moment and weren't going to miss the event, even though it meant staying even longer into the night. They found it quite comical that astronomers got so excited about seeing some spots (images of the fibres) and lines (spectra of light through the fibres) on the screen. There were lots of high-five's going around the room.

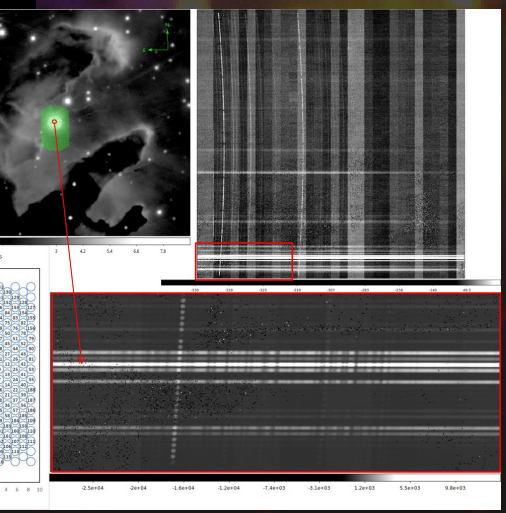
Next, I inserted the grating, snapped a few-second exposure and got our first on-sky NIRWALS star spectra!! There was almost an air of disbelief that we've actually reached this milestone, at long last! We did a few more pointing tests on stars to determine the orientation of our fibre bundle on-sky. After this, I had planned to observe a cool system of three merging galaxies containing lots of ionised gas that would show up as emission lines in our spectra, but we had to change plans due to the guider not working. This limited us to short 60 – 90 second exposures. So we went to the well-known Eagle Nebula for our official first light observation. The onlooking students were most impressed by the beautiful SALTICAM acquisition images of the pillars of creation, but we astronomers knew that the resulting spectra signified the beginning of much science to come.



The tension mounts in the SALT control room.











After the hard work and suspense comes the catharsis with happy celebrations.

Images *left*, *top* to *bottom*:
First star light: Just imaging mode, to see starlight in the fibres.
First star spectra from the fibres that contained some of the brighter blobs, complete with loads of dark absorption lines at the red end.
Official first light spectra of the Eagle Nebula with the object fibre configuration overlayed on the image. The spectrum of one of the central fibres is pointed out.

Sound bites

Moses Mogotsi (SAAO; SALT Astronomer and local NIRWALS liaison):
First Light with NIRWALS was very exciting! I felt a sense of pride and accomplishment for all the hard work that the team has put into building and testing the instrument, and preparing the telescope for NIRWALS. Its an exciting step forward for SALT, because it opens up the near-infrared wavelength regime and its the first IFU instrument on the telescope. I look forward to using it for some of my science and to see what the community uses it for.

Joshua Oppor (UW; graduate student in astronomy):
As a graduate student working on the NIRWALS project, I was responsible for the fabrication, packing and leading the installation of the 40-meter-long fibre optic cable. I was elated when I first saw light from each fibre show up on the screen. This was the first time I had confirmation that the fibres had safely and properly been strain-relieved from the top of the telescope down into the spectrograph. I could finally relax a bit knowing that my major contribution to the project had been safely and successfully installed. A huge sense of relief.

Lisa Crause (SAAO; SALT Observatory Scientist):
So much work goes into getting a new instrument to this momentous stage, and there's inevitably so much more to do once it gets to be on-sky in any kind of routine fashion. But the tension and excitement of achieving first light is one of the great joys in this business and so I'm absolutely delighted for all involved that everything worked so beautifully — particularly given the tight time constraints with the Wisconsin team due to leave the next day! It was also a fantastic bonus that we happened to have a number of undergraduate astronomy students up there on an internship, and so they got to experience this rare privilege in person. We could tell right away, with great relief, that the delicate fibres that we had been worried about were all safe and well. Now we can't wait to see what all NIRWALS can deliver scientifically. Huge congratulations to the whole team for reaching this epic milestone!

Mike Smith (UW; Engineer):
The night of first light was a bit of a blur. The schedule had been a little crazy trying to get the fibre installed and the instrument cooled after a few delays in shipping had shortened the time we had available. I clearly remember people from all over the mountain congregating at SALT; it was festive. I felt quite a bit of stress as we waited to see how the instrument performed. Then there were a few comical moments as some minor missteps were made in configuring the telescope — so that it looked for a moment like no light was getting through. And then huge relief and a big cheer as we saw first an array of beautiful spots and then the first spectra of astronomical objects. Just a feeling of excitement and relief. And a great appreciation for the amazing colleagues who had worked on this instrument and had not had the opportunity to be there for that moment. I headed to bed before the celebrations, knowing I needed to get up early the next day for a little more work on the instrument before our return to Madison.

Jonathan Love (SAAO; Mechanical Technician) and the SALT Tech Ops team:

The weeks leading up to going on-sky with NIRWALS was quite a suspenseful and nerve-wrecking time for the coffee fuelled and pizza driven Tech Ops team. In the final week, the entire Sutherland Tech Ops team was engaged with installation of the NIR fibres, modifying the FIF mechanism for the new NIR IFU's and installing the NIR calibration light source, finishing on 6 July. Although the observers had problems with the FIF that night, they still managed to get light from the calibration system to NIRWALS. On 7 July, the team went back to the drawing board and made some modifications to the FIF to better operate with the NIRWALS IFU's. The installation of the NIR calibration system hardware was also completed that day after the team pushed through long shifts.

For the Tech Ops team, there was quite a mixture of emotions when the NIRWALS first light spectra were acquired. Of course there was great delight in achieving this momentous milestone and seeing smiles on astronomers' faces when they looked at the data (to us the data didn't make much sense). Given the long working hours and constant mechanism faults that week, there was also frustration because the team had faults to repair in the couple of hours before dayshift started again. Overall everyone involved since the NIR-SA project started in 2017 felt an enormous sense of relief and achievement. This enormous task would not have been possible if we did not have such a great team of knowledgeable, willing and able Karoo techies that are able to quickly turn problems that look like mountains into molehills and then wipe them flat!



SOUTHERN AFRICAN LARGE TELESCOPE

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2 ABOUT SALT



The Board of the Southern African Large Telescope (SALT) is proud to present its Annual Performance Report for the period 1 January 2022 to 31 December 2022.

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 three 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 Rutgers University (RU), the Nicolaus Copernicus Astronomical Centre of the Polish Academy of Sciences (POL), Dartmouth College (DC), the University of Wisconsin–Madison (UW), and the Inter–University Centre for Astronomy and Astrophysics in India (IUCAA). Smaller shareholders include the American Museum of Natural History (AMNH) and the UK SALT Consortium (UKSC), with the latter representing the Universities of Central Lancashire, Keele, 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 (GU), the University of Canterbury (UCN) and the University of North Carolina (UNC), as well as the University of Nottingham of the UKSC, 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.

ABOUT SALT

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

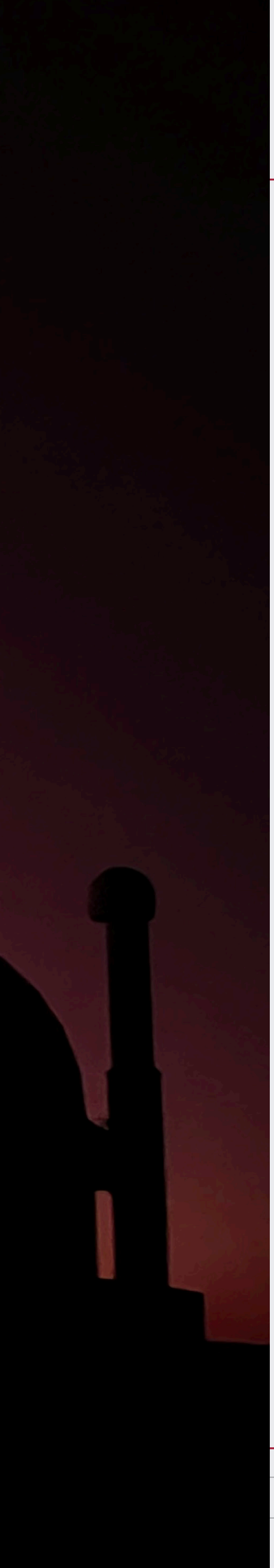
Drive human capital development and science engagement

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.



3

CHAIRMAN'S OVERVIEW



CHAIRMAN'S OVERVIEW

2022 was an exciting year for SALT, with the arrival of a new instrument at the telescope and the return to normal operations as COVID-19 restrictions were relaxed. It was a banner year for publications, with a record of 68 refereed papers which used SALT data. Highlights of a number of these publications are presented throughout this report and represent the diverse array of projects which can be done with SALT's general purpose instruments.

The fibre fed near-infrared spectrograph NIRWALS (NIR WAshburn Labs Spectrograph) saw first light on 7 July. This first commissioning run was successful, though it did identify an issue with the facility's glycol cooling (related to South Africa's electric power load-shedding) and the relative positioning of the sky and object fibre bundles. Work to diagnose and solve these issues is ongoing, and it is anticipated that the next commissioning run for NIRWALS will be in April.

In other instrument development news, good progress is being made on the laser frequency comb (LFC) for HRS. All of the hardware components required to build the LFC have been procured and have arrived at SAAO in Cape Town. Assembly of the LFC should be completed in 2023, and it is anticipated that the LFC will be operational in 2024. The LFC will provide precision wavelength calibration for the high stability mode of HRS, which should enable radial velocity measurements with meters per second accuracy.

In November, the board met in Cape Town for the first time in five years and took the opportunity to visit Sutherland and see the telescope in person. At this board meeting, three new directors from South Africa were appointed and welcomed to the board: Drs Vanessa McBride, Sharmila Goedhart and Itumeleng Monageng. This raises the number of South African board members to four, in recognition of the larger role the National Research Foundation has taken in paying operating costs of the telescope over the last several years.

Staffing remained a challenge in 2022, but the hiring of several highly qualified individuals has helped to maintain SALT's productivity. The board is extremely grateful for all of the hard work by the staff over the last few years. COVID-19 restrictions required considerable changes in the operations of SALT, which were enabled by our dedicated staff. The board expressed its appreciation for the dedication and hard work of all of the staff during the pandemic by co-hosting an end of year holiday party.



Prof. Brian Chaboyer
Chairperson, SALT Board





4

SALT 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 ~$2890/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 ~$3860/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 (~$10M) 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/**

SALT PARTNERS

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 MeerKAT initiatives spurring much of this growth. The entire South African community has access to SALT. There are now over two hundred PhD astronomers, and students are encouraged to participate in SALT projects and to propose for time. 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. 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 and galaxy evolution (particularly understanding the fuelling of star formation and recycling of gas in the baryon cycle). 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 HRS.

SALT Board members:
Vanessa McBride, SAAO/OAD
Fulufhelo Nelwamondo, NRF
Sharmila Goedhart, SARAO
Itumeleng Monageng, SAAO/UCT

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 2022, the astronomy group comprised nine faculty, four emeritus faculty, five postdoctoral associates (including an LSSTC Catalyst Fellow), and 26 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 (FP) 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 (SN) explosions, observing mostly type Ia SNe 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 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 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.



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

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.

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.

SALT Board member:
Jack Hughes

SALT PARTNERS

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 international astronomical organisations. About 250 astronomers are employed at six separate universities and two institutes of the Polish Academy of Sciences (PAS). Some of these form the Polish SALT Foundation, which has a 10% share in the construction and running costs of SALT. There are five main SALT partner institutions.

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. It is the coordinator of the SALT project, with M. Sarna being Poland's Board director. He has been highly active in the Board and other SALT committees. J. Mikołajewska is a member of the STC, being highly involved in several SALT committees. At present 70 scientists are working at CAMK along with 41 PhD students. They are involved in a number of major international observational projects (*e.g.*, CTA, *Athena*, SALT, LIGO-VIRGO, BRITE), and collaborate with scientists all over the world. A very important observation project is Araucaria with the principal aim to provide an improved calibration of the local extragalactic distance scale. CAMK's participation in the project is lead by G. Pietrzyski. Collaborations on SALT science (mostly with SAAO and AMNH) include: the search for symbiotic stars 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. SALT data is used in 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, located in Piwnice village, 15 km north of Toruń, is home to a VLBI station and a few optical instruments. The telescopes are used mainly for student training and modest research projects. SALT researchers 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 (Poland and 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 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 (with a coronagraph located near Wrocław) and on pulsating stars (with SALT among others). Satellite observations also play an important role in these investigations.

SALT Board member:
Marek Sarna, CAMK



The Shattuck Observatory on campus.

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 six faculty members, two post-doctoral fellows and about ten graduate students.

SALT Board member (chair)
Brian Chaboyer

SALT PARTNERS

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.

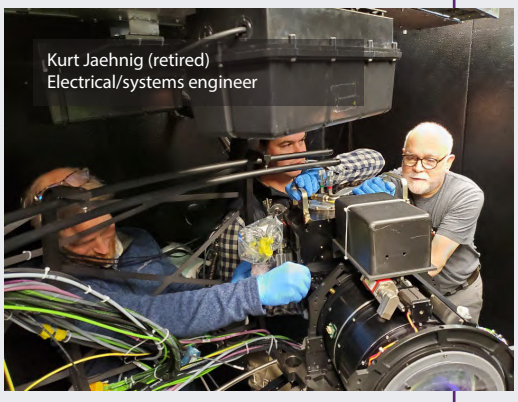
One of two doctorate-granting universities in the University of Wisconsin System, UW–Madison has the specific mission of providing "a learning environment in which faculty, staff and students can discover, examine critically, preserve and transmit the knowledge, wisdom and values that will help ensure 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 (RSS). Washburn Labs recently completed and delivered a near-infrared, integral-field spectrograph for SALT, called NIRWALS. The Washburn Labs team is working with SALT engineers and astronomers to commission the instrument for use in 2023. UW–Madison plans to undertake large surveys with this new facility instrument.

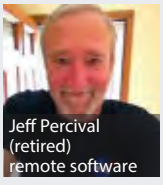
Wisconsin astronomers have traditionally used SALT to understand the kinematics and distribution of ionised gas in and around galaxies, the stellar content and dynamics of nearby galaxy discs, as well as for redshift surveys to measure the distribution of mass in galaxy clusters. Recently, there is increasing interest in high-resolution spectroscopy of multiple stellar systems. With the rapid growth in recent years of a now-large, inter-disciplinary exoplanet group across departments in Astronomy, Chemistry, Physics, and Atmospheric Sciences, there is an anticipated high demand for high-stability spectroscopy for identification and characterisation of exoplanet systems.

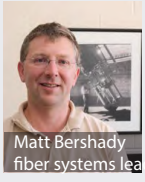
SALT Board member:
Matthew Bershady

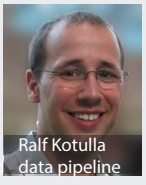












Inter-University Centre for Astronomy & Astrophysics (India)

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 used 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 NIRWALS spectrograph.

SALT Board member:
Somak Raychaudhury

View of IUCAA's campus.



SALT PARTNERS

UK SALT Consortium

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



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. UKSC has successfully hosted a half-dozen SALT–Stobie scholarships, greatly enhancing the production of SA astronomy PhDs. From 2018 – 2020, the "Global Challenges" research funding was used 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, has been active in other SALT committees, currently as a member of FAC. UCLan has made extensive contributions to the SCBP, has hosted successful SALT–Stobie scholarships, has provided UCLan's distance learning university-level Astronomy courses (at discounted rates) for SALT staff, and is supporting visiting graduate students. SALT science interests involve collaborations within UKSC (with Keele and Armagh) and with SA (mostly 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 catastrophically disintegrating planets, to studies of variable star populations and unique individual variables from SuperWASP (A. Norton, M. Lohr). Norton has recently focussed on 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", which combines *Herschel* wide-area sub-mm observations with multi-wavelength ancillary data to generate the largest (> 500) sample to date of homogeneously selected lens candidates, 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, with 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. AOP is now the UKSC administrating institution.

At **Keele University**, J. van Loon's interests in SALT have been to exploit the RSS-FP 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 High School.

The **University of Nottingham** left the consortium in 2021. It had had significant involvement in SALT administration (UKSC Board director for four years and Chair of the FAC for three years), as well as part-time funding a post-doc and two graduate students to work on technical and software development for SALT in its early years.

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-LSP "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. 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

The American Museum of Natural History (USA)

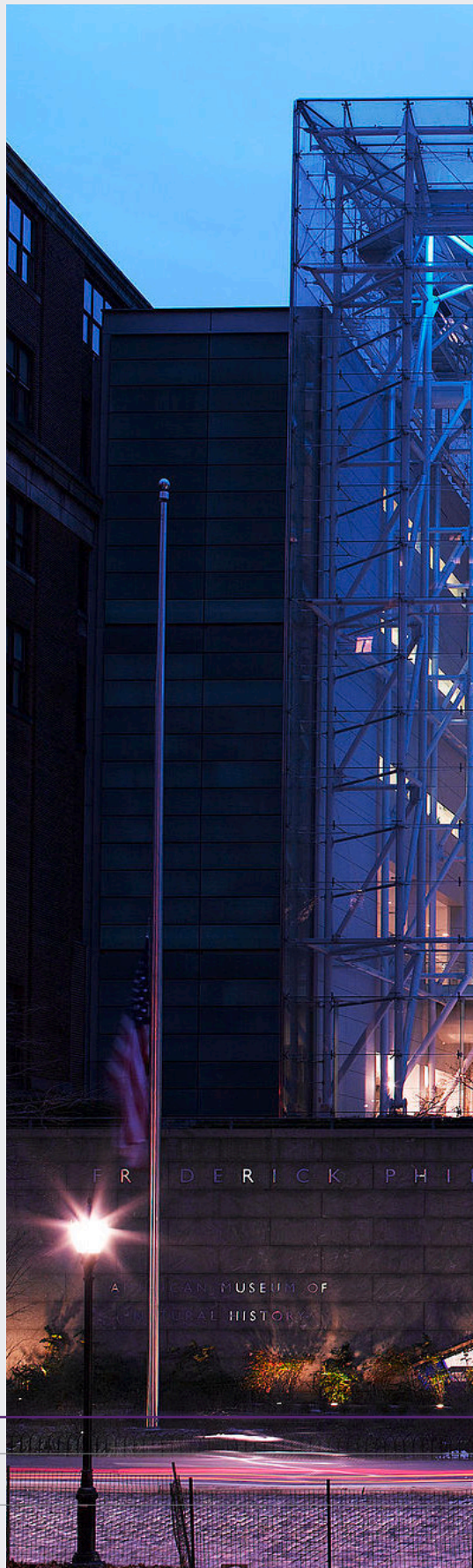
The American Museum of Natural History (AMNH) is one of the world's preeminent scientific and cultural institutions. Since its founding in 1869, the Museum has advanced its global mission to discover, interpret, and disseminate information about human cultures, the natural world, and the Universe through 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 been published in 2022, and SALT/HRS is now being used to confirm a second planetary signal from this survey. J. Faherty is interested in brown dwarfs and has recently obtained SALT spectroscopy on objects newly identified in a citizen science project.

SALT Board member:
Michael Shara



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

SALT PARTNERS





Image credit: Taken from the Legacy Survey image resource



5 SCIENCE HIGHLIGHTS



5.1 SCIENCE HIGHLIGHTS

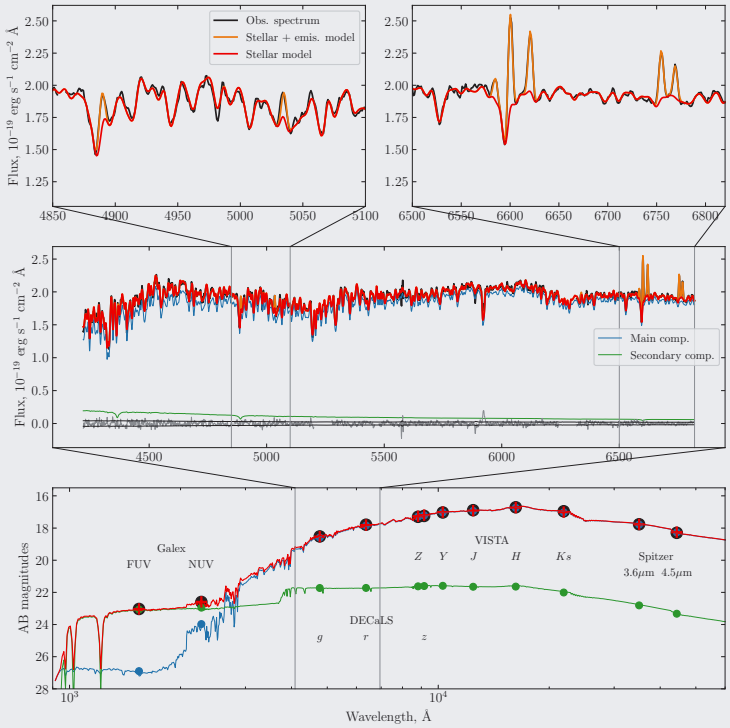
Extragalactic astronomy

NGC 254: A double-ringed S0 galaxy with counter-rotating gas

Katkov, I. Y., et al. 2022/02, A&A 658, A154: Star formation in outer rings of S0 galaxies. IV. NGC 254: A double-ringed S0 with gas counter-rotation

Galaxies are a very diverse class of astrophysical objects and exhibit a variety of physical properties and morphological shapes. The main research objectives of galaxy physics are to identify the main physical processes that lead to a variety of observational properties. Ivan Katkov from New York University in Abu Dhabi decided to study lenticular, or S0, galaxies with very prominent morphological features — rings. Lenticular galaxies, that is, disc galaxies without spiral arms, were introduced by Edwin Hubble in 1936 as a transitional type between elliptical and spiral galaxies. Outer rings are a common attribute of S0 galaxies. The imaging statistics reveal that about half of the S0 – S0/a galaxies possess outer stellar rings. Among these, about 50% are also detected in the UV-bands, suggesting recent star formation with probably some amount of gas to fuel this star formation. The origin of the cold gas in S0 is still debated: although it is present in most S0 galaxies, its rotation is often decoupled from that of the stellar component, especially in an isolated environment. This suggests a recent external accretion of gas from an arbitrary direction. However, the conditions provoking star formation in the gas accreted by S0 are not fully understood yet.

Katkov and his colleagues investigated the beautiful double-ring galaxy NGC 254 by combining deep long-slit spectroscopic data from SALT/RSS with images taken from publicly available archives. They found that the ionised gas rotates in the opposite direction to the stars, indicating its external nature. They suggest a scenario of quite recent (about 1 Gyr ago) outer gas accretion from a retrograde orbit by a previously gas-rich disc galaxy. As a consequence of this event, the primary, co-rotating gas of the galaxy has lost its momentum and has fallen into the centre, feeding the stellar nucleus rejuvenation and AGN activity. The slightly disturbed morphology of the galaxy also suggests that a merger happened in the past. Using an advanced technique of simultaneously modeling the optical spectrum and the broadband photometry, the team found that the externally accreted counter-rotating gas formed two star-forming rings, contributing, to date, ~1% to the local stellar density. The authors' spectro-photometric approach has broadened the horizon regarding the revision of the frequency of large-scale stellar counter-rotation phenomena.



See image page 24 – 25
Galaxy NGC 254 and its environment, in composite colours, taken from the Legacy Survey image resource.

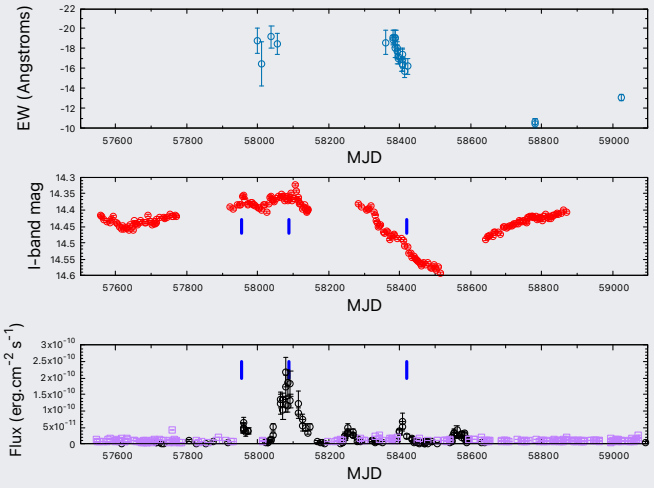
Left: Result of two-component spectro-photometric modeling of the spatial bin at R = +18 ± 3". *Middle* and *top*: spectrum (black) and best-fit spectral model (red). Blue and green depict two stellar components of the model. Orange lines highlight the emission-line model. Residuals are grey with the error levels in black. Bottom: SED of the model with observed magnitudes (black) and the best-fit SED model (red). Blue and green circles correspond to SED models of individual components whose low-resolution spectra are shown by coloured lines.

SALT disentangles the neighbouring pulsars SXP 15.3 and SXP 305

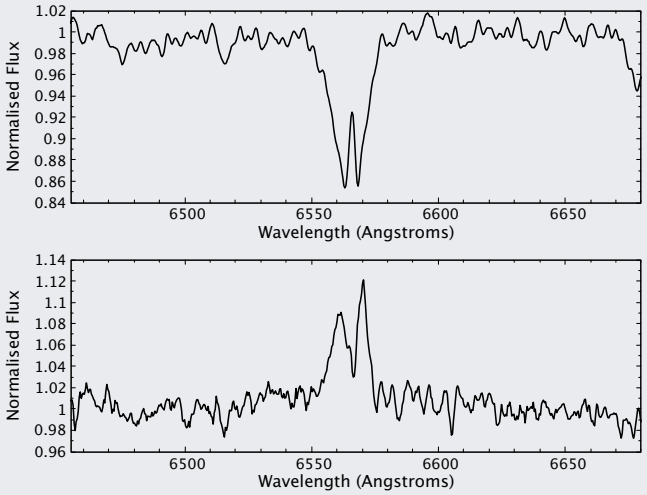
Monageng, I. M., et al. 2022/04, MNRAS 511, 6075: Disentangling the neighbouring pulsars SXP 15.3 and SXP 305

Be X-ray binaries (BeXRBs) make up the largest subclass of high-mass X-ray binaries and comprise a massive early B-type donor star ("Be" star) and an accreting degenerate compact object (either a neutron star or black hole) in an eccentric orbit. The Be star has a geometrically thin Keplerian disc that supplies the matter that is accreted by the compact object, resulting in X-ray outbursts. The X-ray outbursts in BeXRBs are generally separated into two flavours: type I (or normal, with luminosities < 10^{37} erg/s) and type II (or giant, with luminosities > 10^{37} erg/s). The variable Be disc behaviour is traced through the infrared excess and emission lines in the optical spectra, the strongest and best studied of which is the Hα line. The Small Magellanic Cloud (SMC) hosts a significant fraction of the BeXRB population, which makes it an ideal laboratory to study various aspects of them. The *Swift* SMC Survey (S-CUBED) is an X-ray programme that uses the *Swift* X-ray telescope to monitor the SMC at a high cadence and covers the full optical extent of the galaxy weekly.

Itumeleng Monageng (SAAO/UCT) and his colleagues (mainly from the University of Southampton and Pennsylvania State University) studied two SMC BeXRBs, SXP 15.3 and SXP 305, that are spatially separated by 7 arcseconds. Previous studies of these sources has led to confusion about the origin of the emission as a result of the small separation. Data obtained from the S-CUBED programme showed repeating outbursts coming from the combined region of the two sources, the origin of which was unclear. The team monitored these two sources with SALT/RSS to study the variability of the Hα emission line from their Be discs. Combining them with photometric fluxes from OGLE, they demonstrated that the size and structural changes in the Be discs are such that the X-ray outbursts originate from SXP 15.3. They also explored the timing at the different wavelengths, which shows the optical outburst profile modulated at twice the frequency of the X-ray outbursts. This unusual behaviour is proposed to be due to complex geometric orientations of the Be disc and neutron star orbital plane.



Long-term Hα equivalent width (top panel) and OGLE I-band (middle panel) light curves of SXP 15.3, together with the S-CUBED light curve of the combined field of SXP 15.3 and SXP 305. The black circles in the bottom plot indicate detections while the purple squares indicate upper limits. The blue markers indicate the epochs of the 15-second pulse period detections.



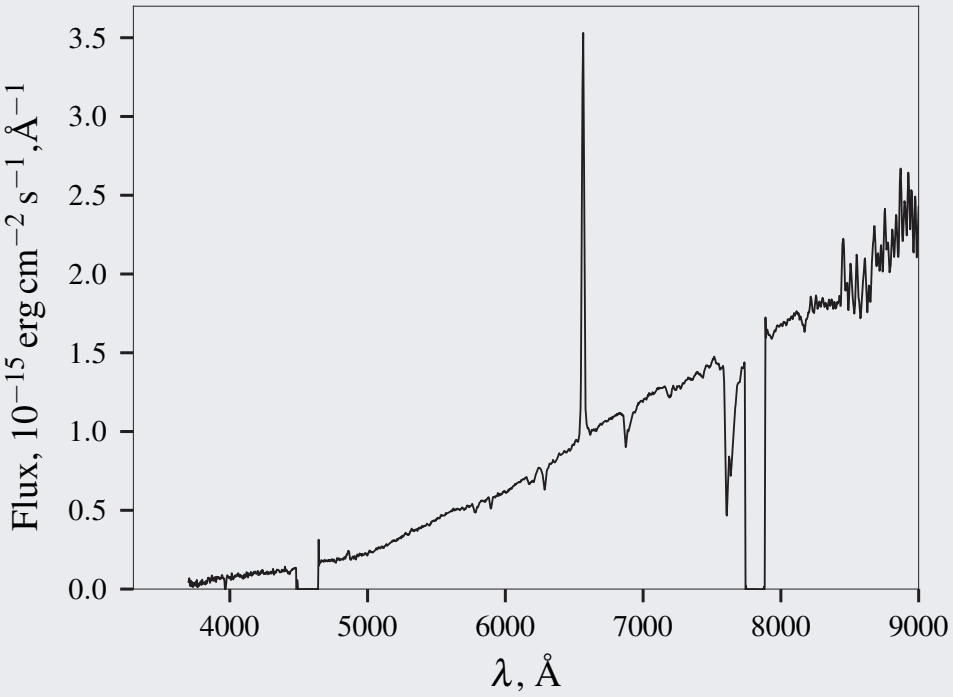
Hα line of the optical counterpart of SXP 305 from SALT. The profiles were obtained on 29 October 2019 (top) and 25 June 2020 (bottom).

New X-ray pulsar discovered in the eROSITA all-sky survey

Doroshenko, V., et al. 2022/05, A&A 661, A21: SRGA J124404.1-632232/SRGU J124403.8-632231: New X-ray pulsar discovered in the all-sky survey by the SRG

The primary goal of the *Spectrum Roentgen Gamma* (*SRG*) X-ray satellite mission, launched in July 2019, is to conduct the most sensitive X-ray survey to date. In particular in the soft part of the band covered by the eRosita instrument (0.2 – 10 keV) the sensitivity is improved by a factor of 20 – 40 compared to *ROSAT*, which of course implies that many thousands of new X-ray sources are being discovered. Based on the eRosita data, the team around Victor Doroshenko from Tübingen, Germany, have identified several candidate X-ray binaries for dedicated follow-up observations. One such candidate, SRGA J124404.1–632232, has been observed with *NuSTAR*, *Swift*, and SALT and was indeed confirmed as a new Be X-ray binary. Data from *NuSTAR*, eRosita and ART-XC (the second instrument onboard *SRG*) allowed the team to investigate the X-ray spectrum of the source in a broad energy band, and *NuSTAR* data also allowed a search for possible pulsations. As a result, a highly significant coherent pulsed signal with a period ~538 s was found, thereby establishing the object as a new X-ray pulsar.

Inspection of archival Vista VVV data and dedicated follow-up observations with SALT of the region around eROSITA's X-ray position (conducted as part of the "Observing the Transient Universe" programme, PI David Buckley), allowed the team to identify a plausible optical counterpart of the pulsar. The SALT spectroscopy revealed the presence of a prominent Hα emission line, thereby confirming the identified counterpart and establishing the binary as a new BeXRB. Inspection of the available archival OGLE data for the counterpart helped to identify a tentative orbital period of the system of ~138 days. The observed equivalent width of the Hα line at the time of the SALT observation seems to be consistent with this identification. The results of the analysis of SALT (led by team members at SAAO) and X-ray data (led by the eRosita consortium) were published in a special issue of Astronomy & Astrophysics dedicated to the Early Data Release of eROSITA and Mikhail Pavlinsky ART-XC on the *SRG* mission.



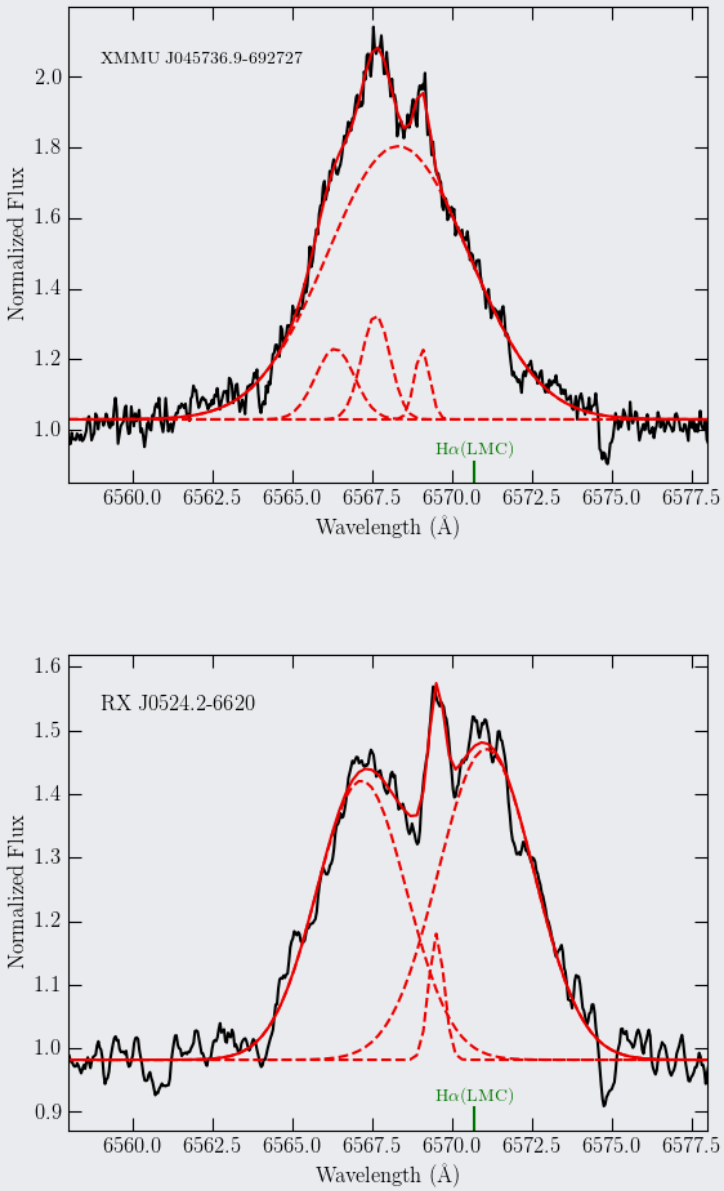
SALT/RSS spectrum of the identified optical counterpart of SRGA J124404.1–632232 with the prominent Hα emission line.

SALT reveals structures in their circumstellar discs of new Be/X-ray binaries in the LMC

Haberl, F., et al. 2022/06, A&A 662, A22: Three new high-mass X-ray binaries in the Large Magellanic Cloud

The Magellanic Clouds (MCs) offer a unique laboratory to study the population of high-energy sources in a system of interacting galaxies. The most numerous hard X-ray sources in the MCs are high-mass X-ray binaries (HMXBs). In Be/X-ray binaries (BeXRBs), a subclass of HMXBs, the Be star ejects matter in the equatorial plane, leading to the formation of a circumstellar decretion disc. In most BeXRB systems a neutron star accretes matter from this disc, which powers X-ray emission. Highly sensitive X-ray telescopes provide the best tools to discover BeXRBs, not only in the Milky Way, but also at distances of the Magellanic Clouds.

Frank Haberl and Chandreyee Maitra (Max Planck Institute for Extraterrestrial Physics, Germany) with their collaborators obtained SALT/HRS spectra of two new BeXRB pulsars, which they discovered in their *XMM-Newton* observations of LMC fields. Strong Hα emission lines confirm the BeXRB nature of the two objects. Modeling of the highly structured lines allowed the authors to infer constraints on size and inclination of the circumstellar discs. The complexity of the lines is probably caused by the presence of the neutron star, which likely leads to additional distortions of the circumstellar disc.



SALT/HRS spectra of XMMU J045736.9−692727 (left) and RX J0542.2−6620 (right) around the Hα line.
The spectrum of RX J0542.2−6620 is smoothed using a rolling average filter with kernel size 5 and the narrow central line is a residual feature from sky background subtraction. The green vertical line indicates the wavelength shifted to the rest system of the LMC.

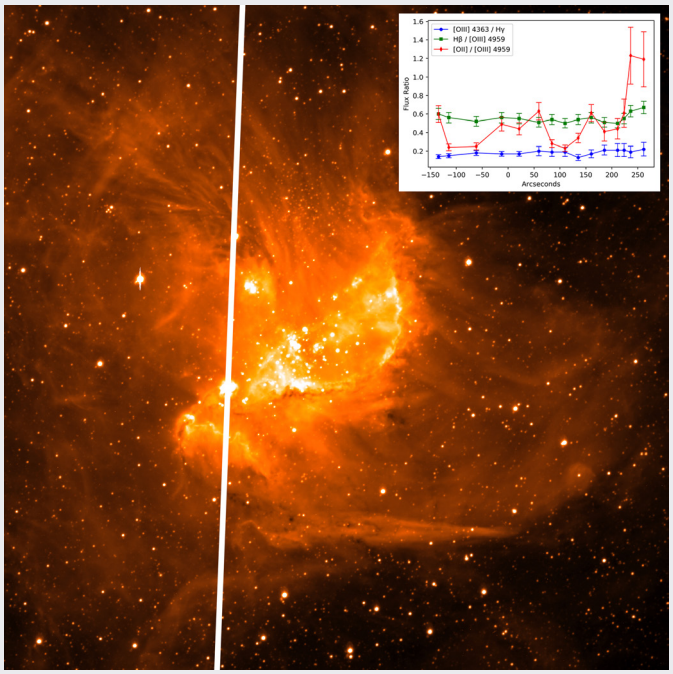
Ionisation and star formation in the giant [H II] region SMC–N66

Geist, E., et al. 2022/06, PASP 134, 064301: Ionization and Star Formation in the Giant H II Region SMC-N66

[H II] regions are regions of space where hydrogen gas is ionised by the radiation from massive, young stars. The physical structure of [H II] regions can be affected by phenomena like stellar winds and supernovae. An interesting process can occur in [H II] regions when the ionising radiation from massive O stars leaks outside the bounds of the [H II] region and influences the surrounding host galaxy.

A great example of such an [H II] region is N66 in the Small Magellanic Cloud (SMC). It is powered by a star cluster named NGC 346 that contains numerous young and bright O stars that are delivering ionising radiation into their surroundings, producing the N66 [H II] region. N66 is the largest star forming site in the SMC, with a diameter of ~150 parsecs and at least 50 O-type stars. Due to these conditions, N66 offers an excellent opportunity to measure the properties of a very young [H II] region in a low-metallicity dwarf galaxy. It is also beneficial in studying the balance between stellar H-photoionisation rates, nebular recombination rates, and mid-infrared emission. Importantly, this [H II] region also has the potential for leaking ionising photons into the SMC. If this is the case, it would be significant because NGC 346 contains a large fraction of the total O-star population in the SMC.

Emily Geist and her co-authors took long-slit spectra of N66 with SALT/RSS that offered critical sensitivity to the near-UV spectral region since it was essential to measure the [O II] emission line at 3727Å. The spectra were flat-fielded and bias-corrected. The observed ratio of I(Hβ) / I(Hα) remains constant to better than 10% along both of the SALT slits. This implies that the level of interstellar obscuration is fairly constant across much of the nebula, and the structure of the nebula is not strongly affected by dust obscuration. The data show that ionised gas extends over the full area of the nebula, with a decrease in F([O III]) / F([O II]) and F(Hβ) / F([O III]) only at the very end of the slit.



The team positioned the SALT spectrograph slit to cross the outer boundary of the N66 [H II] region that was defined from multi-wavelength images. The ratio of I([O II]) / I([O III]) sharply increases in the northern edge of the nebula. This could be a result from the nebula being matter-bounded in that area, or running out of ionising photons to make a diffuse ionisation front that bounds this region. The line ratios in this transition zone vary in ways that are consistent with a declining contribution from emission lines in N66 and an increasing component from diffuse ionised gas in the SMC. This result suggests that diffuse ionising radiation escapes from N66. However, given the limited coverage provided by the existing data, further observations are required to confirm whether the N66 nebula leaks ionising radiation.

Image of the N66 region taken with a narrow-band Hα filter at the VLT. North is up and east is to the left. The solid white line on the image marks the 8' length of the north-south slit used to obtain emission line ratios from the SALT spectra. The graph in the upper-right corner of the image shows the emission line ratios running from south to north.

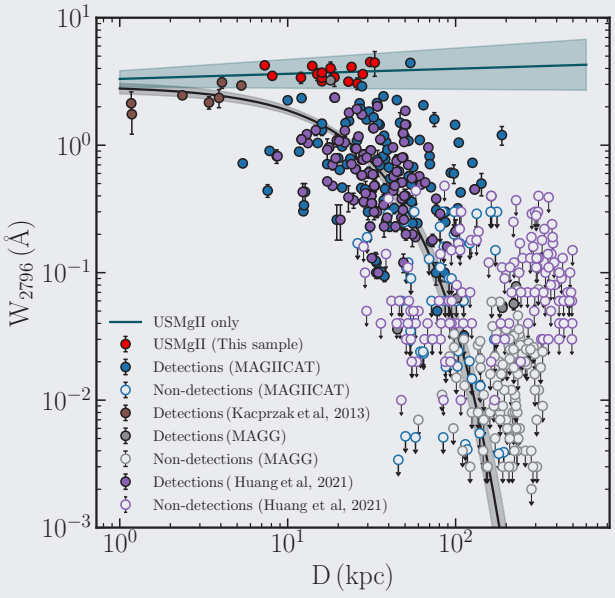
Probing large scale gas flows with strong [Mg II] absorption systems

Guha, L. K., et al. 2022/07, MNRAS 513, 3836: Host galaxies of ultrastrong Mg II absorbers at z 0.5

According to our current understanding of galaxy formation and evolution, galaxies evolve through a slowly varying equilibrium between gas accretion from the intergalactic medium (IGM), large-scale winds to the circumgalactic medium (CGM), and the in-situ star formation in the galactic disc. Galactic-scale outflows with velocities of ~100 km/s, probed by 'down-the-barrel' low-ionisation (*e.g.*, [Mg II] and [Fe II]) absorption lines, are ubiquitous in high-redshift star-forming galaxies. Probing star-forming galaxies using background quasar sight lines at very low impact parameters (*e.g.*, within the regions influenced by winds over a characteristic time-scale of star formation) can provide vital clues as to the role played by large-scale winds in shaping the physical conditions of the CGM. As it turns out, there are two independent ways to pick such quasar-galaxy pairs (QGP) – a) Ultra-Strong [Mg II] absorption systems (USMgII) and b) Galaxies On Top of Quasars (GOTOQ).

USMgII systems are defined as the [Mg II] absorption systems with the rest equivalent width of [Mg II] λ2796 (W_{2796}) line ≥ 3Å, corresponding to Δv > 320 km/s, which makes the USMgII systems an ideal tracer of the large-scale gas flows operating around the galaxy. Given the anti-correlations between W_{2796} and the impact parameter D, the USMgII systems are expected to have very small impact parameters. The SDSS fibre-fed spectroscopic observations register photons from all the objects that fall within the fibre, which can allow the detection of nebular emissions associated with the [Mg II] absorption. Such QGPs are known as GOTOQs and, by construction, have extremely small impact parameters (D ≲10 kpc). Since the background quasar sight lines pass through within about ten kpc from the star-forming discs of the [Mg II] absorbing galaxies, these systems provide excellent examples to probe the star-burst-driven galactic winds.

Using SALT over the past few years, Labanya Guha and R. Srianand (IUCAA) with their collaborators have been carrying out a large survey to understand the role of large-scale galactic winds on galaxy evolution using pre-defined samples of the USMgII systems and GOTOQs. To understand the nature of the USMgII host galaxies in the redshift range z = 0.4 – 0.6, they have compiled a sample accessible by SALT, using the SDSS [Mg II] / [Fe II] absorber catalogue. It comprises 27 USMgII systems out of which 21 have been observed with SALT, resulting in 18 with USMgII host galaxies identified. The range of impact parameters found (7 kpc to 79 kpc, with a median value of 17 kpc) is much larger than the value predicted by the W_{2796} vs D relationship for the general population of [Mg II] absorbers: At a given D, USMgII host galaxies are more luminous and massive than typical [Mg II] absorbers. However, the measured star formation rates are slightly lower than that of main-sequence galaxies with the same M^* at z ~ 0.5. The team reports a correlation between $L_{[O\ II]}$ and W_{2796} for the full population of [Mg II] absorbers, driven mainly by the host galaxies of weak [Mg II] absorbers that tend to have low $L_{[O\ II]}$ and large impact parameters. They find at least 33% of the USMgII host galaxies (with a limiting magnitude of $m_r \leq 23.6$) are isolated, and the large W_{2796} in these cases may originate from gas flows (infall/outflow) in single halos of massive but not starburst galaxies. Galaxy interactions could be responsible for large velocity widths in at least 17% of cases.



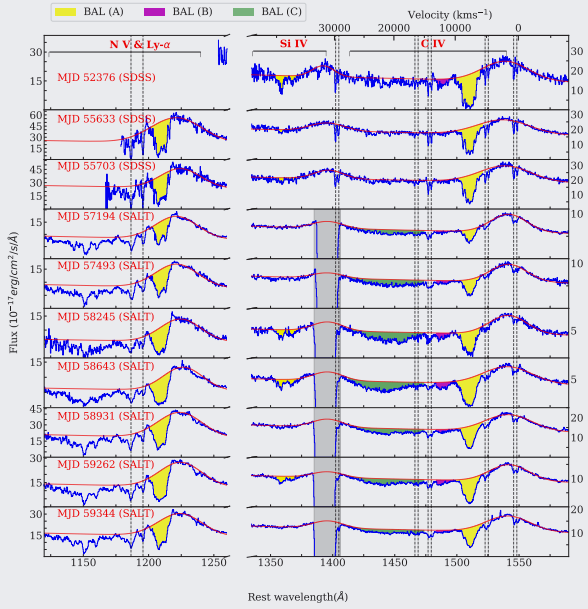
Scatter plot of W_{2796} vs D. SALT observations are shown in red. Black and cyan-green solid curves with shaded regions show the best fit and errors for the full sample and USMgII systems, respectively. There is evidently no anti-correlation between W_{2796} and D for the USMgII absorbers.

Coordinated time variability of multi-phase ultra-fast outflows in a BAL quasar

Aromal, P., et al. 2022/08, MNRAS 514, 1975: Coordinated time variability of multi-phase ultra-fast outflows in J132216.25 + 052446.3

PhD student P. Aromal from IUCAA, with his collaborators, has analysed the interesting broad-absorption line (BAL) quasar J132216.25+052446.3 (or J1322+0524) for the following reasons: (i) Presence of a BAL component consisting of multiple narrow absorption features that are separated roughly by [C IV] doublet splitting (such a signature, usually referred to as 'line-locking', is considered evidence for line-driven acceleration in disc wind models). (ii) Emergence of a very high-velocity flow (with ejection velocities in the range 15000 – 28000 km/s) revealed by [C IV] and [N V] absorption. Absorption with such large velocities and spread are expected in standard disc-wind models. Thus this component could represent newly ejected material from the accretion disc, in contrast to the transverse motion of clouds usually invoked to understand newly emerged absorption. (iii) Availability of ten epochs of spectroscopic monitoring data spread over 19 years and good ZTF photometric coverage over the last 5 epochs (with at least one spectrum per year) provides the chance to constrain different time-scales related to this BAL quasar. (iv) Presence of apparently correlated variability between different BAL components and the [C IV] broad emission line.

Aromal performed the time variability analysis of BALs (spread over the velocity range of 5800 – 29000 km/s) in the spectrum of J1322+0524 (z_{em} = 2.04806) over 19 years. The strongest component (BAL-A; 5800 – 9900 km/s) with 'line-locking' signatures, shows correlated optical depth variability in the [C IV], [N V] and [Si IV] absorption without major changes in the velocity structure. A very broad and shallow absorption (BAL-C; 15000 – 29000 km/s) emerged during the monitoring period, coinciding with a dimming episode. All the identified absorption lines show correlated variability with the equivalent widths increasing with decreasing flux. Together with the [C IV] emission line variability, this is consistent with ionisation being the main driver of the correlated variability. The observed UV-continuum variations are weaker than what is required by the photoionisation models. This, together with a scatter in the [C IV] equivalent width at a given continuum flux, can be understood if variations of the [C IV] ionising photons are much larger than that of the UV continuum, the variations in the ionising photon and UV fluxes are not correlated, and/or the covering factor of the flow varies continuously. In conclusion, the authors suggest BAL-A is produced by a stable clumpy outflow located beyond the BAL region and BAL-C is a newly formed wind component located near the accretion disc, both responding to changes in the ionising continuum.



Continuum fits (red) to the rest frame spectra (blue) of J1322+0524 (with respect to z_{em} = 2.0498). Vertical dashed lines indicate different narrow absorption lines. Absorption line variability of broad components (shaded regions) are apparent. The velocity scale for [C IV] BAL with respect to the systemic redshift is provided at the top. Grey shaded regions represent the CCD gaps in SALT spectra.

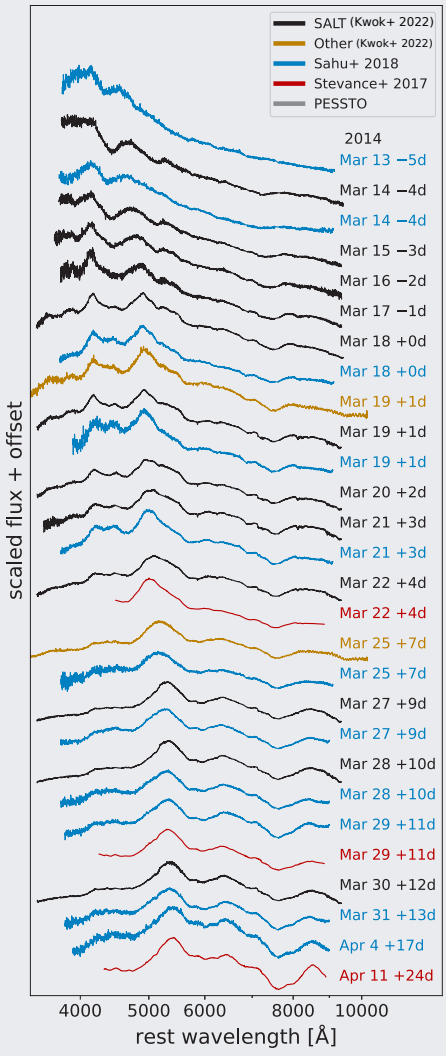
Optical SALT and ultraviolet HST observations of SN 2014ad

Kwok, L. A., et al. 2022/09, ApJ 937, 40: Ultraviolet Spectroscopy and TARDIS Models of the Broad-lined Type Ic Supernova 2014ad

Some very massive stars lose part or all of their outer layers of hydrogen and helium before they collapse, perhaps due to stripping from powerful stellar winds or a binary companion, resulting in type Ic supernova (SN Ic) explosions. A rare and extreme variant of SN Ic, called broad-lined SN Ic (SN Ic-bl), exhibits the customary lack of hydrogen and helium in their spectra but displays distinctive and exceptionally broad, blended spectral features. These Doppler-broadened features are caused by high, relativistic velocities nearing 10% of the speed of light. The excess energy that drives the high velocities is thought to be supplied by a central engine such as an accreting black hole or a magnetar, a rapidly spinning neutron star with strong magnetic fields. When the central engine launches high-energy collimated jets, a gamma-ray burst (GRB) can be associated with the SN Ic-bl. These rare SNe are the only SN type directly observed to have GRB counterparts; however, not all SN Ic-bl have associated GRBs, and we do not fully understand why. Potential explanations include GRB jets that are off-axis from our line-of-sight or lower energy jets that are smothered by thick surrounding material, which is then accelerated to the high velocities we observe.

Analysis of the spectra of these SNe is essential to understand the different physical conditions that give rise to regular SN Ic, SN Ic-bl, and SN Ic-bl with GRBs. Over time, as the SN ejecta expands and dilutes, light escapes from interior regions so we can see deeper into the SN. When modeled, this spectral time series can reveal important information about the structure of the ejected material's velocity, temperature, density, and elemental composition, all of which provide clues about its progenitor system and energy sources.

SN 2014ad, an SN Ic-bl without an associated GRB, has a rich spectral dataset, making it an excellent object for detailed study. Rutgers PhD student Lindsey Kwok led a publication presenting the first ultraviolet (UV) spectra of a SN Ic-bl from HST, nicely complemented by near-infrared (NIR) spectra and by optical spectra from SALT, which span almost 120 days and account for 40% of all spectra. Kwok and her collaborators found that the UV spectra of SN 2014ad do not show strong features and they measure ejecta velocities that are even higher than most SNe Ic, both with and without observed GRBs. Using a Monte-Carlo radiative transfer spectral synthesis code, they modeled the UV+optical spectra and found that high densities at high velocities (large radii) were required to reproduce the observed spectra. This in turn suggested a higher total ejecta mass than previously estimated from analysis of the SN's light curve (total brightness vs time). Fits to the late-time nebular spectra (>150 days), when the ejecta is so dilute that the light streams freely from all interior regions of the SN, revealed that the emission is centrally concentrated. To avoid unrealistically high total masses, the team suggests that the density profile may flatten at low velocities (corresponding to small radii), and the nebular emission may be explained by excess emission from the central engine.



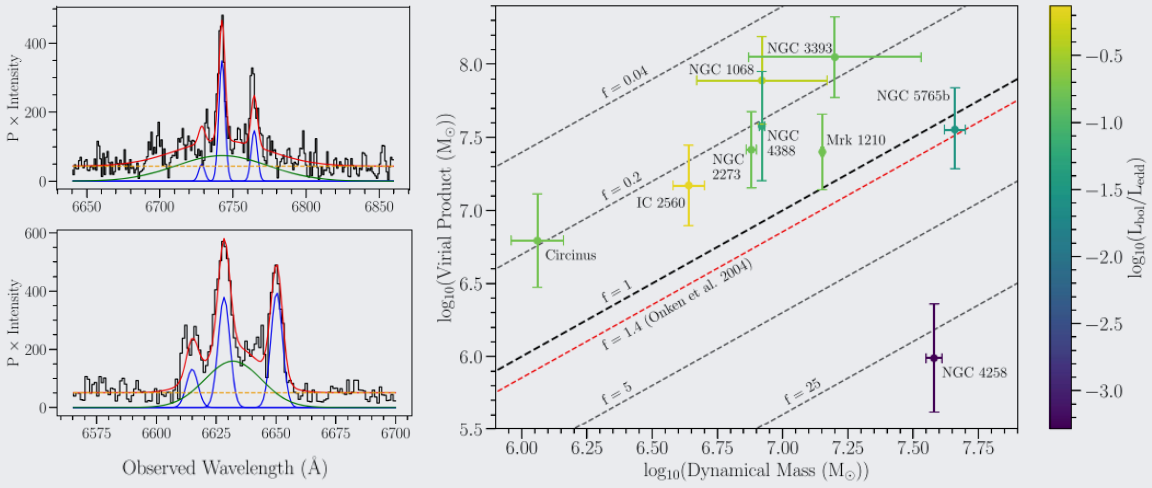
Examples of optical spectral time series of SN Ic-bl 2014ad. SALT spectra are shown in black. The wavelength axis is redshift-corrected to the host-galaxy's rest frame. The fluxes have been corrected for total reddening and are scaled and vertically shifted for clarity.

SALT spectropolarimetry of hidden broad lines in nearby megamaser galaxies

Linzer, N. B., et al. 2022/10, ApJ 937, 65: Spectropolarimetric Measurements of Hidden Broad Lines in Nearby Megamaser Galaxies: A Lack of Clear Evidence for a Correlation between Black Hole Masses and Virial Products

Water megamasers are extremely luminous sources of 22 GHz radiation generated by the amplification of microwave signals through stimulated emission. They can be found within a few parsecs of the central supermassive black hole (BH) in active galactic nuclei (AGN). These masers may be used to probe the kinematics of this inner region and provide the most accurate measurement of the BH mass. Such measurements require excellent spatial resolution that is only achievable for galaxies within ~100 Mpc using present-day technology. At larger distances, BH masses are often estimated using single-epoch scaling relations for AGN. This method requires only the luminosity and the velocity dispersion of the broad-line region (BLR), to calculate a virial product, and an additional pre-factor to determine the BH mass. The accuracy of these single-epoch masses, however, is unknown, and there are few empirical constraints on the variance of this pre-factor between objects.

In her project, graduate student Nora Linzer from Princeton University, together with her co-authors, attempted to calibrate single-epoch BH masses using SALT/RSS linear spectropolarimetry of nine nearby megamaser galaxies with known disc dynamical BH masses. Among these nine objects, they found evidence of a hidden polarised broad line in three. Combining with other literature values, they compared the known dynamical mass and the virial product to calibrate single-epoch BH masses using the RSS spectra (left figure panels). The right figure panel shows that there is no strong evidence for a correlation between the virial products used for single-epoch masses (derived from the RSS spectra) and dynamical mass (probed by the water megamaser dynamics), either for the megamaser sample alone or when it is combined with dynamical masses from reverberation mapping modeling. Furthermore, there is evidence that the virial pre-factor *f* (dashed lines) varies between objects, but there is no strong evidence for a correlation with other observable parameters such as luminosity or relative accretion rate (as probed by the Eddington ratio of the BH). Although the team cannot definitively rule out the existence of any correlation between dynamical mass and virial product, they find tension between the allowed *f*-values for masers and those widely used in the literature. Linzer and her co-authors conclude that the single-epoch method requires further investigation if it is to be used successfully to infer BH masses.



Left panels: Polarised intensity spectra of NGC 5765b (top) and IC 2560 (bottom). The narrow lines are represented in blue, the constant background with a yellow dashed line, and the total fit in red. The fit includes an additional broad feature represented in green. *Right panel*: Comparison between the known dynamical mass and the virial product without including an *f*-factor. Each object is coloured by its Eddington ratio. The diagonal dashed lines represent the predicted BH masses from the virial product using different values of *f*. The centre, bold line has *f* = 1, and each line below (above) increases (decreases) *f* by a factor of 5. The red dashed line represents a standard value of *f* = 1.4 calibrated with the FWHM.

Wavelength-resolved reverberation mapping of quasar CTS C30.10

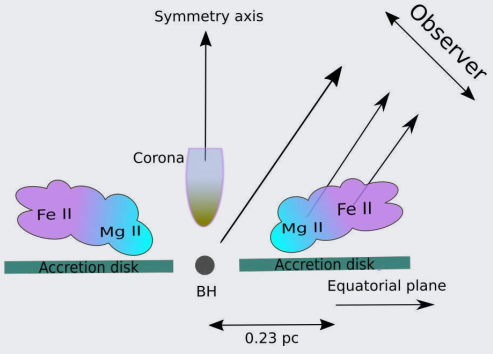
Prince, R., et al. 2022/11, A&A 667, A42: Wavelength-resolved reverberation mapping of quasar CTS C30.10: Dissecting Mg II and Fe II emission regions

The recent measurement of the Hubble constant in the local Universe, using SNe Ia, challenges the standard Λ-CDM cosmology: The measurement of H0 from the early Universe using the Planck data has a 4σ tension with the local measurement. The issue has become a key question for present-day astronomy and raised many serious questions regarding the standard cosmological model. However, before any conclusions about the need for new physics are drawn, improvements in the local measurements are clearly needed. To provide robust conclusions, we need to have many independent individual measurements of the Hubble constant, and we have to discuss carefully the biases that might be present in each method. AGN/quasars are the most luminous sources in our Universe, hosting a supermassive black hole that accretes matter from the surroundings. They cover quite a range of redshift, which makes them suitable for cosmological measurements.

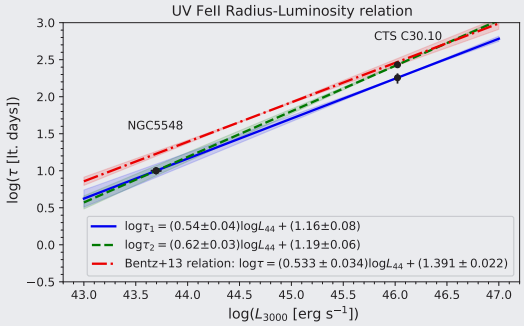
Reverberation mapping is a technique that has been extensively used to study the inflow and outflow in these sources and to measure the black hole mass by determining the time delays between continuum and line emission. Recently, this method has been proposed to be used also for cosmological studies. One of the results of the reverberation mapping is the radius–luminosity relation (R-L), where the size of the broad-line region (BLR), as measured by the time lag, is proportional to the bolometric luminosity of the AGN, $L^{0.5}$, resulting in a cosmologically independent luminosity distance, which can be used to estimate the expansion rate of the Universe.

For cosmological purposes, observations of high redshift quasars ($z \sim 1$) are needed, and SALT is ideal to observe sources at high redshift because of its large collecting area. A group around Bożena Czerny from the Polish Academy of Sciences has been monitoring a few high redshift bright quasars using SALT. Raj Prince from her team reports now the results for the quasar CTS C30.10, which was monitored for almost 12 years. While SALT provides the spectroscopy, photometric observations (crucial for reverberation mapping studies) come from other ground-based observatories.

Prince and his collaborators have constructed photometric (continuum) and spectroscopic (emission lines-based) light curves for their reverberation technique. In addition, they provide a wavelength-resolved reverberation mapping where the emission line is divided into multiple parts and the light curve created for each part. The time delay is measured using the emission lines and continuum light curves. The team investigated the inflow and outflow characteristics in the source and, based on the time-delay measurement of [Mg II] and [Fe II] emission lines, propose a possible scenario for the location of these clouds (see cartoon). The source has been added to the standard R-L diagram for the [Mg II] emission line. In addition, the R-L relation for [Fe II] pseudo continuum emission lines has been derived for the first time.



The schematic representation of [Mg II] and [Fe II] emission regions.



Preliminary R-L relation for the [Fe II] pseudo-continuum. Of the two time delay solutions for CTS C30.10, the longer time delay of 270 days is more consistent with a published R-L relation renormalised to the 3000 Å monochromatic luminosity. The shaded regions depict 1σ confidence intervals of individual R-L relations.



5.2

SCIENCE HIGHLIGHTS

Stellar and Galactic astronomy

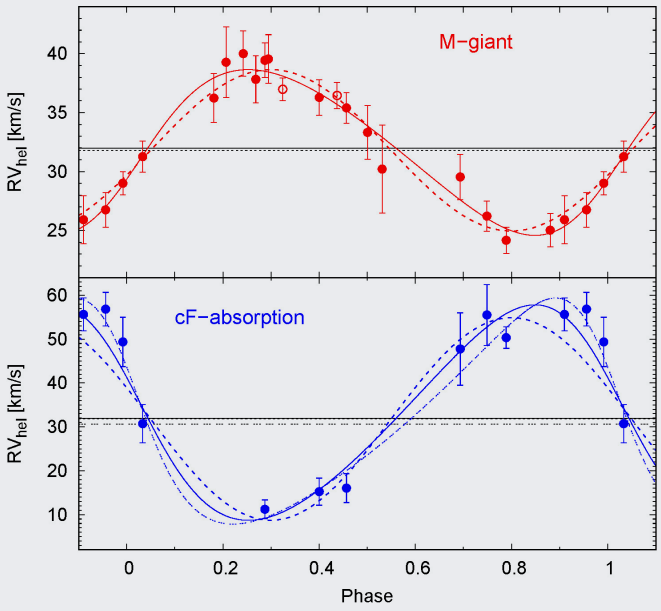
SALT uncovers the nature of the jet-producing symbiotic binary St 2-22

Gałan, C., et al. 2022/01, A&A 657, A137: The symbiotic binary St 2-22: Orbital and stellar parameters and jet evolution following its 2019 outburst

Symbiotic stars (SySt) are one of the most active classes of binary systems. They are composed of two evolved stars that vastly differ in appearance. One is a cool giant that is inflated to tens or hundreds of solar radii, while the second is a hot white dwarf (WD). Only a handful of these stars — roughly a dozen — were observed to produce collimated jets. One of them, St 2-22, has been observed over the last years with SALT/HRS by Cezary Gałan and Joanna Mikołajewska from CAMK (Poland), together with their collaborators. They derived a spectroscopic orbit and complete set of parameters of the components, adding St 2-22 to a rare group of well-studied, jet-producing SySts. Spectroscopic data complemented with photometric monitoring over 16 years allowed them to detect when the jets were launched and to study their evolution.

Gaia DR3 gives a parallax of $\pi = 0.085 \pm 0.023$ mas for St 2-22, resulting in a distance ≈ 6.9 kpc. The obtained orbital period of 918 ± 6 days is consistent within 3σ errors with that from the periodic analysis of the light curves. The radial velocities of the cF-shell absorption lines (a set of lines closely resembling spectra of A – F supergiants; mostly from [Ti II], [Fe II], and [Cr II]) are in anti-phase with the red giant (see figure). They are attributed to the orbital motion of the white dwarf. The eccentric solution is favoured ($e = 0.16 \pm 0.07^{o}$, $\omega \sim 270^{o}$). The semi-amplitudes of the radial velocity curves indicate a mass ratio $q = 3.50 \pm 0.53$, and the masses of the components are: $M_g \sin^3 i = 2.35 \pm 0.55$ M$_\odot$ and $M_{WD} \sin^3 i = 0.67 \pm 0.15$ M$_\odot$. Their orbital separation is $a \sin i \sim 2.67$ AU. The lack of eclipses sets the upper limit for the orbit inclination, $i \lesssim 70^{o}$, whereas the lower limit $i \gtrsim 52^{o}$ results from the fact that the WD cannot exceed the Chandrasekhar limit ($M_{WD} \lesssim 1.4$ M$_\odot$). This indicates a moderately massive WD ($M_{WD} \gtrsim 0.8 \pm 0.2$ M$_\odot$). The red giant mass is then $M_g \gtrsim 2.8 \pm 0.7$ M$_\odot$. The estimated radius of the red giant ($R_g = 117 \pm 20$ R$_\odot$) is below filling the tidal lobe even at the periastron. In the wings of the Hα emission line during outbursts, satellite components are observed that accelerate and decelerate with a velocity in a range from ~1500 up to nearly 1800 km/s. They are attributed to a launch of bipolar jets. It has been estimated that the jets are quite strongly collimated ($\varphi \sim 10^{o}$) and that the binary inclination should be close to the upper limit $i \sim 70^{o}$.

Both the outburst behaviour and the binary parameters of St 2-22 so closely resemble the classical symbiotic binary Z And that the two systems appear like twins. The most notable difference is the orbital separation, which is slightly larger in the case of St 2-22. In both systems, ejection of strongly collimated jets during the late outburst phase was observed with gradual changes within the 200 – 300 km/s range on a time scale of several months.



SALT/HRS radial velocity curves (filled circles) complemented with FEROS data (open circles) of the cool (top) and hot (bottom) components folded with the orbital period. Lines show synthetic curves: for the case of the eccentric orbit (solid), circular orbit (dashed), and from the solution for cF-absorption lines only (dot-dashed). The corresponding horizontal lines represent the systemic velocities.

Some interesting short-period variable stars

Ramsay, G., et al. 2022/06, MNRAS 513, 2215: The OmegaWhite survey for short-period variable stars - VII. High amplitude short-period blue variables

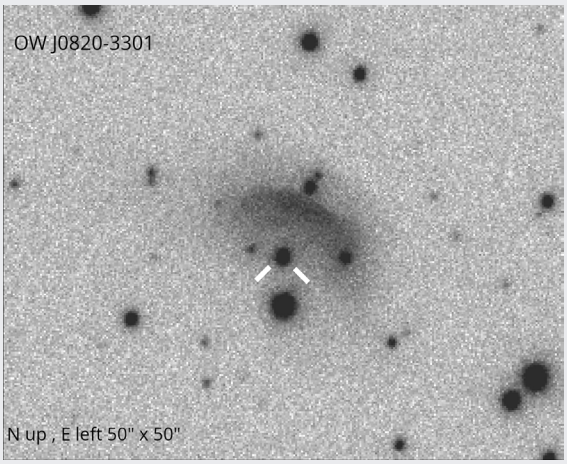
The OmegaWhite (OW) survey was conducted using ESO's VLT Survey Telescope (VST) between 2011 and 2018 with the strategy to take a continuous series of 39-second exposures of the same field in the *g* band for 2 hours. The fields are located within 10 degrees of the Galactic plane and cover more than 400 square degrees in total. As a key part of the OW strategy, follow-up photometry and spectroscopy were taken of objects identified as interesting with the main impetus to discover ultra-compact binary systems, which contain two degenerate stars orbiting around each other on a timescale shorter than an hour.

Gavin Ramsay from Armagh Observatory reports on the finding of nine short period variable stars, which the international team (including members from UCT, SAAO, Radboud University, Caltec, Texas Tech University and Northwestern University) had found using the OW survey and follow-up observations with the 1-m and SALT telescopes at SAAO. Four of these stars are members of a new class of variable stars, the blue large-amplitude pulsators (BLAPs). One star is a binary comprising a B-type syb-dwarf (sdB) and a white dwarf. The remaining four are rare types of pulsators.

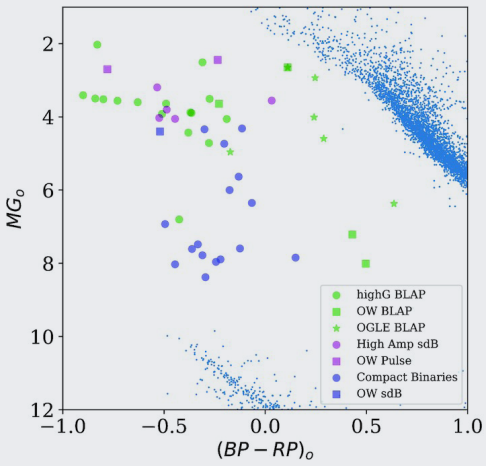
OW J0820–3301 shows a modulation on a period of 7.4 minutes and has a temperature and gravity similar to the high temperature V361 Hya variable stars. Intriguingly, a nebula was discovered in the immediate vicinity using the VPHAS+ survey. Further observations are required to determine if the nebula and variable star are physically associated, but if proved right it could give insight to the star's recent evolutionary history.

Three of the four BLAP stars show notches just before flux maximum, which can only be detected using high time resolution photometry. They are similar to features seen in 'Bump' Cepheids. A dedicated series of spectra obtained with SALT allowed Ramsay and his collaborators to identify OW J0815–3421 as a compact binary containing a white dwarf and an sdB with a period of 73.6 minutes, making it one of only six white dwarf–sdB systems with an orbital period shorter than 80 minutes.

SALT spectra of all the nine stars allowed the team to place them on the temperature – log g plane. The four stars that were identified as BLAPS could be compared with other known BLAP stars. The team found a separation between low gravity BLAPS (such as identified using the OW survey) and high gravity BLAPS.



A VPHAS+ image in Hα of the immediate field surrounding OW J0820–3301, which is a V361 Hya variable star (indicated). An extended nebula lies to the north.



The observed colour–absolute magnitude diagram for the BLAPs and other high amplitude pulsators as identified in the OW survey. Also shown for comparison are high-gravity BLAPs, compact binaries and high amplitude sdB stars.

SALT identifies rare cataclysmic binaries

Schwope, A., et al. 2022/05, A&A 661, A42: Identification of SRGt 062340.2-265751 as a bright, strongly variable, novalike cataclysmic variable

Schwope, A., et al. 2022/05, A&A 661, A43: Discovery of eRASSt J192932.9-560346: A bright, two-pole accreting, eclipsing polar

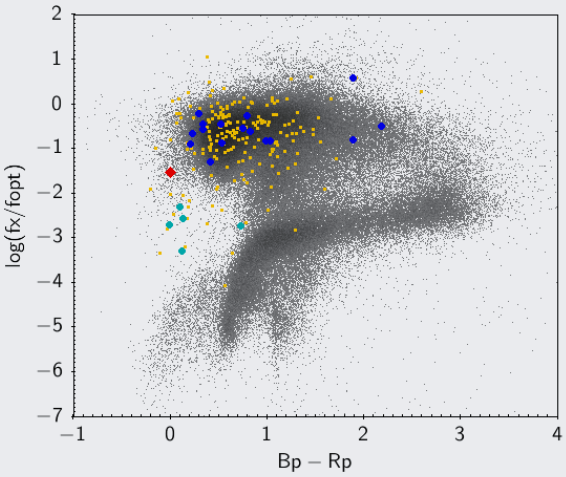
The eROSITA (extended Roentgen Survey with an Imaging Telescope Array) instrument on the *Spektrum-Roentgen-Gamma (SRG)* satellite performed four independent X-ray all-sky surveys (eRASS) between 2020 and 2021 in the energy band 0.2 – 10 keV. Its scanning strategy allows us to probe various timescales, from seconds (the time a given source moves through the field of view), to 4 hours (the time between individual scans, an eRODAY), to years (each eRASS lasts half a year). The stacked eROSITA source catalogue will contain several million objects. To compile complete populations of the various X-ray emitting source classes, comprehensive optical follow-up programmes were initiated and will run over the coming years, which allows us to focus on the identification of transient X-ray sources.

Cataclysmic variables (CVs) are close compact binaries with Roche-lobe filling donor stars and mass-accreting white dwarfs (WD). They typically orbit each other within a few hours. Accretion may happen via discs onto non-magnetic WDs, but the discs may be truncated or completely suppressed if strong magnetic fields are involved. Accretion may then happen via streams and curtains. In such scenarios, the quasi-radial infall of the matter leads to strong accretion shocks and subsequent cooling, which makes magnetic CVs prominent X-ray emitters with pronounced orbital or spin-phase dependent variability. In non-magnetic CVs, X-rays are thought to originate from the so-called boundary layer between the disc and the WD. This region is much larger than an accretion hot spot and variability, if any, is not necessarily expected to be prominent.

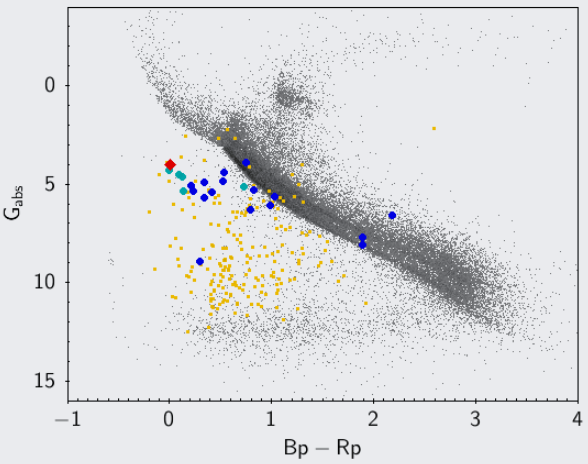
Via the *SRG*/eROSITA variability triggers, Axel Schwope (AIP, Germany) and his colleagues identified two new CVs through SALT follow-up spectroscopy, which show some rare or even unique properties. Further ground- and space-based observations, including SAAO facilities (SHOC, HIPPO), *Gaia* and *TESS*, were used to characterise the new findings. Both objects were initially selected through their pronounced on/off pattern between individual X-ray surveys. Closer inspection revealed 100% variability also between eRODAYs.

The SALT/HRS identification spectrum of the new, bright (G = 12.5^{m}) transient SRGt062340.2–265751 firmly classifies the object as a novalike CV at a distance of 495 pc. Surprisingly, a highly significant *TESS* period of 3.941 h, tentatively identified as the orbital period of the binary, could not be confirmed when the object was re-observed, neither with *TESS* nor with SHOC attached to the SAAO's 1-m telescope. Also, the locations of the new object in typical X-ray/optical diagnostic diagrams (right) are highly peculiar. By CV standards, it is extremely blue and optically very luminous. On the other hand, the new object has a comparatively low X-ray luminosity. All these properties were hampering a final classification and were used to launch further detailed observations from the ground (SAAO) and in space (XMM-Newton). Is SRGt062340.2–265751 the foundation member of an as-yet undefined new sub-class of CVs? The authors were puzzled by the fact that such a bright object could remain undetected so far.

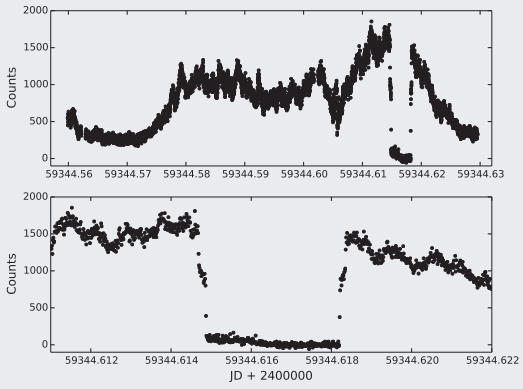
The second new CV, eRASSt J192932.9–560346, was also reported by the *Gaia* alert team due to pronounced optical variability. SALT/RSS spectroscopy uniquely identifies the object as a CV. The 100% modulation of the X-ray flux between eRODAYs triggered high-speed photometry and polarimetry with HIPPO and revealed a structured eclipse of the WD in the system every 92.5 minutes and lasting 288.0 seconds. Eclipse ingress and egress each show two steps, corresponding to two accretion spots on the 'northern' and 'southern' hemispheres of the WD, which furnishes a rare opportunity to study accretion physics on a strongly magnetic WD. The shape of the eclipse and the pattern of the light curve outside the eclipse identify the object as a strongly magnetic CV, a so-called polar or AM Herculis binary.



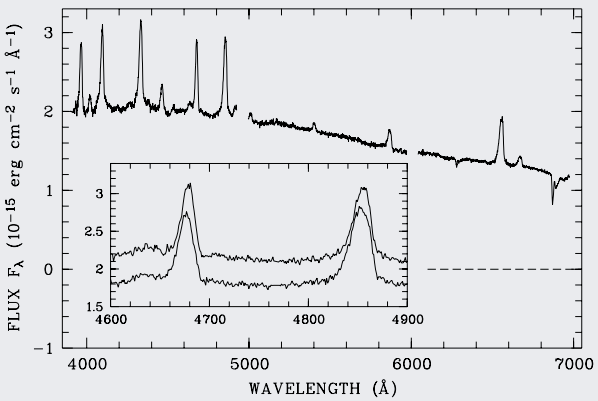
Colour-magnitude diagram for eRASS2 sources. Each grey dot is an eRASS2 source that is matched (within 8 arcsec) with a *Gaia* source out to 500 pc. Dark yellow dots: CVs from the final Ritter & Kolb catalogue; green dots: nonmagnetic high-accretion rate objects; blue dots: intermediate polars (magnetic CVs). The new CV SRGt 062340.2−265751 is identified by the red symbol.



X-ray to optical colour-colour diagram. Symbols are the same as in the CMD (where the *Gaia* matches here are mostly stars at low and mostly AGN at high flux ratios). The new object clearly shows extreme properties.



Fast (1 s) photometry of eRASSt J192932.9−560346 from HIPPO observations undertaken on 9 May 2021. Details of the eclipse are shown in the lower panel, in which the ingress and egress resolve the two accretion spots.



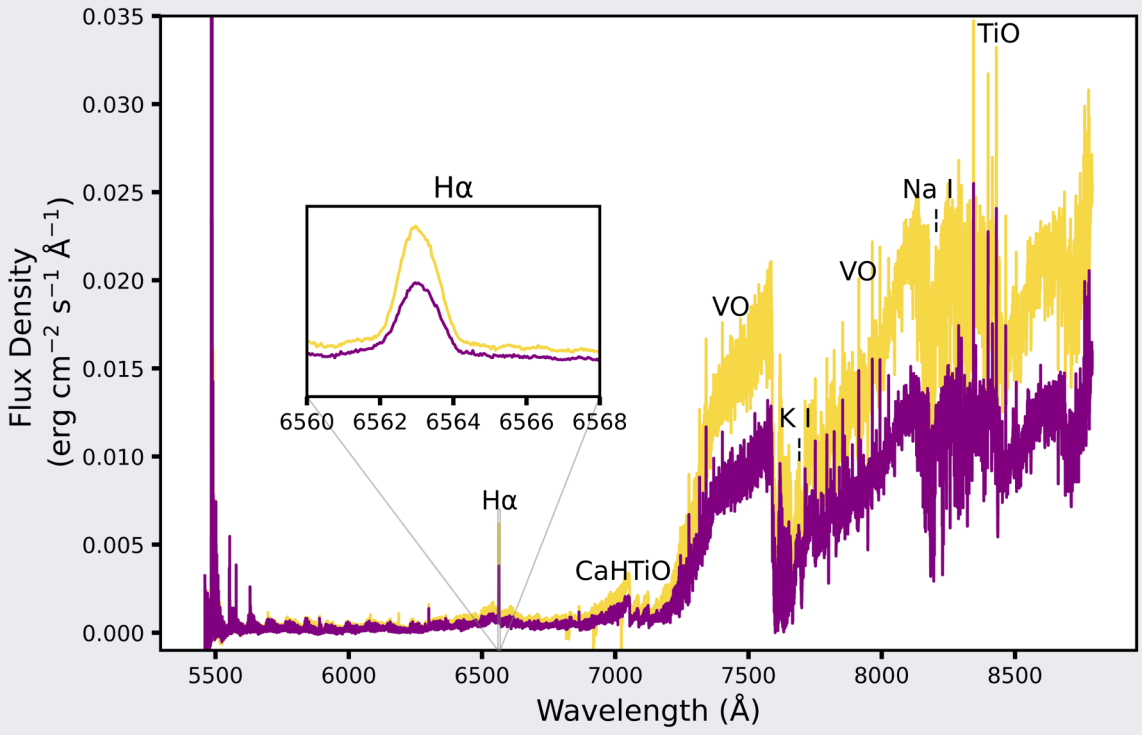
SALT spectra obtained of eRASSt J192932.9−560346 on 6 May 2021. The inset shows spectral variability between two successive spectra separated by 5 minutes. Note the strong [He II] λ4686 line indicating a pronounced soft X-rays source, immediately hinting at a magnetic CV.

Serendipitous discovery of radio flaring behaviour from a nearby M dwarf

Andersson, A., et al. 2022/07, MNRAS 513, 3482: Serendipitous discovery of radio flaring behaviour from a nearby M dwarf with MeerKAT

Alexander Andersson from the University of Oxford and his co-authors report on the serendipitous discovery of a new radio transient with the South African MeerKAT telescope. The transient, found in a field surrounding the black hole XRB H1743–322, was detected three times over 11 weeks of observations. It is one of a small but growing number of transients now being detected by wide-field radio surveys. The radio emission alone tells us some things about the transient — likely emission mechanism, for example — but a multiwavelength counterpart and spectral information is needed for more detailed information.

Following the discovery, Andersson and his collaborators used MeerLICHT and *Gaia* photometry to associate the optical counterpart SCR 1746–3214 with the radio transient. SALT observations (two consecutive 1000s exposures using HRS) were taken as part of the transient follow-up programme led by David Buckley and serve for three main purposes: determination of spectral classification, magnetic activity and rotation. The spectra, as seen in the figure, show clear evidence of metals and molecular lines past 700nm — matching well the type of a mid-M dwarf. Secondly, a clear Hα emission line (equivalent width of −5.5 ± 0.2 Å) — a sign of magnetic activity by reconnection in the upper layers of the star. Finally, the broadening of the spectral lines match the inferred rotation period from TESS photometry (caused by, *e.g.*, star spots), putting SCR 1746–3214 in the population of fast rotating stars. These SALT results, complemented by other optical, radio and X-ray data, create a picture of a fast rotator (~32 km/s), where magnetic reconnection events occur in the corona, accelerating electrons to produce radio emission and optical flares. The activity of M dwarfs probes stellar coronal physics, whilst also having implications for the habitability of planetary systems.



Two reduced spectra of SCR 1746–3214, taken by SALT. Some notable spectral features have been indicated, including clear Hα emission and molecular lines. Inset is a view of the Hα emission line, which shows rotational broadening.

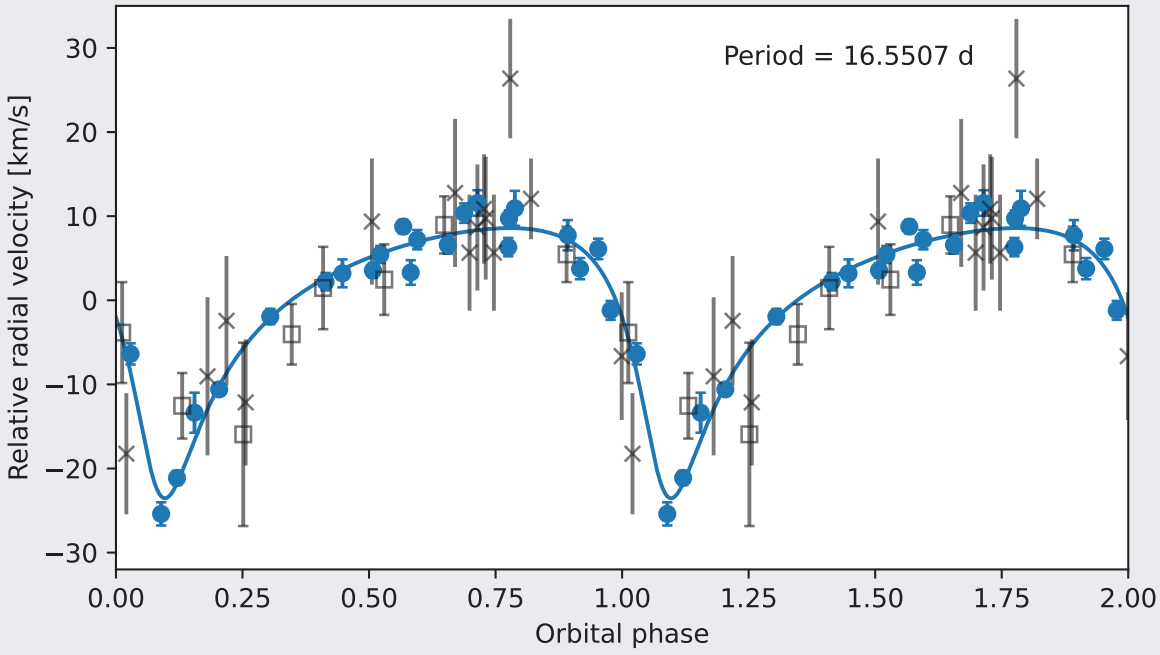
SALT supplies an improved binary solution for the gamma-ray binary 1FGL J1018.6–5856

van Soelen, B., et al. 2022/09, MNRAS 515, 1078: Improved binary solution for the gamma-ray binary 1FGL J1018.6-5856

1FGL J1018.6–5856 is part of a rare class of high mass binary systems called gamma-ray binaries. These systems show persistent, orbitally modulated gamma-ray emission up to very high energies. All of these systems consist of a compact object in the mass range of a neutron star or a black hole in orbit around an O- or B-type star. Two scenarios have been proposed to explain the non-thermal emission: the first is a microquasar scenario, where the emission is produced in a relativistic jet that is either stronger than typical microquasars or more closely aligned to our line of sight; the second is that the compact object is a young pulsar and a shock forms between the pulsar and stellar wind, with particle acceleration occurring in the shock. The second scenario is the more favoured as gamma-ray binaries do not, in general, show the variability signatures typically associated with microquasars.

Unusually, 1FGL J1018.6–5856 shows two maxima in its X-ray light curve, something not seen at other wavelengths. While two maxima have been observed for other gamma-ray binaries, this is normally associated with the massive companion being a Be star, and the compact object passing through the circumstellar disc, which is not the case for this source. While some model suggestions had been put forward, the possible emission mechanism that could work would depend on where in the orbit the emission occurred.

Brian van Soelen from the University of Free State (South Africa) and his team have obtained radial velocity measures with SALT/HRS, as well as an updated orbital period derived using ~12 years of Fermi-LAT observations, resulting in an improved orbital solution for the source. The solution placed the narrow peak in the X-ray and gamma-ray light curves near the inferior conjunction/periastron, while the second maxima was closer to apastron. This suggests that the geometry for the system is important as the observed emission may be constrained to regions when the outflow from the pulsar shock is pointing along the line of sight. The second maximum in the X-ray light curve may be occurring during the variable emission induced due to clumps in the stellar wind interacting with the shock.



Relative radial velocities measured for 1FGL J1018.6–5856 folded on a 16.5507 day period.
Filled blue circles show the new SALT observations, while the grey points are from previous observations.

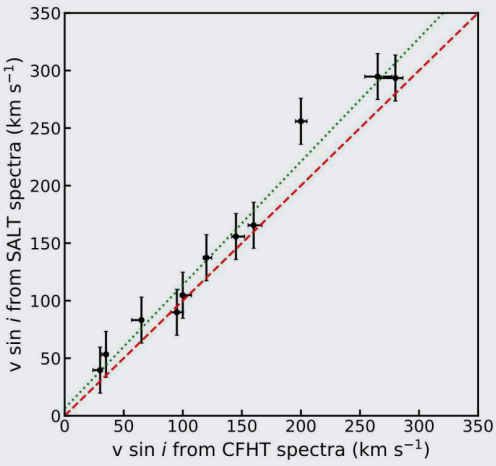
SALT investigates the split main sequence of NGC 2422

He, C., et al. 2022/10, ApJ 938, 42: The Role of Binarity and Stellar Rotation in the Split Main Sequence of NGC 2422

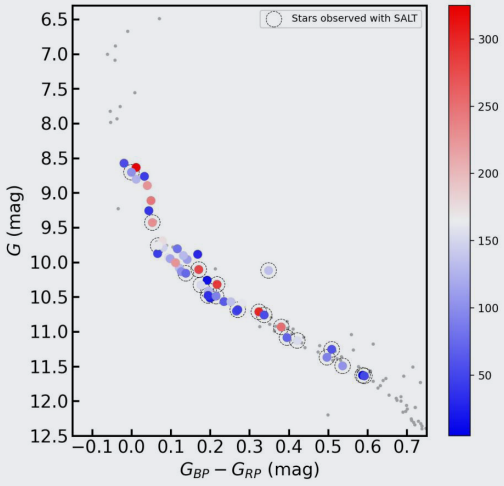
In addition to the extended main-sequence turnoffs widely found in young and intermediate-age (~600 Myr to 2 Gyr old) star clusters, some younger clusters also exhibit split main sequences (MSs). Different stellar rotation rates are proposed to account for the bifurcated MS pattern, with red and blue MSs (MS on the redder side and bluer side in a cluster's colour–magnitude diagram, respectively) populated by fast and slowly rotating stars, respectively. For their project, Chenyu He and his collaborators used spectra obtained with the Canada–France–Hawaii Telescope (CFHT) and with SALT to measure the projected rotation rates $v \sin i$ of stars along the split MS of the young Galactic open cluster NGC 2422.

The team obtained RSS-MOS spectra of 22 A- and F-type stars. The resolution of the spectra is ~ 4000 with a signal-noise ratio of ~200 at a wavelength of 4884.4 Å. The observed absorption line profiles of Hβ (4861 Å) and the [Mg I] triplet (5100 – 5200 Å) are fitted to get the parameters of T_{eff}, log g, [Fe/H], $v \sin i$ and RV of the 22 stars. Eleven of these stars were also observed with CFHT. The $v \sin i$ values of both data sets agree well.

As a result, the colour–magnitude diagram shows the stars observed with SALT as dashed open circles. The authors find that the $v \sin i$ values of the observed split MS stars are weakly correlated with their loci in the colour–magnitude diagram. This is caused by the contamination of a large fraction of red MS stars that have low projected rotational velocities. The authors fitted the spectral energy distributions (SED) of the stars with $v \sin i < 200$ km/s. Based on the result, they suggest that the slowly rotating stars at the red MS may hide an unresolved binary companion: The hidden companions make these stars appear redder than their single counterparts located at the rMS, which breaks the expected $v \sin i$ – colour correlation.



Comparison of derived $v \sin i$ values from CFHT and SALT spectra for the 11 stars observed with both facilities. The error bars show the 2σ uncertainties. The red dashed line is the equal-value track. The dotted green line shows the best-fitting line $(v \sin i)_{SALT} = 1.07\ (v \sin i)_{CFHT} + 6.40$ km/s.



Colour–magnitude diagram of the stars with with measurements of $v \sin i$ (colour coded). The dashed open circles show stars that were observed with SALT. The photometry data comes from *Gaia* EDR3.



5.3

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 2022 (2021-2 and 2022-1) a total of 109 proposals were accepted by the various TACs. Eight of these were **DDT proposals**, receiving a total of 34 kiloseconds of observing time. There are four **commissioning proposals**, dealing with NIRWALS, RSS throughput and the HRS pipeline. There is a new proposal class called ORP (for **OPTICON-Radionet Pilot**) with one proposal on a pilot project. Only one **Large Science Proposal** (LSP) had been submitted in 2022, which is the ongoing transient science project led by David Buckley. A total of 58 proposals were normal **science proposals** (SCI), with 10 submitted in both semesters and 7 more carried over from earlier years. There were 36 **multi-semester** proposals (MLT) with 13 repeats (submitted both semesters); 14 were newly submitted and accepted in 2022 and 9 were carried over from previous semesters. The oldest, which started in 2018-1, is the quasar monitoring programme by Bożena Czerny (CAMK), and Raj Prince's report on one of the quasars can be found above in the extragalactic science section.

In 2020, SALT joined the in **OPTICON/Radio-Net Pilot programme (ORP)**, which is an EU-funded program that offers trans-national telescope access to both optical and radio telescopes to researchers in countries who do not have access to such facilities. Information about the ORP programme and/or how to apply for trans-national telescope access can be found on their website: https://www.orp-h2020.eu. SALT is the largest optical telescope available to ORP users. SALT offers up to 50 hours per semester of SALT time. ORP issues two calls for proposals per year (starting in 2022-1 semester), the results of which are received by SALT well ahead of our own call for proposals for that period.

The longest-lasting and highly successful Large Science Proposal 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 (reasonable) 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. Currently, it involves 69 co-investigators, including 15 postdocs or early career researchers and 14 postgraduates students. Five SALT partners are involved in the programme: South Africa, Poland, UK SALT Consortium, IUCAA and University of Wisconsin-Madison. Observations for the year 2022 comprised a total of 205 successfully completed observations, totalling 431,302 s of allocated time. A total of 26 observation attempts were aborted or rejected due to unacceptable observing conditions or technical issues. 100 different objects were observed, some more than once, covering the following object classes with percentages of time and number of objects:

Compact binary White Dwarfs, including Cataclysmic Variables and related objects (30.7%; 18 objects)
Be X-ray binaries (12.3%; 9 objects)
Black Hole binary candidates from *Gaia* (10.4%; 15 objects)
Active Galactic Nuclei, including eROSITA "changing look" systems and flaring blazars (9.8%; 11 objects)
Novae, recurrent novae (9.5%, 7 objects)
Gaia/ASASSN transients (7.7%; 13 objects)
EX Orionis Young Stellar Object outbursts (6.3%; 1 object)
Tidal Disruption Events, Quasi Periodic Eruptions and other nuclear transients (4.0%; 7 objects)
Low Mass X-ray binaries and related objects (2.8%; 3 objects)
Pulsars, including MeerKAT radio sources and eROSITA isolated neutron stars (2.4%; 2 objects)
Spectropolarimetry calibrations (2.2%)
Supernovae (1.4%; 3 objects)
Near Earth Objects (0.5%; 1 object)

Many of the observations for 2022 were following up on new discoveries from the eROSITA X-ray survey, including compact binary white dwarfs, changing-look AGN, TDEs and other nuclear transients. A number of *Gaia*-detected microlensing and nuclear events were also observed.

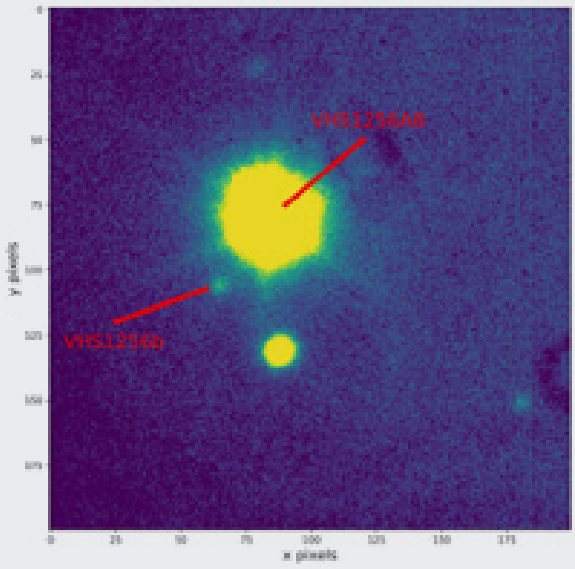
The scientific progress, counted as published refereed papers, reached 62 by the end of 2022, with 25 refereed papers featuring results for this programme published during the 2022 calendar year (three of which refer to the programme in general). In addition, six papers have been accepted, based on results from 2022, and are currently in press. Data from the project are also regularly presented at conferences and in Astronomer Telegrams. Major highlights for 2022 include:

- Discovery and followup observations of a second AR Sco-like white dwarf pulsar [paper submitted];
- Discovery of the first example of a helium supersoft X-ray source, in the LMC [paper accepted for Nature and due to be published in March 2023];
- Possible identification of a third Quasi Periodic Erupting X-ray source from eROSITA observation of a non-active galaxy;
- Discovery of 6 new examples of Be X-ray binaries in the Magellanic Clouds;
- Tracing the entire eruption event of EX Lupi, a EXOr young stellar object;
- Followup of several new magnetic CVs and double degenerate AM CVn discoveries from eROSITA.

SALT observes low-mass stars

Jackie Faherty from AMNH and her team have used SALT's low resolution optical spectrograph to follow-up on newly identified members of the 20 pc sample of stars, as well as primaries in newly identified co-moving, low-mass systems. All of the targets were found through the citizen science project named "Backyard Worlds: Planet 9". The spectra have been reduced and will soon be included in two separate publications. One will be a compilation of the mass function created from the 20 pc volume, where the SALT data will characterise several new members. The other will be a follow-up of co-moving systems found through the Backyard Worlds collaboration and will be led by one of the citizen scientists. For example, the directly-imaged planetary-mass companion VHS1256B was observed with SALT (PI Johanna Vos). A JWST spectrum of VHS1256B was published by the JWST High Contrast Exoplanet Early Release Science Team earlier in the year. This is a highly interesting planetary-mass companion at the exoplanet/brown dwarf boundary and is known to exhibit extreme spectroscopic and photometric variability, presumably due to condensate clouds composed of iron and/or silicates rotating in and out of view.

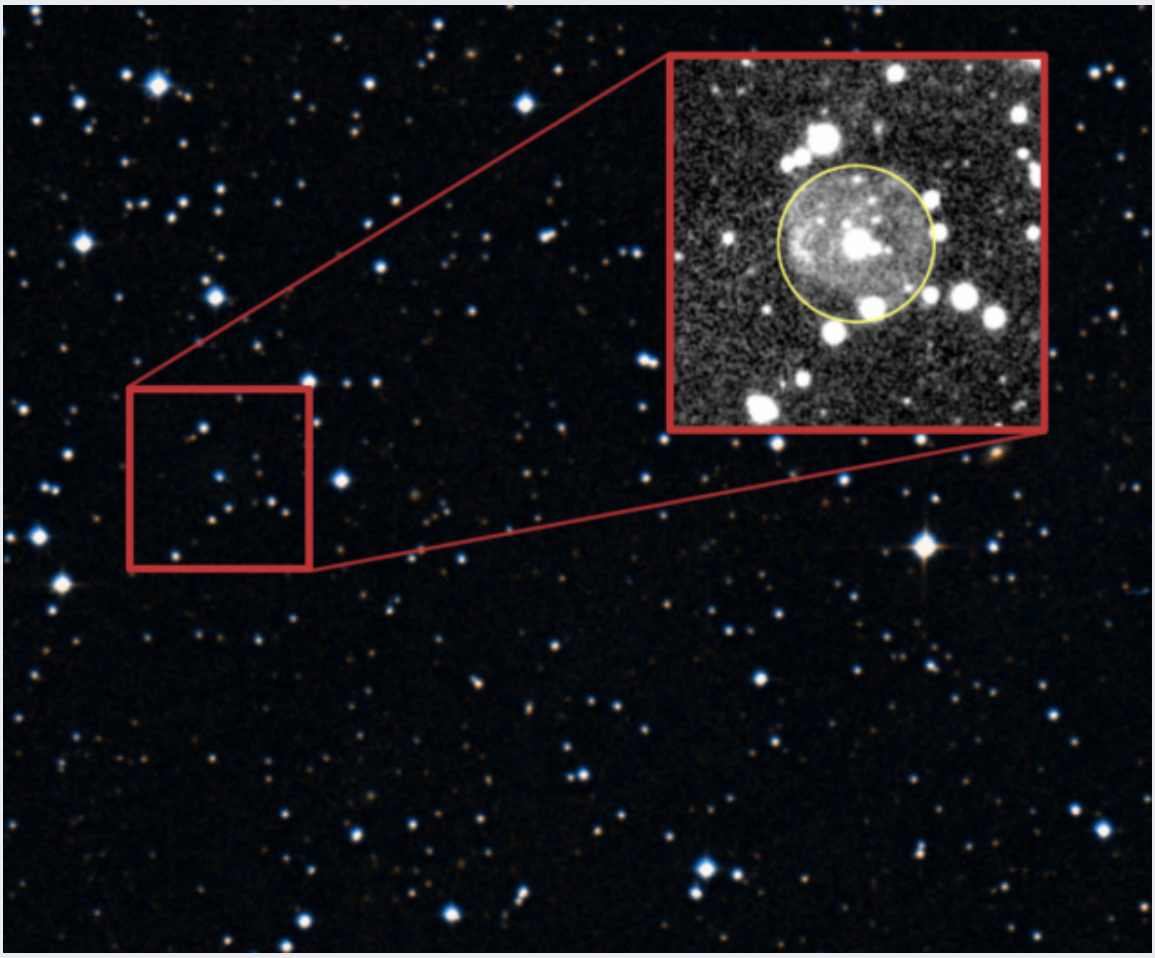
Photometric monitoring observations were obtained with SALT at multiple epochs during summer 2022. The planned publication will detail SALT's long-term variability monitoring campaign of this target. The results from this programme will be combined with data from the team's worldwide network of telescopes to examine the long-term cloud-driven variability trends of VHS1256b to add context to the JWST Early Release Science results. This is an initiative undertaken by a subset of the JWST Early Release Science Team.



Raw SALTICAM image of the VHS1256 system, which consists of an unresolved M dwarf binary host VHS1256AB and the planetary-mass companion VHS1256b.

The SALT survey of helium-rich subdwarfs and other stars

Simon Jeffery from Armagh Observatory is PI of the SALT survey of helium-rich hot subdwarfs that aims to explore evolutionary pathways amongst groups of highly-evolved stars. Preliminary results for the first 100 stars were published in 2021. RSS observations of over 200 subdwarfs have now been completed and include discoveries of additional extreme helium stars, chemically peculiar subdwarfs and short-period binaries. In addition, multi-epoch HRS observations have been carried out to follow-up possible binary and pulsating stars and, for extreme helium stars, to track long-term changes over a 40-year baseline. A surprising discovery in the sample was a number of extremely hot subdwarfs showing ionised helium in emission. On analysis, these turned out to be eight extremely hot white dwarfs and pre-white dwarfs, all having surface temperatures in excess of 100,000 K. They include two PG1159 stars, one DO white dwarf (defined as not exhibiting neutral helium lines), three O(He) and two O(H) stars. One of the O(H) stars is the central star of a newly-discovered planetary nebula, the other is the hottest 'naked' O(H) star. Both of the PG1159 stars are GW Vir variables, one being the hottest GW Vir star measured and a crucial test for pulsation stability models. The DO white dwarf is also the hottest in its class.



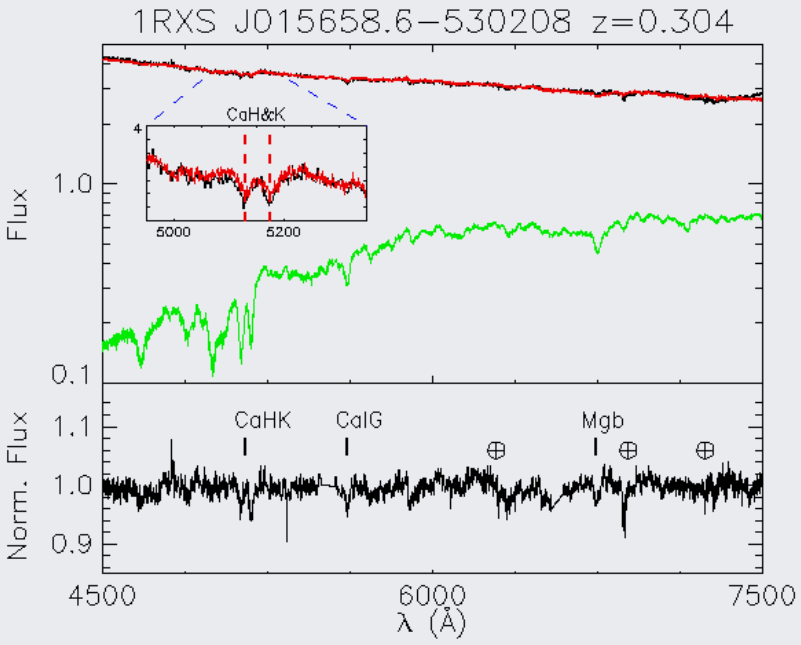
A sky survey image centred on the newly-discovered O(H) star SALT J203959.5–034117. – Credit: Tom Watts (AOP), STScINASA, The Dark Energy Survey

Redshift determination of BL Lacs for the CTA project

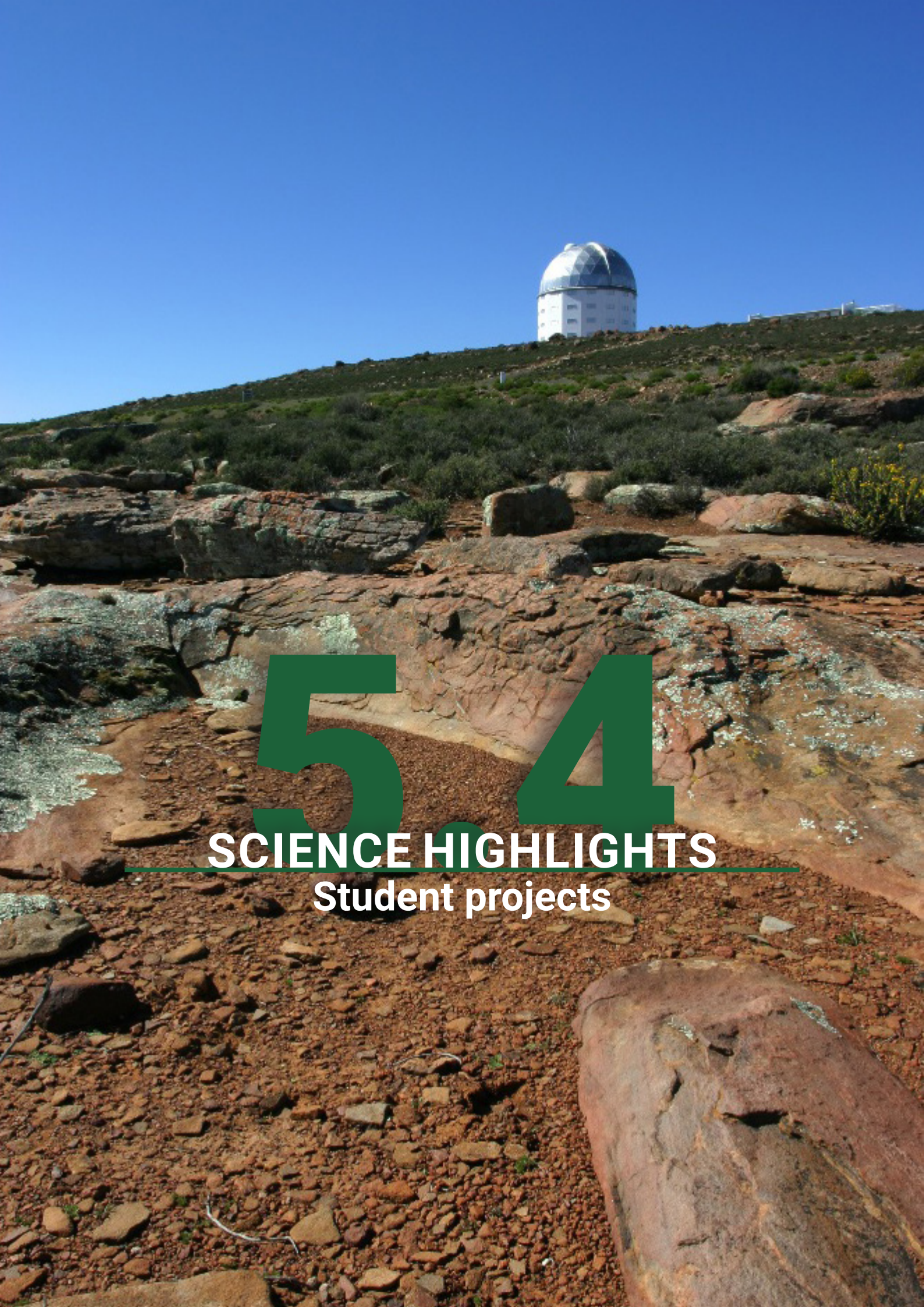
Kasai, E.K., et al., 2022/03, 37th International Cosmic Ray Conference, Proceedings of Science, PoS (ICRC2021) 881: Southern African Large Telescope Spectroscopy of BL Lacs for the CTA project

Eli Kasai of the University of Namibia and his colleagues are working on a project to prepare for the expected large numbers of AGNs that will be detected with the future CTA (Cherenkov Telescope Array) observatory. In the last two decades, over 200 sources (both Galactic and extragalactic) have been detected by ground-based high-energy experiments. Active Galactic Nuclei (AGN) make up about 40% of these sources, the majority of which are blazars, *i.e.*, their jets are closely aligned with the line of sight. Three quarters of these are classified as high-frequency peaked BL Lac objects. BL Lacs have nearly featureless, continuum-dominated spectra, which makes it difficult to obtain redshifts. It is expected that a significant fraction of the AGN to be detected with the future CTA will have no spectroscopic redshifts, compromising the reliability of BL Lac population studies, particularly of their cosmic evolution. In 2019, Kasai and his colleagues started the CTA redshift determination group dedicated to measure the redshifts of a large fraction of the AGN that are likely to be detected with CTA, using SALT. To date, 28 BL Lacs have been observed. Another 15 – 20 BL Lacs will be observed in the next two years, covered by a mulit-semester observing programme.

Kasai and his colleagues have presented their ongoing project at a number of conferences, highlighting results from the project so far:
* 37th International Cosmic Ray Conference, online, July 2021
* 10th International Fermi Symposium, Johannesburg, South Africa, October 2022
* H.E.S.S. 20th anniversary, Windhoek, Namibia, October 2022
* IAU Symposium 375, Kathmandu, Nepal, December 2022



SALT/RSS spectrum of 1RXS J015658.6530208. *Top*: Flux-calibrated and telluric-corrected spectra (black) and best fit galaxy models (red), where the galaxy component shown in green is assumed to be elliptical. *Bottom*: Normalised spectrum illustrating the absorption features used for redshift determination. The plus symbols represent atmospheric telluric absorption features.



5.4 SCIENCE HIGHLIGHTS

Student projects

SCIENCE HIGHLIGHTS

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 2022 can also be found in the research section.

The GLEAM 4–Jy (G4Jy) sample is a compilation of 1,863 of the brightest, extragalactic radio-sources in the southern sky, the vast majority of which are AGN with powerful radio-jets. Over 500 G4Jy sources have already been observed as part of a SALT multi-semester spectroscopic campaign led by Sarah White (SARAO/Rhodes University, South Africa). Even though such "radio-loud" AGN have been studied for over 50 years, we are yet to understand exactly how radio jets are launched, and their overall impact on the surrounding host galaxy over cosmic time. White's PhD student **Katlego Sejake** (University of Pretoria, co-supervised by Kshitij Thorat) will reduce the new SALT/RSS spectra to derive redshifts. These will enable her to calculate intrinsic properties of the AGNs, such as their radio power. In addition, she hopes to derive supermassive black-hole masses for a subset of the sample. A catalogue of newly-determined redshifts will be made available to the community.

Gas flows are an important aspect of galactic feedback and the regulation of star formation in galaxies. Nearby starburst galaxies and LIRGs provide an extreme environment where feedback and the changes due to it can be studied in great detail. **Petro van Rensburg**, PhD student at UCT and supervised by Moses Mogotsi, Petri Väisänen (both SAAO) and Matthew Bershady (SAAO/UW) works on a project to search for traces of outflows and inflows in a sample of nearby starburst galaxies and LIRGs in the SUNBIRD survey using SALT/RSS long-slit observations, as well as NIR IFU and ALMA data. She wants to characterise the galaxies using observations of the multi-phase gas (neutral and ionised) kinematics and stellar kinematics. Petro will then use the relationship between gas flows, star formation and other galaxy properties to study feedback and the fueling of star formation. Understanding the flow of the gas and its relation to star formation will, in turn, help to understand galaxy evolution.

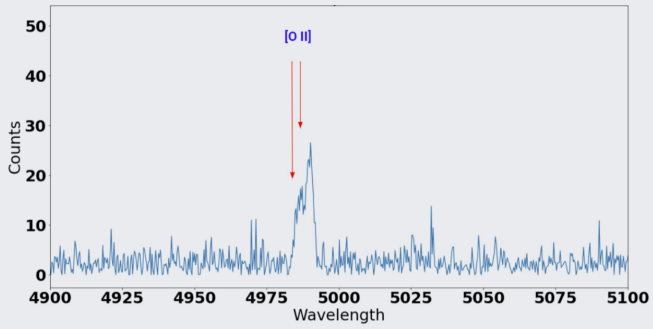
Johsua Oppor is a PhD student working with Matthew Bershady at the University of Wisconsin–Madison, studying the 3D distribution of ionised gas in nearby disc galaxies. Joshua is using data from the ongoing HI survey "Looking At the Distant Universe with the MeerKAT Array (LADUMA)" and spectroscopic data from RSS-VIS on SALT. LADUMA is detecting HI emission out to z = 1.4 in a field encompassing the Extended Chandra Deep Field South (ECDFS). As the deepest HI survey to date, it also enables the spatially resolved study of low column density HI in the outskirts of low redshift galaxies, providing an excellent tracer of dynamical mass. The combination of MeerKAT HI and SALT optical data thus provides a unique dataset within which the study of diffuse ionised gas (DIG) and neutral gas kinematics can be done in tandem. Spectroscopic follow-up on 12 nearby disc galaxies in the LADUMA field has been completed. Joshua will use common emission lines such as Hα, Hβ, [N II], [S II] and [O III] and emission line-ratio diagnostics to discriminate between [H II] and DIG-dominant regions and their kinematics.

PhD student **Melissa Morris** is working with Eric Wilcots at the University of Wisconsin–Madison and studies gas in galaxy groups. Hot, diffuse (circumgalactic) gas is likely responsible for quenching star formation of galaxies in these environments, but directly observing it is difficult because it is often not hot or dense enough to be detected by current X-ray telescopes. However, by observing the effect it has on radio galaxies with bent jets, it is possible to constrain how much circumgalactic gas exists, which helps to understand how effectively it can quench star formation. Melissa will thus be able to make a more complete census of baryons in these environments. She makes use of RSS-MOS observations of galaxies in these groups, which is necessary to characterise the group dynamics that underpin her estimate of how much circumgalactic gas is present. **Yesenia Beltran**, an undergraduate who worked with Melissa and Eric Hooper over the summer of 2023 as part of NRAO's RADIAL program, discovered what could likely be two bent radio AGN in the same group. The team is carrying out additional RSS-MOS observations to confirm this and, if confirmed, measure the density of gas in two locations of the same group.

SALT multi-object spectroscopy to reveal physical properties of [O II]-emitting galaxies at z < 0.4

George Kharchilava, Rutgers University (USA), Senior Honors 2022

Eric Gawiser's student George Kharchilava (Rutgers University) has used SALT/RSS-MOS to study [O II]-emitting galaxies at z < 0.4. They were originally discovered by the HETDEX survey via blind R ~ 800 spectroscopy covering 3500 – 5500 Å, with emission line fluxes of at least 10^{-16} erg/cm^2/s. The combination of six spectroscopic settings, two each with the PG3000, PG2300, and PG0900 gratings, obtained full wavelength coverage from 3500 – 9500 Å. George used Matt Hilton's RSSMOSPipeline to reduce the data, after customising the wavelength calibration module for the settings used. This dataset will provide a wide range of information about these galaxies' ISM conditions, including electron densities, ionisation parameters, velocity dispersion, dust reddening, metallicities, and star formation rates.

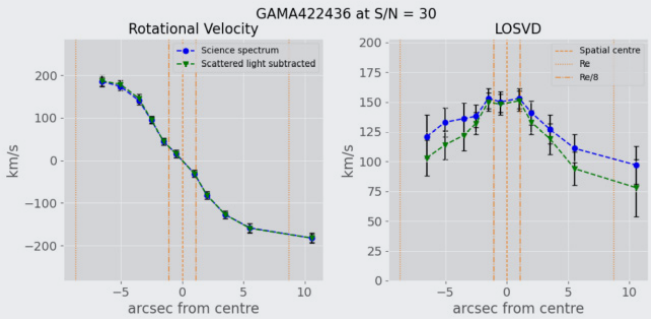


An [O II] doublet spectrum obtained with the PG2300 grating, separated by 2.7 Å.

SALT observations of dusty early-type galaxies

Ron W. Savage, Jeremiah Horrocks Institute, University of Central Lancaster (UK), MSc 2022

SALT/RSS spectroscopic observations of a sample of early-type galaxies (ETGs) were analysed by Ron Savage (an Astronomy Distance Learning graduate at UCLan), supervised by Anne Sansom. These ETGs were unusual in being detected with large dust components (from Herschel-ATLAS and GAMA galaxy survey observations) and in molecular gas (from IRAM-30m observations). For his masters project, Ron reduced the spectral data for 15 galaxies, measured their kinematics and looked at their star formation histories with the widely used ppxf software for stellar population analysis. There were few obvious irregularities in the kinematics in these unusual ETGs, and most appeared dominated by old stars. However, evidence for young components in their stellar populations was tentatively found in four cases. The figure shows example results of kinematics for GAMA422436, which is classified as a lenticular galaxy (S0–Sa) and has an old stellar population, but contains ~10^7 $M_\odot$ of dust and has molecular gas. Further work on the stellar population analysis will be carried out in future to measure the stellar population characteristics of these ETGs more accurately in order to investigate their histories.



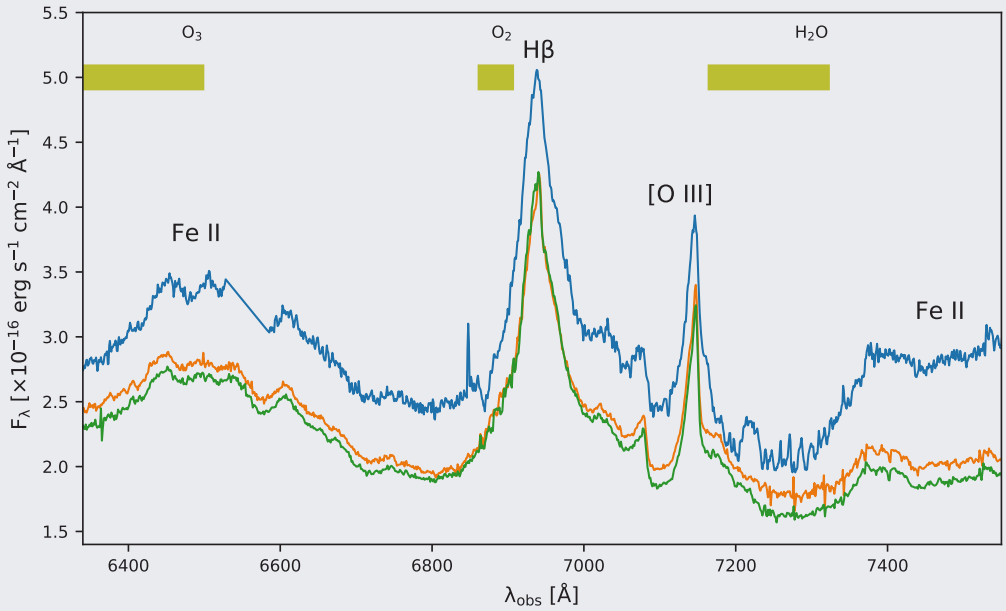
Rotational velocity and line-of-sight velocity distribution derived for GAMA422436 using SALT/RSS observations.

Properties of dusty galaxies in the field around the South Ecliptic Pole

Aleksander Herzig, Jagiellonian University (Poland), MSc 2022
Hryniewicz, K., et al. 2022/04, A&A 660, A90: AGN in the ULIRG HE 0435−5304

As part of his masters project to study dusty galaxies, Aleksander Herzig, supervised by Agnieszka Pollo (Jagiellonian University, Poland), used SALT Director's Discretionary Time (DDT) to obtain spectra of the quasar HE 0435−5304 and its neighbouring sources with RSS-MOS. Previously, HE 0435−5304 appeared in the literature with redshift values ranging from ~0.4 to 1.23. The SALT data allowed Aleksander to accurately determine the redshift of HE 0435−5304 to be z = 0.425 based on the [O II] line – the narrowest line in the spectrum. With this value, HE 0435−5304 is a prominent — but not extreme — ultra-luminous infrared galaxy (ULIRG), *i.e.*, an actively star forming galaxy hosting a relatively massive and luminous AGN, with star formation properties typical for this class of objects observed in the field around the South Ecliptic Pole.

The properties of the AGN inside HE 0435−5304 were presented in more detail in a publication led by Krzysztof Hryniewicz. The AGN was found to be a prominent iron emitter from the extreme type-A population (population A is known to have narrower lines with systematically higher accretion rates) and placed very close to the narrow-line Seyfert 1 group in the quasar main sequence diagram. HE 0435−5304 is most probably going through a merger phase which triggered both the AGN activity and an episode of star formation in the host galaxy. The host galaxy stellar mass is typical for this category of sources, although the mass of the supermassive black hole powering the AGN is higher than the average for this stellar mass. A comparison of the SALT spectrum of HE 0435−5304 with four years older MUSE spectra from the ESO archive suggests that HE 0435−5304 is in the phase of changing its broad and intermediate line regions. This may imply that it hosts either a binary supermassive black hole or a warped or precessing accretion disc which modulates parameters of spectra over time. This conclusion is supported by photometric data spanning over two decades, which consistently show a decrease in the source's brightness. It makes HE 0435−5304 an interesting candidate to follow up in the future to verify these hypotheses.

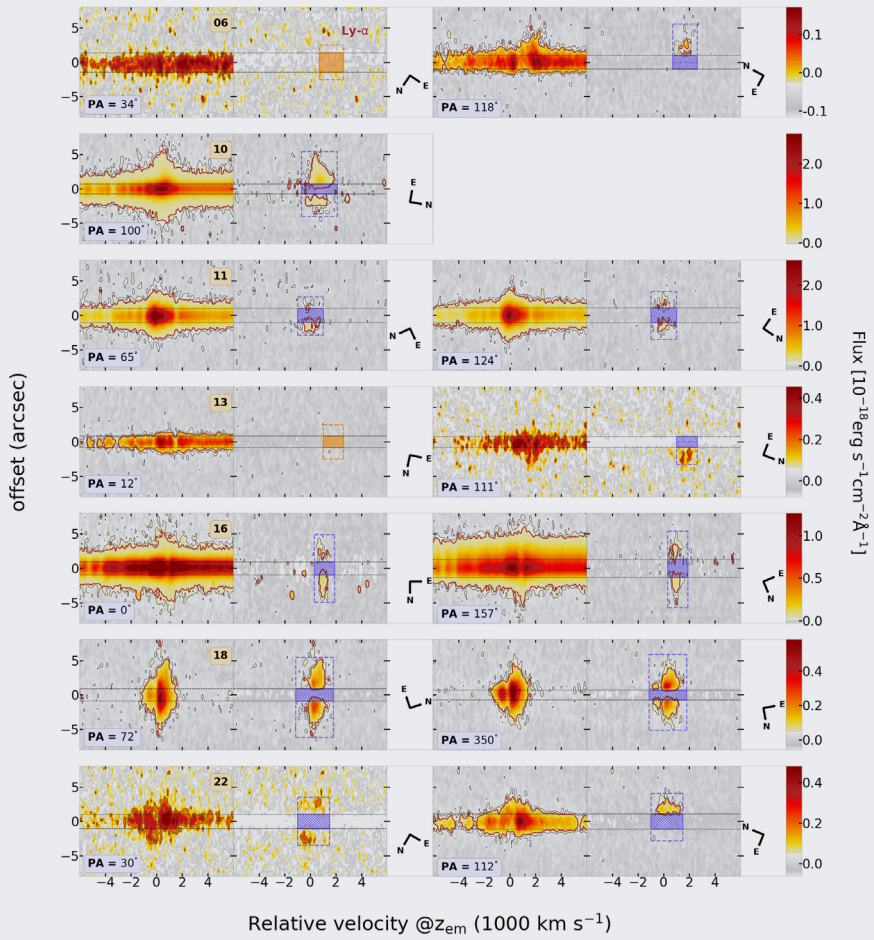


Observed spectra of HE 0435−5304. The SALT spectrum is plotted in blue, while the VLT spectra are in orange and green. The most prominent spectral features of the quasar are labeled as: Hβ, [O III], [Fe II]. Those are the emission lines of hydrogen, oxygen and iron atoms produced mostly in the broad, intermediate and narrow line regions. Yellow bands mark spectral ranges of atmospheric absorption from oxygen, ozone and water molecules (O_2, O_3 and H_2O, respectively).

Spatially resolved Lyman-α emission around radio bright quasars

Gitika Shukla, IUCAA (India), Ph.D. 2022

Gitika Shukla obtained her PhD at IUCAA, supervised by Raghunathan Srianand. For her project, she 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 was to map the extended Lyα emission from these powerful radio-loud AGNs (RLQs), which are brighter than 200 mJy at 1.4 GHz and were 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 explored in detail the relationship between the properties of diffuse Lyα emission and various quasar properties. She found a strong dependence of the Lyα halo detection rate on extent of the radio source, spectral luminosity of RLQs at 420 MHz (L420MHz), and presence of associated [C IV] absorption and nuclear [He II] emission line equivalent widths. As seen in previous surveys, the FWHM of diffuse Lyα emission in the case of confirmed detections is much higher (>1000 km/s in all except one). Using the samples of high-z RLQs and galaxies from the literature, she confirmed the correlation between the Lyα halo luminosity and its size with L420MHz. The same quantities are found to be correlating weakly with the projected linear size of the radio emission. 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.



Long-slit 2D spectra of seven RLQs showing presence of extended emission. Each row shows the spectra along the PA before and after spectral point spread function (SPSF) subtraction. Black dashed horizontal lines mark the SPSF FWHM. Clear detections are shown by blue boxes and the non-detections by orange. These boxes are used for measuring the Lyα halo size (at 3σ flux levels) for clear detections and the total flux (flux limit) for the others. All spectra are smoothed by 3 × 3 pixels to improve the SNR and to remove the pixel-to-pixel correlation. The 3σ and 5σ flux contour levels are shown in black and brown, respectively. North and East directions are indicated.

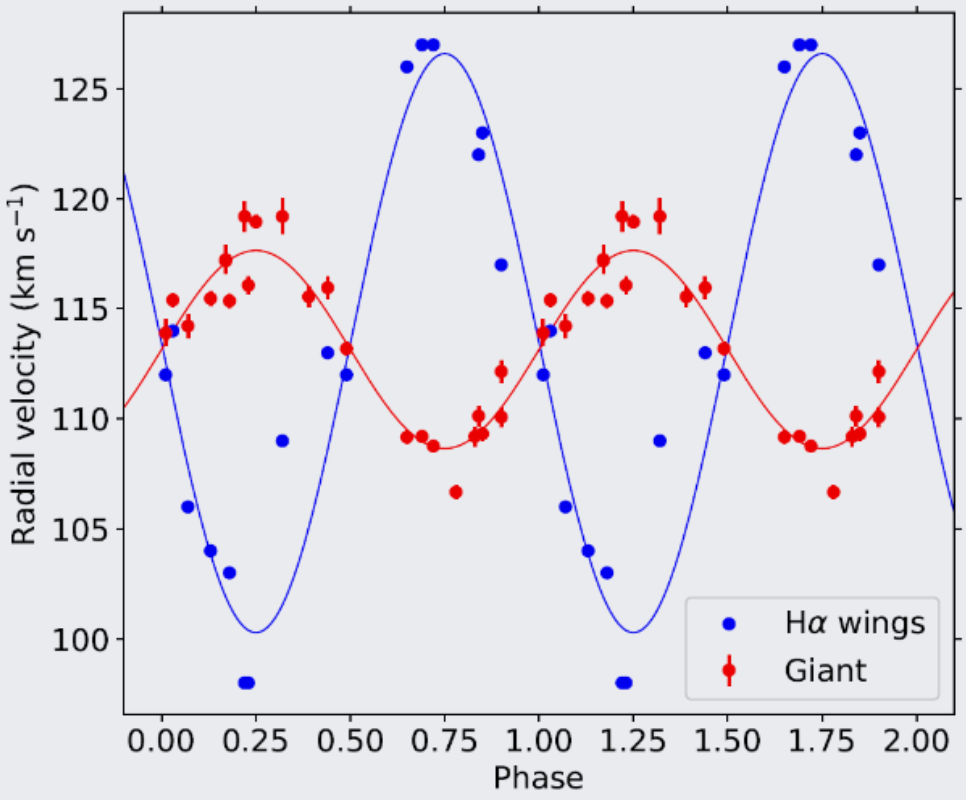
The symbiotic binary Lin 9: orbital parameters and outburst activity

David Modiano, Anton Pannekoek Institute for Astronomy, University of Amsterdam (The Netherlands), Ph.D. 2022

The PhD thesis "Searching for transients in the ultraviolet" by David Modiano from the Anton Pannekoek Institute for Astronomy of Amsterdam University (supervisor Rudy Wijnands) is partly based on a study of the Magellanic symbiotic binary Lin 9, which was done in collaboration with Joanna Mikołajewska from CAMK/PAS in Poland.

Lin 9 was classified as a new Z And-type outbursting symbiotic star in the SMC based on a SALT/RSS spectrum obtained by SALT Astronomer Brent Miszalski and his Polish colleagues in 2014. Since 2017, the binary has been included in SALT/HRS monitoring of Magellanic symbiotic stars and Galactic recurrent novae, with the aim to derive their orbital parameters (led by J. Mikołajewska). The SALT/HRS spectra, combined with UVOT photometry, allowed David to derive an orbital period for Lin 9 of 594.2 days. The system is not eclipsing and the orbit inclination is ≈ 40 – 60°. Double-line spectroscopic orbits indicate that the component masses are M_{WD} ≈ 0.3 – 0.5 $M_{\odot}$ and M_g ≈ 0.9 – 1.5 $M_{\odot}$.

In 2020, Lin 9 began a new active (outburst) phase that is still ongoing. Both the photometric and spectral evolution are consistent with Z And-type activity, and among the most remarkable events is the emergence of narrow emission features in the wings of the H line, at radial velocities of ~ −1200 km/s and potentially at ~ +1200 km/s, in the spectra taken in November 2021. Similar features have been observed in some symbiotic stars during Z And-type outbursts and have been attributed to the presence of collimated outflows in the system.

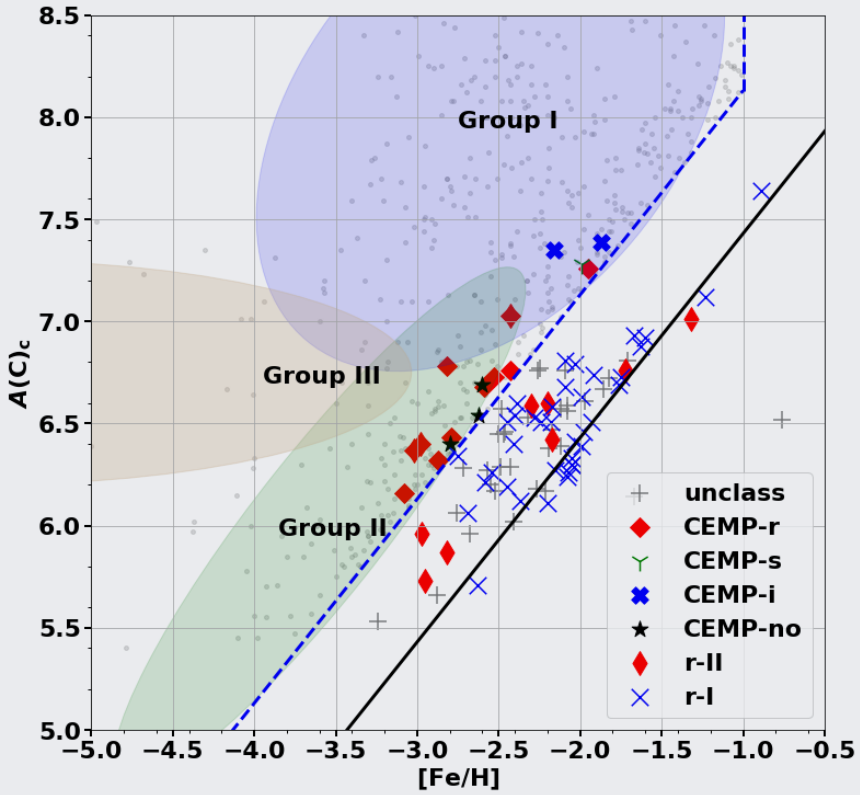


Radial velocity curves phased with the orbital period and orbital solutions for the M giant absorption lines (red) and the WD traced by broad emission line wings (blue).

The search for and study of CEMP stars

Joseph Zepeda, Notre Dame in South Bend Indiana (USA), Ph.D. 2022
Zepeda, J., et al. 2022/03, ApJ 927, 13: Metal-poor Stars Observed with the Southern African Large Telescope II. An Extended Sample

Timothy Beers' PhD student Joseph Zepeda graduated from Notre Dame in South Bend Indiana (USA) with a project that reports on the results of the observation and study of carbon-enhanced metal-poor (CEMP) stars. Using high resolution (R ~ 40,000) spectroscopic observations of over 100 metal-poor stars taken at SALT, he measured elemental abundances and then used these measurements to assign stars to a variety of chemically peculiar stellar classifications. Of particular interest were CEMP stars and classifications based on n-capture abundances. Joseph found 17 CEMP stars (11 of which were newly discovered), 38 *r*-I stars (moderately enhanced in *r*-process elements; 31 new), and 11 *r*-II stars (strongly enhanced in *r*-process elements; 8 new). He compiled a sample of CEMP stars, classified as such by medium and high resolution ($R \geq 4350$) spectroscopy. Combining 6D position and velocity information from *Gaia* with the spectroscopic observations, Joseph used the AGAMA programme to derive orbital parameters, and the HDBSCAN programme to perform a density based clustering over the orbital energy and actions (E, J_r, J_φ, J_z). He then separated the CEMP star sample with orbital parameters by CEMP morphological groups and performed a statistical analysis of the similarities between the elemental abundances within the different clusters of stars. Finally, Joseph demonstrates that the carbon abundance of Group II CEMP stars cannot be explained by local events, unlike Group I CEMP stars.



Yoon-Beers diagram of the evolutionary corrected carbon abundance $A(C)_c$ vs [Fe/H] for the sample stars with available carbon measurements, corrected for evolutionary effects. The blue dashed line shows the adopted criterion for CEMP stars, [C/Fe] > +0.7. The black solid line corresponds to [C/Fe] = 0. The sub-classifications assigned by Joseph are explained in the legend. The different morphological groups of CEMP stars are shown by the coloured ellipses. Literature CEMP stars from the SAGA database are shown as grey dots.

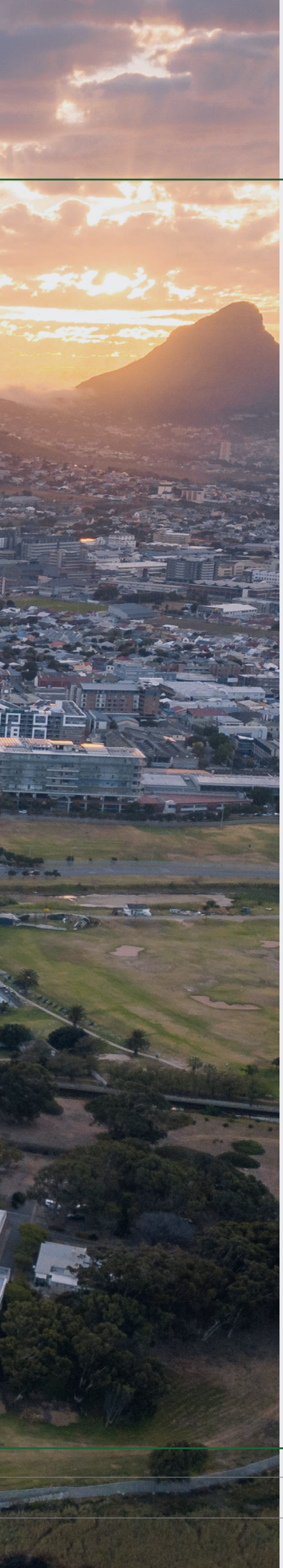


5.5

SCIENCE HIGHLIGHTS

SALT Workshop





SCIENCE HIGHLIGHTS

SALT Workshop

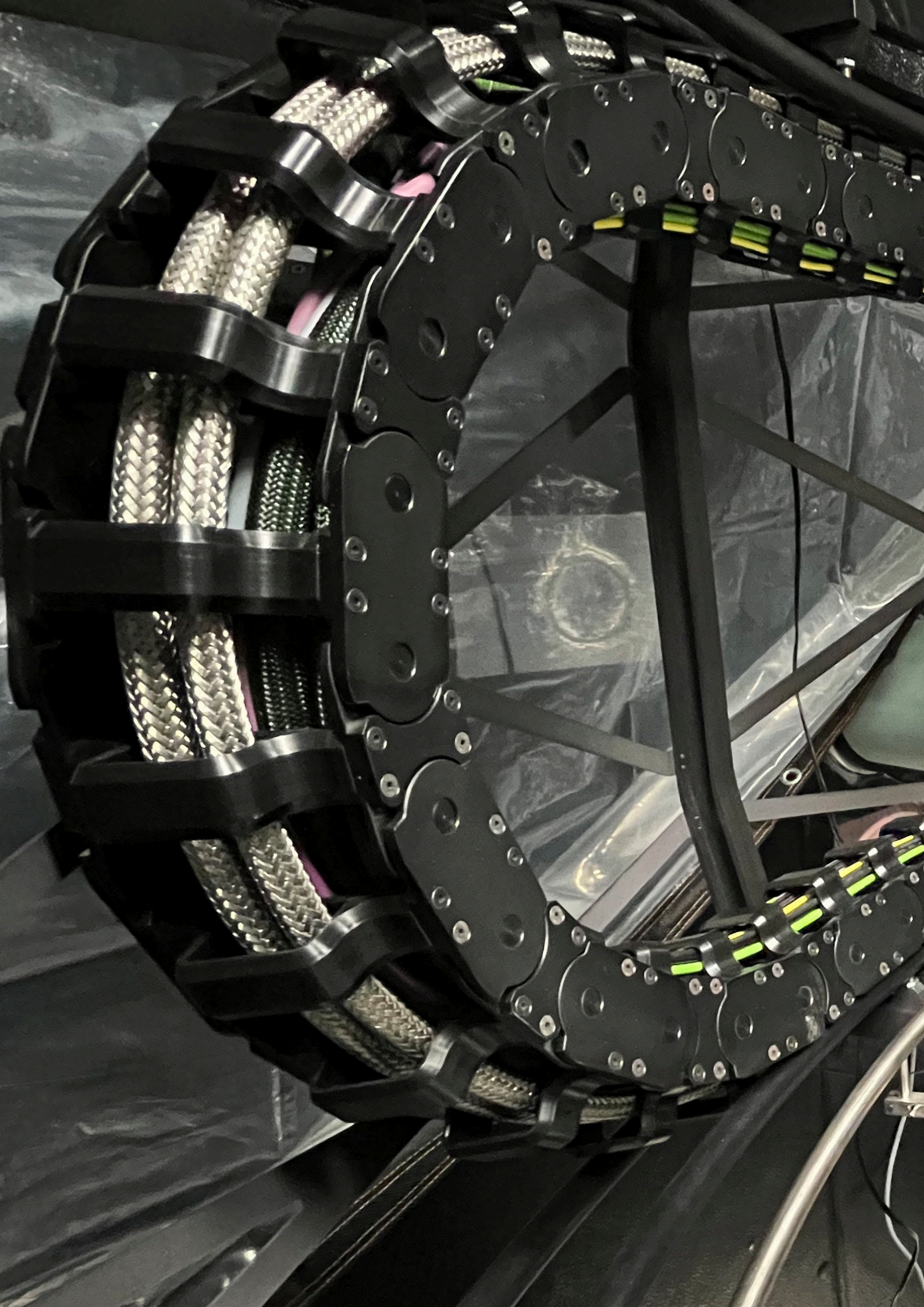
14 – 15 November 2022 at SAAO, South Africa

The Astronomy Operations team hosted a two-day practical workshop on SALT on 14 and 15 November 2022, in hybrid form, at the South African Astronomical Observatory in Cape Town and on Zoom. This was the first SALT-focused workshop or conference since the pandemic struck, and it garnered significant interest, with more than 160 registrations. Over 50 people attended in person and there were about 40 people online at any time, joining from different countries and time zones across the world. SALT funded the workshop attendance for five early-career researchers based elsewhere in South Africa (Durban, Mpumalanga and Potchefstroom), who were also able to visit SALT and the other telescopes in Sutherland after the workshop.

The workshop provided an overview of how the telescope works, tools available for preparing for observations and best practice for analysing SALT data. The Astronomy Operations team highlighted tips and tricks for optimising SALT time and provided detailed information on the proposal tools, data reduction processes and pipelines, the SALT data archive, and how to use particular RSS modes such as polarimetry and multi-object spectroscopy. There were also talks on new and upcoming instrumentation, with an overview by Lisa Crause, the latest on the RSS slitmask integral field units by Sabyasachi Chattopadhyay and the new NIRWALS instrument by the instrument PI, Marsha Wolf. Guest speaker Matt Hilton gave two talks on the tools he has developed to effectively observe galaxy clusters, showcasing how he designs masks for the RSS multi-object spectroscopy mode and his RSS data reduction pipeline. Anja Genade presented her work on the challenging task of calibrating SALTICAM images to do photometry of solar system targets such as Centaurs. There was time for discussion and practical work between talks.

The talk slides are available for download from the Programme page on the workshop website: www.saltworkshop2022.salt.ac.za
and the Zoom recordings are available for download via Owncloud at:
https://cloudcape.saao.ac.za/index.php/s/76PzO92fsVUe4fB.







6 OPERATIONS



6.1 OPERATIONS

Astronomy operations

The highlight of the year, of course, was the arrival, first light and first part of the on-sky commissioning observations of NIRWALS, the new NIR spectrograph on SALT. This IFU spectrograph extends SALT's wavelength range in the red to 1700 nm (see also the information given on page 2). Commissioning of the instrument should be completed in 2023. The Call for Proposals for semester 2023-1 includes a call for NIR proposals on a "shared risk" basis.

Other milestones of the year include the release of an API for submitting SALT observations and of Imephu, a package for the creation of finding charts. The new SALT Web Manager was nearly completed at the end of the year. And in November, we removed the PG0300 grating from the telescope and installed a PG0700 grating that has a better fit to the size of the detector. Observations with this new grating are going well.

This year we also held several engagements with the SALT community, the main event being a 2-day hybrid SALT workshop on 14 – 15 November, which gave an overview of the telescope, recent news and tools available for preparing observations and making use of the data. Just over 50 people attended in person and about 40 people joined the Zoom sessions online.

Two members of AstroOps also attended the bi-annual SPIE conference on Astronomical Telescopes + Instrumentation in Montreal (Canada) this year. Encarni Romero Colmenero presented an update on SALT (from instrumentation updates and upgrades to usage and science statistics). Christian Hettlage presented the new SALT API and Web Manager. Both presentations were well received.

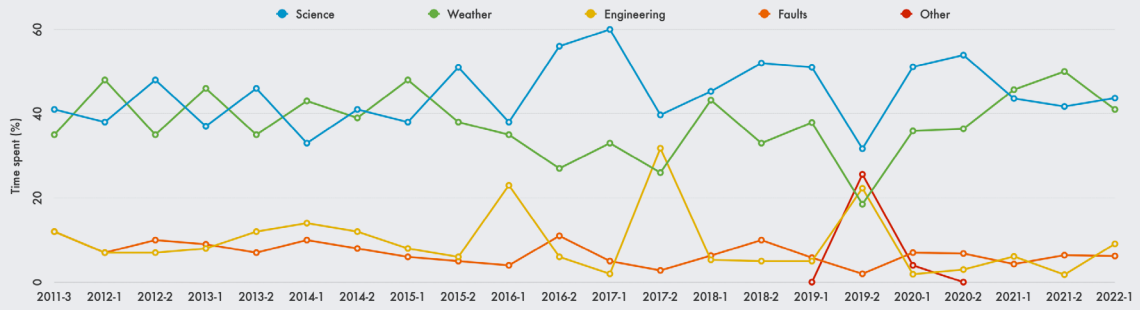
While remote operations are really successful at SALT, we also know that they are not quite as efficient as being at the telescope in-person, as many small inefficiencies due to the network slowly add up. Therefore, just as the rest of the world is slowly returning to normal after the COVID-19 pandemic, SALT Astronomy Operations progressively moved this year from mostly remote operations to observations made mostly in person at SALT. Of course, we retain the flexibility of remote operations for practical reasons — and the combination works really well for the team.

Semester statistics

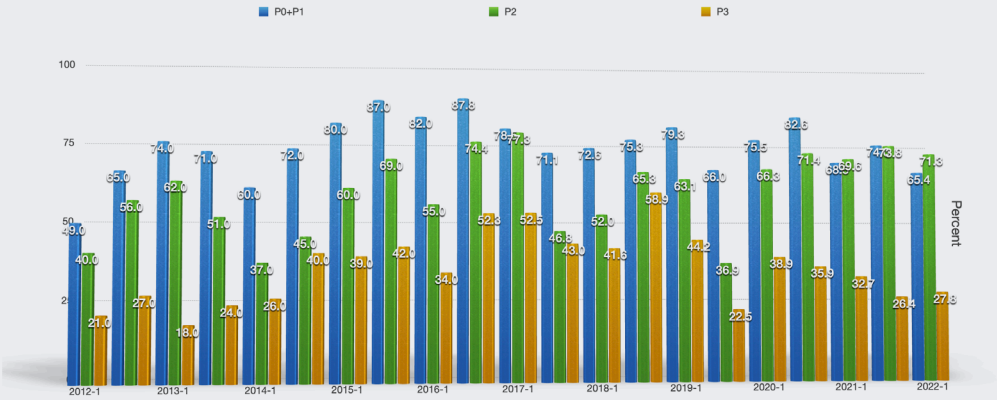
Our completion levels this year are similar to last year's. Semester 2021-2 suffered from 50% weather loss — the worst on record since the start of science operations. Semester 2022-1 saw much better weather, but higher engineering and technical downtime due to the arrival of NIRWALS. In addition, the technical downtime delayed the commissioning work until October, which, being the last month of the semester in combination with the time when many popular extragalactic fields come up, also had an impact on our completion levels.

The impact of the combination of the terrible weather in 2021-2 and the higher engineering time corresponding to the commissioning of NIRWALS can be seen in our time usage per semester, where the science time has dropped significantly for semesters 2021-2 and 2022-1. Please note that we used "other" in red to indicate the time lost due to the COVID-19 lockdown and related network issues in 2020.

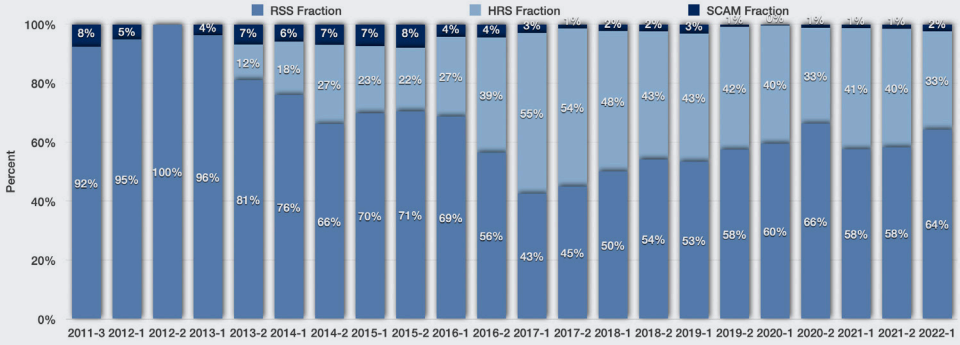
In terms of instrument usage, RSS continues to be our main workhorse instrument, dominating our very best conditions (dark, clear, good seeing nights). HRS, on the other hand, is our main instrument for bright nights and worse seeing conditions.



SALT time usage per semester.



Completeness per priority in percent.

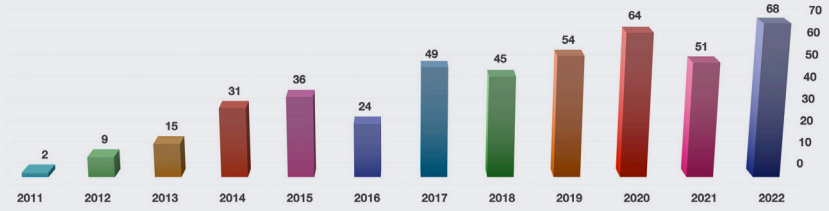


SALT instrument usage per semester.

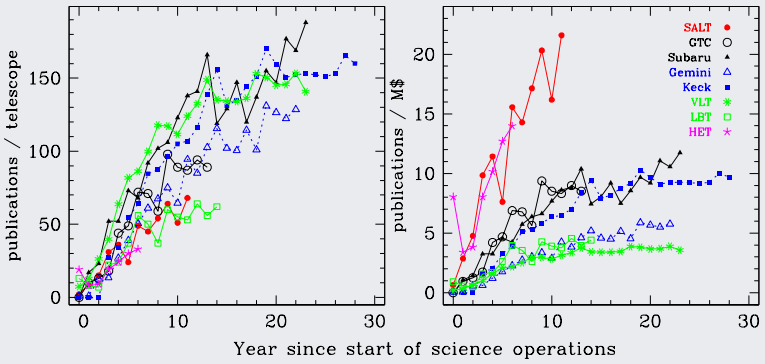
Publication statistics

This year we again broke the record in terms of number of annual SALT publications with 68 publications (one of which on an instrument-related topic). SALT continues to follow a similar publication growth to other similarly-sized telescopes around the world. In terms of cost per paper, SALT continues to deliver excellent value, with much lower costs than similarly-sized single telescopes around the world. This year, there were some more publications on Galactic sciences (35) than on extragalactic topics (25), with seven additional papers on supernovae/Gravitational wave events. Four of the publications dealt with exoplanets.

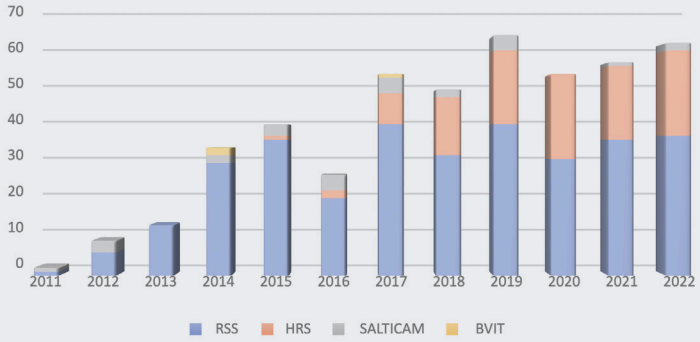
RSS continues to be our main source of publications, with HRS contributing to about a third over the last few years. SALTICAM's lack of guidance and difficulty maintaining focus has made it less attractive to our users, resulting in very few publications in the last two years.



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



Refereed publications since science operation started for major telescopes.
Left: publications per year and per telescope; *right*: publications per year and per operation cost in million US Dollars.



Instrument usage in SALT publications.

User support

To improve our efficiency at the telescope, we developed a new queue-scheduler, which came online at the end of 2021 and is working very well. This queue-scheduler is the basis for a new semester simulator, which has been completed in 2022. It is being used to study the observing queue and the various parameters that we use to determine it, to find ways to improve our efficiency and completion statistics. Astro Ops also developed a new Metrics and Data Quality website, to which we continue to add information.

SALT Astronomer Danièl Groenewald has been working on linear spectropolarimetry user support and calibrations together with the original RSS PI, Ken Nordsieck (UW). The full set of calibrations is nearing completion and is expected to be released in early 2023, with a publication to follow soon after.

A dedicated pipeline for NIR is being developed by SALT Astronomer Enrico Kotze, in conjunction with the NIRWALS team at UW. This is planned to be available to our users when the instrument is commissioned, or soon thereafter. SALT Astronomer Moses Mogotsi is the local liaison for NIRWALS.

The new Web Manager, which should make data perusal and retrieval easier for our users, is being launched in January 2023.

Personnel

Elizabeth Naluminsa, our dedicated SALT Fabry-Pérot postdoc, resigned from her position in December 2022 to take up a faculty position at Makerere University in Uganda.



6.2 OPERATIONS

Technical operations

The Tech Ops team had a busy year to maintain operations and complete projects while facing resource constraints due to the resignation of key staff. For the semesters 2021-2 and 2022-1, the telescope's average technical downtime remained around 6.3%. Most of the time was taken up with intermittent failures on SALTICAM, RSS and the FIF guidance system, all of which were addressed and remained in good working condition. We last reported that internet outages were a major contributor to our downtime. Thanks to the SAAO, a backup fibre link was commissioned in October 2022 and no downtime has been experienced since. This has hugely helped with ensuring efficient remote observing when required. Some staff also attended the SPIE Astronomical Telescopes + Instrumentation conference in Montréal, Canada in July 2022. This was the first in-person conference since 2018 (the 2020 conference in Japan was canceled due to COVID-19). After the conference, two staff members took the opportunity to visit our sister telescope, the Hobby–Eberly Telescope in Texas, to learn more about the systems they have in place.

SALT has made considerable progress with ongoing projects. One exciting milestone was the University of Wisconsin's NIRWALS instrument, which was shipped to South Africa in May 2022. Work is ongoing to complete the NIRWALS integration, with final commissioning expected to take place during the first part of 2023. The RSS shutdown (mainly to install the new RSS collimator Doublet and Triplet lens groups) was rescheduled to February/March 2023 due to resource constraints and ongoing NIRWALS and RSS Dual (aka MaxE) work. The RSS Dual design made good progress in 2022: The preliminary design review (PDR) for the optics was held in November 2022, with an external review panel that gave very positive feedback to the team. The second part of the PDR, for the opto-mechanical design, will be held in early 2023. The new RSS-VIS and Red Detector project is making some good progress, although the critical design review (CDR) had to be rescheduled to mid-2023 due to some delays experienced with hardware verification testing and software engineering resource constraints. The PG0700 grating is now installed in the RSS and ready for science. The manufacturing of new, better-quality RSS long-slits has had its first review, and while we have found deficiencies in the samples received from two different suppliers, we do have a better understanding of the product and testing thereof. We will continue with manufacturing more samples in-house, applying what we have learnt. The Laser Frequency Comb for the HRS has also made good progress, with installation and commissioning expected around mid-2023. On the other hand, the FP etalon upgrade faces continuous delays from the coating vendor. We are awaiting test results from similar sized etalons that were coated for another client before we decide on a way forward.

The primary mirror segment recoating schedule experienced some delays due to the long implementation of the new coating plant controller and because of quality and efficiency problems experienced with the coating plant. Much effort has been put into understanding the various efficiency and quality problems of the plant. After implementing improved data collection and analysis for each coating procedure, and changing the parameters and configurations accordingly, we improved the reflectivity from an average of around 70% to around 88%. The team has now also managed to get ahead of the coating schedule for the current cycle.

As with many other entities, we are also experiencing delays with the manufacturing and procurement of various products from external vendors. We are, however, keeping maintenance of the telescope on schedule and we are scheduling our projects accordingly. We were fortunate to have received some of the more important long-lead items before these delays started.

Personnel

Keith Brown, who was our Senior Electronics Engineer, resigned in March 2022 to take up a post at the SKAO, and software developer Deneys Maartens resigned in July 2022 to take up a post in the Netherlands. Dillon Klaasen, who joined the team only in 2021, has also resigned.

We welcome our new staff:

- Tasheen Naicker, Senior Mechanical Engineer, started in February 2022;
- Shamiel Adams, Software Engineer, started February 2022;
- Deon Lategan, Engineering Consultant, started March 2022, and
- Willem (Wimpie) van der Westhuizen, Senior Electronics Engineer, started 28 November 2022.

Two other software engineering posts were advertised, and we hope to fill one of the posts by end-January 2023, while filling the more senior post is still proving to be a challenge.

Health and safety

We are happy to report that there were no injuries to staff during the reporting period.



6.3

OPERATIONS

Instrument news

A four-week downtime period of major RSS optics upgrades has been penciled in for March 2023. RSS will be offline for this period, but HRS and SALTICAM will be on-sky for the duration of the upgrades. With the PG0700 grating installed recently and a new long-slit letterbox installed during 2021/22, the major task for the upcoming shutdown will be the replacement of the collimator doublet and triplet, which will take up the majority of the downtime. Minor tasks will include upgrading the leak detection system and making measurements of various parts of the RSS system, not to mention several collimator checks and pre- and post-lift general engineering (baseline and commissioning) tests — certainly enough to keep SALT Ops busy!

The Big 5 — progress on the RSS upgrade

PG0700 grating installed and available

The new 700 l/mm VPH grating (PG0700) was installed and successfully aligned in November 2022. Testing and early science data look good. The grating is now fully available for all users and has been added to the latest versions of the PIPT and RSS simulator. A final set of test data was taken just before the year-end holidays to determine the best focus range for the grating. The PG0900 focus model has been modified based on this data and applied to PG0700. We will monitor the best focus as the seasons change (as we do for other gratings) and adjust the focus range for the winter months if necessary.

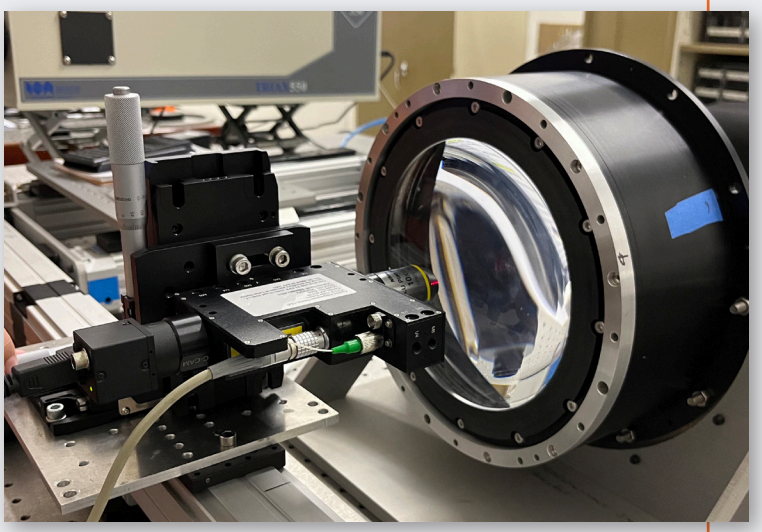
The PG0300 grating has been permanently replaced by the PG0700. If there are any questions about using the new grating for your science, please do not hesitate to contact the SALT team.

The new doublet & triplet

Two of the lens groups in the RSS collimator suffered degradation many years ago and we have long aspired to replace them with entirely new assemblies to improve the performance of the spectrograph. Working with these very tricky optical materials, which include large crystals of calcium fluoride and sodium chloride (that are extremely sensitive to thermal changes and humidity, respectively) poses numerous challenges. The complexity of these two units — known as the doublet and the triplet — is further compounded by the fact that the lenses are "fluid coupled". The gaps between the two lenses in the doublet and the three elements in the triplet are filled with a refractive-index-matching silicone oil that is utterly determined to escape the associated plumbing within the lens cells and contaminate everything that it possibly can. After various unsuccessful attempts to bond the new doublet lenses into their new cells, the team ultimately decided to contract the engineering company in California that produced the original RSS optics to build these new assemblies for us. The new triplet arrived in Cape Town in March and the doublet followed in November. Both will undergo lab testing early in the new year and then be transported to SALT for installation during the RSS shutdown scheduled to take place during March of 2023.

The new detector

As discussed in last year's report, the RSS detector upgrade project involves replacing the current CCD and controller with a higher efficiency monolithic chip and a CCD controller developed by IUCAA. However, this is just one half of the full RSS detector project. Since the new red arm of RSS (the MaxE project) will use a nearly identical detector package, two CCD's have been procured and work on the existing RSS (RSS VIS) and new red arm (RSS RED) detector packages is progressing in tandem (see below the text on MaxE for further information). The next significant milestone for the project will be the CDR for the detector module in the next few months.



New long-slit samples

As part of our long-term project to replace the full suite of RSS long-slits, four sample slit-masks were procured from two suppliers in November 2022. The companies are both South African precision engineering firms. Each company manufactured two slit-masks to replicate our existing 1.5" x 8' long-slit. From preliminary measurements in the lab, slit straightness, reflectivity and flatness were similar to or better than our existing slits.

The samples were taken up to Sutherland and installed on SALT for testing at the end of November. During the course of the day and night, several arcs, flats and slit-view images were taken using the four samples, alongside our existing 1.5" slit for comparison. From these data, it was immediately obvious that there was a range of quality in the slit-masks. The reflectivity of all four slit-masks was good, but some of them showed imperfections when examined in slit-view images, as can be seen Figures 1 – 3. For example, the new slit-mask shown in Figure 2 (right) visually looks to be of high quality (much better than our existing slit), but, unfortunately, as with all four of the samples we received, it showed imperfections in flat-field images. The mask that appeared visually best in slit-view is in the lower-right corner of Figure 3. Towards the centre of the spatial axis, the quality looks very good. However, the top and bottom edges reveal many imperfections (the dark horizontal bands) that would affect extended object science.

From these initial tests, we concluded that none of the masks were significantly better than our existing slit. Therefore, we decided not to immediately replace our existing 1.5" long-slit with one of the new samples. We will now re-approach the vendor that produced the best sample and work with them to improve the slit-mask until we reach a quality level that is suitable for science. Perhaps the biggest challenge will be to consistently produce the required quality across the entire suite of long-slits that we will eventually require, since the vendors are working at the limits of the machinery available. Updates on this will be presented in the SALT newsletters.

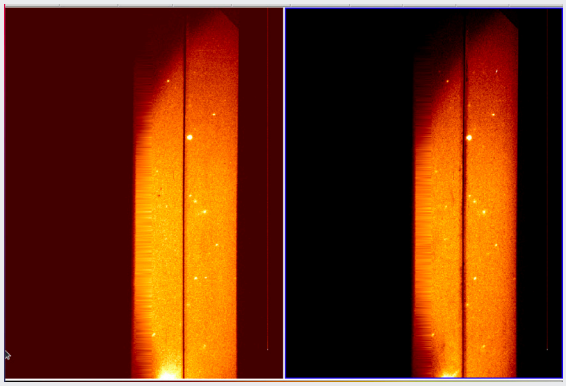


Figure 1

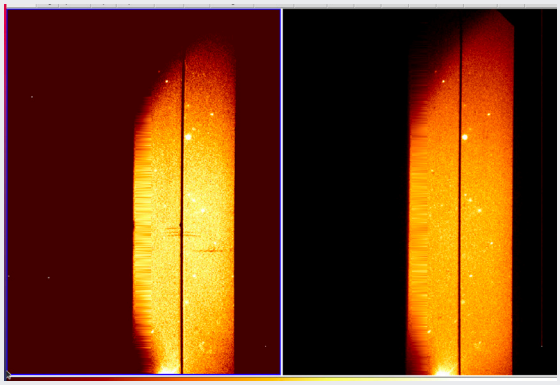


Figure 2

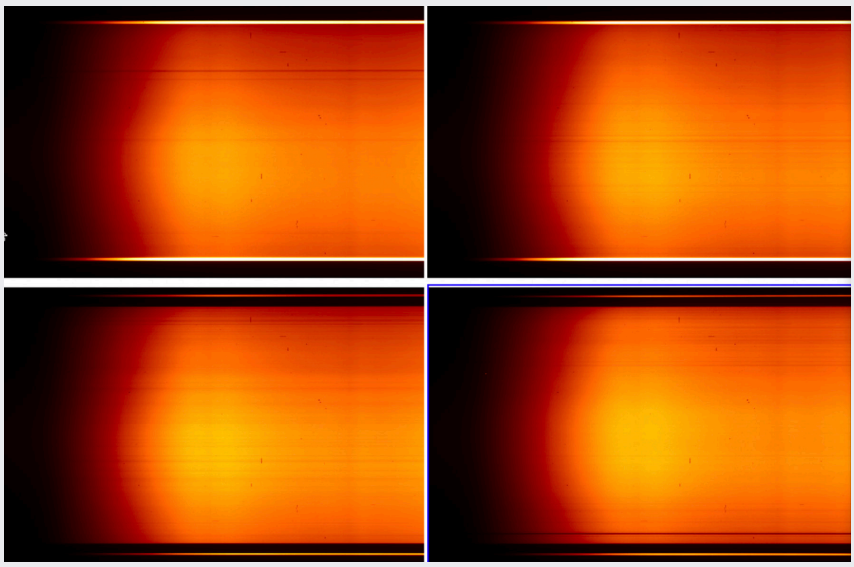


Figure 3

Figure 1: Two of the new samples with bad shadowing along the slit edges — clearly not suitable for science!

Figure 2: Comparison of the existing slit (left) with the best of the new sample slits (right).

Figure 3: Example flat field for each slit-mask sample.

High-Resolution Spectrograph high-stability mode developments

Exciting progress has been made on the SALT HRS high-stability (HS) mode upgrades during 2022. This project will deliver a laser frequency comb (LFC) to provide precision wavelength calibration for the HS mode, as well as a specialist data pipeline to support this new capability. All of which is intended to equip SALT for precision radial velocity work, for the study of exoplanets in particular.

The many components required to build this astrocomb were ordered from vendors around the world and shortly before the year-end holidays, the last (and largest) shipment was delivered to the SAAO in Cape Town. The 13-page packing list was meticulously checked and all components are present and accounted for! The main titanium-sapphire laser that was received at the end of 2021 ended up having to be sent back to the UK for warranty repairs. This took several months and so it was a great relief to get that large crate back in our lab and to confirm that the system does indeed work as intended now.

The SAAO's mechanical workshop has made a number of parts for the LFC and will complete the smaller components in January 2023. Similarly, power supplies and other simple electronics modules for the comb will be built up by members of the SALT Ops team in Sutherland early in the new year.





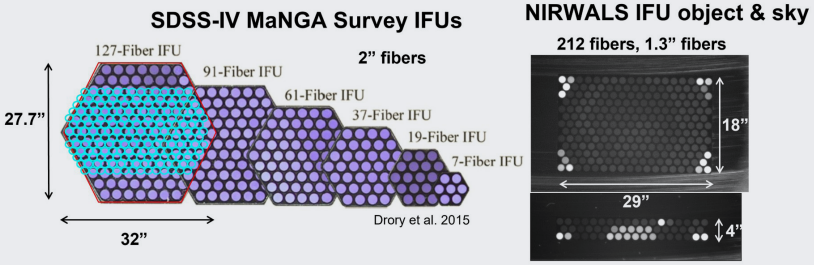
The HS pipeline development work is being done by a committed long-term SALT HRS user, Daniel Holdsworth at the University of Central Lancashire (UCLan), one of the founding institutions of the UK SALT Consortium. SALT has bought out 80% of Daniel's time over a two-year period to allow him to work on the pipeline, while still being based at UCLan.

The next step is for the project lead — Richard McCracken from Heriot-Watt University in Edinburgh — to visit Cape Town in early February 2023 to test and begin assembling the various elements that make up the LFC. That initial visit will just be for a few days, and then he and his team will return to South Africa a few months later to carry out the assembly and integration of the comb up at SALT.

It is extremely exciting to see this project progressing rapidly and we look forward to getting the LFC hardware installed next year. The pipeline development will continue in parallel and is due to be completed in the first half of 2024.

NIRWALS commissioning

The year 2022 saw the arrival and installation of the new near-infrared spectrograph (now officially called NIRWALS: Near Infrared Washburn Astronomical Laboratories Spectrograph). The instrument structure and enclosure, optics and detector system arrived in May, while the fibre cable arrived later, in June. The University of Wisconsin (UW) team, led by PI Marsha Wolf, worked tirelessly with the SALT team on the installation and testing of the various aspects of the instrument over the first phase of commissioning: The spectrograph was installed and tested at the operating temperature (−40° C), optical alignment was done, and the fibre cable was installed in early July.



The final NIRWALS IFU configuration. *Left*: NIRWALS' object bundle (bright blue) compared to SDSS-IV MaNGA IFUs. *Right*: The object (top) and sky bundle (bottom), where the dark fibres show the final fibre configuration.

An enormous amount of work went into assembling and polishing the fibre cables, and into determining the optimal configuration and arrangement of the individual fibres on the slit to minimise the effects of non-telecentricity and to improve sky subtraction. This was done and finalised before the fibre cable was shipped to SALT. The final configuration is shown below, with a 212-fibre object bundle that covers 29" x 18" on-sky and a 4" x 18" sky bundle for simultaneous sky observations, each fibre having a 1.3" diameter. Unfortunately, two sky fibres were damaged before the instrument was shipped, leaving the sky bundle with 36 fibres.

This was the first time so many fibres (248) had to be routed from the tracker down to an instrument in the spectrometer room below the telescope. Particular care had to be taken while routing the fibre cable through the telescope to ensure that the fibres will not get damaged during routine telescope operation.

After installation of the fibre cable, the instrument was modified and set up for operations. On 7 July 2022, NIRWALS had successful first-light on-sky observations. Short exposures of the Eagle Nebula and a number of bright stars were taken, along with some exposures using the telescope's calibration system.

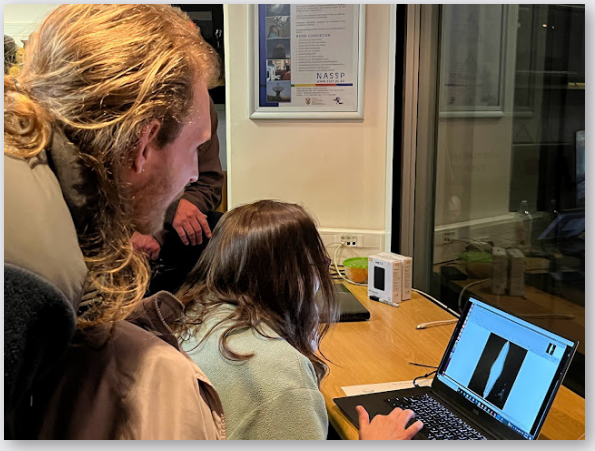
The SALT team also had to prepare the telescope for NIRWALS. This included replacement of the existing atmospheric dispersion compensator (ADC) with one that also transmits in the near-infrared. The fibre-instrument feed (FIF) also had to be adapted to enable the installation of the fibre bundles and provide the required range of motion. The separation between fibre bundles can be adjusted by moving the FIF jaws. The instrument will be used in bisector mode, and when the separation between the fibre bundles is changed, each bundle has to be tilted to the desired telecentric angle for that specific SALT field position. In addition to these adjustments, a new acquisition camera with a larger field of view was installed to simplify acquisitions.

A NIR calibration system was added to the existing system. This addition consists of an integrating sphere, with a new suite of lamps (neon, argon, krypton and QTH) and an NIR transmissive light guide to feed light from these lamps into the calibration system optics. The integrating sphere has the additional benefit of enabling the simultaneous use of different lamps in a single exposure. There were also many software changes and improvements to the telescope, proposal submission tools and operations software. This includes the creation of new software interfaces and upgrades to telescope systems to incorporate the new instrument.

Photos of the team during the fibre installation.

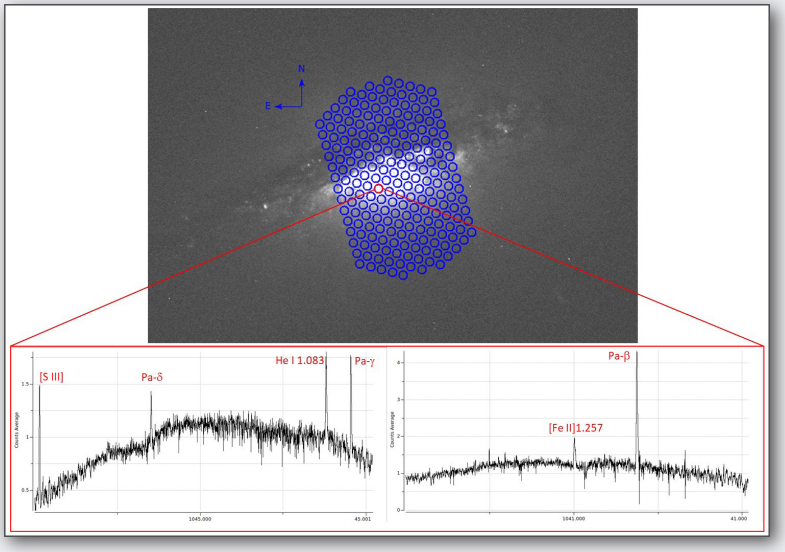






Joshua Oppor and PI Marsha Wolf looking at the calsys first-light data.

Phase 2 commissioning began in October with adjustments to the FIF, re-ordering the slit V-groove blocks (*i.e.*, how the fibres are arranged on the slit), aligning the slit and re-cooling the instrument. In addition, the SALT Tech Ops team received further training on how to maintain the instrument. This was followed by a week of on-sky commissioning tests. Various standards, stars and extragalactic sources were observed.



Top: NIRWALS IFU footprint overlayed over the ULIRG NGC 1482. *Bottom*: Examples of spectra from one of the fibres taken at different grating settings. These are as yet uncalibrated, though an observation of the sky was subtracted from the target. – Credit: Marsha Wolf.

The operations software, acquisition, positioning, offsets and other telescope and instrument aspects were tested, and the NIRWALS calibration system was used to obtain calibration data and test the instrument across most of its wavelength range (0.8 to 1.65 microns). Calsys calibration of the remaining 0.5 micron (up to 1.7 microns) will be added later. In particular, we tested the ability to perform telescope and FIF offsets (for nodding, dithering and mapping purposes) and to use blind offsets for sky subtraction. The success of these observations was highlighted by the observations of the ULIRG NGC 1482, which has a known ionised gas outflow. It was observed using multiple grating angles and the observations were split into object frames and blind offsets to sky. After the sky subtraction, a number of bright emission lines could be seen in the spectra.

The NIRWALS data reduction pipeline has also been developed. There will be a primary pipeline, which applies bias and flat fielding corrections and puts the data and their headers in a state for further reduction. Similar to MIDAS for HRS, there will be a secondary data reduction pipeline that will reduce the data to produce extracted and wavelength calibrated (and potentially sky subtracted) data that is ready for science. The main components of the pipeline have been completed and adjustments are being made using commissioning data from the instrument. Before the data get processed by the pipeline, a pre-processing step is needed to perform a number of corrections, produce bad pixel maps and convert the raw data into 2D fits images. The former are critical to optimally deal with the bad pixels that are due to the degraded detector. The pre-processing software is being developed by the UW team, and the data from the first part of the on-sky commissioning is being used for the development and optimisation of this software.

While the data from the first stage of on-sky commissioning is being analysed and the pre-processing software is being improved, work has gone on to improve the cooling system and fault logging to minimise risk to the instrument when there are power cuts. The detector interface and instrument control interface software is also being improved. The instrument will be cooled again in early 2023 to begin the next stage of tests that will lead us into the last phase of on-sky commissioning. We aim to begin shared-risk observations using NIRWALS after this phase of on-sky commissioning is complete.

The MaxE project (RSS Dual)

The MaxE project aims to upgrade the current RSS instrument (RSS-VIS). It involves adding an optical arm covering the red wavelengths (so-called "Red Arm") thus forming an enhanced spectrograph which simultaneously covers both visible and red wavelengths, called "RSS Dual". This will, amongst other use cases, enhance the capability of the SALT telescope to perform transient identification spectroscopy and thus support the SAAO goals in transient science. The work involves the development of a fold mirror/dichroic mechanism which will enable Dual and VIS mode selection, as well as a new red fold mirror, doublet, grating and camera, cryogenic detector, control electronics and user interfacing software. The PI and co-PI of the instrument are David Buckley and Lee Townsend, respectively.

During 2022, the project made further progress on the Red Arm design. The opto-mechanics and overall structural designs made great strides after the team was augmented with new personnel at the beginning of the 2022. We also received some key long-lead items, including the Teledyne 6K x 6K CCD and the optical blanks.

A developing risk for the project has been the resignation of three personnel involved in the software for the SALT OCS, instrument control software and detector software, respectively. The impact thus far on the overall project schedule has been minimal but the window for filling this gap without impacting the project is closing. Recruitment is in progress to fill the vacancies.

The team's next major milestone is the project and system-wide preliminary design review (PDR), which is scheduled for the first half of 2023.

Summary of the main RSS Dual spectrograph design parameters

Parameter	Blue Arm	Red Arm
Collimator focal ratio	f/4.2	
Collimated beam diameter	150 mm	154 mm
Nominal slit width	1.5 arcsec	
Slit height	8 arcmin	
Waveband	360 – 630 nm	630 – 900 nm
Resolving power	~ 600 – 1000	~ 1600 – 2400
Camera focal ratio	f/2.2	f/1.55
Camera magnification	0.52	0.35
Camera field of view	16°	22.2°
Detector	Mosaic of three 4K×2K CCDs, 15 µm pixels*	Monolithic 6K×6K CCD, 15 µm pixels
Detector plate scale	118 µm / arcsec (7.8 pixels / arcsec)	78 µm / arcsec (5.2 pixels / arcsec)
Grating	900 l/mm at 12.5°, Littrow	1184 l/mm at 33.3°, off-Littrow

*To be upgraded to a monolithic 6K x 6K CCD as well.

Opto-mechanics, structure and optics

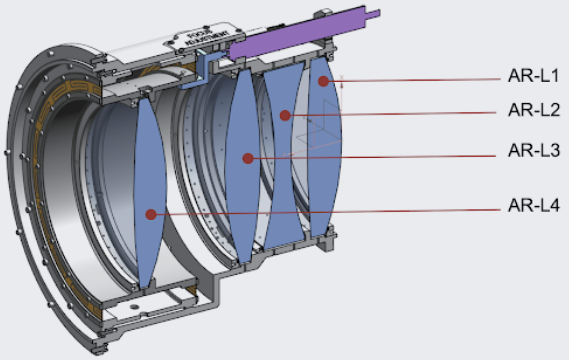
An external review with the aim of confirming readiness for optical blank procurement was concluded favourably in November 2021. Ordering of these long-lead time glass blanks was completed and all blanks have been received. The optical PDR last November was also successful. One aspect queried was the trade-off between resolving power and wavelength coverage — should the red cut-off be extended by 30 – 50 nm to cater for future CCD upgrades? This question will be reviewed with the science community before manufacturing.

The matured optical integration and alignment plan confirmed that the lenses can be successfully mounted and aligned to within tolerances, given the opto-mechanical design (see camera layout). Successful order-of-magnitude quotations for the manufacture of all the lenses have been received. Quotations on the manufacture and coating of other elements, such as the fold mirrors and dichroic are also progressing with vendors.

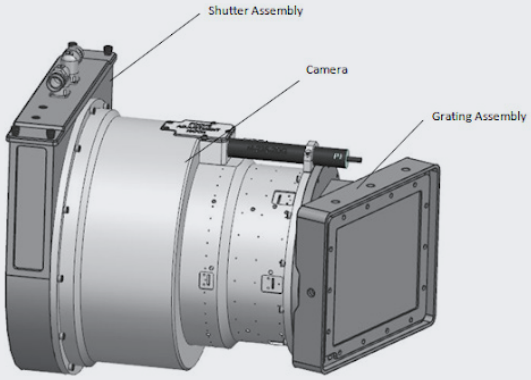
A finite element analysis (FEA) of the existing RSS structure was performed to assess the level of flexure that can be expected during operation. Initial metrology checks of the actual system to correlate the FEA results with measured data were done with dial gauges, which unfortunately highlighted some non-linear behaviour present in the tracker's Tilting Platform structure. More comprehensive metrology was subsequently carried out, and the flexural behaviour is now well characterised and understood. The new data will be incorporated into the FEA model, resulting in a more representative model that will allow the development of a stable structure for supporting the grating and camera, and to predict overall structural behaviour once the Red Arm components are added. In addition, this model will assist with analysing existing anomalies in the RSS-VIS behaviour.



The 250 mm diameter x 52 mm thick S-LAL8 blank for AR_L3.



Opto-mechanical layout of the camera showing the first four camera lenses (AR_L1 – AR_L4). In this design AR_L4 is used as the focusing element and can translate axially on a flexure mount. The fifth camera lens, not shown here, forms the cryostat window and is included as part of the cryostat assembly.



Grating-camera assembly.

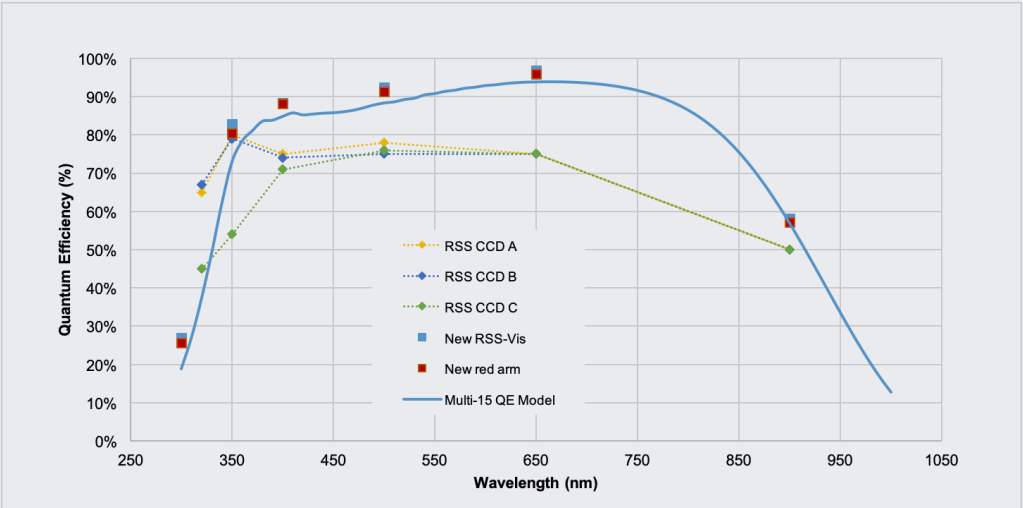
Red Detector

The detector team's main focus this year has been on characterising the performance of the IDSAC* controller, making heavy use of the lab 6K x 6K test cryostat commissioned in 2021. Working closely with the IUCAA development team, hardware modifications were made to the controller units in hand to resolve some signal output issues. This allowed much better control over the system noise and dynamic range, and we can now achieve CCD-limited noise output and the full dynamic range for key gain settings.

Another exciting moment was when the two 6K x 6K science CCDs from Teledyne were received, along with their electro-optical test results. The quantum efficiency of the two devices are remarkably similar in performance (see plot), and the device with the slightly better blue performance has been selected as the RSS-VIS chip, and the other for the Red Arm.

Aside from the two highlights, much effort was spent this year defining and agreeing on interfaces between the detector and other new and existing systems, and finalising component selection for key systems.

*IUCAA Digital Sampler Array Controller, https://arxiv.org/abs/1807.05528



Quantum efficiency (QE) of the new CCDs and the three existing CCDs (A – C). The performance at 350 nm is marginally better than for the existing blue chip, and both devices far exceed the existing CCD performance from 400 nm – 900 nm. The blue line shows the Teledyne analytical model plot for this device configuration; the good agreement of the model with the test data allows one to get a realistic estimate of performance in between data points.



6.4

OPERATIONS

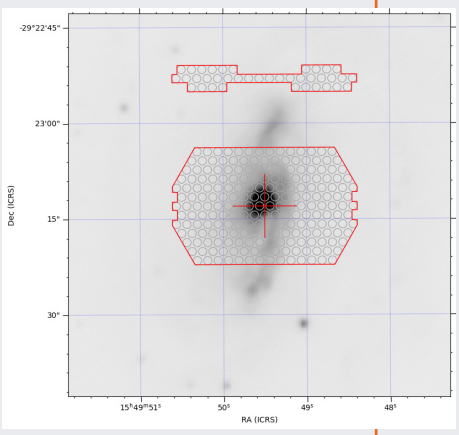
Software updates

The software team has been working closely with our Wisconsin colleagues to integrate the **NIRWALS** instrument into the SALT software architecture. Important telemetry is logged via the Event Logging Software. This system is designed to alert the operations team to changes in the instrument environment that require attention. The Telescope Control System (TCS) software uses a text-based control language, the SALT Control Language or SCL, that allows instruments to send pointing offsets to the payload software. This capability has been added to the NIRWALS control software to enable dithering and mosaic procedures. NIRWALS has also been developed with a similar execution engine to the RSS, which allows for multiple hardware mechanisms to be configured with patterns of sequential and parallel commands to allow for optimal configuration times. Of the systems currently receiving a lot of the team's attention, the NIRWALS detector interface and control system is taking priority. The team found that some operations, for example aborting sequences, required modification to conform more closely with SALT's night time standard operations. Fortunately, the team at IUCAA has been working with our team to optimise the system.

The work for NIRWALS would not have been possible without major **upgrades to the supporting systems**. These include the proposal and observation tools such as the Observation Control System (OCS) that was extended for NIRWALS, as well as updating the Principal Investigator Planning Tool (PIPT), the Observation Planning Tool Interface (OPTI) and Science Database (SDB) to support NIRWALS proposals. For the TCS Pointing model, the Rho drift correction model was implemented and commissioned and the atmospheric dispersion compensator (ADC), moving baffle and pupil mask trajectory modelling for the new hardware and NIRWALS observations was added. On the payload side, NIRWALS Calsys control was added as well as the new ADC moving baffle and pupil mask hardware support. The fibre instrument feed (FIF) mount model support for the NIRWALS integral field units (IFU) was also added to the payload.

With the arrival of NIRWALS in South Africa necessitating software changes in the **PIPT**, the opportunity was used to give the calculation of overheads a complete overhaul, making it easier to make changes in future. Other improvements to the PIPT were the addition of OPTICON-Radionet pilot proposals and a significant reduction of the submission time for solar-system object proposals. Both the PIPT and the RSS Simulator were also updated to handle the new PG0700 grating.

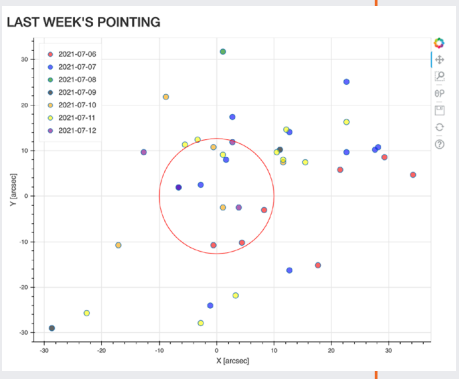
To generate **finder charts** for NIRWALS observations, a Python library, Imephu, was written, which lets the user generate finder charts either programmatically or via a command line tool using a YAML configuration file. It can be installed with pip. Contrary to the existing tool, Imephu lets the user choose their own background FITS image and the chart size, so that the placement of the NIRWALS science and sky bundles can be displayed in full detail. While geared primarily for SALT, Imephu is written in a way so that it can be used for other telescopes as well.



Finder chart for NIRWALS generated with Imephu.

A main focus of this year's work was the **Web Manager**. Various features were added, such as listing MOS observations and masks and handling NIRWALS setups. Emphasis was put on adding meaningful tests to ensure long-term stability of the software. As a consequence, a standalone and pip-installable Python package, pytest-pymysql-autorecord, was written which intercepts and stores database requests. This allows realistic tests to be included in a continuous integration workflow. The new Web Manager is scheduled to go live in the first quarter of 2023. The backend API of the Web Manager will be accessible with the help of a Python library, PyAstroSALT. A first version of the library was released, which allows users to submit their proposal and to monitor the submission.

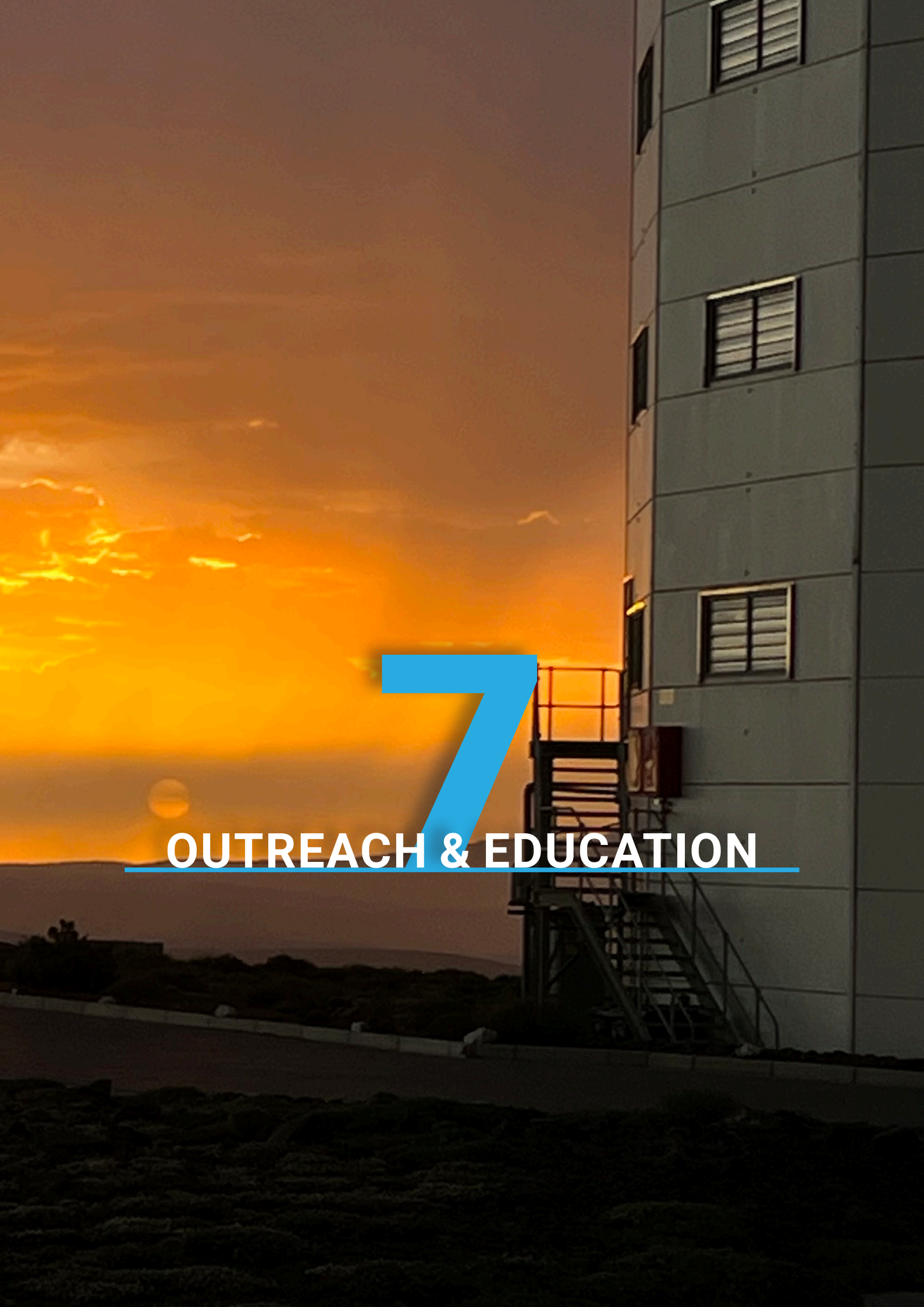
Given the importance of tracking the **telescope performance**, some metrics have been developed to check how SALT has performed in the past compared to now. These included a metric that calculates the overheads of the telescope per semester and for each instrument. This draws a clear picture of how the operations at the telescope are going with time. It also shows where most of the time is spent during operations, which helps to improve the observing efficiency. Another metric is the accuracy of the telescope pointing model over time. This allows the team to monitor the pointing performance of the telescope. Plots for the metrics are generated and displayed online. The figure to the left shows an example.



Metric showing the accuracy of the pointing model over the time span of a week.

The SALT publication statistics pipeline was improved to efficiently extract the necessary publications information from NASA's ADS (that is, title, abstract, publication date, authors and their affiliation). A newly developed Jupyter notebook makes it easy to analyse and visualise the SALT publications data.





7 OUTREACH & EDUCATION



7.1

OUTREACH & EDUCATION

SALT Collateral Benefits Programme

OUTREACH & EDUCATION

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 2022, the SAAO education and outreach teams continued to communicate the beauty, relevance and power of astronomy, despite the disruptive and restrictive nature of the COVID-19 pandemic and associated safety protocols. Our programmes were adapted in alignment with legal restrictions and expectations. A total of 19 694 people were reached and engaged in teacher training and support programmes, learner activities, science festivals and exhibitions, indigenous astronomy, open nights and tours of the observatory, career-based programmes and girl-focused events.

Teacher training, support and development

Believing that empowering and supporting teachers improves classroom practice and has the potential of influencing the learners positively through the empowered teachers, the SCBP staff continues to facilitate teacher workshops and is always available to do team teaching with teachers.

In this vein, from 26 – 29 September, four full-day teacher training workshops, based on the teaching and learning of the "Earth and Beyond" curriculum, were held in the Free State Province (Bethlehem, QwaQwa and Senekal). In response to a call for assistance by the Free State Provincial Government, 125 teachers participated in the workshops. The teachers were provided with relevant curriculum content, exciting pedagogical approaches and resources and information for their classroom practice. In addition, they were encouraged to use the night sky as a resource for teaching astronomy through the use of astronomy planetarium software and naked eye and telescope stargazing sessions. The workshops were well received by both the teachers and the officials from the Department of Education. Accordingly, a further series of teacher workshops is planned and scheduled for various districts within the Free State province for 2023.





In collaboration with the UCT School Development Unit, a 3-hour workshop was facilitated for 18 in-service teachers who were completing the UCT Advanced Certificate in Teaching for Senior Phase. The workshop was held online on 25 October. The relationship with the UCT School Development Unit provides us with an opportunity to reach science teachers from the broader Western Cape, as the teachers were drawn from cities such as George, Knysna, Mossel Bay and Oudtshoorn. It also serves to strengthen our relationship with the schools through the teachers.

Four teachers and a curriculum adviser have won prizes at a teacher competition, which was based on a 3-day online teacher training workshop conducted in the KwaZulu Natal province in 2021. The teachers were required to criticise the SCBP teacher workshop, to reflect on how they had adapted the content from the workshop in their classroom, to indicate what they found relevant and to point out what they considered irrelevant or not applicable in their classrooms. The winners were flown to Cape Town in May and given an opportunity to spend time at Sutherland, where they visited SALT and experienced stargazing with the visitor telescopes.

Learners activities

The SCBP learner based programmes include curriculum-aligned activities such as lab based workshops, co-curricular activities such as the astronomy quiz and astronomy debates, and extra curricular programmes such as career info based activities, robotics, holiday and girl-focused programmes. A total of 9443 learners were reached in this way.

A senior phase natural science programme was initiated and implemented for Grade 7 learners in the Siyabulela and Ntwasahlobo primary schools in Khayelitsha. This programme is intended to support the completion of the laboratory work and experiments linked to the natural science course. For the first quarter, the focus was on “Matter and Materials”. This involved using home based and, in particular, kitchen based products to complete the prescribed experiments. The intent is firstly to demystify science and secondly to encourage learners to repeat the experiments at home. During the last quarter of the year, the focus was on space and astronomy based “Earth and Beyond” themes and included activities based on scales in the solar system, telescopes, tides, moon phases and seasons.

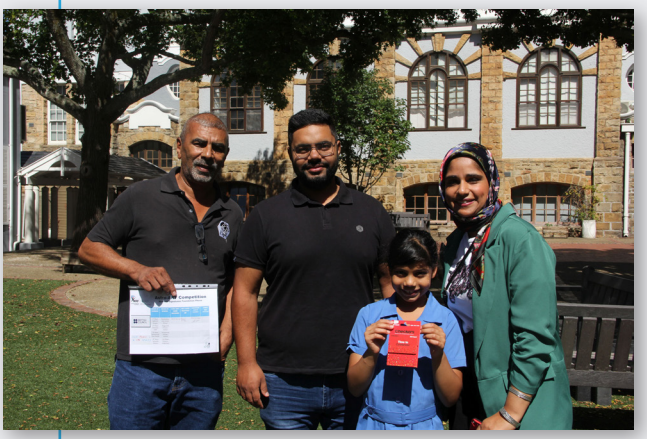
A Universe Awareness inspired programme of activities was implemented in Sutherland, Swellendam, Prince Albert and Cape Town. The aim of this project is to use astronomy to inspire learners and to stimulate interest in science through astronomy based activities. It is also intended to support the teaching and learning of the “Earth and Beyond” theme through presentations, workshops, hands-on activities, demonstrations and stargazing sessions. A total of 292 learners from Bontebok Primary in Swellendam participated in the programme from 26 – 28 September and 228 learners from Parkhurst Primary in Cape Town on 1 November.







Astro-art competition



In partnership with the “Our Place in Space” project, an AstroART competition was implemented for all primary school learners in December. The competition was divided into two categories, foundation phase and intermediate phase of the general education and training band of the schools (Grade R-7). We had a wonderful response and received a total of 4392 entries, of which 1672 were foundation phase and 2720 were intermediate phase entries. In addition to four individual prizes per category (in the form of gift vouchers), the school with the most entries per category received a prize of R10 000. The happy winners were Pacaltsdorp Primary in George and Morgenson Primary in Hanover Park, respectively. This project is part of our collaboration with space and astronomy outreach professionals based in Ireland and Vietnam. The winning entries will be exhibited in an Art & Space exhibition, which will be organised by the British Council in 2023.

Holiday Programme

A week-long June school holiday programme was implemented with a non-profit organisation based in Philippi called Ithemba Labantu, with 97 learners participating in various workshops, presentations and stargazing sessions.



Coding and robotics exhibition

Collaborating with other NRF facilities and DSI entities, SCBP participated in a "Youth in Science and Robotics" programme, which was held in Phillipi in February, with 100 learners taking part in this programme. The SCBP exhibition included banners on SALT and SAAO and a set of iPads, based on astronomy, as engaging and interactive exhibits. SCBP staff also presented planetarium shows in the inflatable planetarium.

Career-based activities

The job shadow programme



During the first two years of the COVID-19 pandemic, the lockdowns and restrictions associated with the pandemic effectively stopped the job shadowing programme. While the coordinator of the programme, Ms Natalie Jones, compiled a brochure in 2021 that answers the most pressing questions about a career in astronomy, requests were increasing for a job shadow at SAAO during 2022. To accommodate the need for this programme, a new, Zoom-based programme was introduced. On 8 June, a Zoom session was held for one student, conducted by SALT astronomer Moses Mogotsi and PhD student Anja Genade, followed by a second Zoom-based job shadow programme on 29 June, involving presentations from SALT astronomer Ros Skelton and Anja Genade. This session ended with questions on various aspects of astronomy including studies, jobs, and challenges from the three participating students. From 20 – 22 September, a hybrid in-person/Zoom-based job shadow programme was completed by one student.

The relaxation and removal of the pandemic restrictions in late 2022 allowed the return to a full in-person job shadow programme on 4 and 5 October. A successful two-day programme for Grade 11 mathematics and physical science learners was held for nine learners, giving them an opportunity to interact, complete activities and learn from astronomers, engineers, technicians, software developers, IT specialists, communicators and educators. They were also provided with opportunities to interact with post graduate students and were given information on university studies and bursaries. This is a highly sought after and a very successful programme and involves a collaborative effort by SAAO professional staff.



Between August 2004 and October 2022, the SAAO job shadow team has officially shadowed 217 learners, fifteen (that we know of) of which have decided to study Astrophysics and many others have chosen careers in Engineering and IT-related fields. Many of them have credited the SAAO Job Shadow programme with being the reason for their clear and concise career choice. Videos on the impact of the job shadow programme can be found on https://www.saao.ac.za/opportunities/internships-job-shadowing/.

Career exhibitions and career talks

Through our partnership with Eskom Science Expo, SAAO was able to offer an exhibition at the provincial finals of the expo on 11 August, reaching 280 learners at the Herzilia High School in Wynberg, Cape Town. A SALT based exhibition was set up, and information on astronomy as a career was disseminated through brochure distribution and in-person interaction.

Encarni Romero Colmenero (Head of Astro Ops) and SALT Astronomer Rudi Kuhn presented talks on SALT, astronomy and astronomy as a career at Wynberg Girls high school and Pinelands high school, respectively.

International career requests

SAAO has received a number of requests from internationally based students, and one of the students, from New Jersey (USA), successfully traveled to Cape Town. He had an opportunity to visit SAAO in Cape Town and spent a weekend with Lisa Crause (SALT Observatory Scientist) in Sutherland, visiting SALT among others. He was afforded opportunities to join the open night programme and had a series of discussions with post graduate students.

Girl-focused programmes

Joining the international community in celebrating the International Day of Girls and Women in Astronomy, a series of five full-day hybrid events (in-person and online) were held in Ladysmith in February. A total of 434 girls from five Ladysmith schools (namely Silindokuhle, Steadville, Bhevu, Qophindlela and Sakhelwe) were addressed and were able to interact with astronomers, space scientists, data scientists, entymologists and food scientists.

The annual girls-in-STEM programme was implemented on 9 August as part of the National Women's Day. A total of 78 girl learners participated in the full-day event, which included presentations by female astronomers, engineers, IT specialists, software developers and also pilots. These were followed by informal discussions and one-on-one question-and-answer sessions on careers, challenges women face during their studies as well as at their workplaces, and how they can overcome them.

Public engagement and awareness

Festivals



SCBP staff participated in the Kirkwood festival held in Kirkwood in the Eastern Cape, 24 – 26 June, reaching 410 learners (through hands-on workshops) and 2200 members of the public (through the public exhibition and the inflatable planetarium shows).

SCBP staff also participated in the National Science Festival, SciFest, in Grahamstown from 7 – 13 September. A total of 56 learners participated in the workshops and 1700 people visited the SAAO exhibition that was based on astronomy in general and SALT astronomy in particular and included an astronomy quiz and a photo booth.



National Science Week

South Africa's National Science Week was celebrated from 1 – 6 August. Its main goals are to inspire the youth to pursue science based studies and to inform the public about the latest advances made through science and technology in South Africa. The SCBP team joined the celebrations, and programmes were implemented in Sutherland in the Northern Cape, Dundee in KwaZulu-Natal and Beaufort West in the Western Cape. In addition, members of the Sutherland public were given free tours for the whole week as part of the 50-year anniversary celebration of the SAAO in Sutherland. A total of 715 learners participated in the workshops and presentations in the Western Cape, while 528 learners were given workshops, presentations and stargazing opportunities in Dundee in KZN.

Open Nights

The Cape Town observatory restarted the open night events, which take place every second and fourth Saturday of each month. They include a public lecture by either an astronomer, a PhD student or a technician. The lectures are followed by a site tour and stargazing through small telescopes. Initially they were held online through Zoom. With the relaxation of the restrictions, the open nights were first limited to 30 people, later a maximum of 60 were accommodated at every open night. A total of 1264 people attended the open nights in 2022.

OUTREACH & EDUCATION

Science communication activities



A new external newsletter, intended to share the relevance and power of astronomy through research and innovative technological developments, has been established in 2022, with the first two issues already being distributed. The first issue focused on highlighting the research successes of PhD students, some of which used data collected with SALT. The second issue focused on the history of SAAO with emphasis on the various telescopes. The forthcoming issue will be on instrumentation and technological development. All issues can be found on https://newsletters.saao.ac.za/.

Following the 2021 production of the 45-minute-long documentary on the gravitational wave counterpart detection by SALT and the MASTER telescopes, an 8-minute trailer for promotion purposes was produced in 2022, which has been shared widely using the SAAO social media platforms. The full video can be found on the SAAO and SALT video gallery websites or on youtube. In the documentary, SAAO Director Petri Väisänen and his colleagues take us on an astronomical journey, with insights into the gravitational wave counterpart discovery in October 2017 and elaboration on the very real importance of collaborating across a global network using multi-wavelength telescopes, sometimes accessing them via remote observing stations, to discover rare astronomical events across the entire sky.

There has been a concerted effort to communicate science in indigenous languages. Dr Itumeleng Monageng and Dr Zwido Khangale translated an article, written by Dr Christian Hettlage on the recent Event Horizon Telescope (EHT) production of an image of a black hole, into Setswana and TshiVenda. Dr Zolile Mguda from UNISA, working with SCBP staff, participated in Umhlobo Wenene interview conducted in IsiXhosa based on the plans to send humans to visit and to settle on Mars. Dr Itumeleng Monageng has become a regular in the Motsweding FM radio station, explaining astronomy concepts and phenomena in Setswana.

In addition, two teaching events were organised: A workshop on how to communicate science to the public for SAAO Masters and PhD candidates, and a session on how to write press releases and how to handle the follow-up media interviews.

Tours in Sutherland

Sutherland Observatory was visited by 5762 people in 2022. They participated in either the day and/or the evening tour programme. The COVID-19 restrictions had a huge impact on the number of visitors at the beginning of the year. However, the number of visitors increased continuously since the restrictions were lifted. These tours serve to inform the public of SAAO infrastructure and research, inspire the public about the beauty of dark skies and excite them about the Universe through stargazing. While the tours are also a source of income generation for the facility, they contribute to the empowerment of the community and the Sutherland town through tourism.



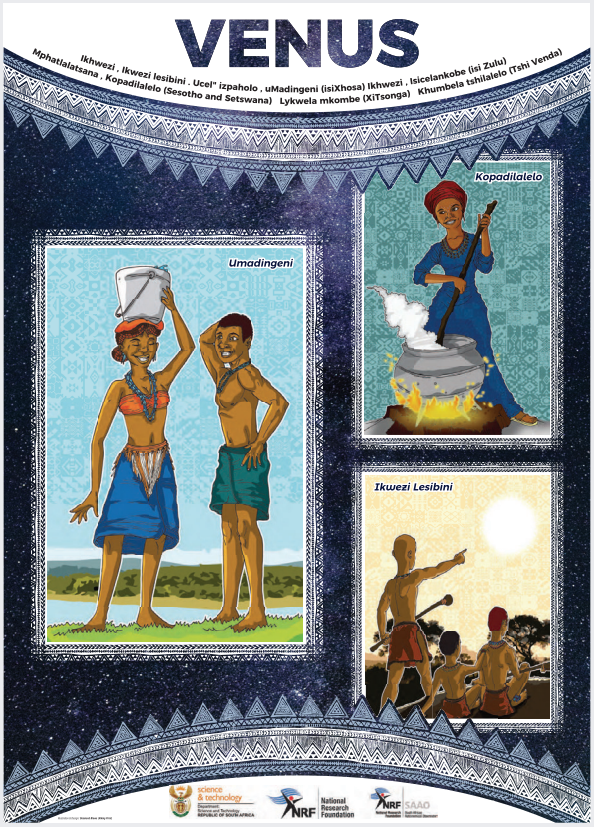
University students at the Sutherland observatory

The Sutherland Observatory remains attractive to both science and art students from various universities. A group of 28 Limpopo University physics students visited the SAAO and were given a tour of the site and attended presentations by astronomers. Another 30 students from the UCT astronomy department visited the Sutherland site, led by Dr Patrick Woudt, Head of the Department of Astronomy at UCT. They were given the tour of the site, conducted stargazing and spent some time on the research telescopes. A total of 27 students from the University of Stellenbosch visited the SAAO site and, as part of their studies, were required to write a report for various forms of media including newspapers and online publications.

Indigenous Astronomy

Ms Rene Braat won a telescope for proposing the winning name for a star and its companion planet: WASP 62 and WASP 62b. WASP 62 was named Naledi (meaning "star" in the Sotho-Tswana group of languages) and WASP 62b was named Krotoa (meaning “Ward-girl”). The names are intended first and foremost to honour black women and their resilient spirit against the adverse conditions they have faced in history. The name Krotoa serves to remember the ancient Khoi female warrior from the 17th century, who fought for her people and acted as an interpreter between her people and the early Europeans on the western coast of South Africa.

Three indigenous astronomy posters, presenting the indigenous knowledge in a multicultural way, were developed and printed. They focus on three celestial objects, namely Venus, Canopus and the Pleiaides.



A programme dubbed “The Magic of Indigenous Astronomy and Story Telling” was held from 14 – 17 March in Sutherland. It involved a team of seven indigenous storytellers and the New Environment World Foundation (NEWF). The programme included a symbolic dome in Sutherland, which seeks to recognise the knowledge of the indigenous people of the Northern Cape in particular and of South Africa in general, stargazing sessions and visits to the telescopes including SALT as well as to the People’s Dome. The second segment of the programme involved recorded interviews with elderly members of the Sutherland community and included interviews with selected SAAO staff members. The third segment was based on interaction, and the storytellers presented indigenous astronomy based stories and legends to the learners from the Sutherland schools. The last segment was a visit to the Sutherland planetarium and the Cape Town planetarium to watch the new indigenous planetarium show and "Cosmic Africa", respectively. The storytellers traveled to Cape Town and flew back to their home provinces.

National Heritage Day was celebrated on 24 September in Mpumalanga, a township near Durban. This event included presentations on isiZulu and isiXhosa astronomical heritage and knowledge, Zulu dances, a demonstration on bead making, talks on modern astronomy and an exhibition on SALT and other telescopes in Sutherland.

Dr Gcina Mhlophe, Ms Buzani Khumalo (SAAO education officer) and other speakers celebrated and gave presentations during the national storytelling event that was held in Durban.

A cultural astronomy event took place on 14 December in Hammersdale. This was led by Ms Buzani Khumalo and the “Let’s read Together” director, Ms Dimeo Koloko. This event was a culmination of efforts geared towards popularising indigenous astronomical knowledge and heritage and further using art to communicate astronomy. A group of learners from schools in Hammersdale were identified, taught and trained in the art of storytelling based on indigenous astronomical heritage. The performance was recorded on video. This event is part of the indigenous astronomy project.

The development of tours based on indigenous astronomy in Sutherland has been initiated. This will increase and diversify the number of offerings to our visitors to SALT and other telescopes and further attract and inspire revisits from past and regular visitors.

OUTREACH & EDUCATION



Sutherland activities

The year 2022 marks the 50-year anniversary of the establishment of the Sutherland Observatory. A number of initiatives were started including social corporate investment programmes, which were held at the Sutherland Community Development Centre. These interventions are intended to contribute towards social development and to alleviate the adverse effects of poverty and starvation.

Thanks to support from the SALT Board, the Sutherland School and Sutherland Community Drives were implemented. A total of 250 learners received beanies, socks and jerseys, while members of SAAO donated items of clothing, bags and toys to 395 members of the community.

In line with its social corporate investment programme in Sutherland, SAAO implemented an initiative dubbed the "Festive Drive". This initiative was aimed at providing gifts for the 65 underprivileged children, who attend the Sneeuvlokkie Crèche. Members of the SAAO staff volunteered to sponsor and purchase gifts for each child in the crèche. A joyous celebration, which featured many age-appropriate activities, was attended by the children and their parents.

Mandela Day was celebrated through donations of blankets by members of staff, which were distributed to the poor members of the community. This was accompanied by food distribution and volunteers from the community contributed towards the cleaning and painting of the community development centre.

Scientific calculators were distributed among 46 mathematics and science learners. This serves as some form of resource support for the learning and teaching of mathematics and science.



National Youth Day was celebrated on 16 June, where 320 learners and youth of Sutherland were addressed by role models. These included a teacher from the Sutherland schools and a husband of one of the employees, Mr Cloete, who had overcome many challenges to obtain various qualifications and degrees.

Thanks to the SALT Board, 100 vouchers worth R500 each for groceries were distributed to 100 indigent individuals in Sutherland. This was done in conjunction with the local Ok Bazaar Stores, the Municipal Manager and municipal leaders.



As part of our efforts to empower the Sutherland youth, a National Student Financial Aid Scheme (NSFAS) workshop was held at the community development centre, which attracted 18 grade 11 and grade 12 learners and their parents. The workshop was aimed at informing them about the funding available for technical studies at TVET as well as to expose them to all opportunities available for studies at universities of technology and other universities.

Planned events for 2023 include the establishment of a Sutherland Astronomy Club for the community, the science clubs for the high and primary schools and the revival of the library linked reading clubs.

The 2022 Sutherland Webinar Series

A new series of webinars on the "History of the Sutherland Observatory" was initiated. This is a follow up to the "Moments in the History of Optical Astronomy", which was implemented in 2020. The new series is aimed at documenting and reflecting on the history of the Sutherland Observatory, shared by those who were part of this history from the early 1970's to the current 2020's. The first two webinars were delivered by Dr Robin Catchpole and Mr Greg Roberts, both former SAAO staff members, who were involved in the identification of the SAAO observatory site in Sutherland in the late 1960s and early 1970s. The next two webinars were delivered by Dr Ian Glass and Mr Willie Koorts, a retired SAAO astronomer and an electronic engineer, respectively. The presentations were on the history of the Sutherland observatory and reflected on the development of domes, instruments and some of the major astronomical projects and discoveries. The next installments will feature past observers, technicians, administrative and kitchen staff. The series will continue throughout 2023. The final presentation will focus on the present-day Sutherland Observatory and its future, including SALT.

Word of Gratitude and acknowledgement

We are grateful to the SALT Board and the SAAO Director and management for all the support given to SCBP. Sivuyile Manxoyi is grateful to all SCBP staff in Cape Town and Sutherland for their commitment to engaging target audiences. Thanks to all SAAO staff for the support, encouragement, guidance and advice given to SCBP staff.

SCBP highlight: Sutherland Community Drive

The Sutherland Community Drive is an SCBP team project that was initiated in 2022 by SAAO Communication Officer Natalie Jones, in collaboration with many staff members in Sutherland and at SAAO across various divisions, and supported by the SALT Board. It is an ongoing event with the aim to distribute donations, from SAAO/SALT staff, to the destitute in the Sutherland community, which is in dire state due to the extremely high unemployment rate. There were five events in total in 2022, including one School Drive and one dubbed the SAAO Festive Drive for the Christmas season.

The Sutherland Community Drive kicked off on Saturday, 28 May. Donations in the form of clothing, shoes, bedding, curtains, toys, etc were graciously received from SAAO and SALT staff. SCBP Manager Sivuyile Manoxyi and Education Officer Buzani Khumalo were present at the event, along with the Karoo Hoogland Mayor (and former SCBP staff member), Anthony Mietas, who thanked both SAAO and SALT for their continued support of the Sutherland Community. The SCBP staff in Sutherland rallied to distribute the donated items to 290 members of the Sutherland community, whilst also running a soup kitchen to sustain the very excited and appreciative community.

The second event took place on 22 June and was called the Sutherland School Drive. In consultation with the principals, Mr Olyn at Roggeveld Primary and Mrs Van der Ross at Sutherland High, it quickly became obvious to Natalie that the needs of the learners were clothing and keeping warm in the frigid winters of Sutherland in the Northern Cape. Funding from both SAAO and SALT helped to purchase beanies for 250 learners (200 from Roggeveld Primary and 50 from Sutherland High). The supplier, after having been informed of the dire situation in Sutherland, took it upon himself to source another donation for 250 pairs of socks and an extra beanie for each learner.



OUTREACH & EDUCATION



On 30 July, items of clothing, donated by SAAO and SALT staff, were distributed to 105 indigent members of the community. Donations of items for infants were specially appreciated. Thanks to the varied and large contributions, people could select items for themselves, which were grouped and displayed on tables according to gender for kids and adults. There were also gadgets and toys available to choose from. The highlight of the event was the collaboration of a food drive initiative. To smooth the process, the women collected the clothing items, whilst the men and children stood in the queues for food. In addition, a 42-inch TV and stand was donated by SAAO staff to the centre.

Based on the success of the Community Drive, SAAO implemented the first Festive Drive at Sutherland. It was held at Sneeuvlokkie Crèche on Friday, 2 December. Refreshments, sweets, decorations and three beautiful Christmas trees were also donated. Each gift was purchased by a staff member for a particular child (selected by name, age and gender) and labeled accordingly. There was great excitement when, on the morning of the event, the boxes filled with the gifts arrived at the crèche. There they were unpacked in front of the kids, who looked on in complete amazement as the gifts were put under the trees. One by one, each of the 65 children took their turn to sit on Santa's lap, though some outright refused! Their gifts were handed to them and they left very happy and excited to open their gift.

The third Community Drive took place on 3 December, reaching 260 people. This time, a gazebo and tables were set up outside the Community Centre, where boerewors rolls were handed out to the community, while inside people could pick and choose to their heart's content.









7.2

OUTREACH & EDUCATION

SALT partner outreach programmes

SALT features prominently at the World Science Forum

Presented for the first time on African soil, South Africa had the opportunity to host the World Science Forum in Cape Town from 6 – 9 December 2022. At these forums scientists, science policy makers and politicians gather to discuss how science can work for the society at large. South Africa hoped to achieve three main goals by hosting the forum in Africa, namely:

- to promote global debate that inspires action;
- to provide support for African leadership in global science policy discussions; and
- to promote South Africa as a strategic partner for global science collaboration in response to societal challenges.

This high-profile event featured prominent speakers alongside South Africa's Minister for Science and Innovation, Dr Blade Nzimande, such as Dr Shamila Nair-Bedouelle, Assistant Director-General for Natural Sciences at UNESCO, and Princess Sumaya bint El Hassan, President of Jordan's Royal Scientific Society. The event was officially opened by the President of South Africa, His Excellency Cyril Ramaphosa.

With South Africa playing host to the SKA project, astronomy featured prominently at the event with SALT among other astronomy bodies taking centre stage throughout the forum. Speakers such as Prof. Catherine Cesarsky, Chair of the SKAO council, were also part of panel discussions at the forum. The highlight of the event for many was the Astronomy Corner being visited by President Ramaphosa and him chatting to the astronomers there. Among those present were Kevin Govender (IAU OAD Director) and Petri Väisänen (SAAO Director), who briefly talked to the president about the cutting-edge science that we are doing, as well as South Africa's role in hosting the IAU General Assembly in Cape Town in 2024. The SALT booth was also visited by many notable scientific leaders from around the world. This provided an excellent stage to showcase what SALT has to offer as a leading scientific institution, as well as a solid platform from which to network and engage with various interested individuals.



SA President Cyril Ramaphosa visits the SAAO/SALT booth.
To the *left* of the president are Kevin Govender, Petri Väisänen and Duduzile Kubheka (BRICS astronomy coordinator).





Left: Lusanda Tamesi (from African Science Stars), Minister of Science and Technology Dr Blade Nzimande, Moloko Makwetja and Pranesthan Govender. *Right*: Visitors engaging at the booth.



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OUTREACH & EDUCATION

Visiting SALT

Delegations and official visits

In 2022, the following parties visited SALT.

27 – 28 January: Parliamentary Portfolio Committee

Ms Nompendulo Mkhatswa (PPC Chairperson)
Dr Wynand Johannes Boshoff
Mr Walter Tebogo Letsie
Ms Kathleen Mahlatsi
Ms Jane Seboletswe Mkhonza
Ms Duduzile Patricia Sibaya
Mr Sanele Zondo
Mr Bafuze Sicelo Yabo
Ms Shanaaz Isaac
Mr Hubert Mathebula (DSI Deputy Director)
Mr Takalani Nemaungani (Chief Director of Astronomy, DSI)





The Parliamentary Portfolio Committee on Higher Education, Science and Technology, accompanied by the National Chief Director of Astronomy, visited Sutherland as part of a tour of NRF facilities in the Northern Cape. Along with a delegation from the DSI and NRF, they visited the Sutherland Observatory, the Sutherland Community Development Centre and the local schools. On the first day, they were given presentations on the varied achievements of SAAO and SALT, followed by questions on how they could assist us in achieving our vision, and how science and research could be used to positively influence education and society as a whole. The committee was treated to dinner at the hostel, followed by a stargazing session at the visitors' telescopes. The next morning the committee visited the Sutherland primary and high schools as well as the community centre, before returning to the observatory for a tour of SALT and the smaller telescopes.

5 – 7 September: National Department of Tourism

Ms Shamila Chettiar (Deputy Director General: Destination Development)
Dr Laeticia Jacobs (Deputy Director: Tourism Integration)
Ms Audrey Dikgale-Mahlakoana (Deputy Director: Multiwavelength Astronomy, DSI)
Officials from the office of the DDG:
Lerato Matlakala
Ngwako Sefako
Raymond Mahole
Tebogo Matolong
Tinyiko Chauke

The Sutherland Observatory was visited by the Deputy Director General of the National Department of Tourism, Ms Shamilla Chattiar. Her entourage included the Deputy Director of Tourism Integration, Dr Laeticia Jacobs, and the Department of Science and Innovation Deputy Director of Multi Wavelength Astronomy, Ms Audrey Dikgale-Mahlakoana. They were met by the Director of SAAO, Prof. Väisänen, and Head of SCBP, Mr Manxoyi, and spent three days in Sutherland. They were impressed with the operations and the overall experience. They committed to support the observatory to further develop astro-tourism infrastructure and operations.



SCBP Director Sivuyile Manxoyi with Laeticia Jacobs from DSI.

OUTREACH & EDUCATION

16 – 18 November: SALT Board

Some of the SALT Board members visited SALT in November, right after the 52nd SALT Board meeting, which was held at SAAO on 16 – 17 November as a hybrid event. This was the first time the Board had met in person since November 2019 in Pune, India. They enjoyed the visit, reacquainting themselves with the telescope. They got the full tour including viewing the new instrument NIRWALS and a recoated mirror segment. They stayed at the hostel and were served a wonderful dinner.





Media visits to SALT

July 2022 — UNISA

South Africa's online university, UNISA, filmed SALT and in Sutherland in July. They plan to use the video footage for educational and science engagement purposes to showcase the astronomy infrastructure within the country.

August 2022 — Carte Blanche: Spacing out

Carte Blanche, a South African news programme that features quality stories, obtained video footage at SALT for an episode dubbed "Spacing out", which aired on 14 August. Presenter Claire Mawisa asked questions about the origins of the Universe and Us, with the focus on the recently launched James Webb Space Telescope (JWST) and its incredibly detailed pictures. The show featured stunning pictures of SALT and the observatory plateau and included interviews with SALT Astronomers Dr Moses Mogotsi and Dr Ros Skelton. This episode can be viewed on https://www.youtube.com/watch?v=7zYhUP_dRm8&t=204s.





SALT exhibitions at science meetings

27 June – 1 July: EAS Annual Meeting, Valencia, Spain

2022 saw the return of the European Astronomical Society (EAS) annual meetings (formerly known as EWASS) in person, after the two previous meetings were held in virtual format. EAS annual meetings are the largest conferences for European astronomy and include plenary sessions and awards of prestigious prizes. EAS 2022 was held in Valencia, Spain and saw a record attendance of over 2000 astronomers.



SALT was strongly represented with Petri Väisänen and Daniel Cunnama operating the stand through the week. There was a powerful African contingent with the Africa Astronomical Society booth alongside SALT, promoting African Astronomy and the IAU General Assembly that will be held in Cape Town in 2024.

Visitors to the stand were very engaged and there was a large amount of interest in SALT and the work it is doing. We conducted a brief perception survey at the stand, showing that the feeling towards SALT was overwhelmingly positive.

2 – 11 August: IAU General Assembly, Busan, South Korea



The XXXI General Assembly of the International Astronomical Union (IAU) was held from 2 – 11 August in Busan, South Korea. Having been postponed by one year due to the COVID-19 pandemic, the meeting took place as the first hybrid General Assembly, with around 1200 in-person participants and around 700 attending online. The conference included seven symposia, ten multi-session Focus Meetings and many more meetings of IAU Divisions, Commissions and Working Groups.

South Africa, which will be the host of the XXXII General Assembly in 2024, put on a strong show to present both current and future facilities on the African continent. SALT and SAAO contributed to a shared exhibition stand along with the GA 2024 organising committee. The SALT portion of the stand, as usual, included the interactive SALT Virtual Tour, stickers, various brochures, SALT-themed Rubik's cubes and SALT Annual Reports. It was operated by Petri Väisänen, Sally Macfarlane and Vanessa McBride.




PALFINGER



8 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 four 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. Brian Chaboyer (Chair)
Dartmouth College, USA

Prof. Matthew Bershady
University of Wisconsin–Madison, USA

Prof. Phil Charles
United Kingdom SALT Consortium, UK

Dr. Sharmila Goedhart
(Appointed Nov 2022)
South African Radio Astronomy Observatory, South Africa

Prof. John P. Hughes
Rutgers University, USA

Dr. Vanessa McBride
(Appointed Nov 2022)
National Research Foundation, South Africa

Prof. Shazrene Mohamed
(Resigned Nov 2022)
National Research Foundation, South Africa

Dr. Itumeleng Monageng
(Appointed Nov 2022)
University of Cape Town, South Africa

Dr Fulufhelo Nelwamondo
National Research Foundation, South Africa

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

Prof. Marek Sarna
Nicolaus Copernicus Astronomical Centre, Poland

Prof. Michael Shara
American Museum of Natural History, USA

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.

CORPORATE GOVERNANCE

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 Technical 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. Brian Chaboyer (Chair), Prof. Phil Charles, Prof. Jack Hughes, Prof. Somak Raychaudhury and Prof. Mike Shara.

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: Dr Lisa Crause (Chair), Prof. Paul Groot, Prof. Matt Bershady, Dr Hermine Schnetler, Mr John Booth, Prof. Joanna Mikołajewska, Dr David Buckley and Prof. Raghunathan Srianand.

SALT Observatory Scientist 2022

Lisa Crause

Corporate Governance Team 2022

Lizette Labuschagne
Surayda Moosa

Technical Operations Team 2022

Paul Rabe (Head)

Shamiel Adams*
Richard Banda
Janus Brink
Keith Browne*
Bryne Chipembe
Alrin Christians
Willa de Water
Timothy Fransman
Denville Gibbons
Johan Hendricks
Nicolaas Jacobs
Sunnyboy Kabini
Dillon Klaasen*
Anthony Koeslag
Deon Lategan*
Jonathan Love
Deneys Maartens*
Thabelo Makananise
Tasheen Naicker*
Jonathan Pieterse
Melanie Saayman
Etienne Simon
Nicolaas van der Merwe
Willem van der Westhuizen*
Eben Wild

Astronomy Operations Team 2022

Encarni Romero Colmenero (Head)

Danièl Groenewald
Christian Hettlage
Alexei Kniazev
Thea Koen
Enrico Kotze
Rudi Kuhn
Nhlavutelo Macebele
Chaka Mofokeng
Moses Mogotsi
Elizabeth Naluminsa*
Xola Ndaliso
Solohery Randriamampandry
Anja Schröder*
Rosalind Skelton
Lee Townsend
Veronica van Wyk

* part-time and/or part of the year





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GLOSSARY & ACRONYMS

1D, 2D, 3D	one, two, three dimensional
ACT	Atacama Cosmology Telescope
ADC	atmospheric dispersion compensator
AdvACT	Advanced Atacama Cosmology Telescope
ADS	astrophysics data system
AGB	asymptotic giant branch
AGN	active galactic nucleus
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
ART-XC	Mikhail Pavlinsky Astronomical Roentgen Telescope X-ray Concentrator
ASASSN	All Sky Automated Survey for SuperNovae
ASSET	Association in Educational Transformation
ATLAS	Asteroid Terrestrial-impact Last Alert System
AU	astronomical unit
BAL	broad absorption line
BEARS	Bright Extragalactic ALMA Redshift Survey
BEC	board executive committee
BH	black hole
BLAP	blue large-amplitude pulsator
BLR	broad line region
BRICS	Brazil, Russia, India, China, and South Africa
BRITE	BRIght-star Target Explorer
CAMK	Nicolaus Copernicus Astronomical Center
CCD	charge-coupled device
CDM	cold dark matter
CDR	critical design review
CEMP	carbon-enhanced metal-poor
CFHT	Canada–France–Hawaii telescope
CGM	circumgalactic medium
CMD	colour–magnitude diagram
Co–PI	co–principal investigator
COVID-19	coronavirus disease 2019
CTA	Cherenkov Telescope Array
CTS	Calan Tololo Survey
CV	cataclysmic variable star
DC	Dartmouth College
DDG	Deputy Director General
DDT	director's discretionary time
DESI	Dark Energy Spectroscopic Instrument
DR	data release
DIG	diffuse ionised gas
DSI	Department of Science and Innovation
EAS	European Astronomical Society
ECDFS	Extended Chandra Deep Field South
EDR	early date release
EHT	Event Horizon Telescope
eRASS	eROSITA all-sky survey
eRASSt	eRASS transient source
eRODAY	eROSITA day
eROSITA	extended ROentgen Survey with an Imaging Telescope Array
ESA	European Space Agency
ESO	European Southern Observatories
ETG	early type galaxy
EU	European Union
EWASS	European Week of Astronomy and Space Science
FAC	finance & audit committee
FEA	finite element analysis
Fermi-LAT	Fermi Large Area Telescope collaboration
FEROS	Fiber-fed Extended Range Optical Spectrograph
FGL	Fermi-LAT first source catalog
FIF	fibre instrument feed
FITS	flexible image transport system
FP	Fabry–Pérot
FWHM	full width half maximum
GA	IAU general assembly
GAMA	Galaxy And Mass Assembly survey
GATS	Global Astrophysical Telescope System
GLEAM	GaLactic and Extragalactic All-sky Murchison Widefield Array survey
GOTOQ	galaxies on top of quasars
GRB	gamma-ray burst
GTC	Gran Telescopio Canarias
GU	Göttingen University
H2RG	HAWAII–2RG detector
HD	Henry Draper
HE	Hamburg–ESO survey
H.E.S.S.	High Energy Stereoscopic System
HET	Hobby–Eberly Telescope
HETDEX	HET Dark Energy eXperiment
HIPPO	high-speed photo-polarimeter
HMXB	high-mass X-ray binary
HRS	high-resolution spectrograph
HS	high-stability
HST	Hubble Space Telescope
IAO	Institute Astronomical Observatory
IAU	International Astronomical Union
IC	Index Catalogue
IFU	integral field unit
IGM	intergalactic medium
IRAM	Institut de Radioastronomie Millimétrique
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
KZN	University of KwaZulu-Natal
LADUMA	Looking At the Distant Universe with the MeerKAT Array
LBT	Large Binocular Telescope
LFC	laser frequency comb
LIGO	Laser Interferometer Gravitational wave Observatory
LIRG	luminous infrared galaxy
LMC	Large Magellanic Cloud
LOFAR	LOw Frequency ARray
LSP	SALT large science programme
LSSTC	Large Synoptic Survey Telescope Corporation
MALS	MeerKAT Absorption Line Survey

GLOSSARY & ACRONYMS

MaNGA	Mapping Nearby Galaxies at Apache Point Observatory
MASTER	Mobile Astronomical System of the TElescope–Robots network
MaxE	Maximum Efficiency spectrograph
MAXI	Monitor of All-sky X-ray Image
MC	Magellanic Cloud
MDM	Michigan–Dartmouth–MIT Observatory
MIDAS	Munich Image Data Analysis System
MLT	SALT multi-semester proposal
MOS	multi-object spectrograph
MS	main sequence
MSc	master of science
MUSE	Multi Unit Spectroscopic Explorer
NASA	National Aeronautics and Space Administration
NCAC	Nicolaus Copernicus Astronomical Center
NGC	New General Catalog
NIR	near-infrared
NEWF	New Environment World Foundation
NIRWALS	Near InfraRed Washburn Astronomical Labs Spectrograph
NRAO	National Radio Astronomy Observatory
NRF	National Research Foundation
NSFAS	National Student Financial Aid Scheme
NuSTAR	Nuclear Spectroscopic Telescope ARray
NWU	North–West University
OAD	Office of Astronomy for Development
OCS	observation control system
OGLE	Optical Gravitational Lensing Experiment
OPTI	observation planning tool interface
OPTICON	Optical Infrared Coordination Network for Astronomy
ORP	OPTICON/Radio-Net Pilot project
OW	OmegaWhite survey
P0 … P4	priority 0 – 4
PAS	Polish Academy of Sciences
PDR	preliminary design review
PhD	doctor philosophiae
PI	principal investigator
PIPT	Principal Investigator Proposal Tool
PN	planetary nebula
POL	Poland
QE	quantum efficiency
QGP	quasar galaxy pair
RADIAL	Radio Astronomy Data Imaging and Analysis Lab
RINGS	RSS Imaging spectroscopy Nearby Galaxies Survey
R–L	radius luminosity relation
RLQ	radio-loud quasar
ROSAT	Röntgensatellit
RSA	Republic of South Africa
RSS	Robert Stobie Spectrograph
RU	Rutgers University
RX	ROSAT survey
SA	South Africa
SAAO	South African Astronomical Observatory
SAGA	Satellites Around Galactic Analogs
SALT	Southern African Large Telescope
SALTICAM	SALT Imaging CAMera
SARAO	South African Radio Astronomy Observatory
SCBP	SALT Collateral Benefits Programme
SCI	SALT science proposal
SCL	SALT control language
SCR	SuperCosmos REsearch Consortium On Nearby Stars survey
S–CUBED	Swift SMC Survey
sd	subdwarf
SDB	science database
SDSS	Sloan digital sky survey
SED	spectral energy distribution
SHOC	Sutherland High-speed Optical Cameras
SIDECAR	system image, digitising, enhancing, controlling, and retrieving
SKA	Square Kilometre Array
SKAO	SKA Observatory
SMC	Small Magellanic Cloud
SN	supernova
SPIE	Society of Photo–optical Instrumentation Engineers
SPSF	spectral point spread function
SRG	Spektrum-Röntgen-Gamma satellite
SRGA	SRG ART-XC source
STC	scientific and technical committee
SuperWASP	Super Wide Angle Search for Planets
SXP	SMC X-ray pulsar (object name prefix)
SySt	symbiotic system
TAC	time allocation committee
TCS	telescope control system
TDE	tidal disruption events
TESS	Transiting Exoplanet Survey Satellite
TMT	Thirty Meter Telescope
TVET	Technical and Vocational Education and Training
U	university
UCLan	University of Central Lancashire
UCN	University of Canterbury
UCT	University of Cape Town
UKSC	United Kingdom SALT Consortium
ULIRG	ultra-luminous infrared galaxy
UNC	University of North Carolina – Chapel Hill
UNESCO	United Nations educational, scientific and cultural organisation
UNISA	University of South Africa
USMgII	ultra-strong [mg II] absorber
UV	ultraviolet
UVOT	Swift's UltraViolet and Optical Telescope
UW	University of Wisconsin–Madison
UWC	University of the Western Cape
VHS	VISTA Hemisphere Survey
VIS	visible
VISTA	Visible and Infrared Survey Telescope for Astronomy
VLBI	very long baseline interferometry
VLS	VLT survey telescope
VLT	Very Large Telescope
VPH	volume phase holographic
VPHAS+	VST/OmegaCAM Photometric Hα Survey
VVV	VISTA Variables in the Via Lactea
WASP	Wide Angle Search for Planets
WD	white dwarf
XMM	XMM–Newton observatory
XMMU	unique XMM source
XRB	X-ray binary
YAML	yet another markup language
ZTF	Zwicky Transient Facility

The SALT consortium is seeking an additional 10%-level partner (~$10M) 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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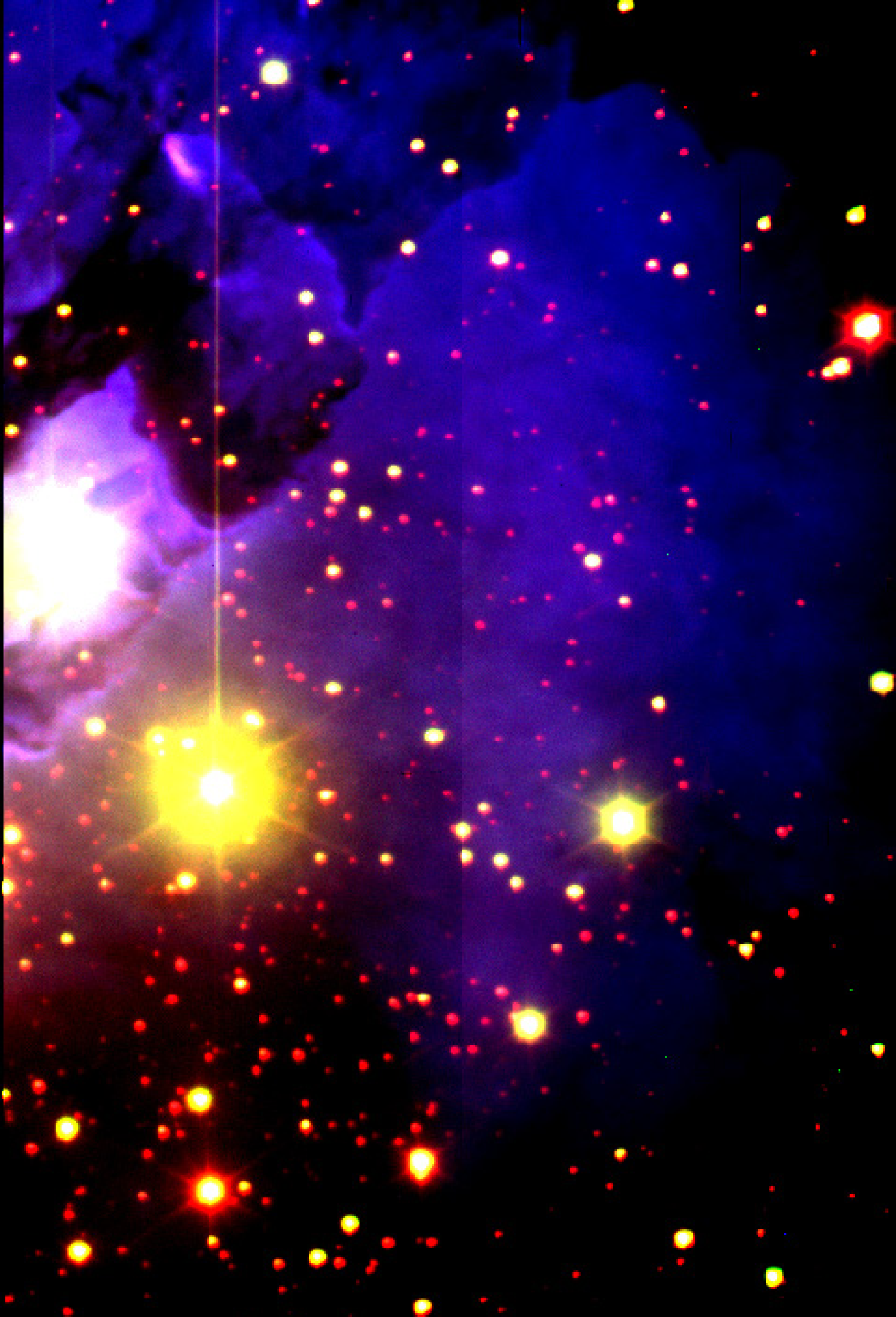
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