SOUTHERN AFRICAN
LARGE TELESCOPE

ANNUAL REPORT

2019


Give me the power of the
KAROO
— the rugged line
Of iron-stone and thorny-bare Karee-tree trunk,
The wine air blowing across wide plains,
Heady with countless herbal scents.
— I.D. du Plessis (transl)


S·A·L·T

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ABOUT
SALT

ABOUT SALT

The Board of the Southern African Large Telescope (SALT) is proud to present its Annual Performance Report for the period 1 January 2019 to 31 December 2019. This report offers an overview of the activities and performance of SALT, highlights a selection of SALT research projects, and introduces the SALT partner institutions/consortia.

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

SALT is owned by the SALT Foundation, a private company registered in South Africa. The shareholders of this company include universities, institutions and science funding agencies from Africa, India, Europe and North America. The South African National Research Foundation is the major shareholder with a ~36 percent stake. Other large shareholders are the University of Wisconsin–Madison, the Nicolaus Copernicus Astronomical Centre of the Polish Academy of Sciences, Dartmouth College and Rutgers University. Smaller shareholders include the Indian Inter–University Centre for Astronomy and Astrophysics in India, the American Museum of Natural History, the University of North Carolina and the UK SALT Consortium, the latter representing the Universities of Central Lancashire, Keele, Nottingham, 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. Two of the original shareholders, Göttingen University (Germany) and the University of Canterbury (New Zealand), have recently left the SALT Foundation, though the latter still received telescope time in 2018. The SALT Foundation is currently looking for new shareholders.

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

VISION AND MISSION

V

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

M

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

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.

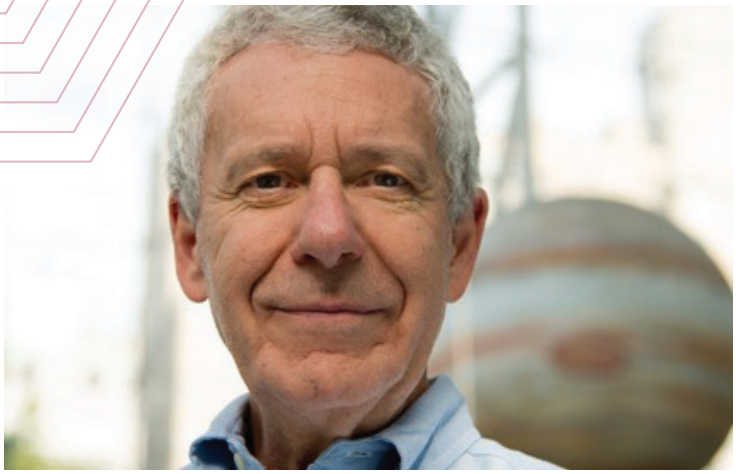
Pursue instrumentation development

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).

Drive human capital development and science engagement

To employ this iconic facility and the ubiquitous appeal of astronomy to encourage widespread interest in science and technology, through outreach to undergraduates, schools and the general public; to train graduate students; to have a special focus on developing and leading professional astronomy and high-tech astronomical instrumentation on the African continent; to promote SALT as a global flagship optical telescope, increasing its visibility and growing its reputation in the international scientific community, as well as national and international media.

Chairman's OVERVIEW



A record number of published, peer-reviewed research papers, 54 in all, capped off a highly productive year for the SALT consortium.

They covered the entire gamut of current astronomical research, from the solar system to the highest redshift objects, and everything in between. SALT remains the most cost-effective, 10-meter-class telescope in the world. The time available for science was also about 8% above the long-term average, thanks to favourable weather and little engineering downtime.

The Technical and Astronomical Operations teams have joined forces again and re-launched the combined SALT Ops team, where the team members work more closely with each other to increase observing efficiency and data quality.

The MaxE instrumentation project, which will enable major upgrades to the Robert Stobie Spectrograph (specifically the addition of a new Red channel to support transient identification spectroscopy) was approved by the Board, after a strong science case for it was presented. Generous funding from the South African National Research Foundation (NRF) enabled an early start on work to support a Conceptual Design review early in 2020.

The new RSS guider has been performing extremely well, enabling rapid acquisitions and fault-free guiding on a regular basis.

The Board has endorsed a study to determine if multiple "mini-trackers" can be deployed over the hundreds of square degrees of SALT's field-of-view afforded by its spherical primary mirror. If doable, they would enable SALT to observe multiple, unrelated targets (for example, LSST or SKA transients) simultaneously and opportunistically over wide swaths of sky. This would happen with no change to the current queue-driven mode of operations.

SALT (and the entire SAAO Observatory) have been increasingly focused on Gravitational Wave follow-ups, with strong partnerships being forged with LIGO team members. SALT's ability to pivot rapidly from planned to Target-of-Opportunity observations is increasingly being seen by the SALT community of users as one of the telescope's greatest strengths.

SALT continues to seek one more partner at the 5 – 10% level, and/or to sell guaranteed time.

Prof. Michael Shara
Chairperson, SALT Board


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 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 ~$3350/h). It may also be in the form of the highest priority time only, which is guaranteed to be observed fully, at 1.5 times that rate. Note that any partner institution may also purchase time beyond their normal share, and reduced rates apply in that case. Finally, the consortium is seeking an additional 10%-level partner (~$9.1M) to support significant second-generation instrumentation development. Interested parties should contact the chair of the SALT Board of Directors, Michael Shara.

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

REPUBLIC OF SOUTH AFRICA

SALT Board members:
Molapo Qhobela (National Research Foundation) | Lisa Crause (SAAO/SALT)

South Africa's National Research Foundation (NRF) is the majority shareholder in SALT, with approximately a one-third 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 SAAO in the Karoo desert (about 370 km from Cape Town), making it one of the darkest 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 electronic departments at the SAAO headquarters in Cape Town include large workshops and a dedicated CCD lab. SALTICAM and the RSS detector package, 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 is 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 objectives of this programme were clearly directed at the benefits derived by society from building this large telescope. The SCBP is mainly directed at schools but also includes outreach to the general public.

South Africa's astronomical community has grown significantly since SALT was built, with SALT and later the SKA/MeerKAT initiatives spurring much of this growth. There are now about two hundred PhD astronomers at institutes around the country and students at all levels of study. Students are actively encouraged to participate in SALT projects and to propose for time on SALT. The entire South African community has access to SALT, and scientists from national research facilities and universities across the country use SALT regularly. South African researchers are active across a wide range of the multi-wavelength astronomy domain. In particular, the strategic vision for SALT, developed by the South African community in 2017, identified two main focus areas for future development which tie in closely with both MeerKAT, the country's precursor to the SKA, and local high-energy astrophysics research. These are transient science, that is, a range of highly energetic phenomena (including exciting events such as the 2017 multi-messenger gravitational wave discovery) 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.

UNIVERSITY OF WISCONSIN-MADISON (USA)

The astronomy department group on top of their building.

SALT Board member: Eric Wilcots

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

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

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

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

RUTGERS UNIVERSITY (USA)

SALT Board member: Jack Hughes

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 1990's 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. Today the astronomy group includes ten faculty, two research scientists, three postdoctoral associates, and 19 graduate students.

Rutgers' astronomers, led by Prof. Ted Williams, participated in the design, development and fabrication of the Robert Stobie Spectrograph (RSS) and led the effort to build the Fabry–Pérot Imaging Spectrophotometer subsystem. Williams and his colleagues utilised 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.

Prof. Saurabh Jha uses SALT/RSS to study supernova explosions, observing mostly type Ia, or thermonuclear, supernovae to investigate their nature and, more broadly, to answer key questions in SN Ia cosmology. In 2017, Jha started a new project to measure binary orbital parameters of a sample of candidate white dwarf binaries with the HRS.

A main area of Prof. John P. Hughes' research focuses on the astrophysics of supernova remnants. Current student Prasiddha Arunachalam is using coronal iron line emission from RSS observations to study ejecta properties in the full sample of known SN Ia remnants in the Large Magellanic Cloud. In collaboration with colleagues in South Africa, Hughes has made dynamical mass measurements of galaxy clusters from the ground-based Atacama Cosmology Telescope to aid in precise cluster mass calibration for constraining cosmological parameters. He has also used SALT for confirmation and redshift measurement of Planck cluster candidates.

Prof. Andrew Baker is involved in two large SALT collaborations: the "SALT Gravitational Lensing Legacy Survey" targets submm-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. In other, related work, Baker's current graduate student John Wu is studying star formation in massive galaxy clusters using the RSS Fabry–Pérot instrument.

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

POLAND

SALT Board member: Marek Sarna (CAMK)

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

The **Nicolaus Copernicus Astronomical Center** (CAMK, or NCAC in English) of the PAS is the leading astronomical institute in Poland. It is located in Warsaw and was established in 1978. At present, 57 scientists are working at CAMK along with 35 PhD students. Astronomers at CAMK are involved in a number of major international observational projects (e.g., CTA, Herschel, SALT), and are actively collaborating with scientists all over the world. Collaborations on SALT science include SAAO and the American Museum of Natural History. The main SALT research interests are: the search for symbiotic stars in the Milky Way and the Magellanic Clouds and the study of individual systems; novae; post AGB binaries and dark matter studies using spectroscopic long term monitoring of selected quasars. Prof. 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. Prof. 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 at the outskirts of Kraków. The Observatory is involved in exploiting large facilities such as H.E.S.S., CTA and SALT and runs one of the LOFAR telescope stations, playing an important and active role in the European LOFAR collaboration. The main scientific programs that use SALT data are studies of giant-size radio galaxies, accretion discs in AGNs using Doppler tomography and timing analysis of their multi-wavelength light curves.

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

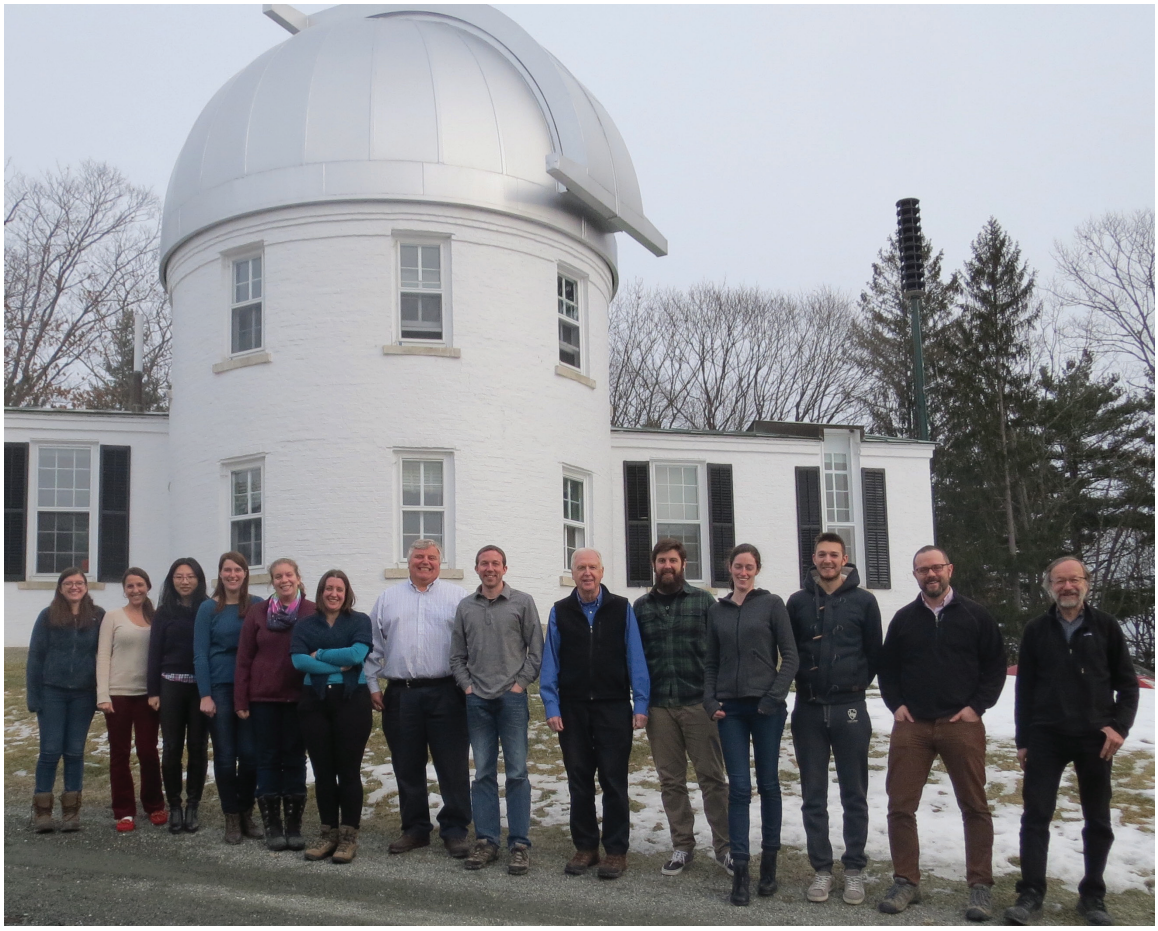
Founded in 1919, the **Institute Astronomical Observatory** (IAO) of Adam Mickiewicz University runs a Global Astrophysical Telescope System (GATS) consisting of two robotic instruments (in Poland and in Arizona) used for photometry and spectroscopy. The third node — a cluster of 0.7-m and 0.3-m telescopes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

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

Top: CAMK Warsaw | Bottom:: CAMK Torun

DARTMOUTH COLLEGE (USA)

SALT Board member: Brian Chaboyer



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

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

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

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

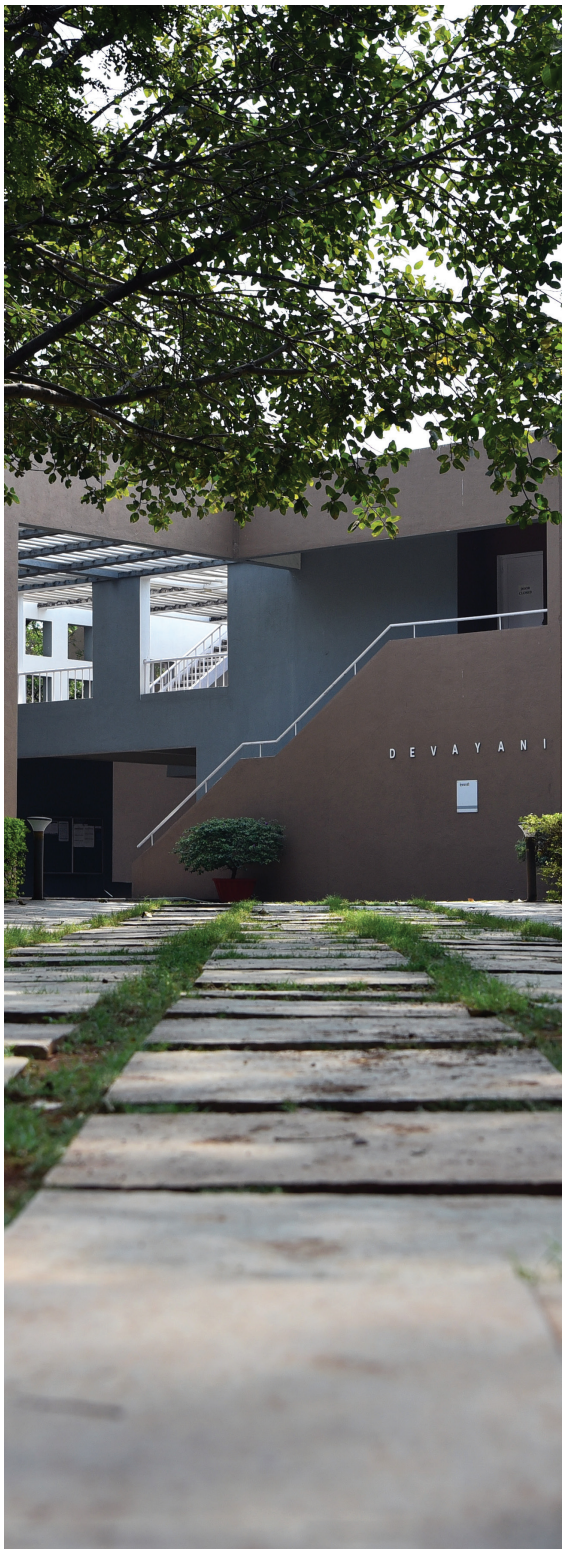
INTER-UNIVERSITY CENTRE
FOR ASTRONOMY & ASTROPHYSICS (INDIA)

SALT Board member: Somak Raychaudhury

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

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

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



View of IUCAA's campus.

UK SALT CONRSORTIUM

SALT Board member: Phil Charles (University of Southampton)

An early and enthusiastic supporter of the SALT project, the UK's consortium (UKSC) consists of 6 astronomy groups, all of whom have had a long-standing involvement with astronomers in South Africa (SA), including providing support for visiting graduate students and postdocs to SA. Furthermore, UKSC has successfully hosted a half-dozen SALT Stobie scholarships, greatly enhancing the production of SA astronomy PhDs. Since 2018, the consortium has been able to use its "Global Challenges" research funding to support SA post-docs to visit the UK for extended periods. UKSC have a wide range of SALT science interests, and are involved as collaborators in a number of major SALT science projects, in particular playing a leading role in the X-ray binaries component of the SALT Transients Large Programme. The following institutions form the UKSC.

SALT scientists at the **University of Central Lancashire** (UCLan) include G. Bromage, A. Sansom, D. Kurtz and D. Holdsworth. Bromage was UKSC's previous Board director and has also been highly active in other SALT committees (e.g. FAC, BEC, SSWG). UCLan has made extensive contributions to the SALT Collateral Benefits Programme (SCBP), has hosted successful SALT Stobie scholarships, and has provided UCLan's distance learning university-level Astronomy courses (at discounted rates) for SALT engineers, operators and other staff for more than 10 years, as well as supporting visiting graduate students. Their SALT science interests involve collaborations within UKSC (with Keele and Armagh) and with SA, in particular with NWU and SAAO.

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

SALT science at **Armagh Observatory** focuses on stellar remnants, massive stars, ultra-compact binary systems, and solar-system science, with extensive effort on stellar pulsations and abundance analyses using SALT's RSS and HRS. They have collaborations within UKSC and with SA (SAAO, UCT and UWC). People involved at Armagh are S. Jeffery, M. Burton, G. Ramsay, J. Vink and G. Doyle, and have recently been enhanced with the arrival of M. Sarzi who is taking on the role of representing Armagh on UKSC.

At **Keele University**, J. van Loon's interests in SALT have been to exploit the RSS Fabry–Pérot mode to map emission as well as absorption features in nearby galaxies, and long-slit spectroscopy of various types of stars and of a peculiar AGN.

The **University of Nottingham** has had significant involvement in SALT administration (UKSC Board director for 4 years and Chair of the FAC for 3 years), as well as funding a post-doc (6 months) and two graduate students (2 months each) to work on technical and software development for SALT in its early years. Science interests (P. Sarre) are in molecular astrophysics and galaxies, making observations with RSS (long-slit and Fabry–Pérot) and HRS.

P. Charles from the **University of Southampton** (current UKSC Board director for SALT) was SAAO Director for 7 years and, together with many of the Southampton Astronomy Group, is actively involved in the SA-led SALT Large Science Programme "Observing the Transient Universe". Southampton's interests focus on black-hole, neutron star and white dwarf X-ray binaries, usually in association with other ground-based (e.g., ASASSN, OGLE, MASTER) and space-based (e.g., Swift, MAXI, Astrosat) facilities, frequently arranging for simultaneous or contemporaneous observing. The Astrosat observations include another major SALT partner, India. M. Sullivan is involved in SN–cosmology studies, which is part of the SALT long-term programme on supernovae. SALT is also used for rapid follow-up spectroscopy of outbursting X-ray sources in the SMC arising from the weekly Swift's S–CUBED monitoring (M. Coe). Also interested in SALT science are C. Knigge, D. Altamirano, T. Bird and P. Gandhi.

UNIVERSITY OF
NORTH CAROLINA AT CHAPEL HILL (USA)

SALT Board member: Gerald Cecil

The University of North Carolina at Chapel Hill (UNC) is the flagship research university and the second largest of the campuses of the University of North Carolina System. Chartered in 1789, the university first enrolled students in 1795, making it one of three schools to claim the title as the oldest public university in the United States. UNC offers degrees through 14 colleges and the College of Arts and Sciences to almost 30,000 students from North Carolina (minimum 85%) and the other U.S. states, as well as from other countries. The campus covers 3 km^2 of Chapel Hill's downtown and is one arm of North Carolina's tech-heavy Research Triangle, the other arms defined by Duke University (Durham) and North Carolina State University (Raleigh). The Morehead Planetarium and Science Center on the UNC campus features a digital projector and professional, fully robotic 0.6-m aperture research telescope with CCD cameras and spectrograph. The telescope is part of the global Skynet telescope network developed and run from UNC.

Astrophysics research at UNC is conducted by two theoretical cosmologists, two experimental nuclear astrophysicists, five observational astronomers, a general relativist, and a gas dynamicist. These faculty are joined by a half dozen post-doctoral fellows and by approximately 25 graduate students. Many efforts focus on the SOAR 4.1-m telescope on Cerro Pachon in Chile that all use remotely from UNC. Its Goodman spectrograph, from which the SALT RSS was derived, was built in the extensive and modern machine shop in the Physics and Astronomy Department.

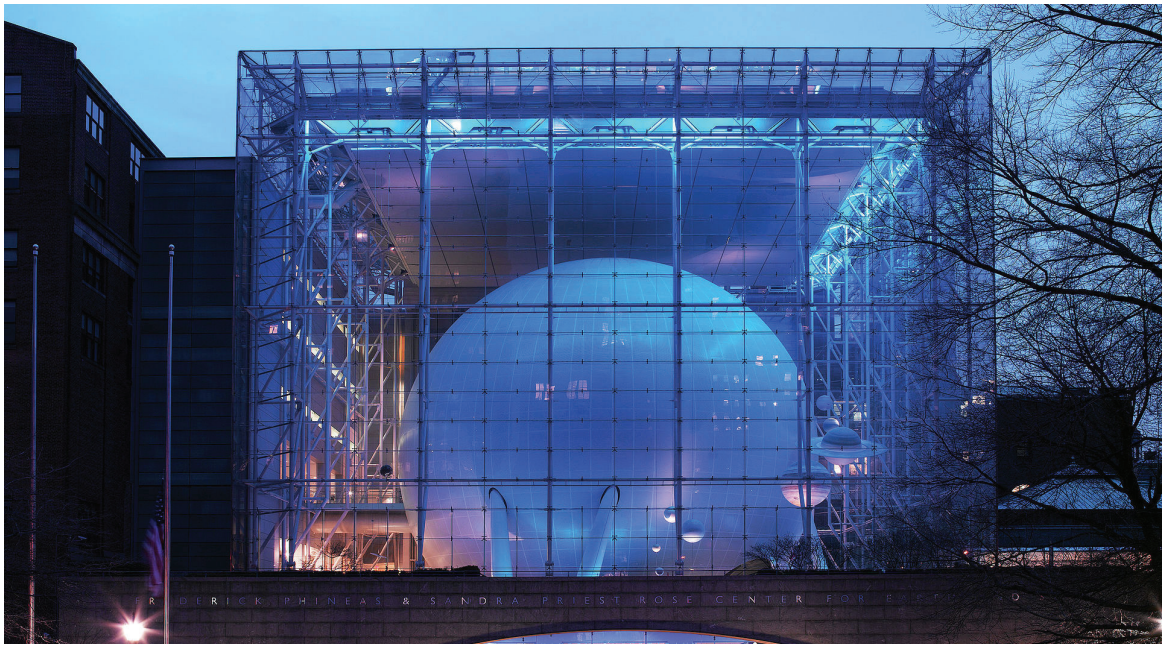
Nicholas Law's group at UNC plans to use SALT for exoplanet follow-up from their Evryscope and TESS surveys (TESS is NASA's next-generation, all-sky transit-detection satellite). The Evryscope is a 700-megapixel array of telescopes on a common mount that together image 8,000-square-degrees of the Southern sky every two minutes from CTIO in Chile. Evryscope is capable of confirming long-period large planets seen only once or twice in TESS's light curves. SALT's HRS will enable false-positive rejection and eventually mass measurements for dozens of planet candidates from the Evryscope and TESS. SALT's Fabry–Pérot capability is of particular interest to UNC astronomers because its wider field and more extensive wavelength coverage complements the Fabry–Pérot system behind SOAR's laser adaptive optics system.

Chris Clemens is working with the SAAO instrumentation group to explore the development of a high throughput spectrograph for SALT using the patented curved volume-phase-holographic gratings that he developed with the late Darragh O'Donoghue (SAAO). That is a major commitment to SALT's future because it will allow very efficient follow-up of time-variable targets from Evryscope and LSST. SALT time is open to everyone at UNC, with priority given to student projects.

UNC's Evryscope located at Cerro Tololo in Chile.

THE AMERICAN MUSEUM OF NATURAL HISTORY (USA)

SALT Board member: Michael Shara (chair)



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

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 5 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 8 story-high glass cube, which houses the Star Theater. The theatre uses high-resolution fulldome 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 spaceshows, 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 continues to serve in that position. Prof. 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.

Shara published recently an HRS-based paper reporting on the spin rates of O stars in Galactic and O+WR binaries. The O stars spin, on average, at half their breakup speeds, much less than mass transfer in these binaries suggests. An efficient method of shedding angular momentum is clearly at work. AMNH Postdoctoral Fellow Sam Grunblatt has initiated an HRS study of hot, southern exoplanet candidates identified with TESS. University of Cambridge PhD student Laura Rogers (in collaboration with Shara) continues to use SALT/HRS to characterise white dwarfs heavily polluted with metals, probably via accretion of asteroids and dust.


SCIENCE
HIGHLIGHTS

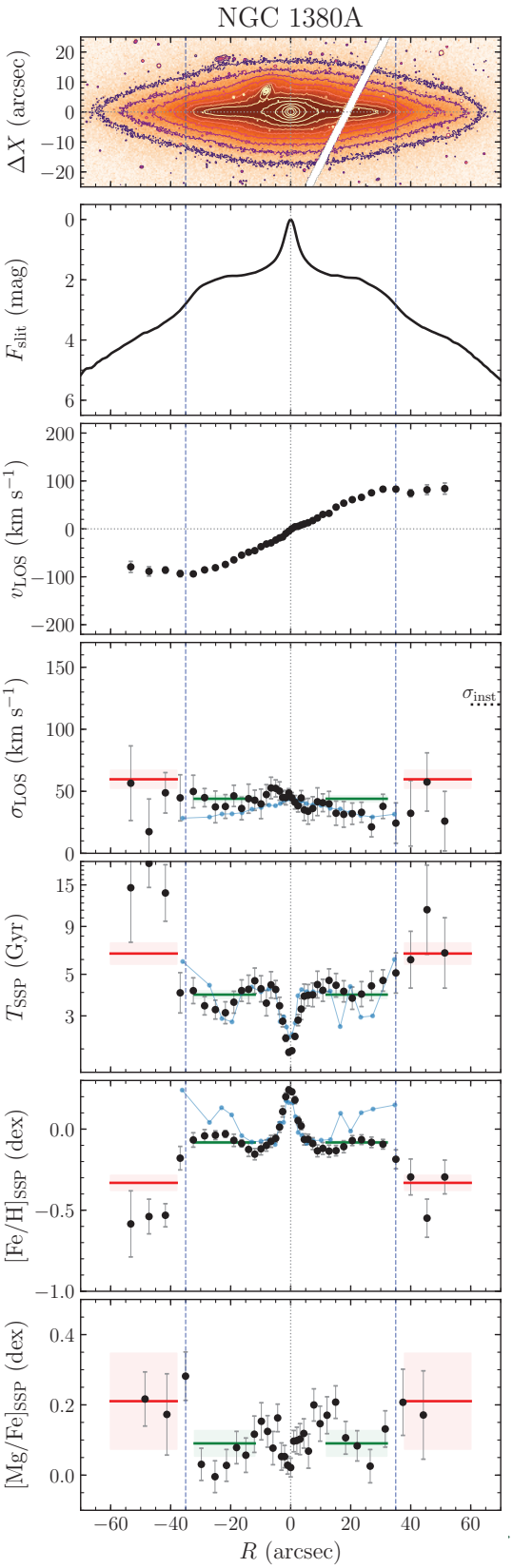

EXTRAGALACTIC ASTRONOMY
SCIENCE
HIGHLIGHTS

The imprint of the thick stellar disc in Fornax cluster galaxies

Most galaxies in the Universe are disc galaxies, whose stars mostly move in a relatively thin disc. Years ago it was discovered that disc galaxies have a complex multilayer structure, consisting of, at least, thin and thick discs. A study of the sub-structures of galactic discs as well as answers to questions like "Which stars populate thin/thick discs?", "How many stars are in a thick disc?", "What size is a thick disc compared to a thin one?" can shed light on galaxy formation and evolution processes over the cosmic time scale. However, due to observational difficulties, there is a lack of information about the stellar populations of the thick disc components in external galaxies. An edge-on orientation of galaxies helps to relatively easily probe the complex vertical structure of the galactic discs, but since galaxies are randomly orientated in space, only a small fraction of disc galaxies are seen edge-on from Earth.

Ivan Katkov from the Sternberg Astronomical Institute in Moscow, together with Alexei Kniazev (SALT Astronomer) and their Russian team, investigated three edge-on early-type disc galaxies (IC 335, NGC 1380A, NGC 1381) in the Fornax cluster of galaxies. They combined deep SALT/RSS spectroscopic data taken along the major axis with high-resolution images from HST. Thus they could identify the radii in the studied galaxies beyond which the thick disc's stars dominate the galaxy light and determine their parameters.

Katkov and his colleagues found that the stellar population properties in the outermost, thick disc-dominated regions show remarkably old ages and a low metallicity. They interpret these findings as a result of the environmental effects of the galaxy cluster. During cluster assembly, galaxies experience so-called ram pressure stripping -- the process of removing gas internal to the galaxy through the intergalactic hot gas pressure. This process effectively removes all gas from the outskirts of a galaxy, stopping the formation of the outermost parts of the thin disc. As a consequence, we observe to date a dominance of the thick stellar discs in the galactic outskirts.



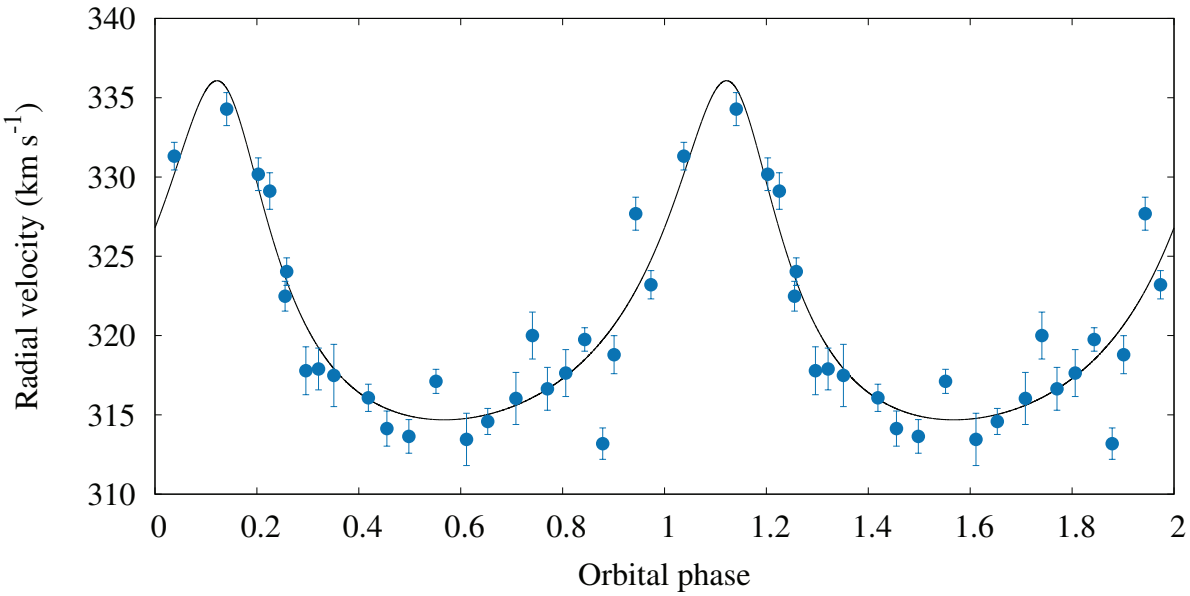
Radial profiles of stellar population properties recovered from SALT spectra of NGC 1380A. From top to bottom: reference image from the HST; surface brightness profile extracted from the spectrum, normalised to zero magnitude at the centre; line-of-sight stellar velocity; line-of-sight velocity dispersion; SSP equivalent measurements of ages, and two metallicities ([Mg/Fe] profiles were derived with Lick indices measurements, which required higher SNR than the SSP fitting and a different spatial binning). Green and red horizontal lines: measurements recovered from the binned spectra (with uncertainties as shaded areas). Light blue: data taken from the literature (at a six times better resolution). Vertical blue dashed lines correspond to radii where photometric profiles indicate a knee.

Katkov, I.Y., et al., 2019/02, MNRAS 483, 2413: The imprint of the thick stellar disc in the mid-plane of three early-type edge-on galaxies in the Fornax cluster

SALT/HRS observes the only known extragalactic gamma-ray binary LMC P3

Gamma-ray binaries are a rare class of high-mass binary systems that show most of their emission occurring in the gamma-ray regime. Very few of these systems are known, with less than 10 sources proposed so far. All of these systems consist of an O- or B-type star that is orbited by a compact object in the mass range of a neutron star or black hole. For two of the systems, pulsed emission has confirmed the presence of a non-accreting pulsar. The most likely scenario is that this is also the case for the other systems, but with the pulsed emission being absorbed in the wind of the companion star. The observed non-thermal emission originates from the shock that forms between the relativistic pulsar wind and the stellar wind.

In order to disentangle the physics occurring in these systems it is important to determine the binary parameters, which, for most systems, must be established from radial velocity measurements of the optical companion. Using SALT/HRS, van Soelen from UFS, South Africa, and his South African colleagues observed LMC P3, the first and only gamma-ray binary discovered outside of the Milky Way, in low-resolution mode 24 times between September 2016 and February 2017. Situated in the LMC, the binary was discovered by the detection of periodic radio, optical, X-ray and gamma-ray emission. Using cross-correlation, the authors could establish the radial velocity and solve for the binary parameters, showing the system to be slightly eccentric ($e = 0.40 \pm 0.07$) with a mass function of $0.001 \pm 0.0004\ M_{sol}$, which suggests a neutron star compact object. Critically, they were able to show that the phases of inferior and superior conjunction correspond to the peaks in the H.E.S.S. and Fermi-LAT light curves, respectively. This supports the idea that the gamma-ray emission observed from these systems is produced by inverse Compton scattering. The maximum inverse Compton emission of high energy gamma-rays will occur at superior conjunction due to the favourable scattering angle, as observed by Fermi-LAT. However, due to gamma-gamma absorption, the peak in the Very High Energy (VHE) gamma-ray light curve (observed by H.E.S.S.) will shift closer to inferior conjunction.



Radial velocity of LMC P3, as measured with SALT/HRS, folded on the 10.301 d orbital period. The black line shows the best fit model used.
-- Credit: H.E.S.S. Collaboration 2018

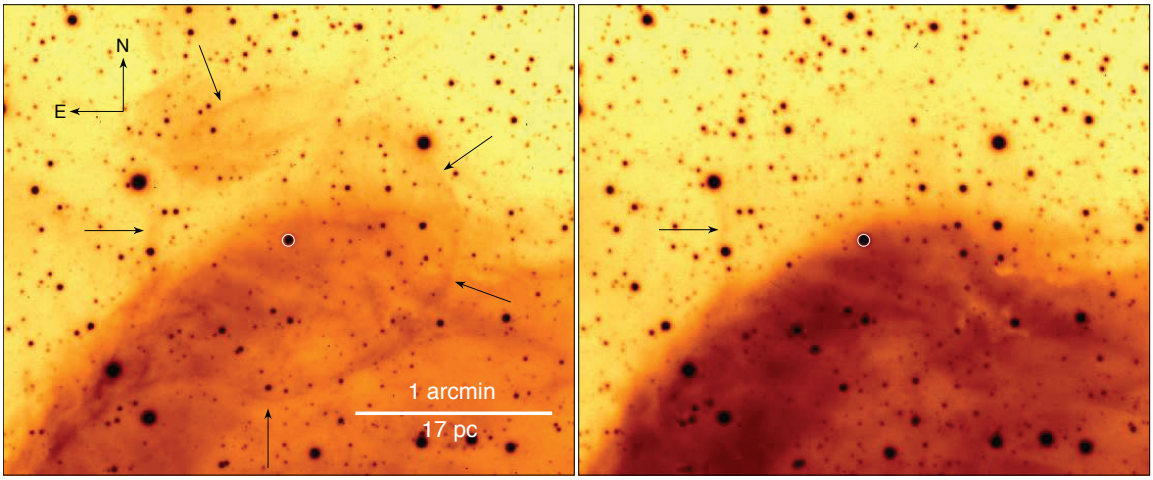
van Soelen, B., et al., 2019/04, MNRAS 484, 4347: The orbital parameters of the gamma-ray binary LMC P3

Discovery of a new supernova remnant in the Small Magellanic Cloud

Compact objects in X-ray binaries are born in supernova explosions. However, to date only four post-supernova binaries have been found within supernova remnants (SNRs). Three of them are located in the Milky Way, and the fourth one in the Small Magellanic Cloud (SMC). It is believed that the paucity of X-ray pulsar/SNR associations exists because the time required for the post-supernova binary to evolve into an X-ray pulsar is much longer than the lifetime of SNRs.

Vasilii Gvaramadze from the Sternberg Astronomical Institute in Moscow and Alexei Kniazev (SAAO/SALT), together with a German colleague, discovered a circular shell around the high-mass X-ray binary (HMXB) SXP 1323 in the SMC using archival data from ESO's VLT. This was interpreted as a remnant of the supernova explosion that led to the formation of SXP 1323's neutron star. Follow-up SALT/RSS optical spectroscopy of the shell allowed them to derive the shell's expansion velocity and to constrain the number density of the local interstellar medium, which in turn led to an estimate of the SNR's age of a few 10,000 years. This age, however, appears to be too young for the neutron star in SXP 1323 to spin down to its current spin period of 1323 s if it was born as a millisecond rotator.

SXP 1323 represents the second known example of HMXBs in the SMC associated with SNRs. Interestingly, the spin periods of neutron stars in both systems are, respectively, the third and second longest known in the SMC. The detection of two SNRs around long-period HMXBs challenges the traditional view on the formation of these objects and hints at the possibility that some neutron stars could be slow rotators from birth.



VLT Hα (left) and O III (right) images of a region containing the HMXB SXP 1323 (marked by a circle) and the circular shell around it (indicated by arrows). The bright emission to the south of SXP 1323 is the foreground H II region N76. Orientation and scale of the images are the same.

Gvaramadze, V.V., Kniazev, A. Y.; Oskinova, L. M., 2019/05, MNRAS Letter 485, 6:
Discovery of a putative supernova remnant around the long-period X-ray pulsar SXP 1323 in the Small Magellanic Cloud

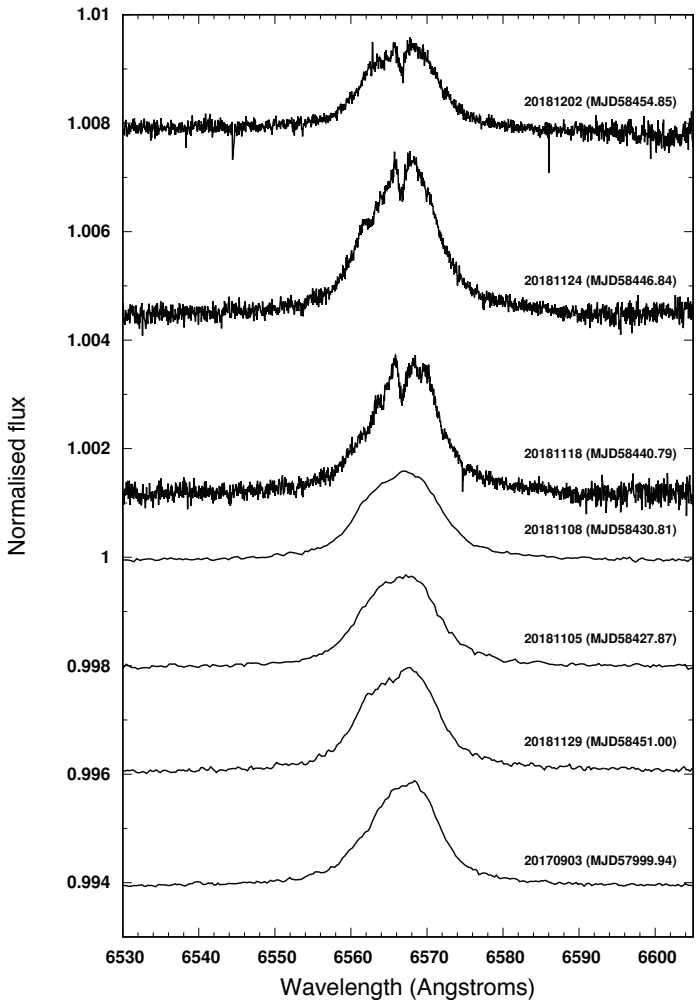
SALT observes two Be X-ray binaries in the Small Magellanic Cloud

Be X-ray binaries, which make up the largest subclass of the high-mass X-ray binary (HMXB) systems, comprise a neutron star in an eccentric orbit around a Be star with a geometrically thin Keplerian disc. The interaction of the neutron star with the Be disc results in the accretion of matter, leading to X-ray outbursts. Such X-ray outbursts occur in two flavours: type I (or normal, with luminosities < 10^{37} erg/s) and type II (or giant, with luminosities > 10^{37} erg/s). The disc variability is traced through the variability of the Balmer emission lines in the optical spectra, the strongest and best-studied of which is the Hα emission line.

Itumaleng Monageng, one of the SALT Astronomers, and his collaborators (mainly from the University of Southampton) have obtained SALT spectroscopic observations under the transient follow-up programme (lead by D. Buckley from SAAO) of two outbursting Be HMXB systems in the SMC, SXP 4.78 and SXP 91.1. The SALT spectra were used together with X-ray (from Swift and RXTE) and photometric data (from OGLE and LCO) to study the interaction between the Be disc and the neutron star in both systems.

The authors monitored SXP 91.1 during its most recent normal outburst, where they used both RSS and HRS observations to investigate different properties of the Hα emission line to study the Be disc variability. Together with long-term photometric data from OGLE, the SALT spectra indicate that the disc has undergone stable variability, with the disc growing and shrinking with the same amplitude over two decades. This degree of stable behaviour is unusual for such systems. The measured Hα equivalent width evolves synchronously with the X-ray measurements, suggesting that the extent of the disc increases until the neutron star comes close enough to disrupt and start accreting the disc matter.

SXP 4.78 was serendipitously discovered exhibiting a giant outburst while Swift observed SXP 91.1, being located in its field of view. The team monitored the source throughout the outburst and showed, using RSS spectra, that the Be disc underwent long-term variability. They find that the increase in optical magnitude and Hα equivalent width is evidence for the Be disc growth and believe that it is this disc growth which supplied the matter leading to the outburst. SALT's blue spectrum permitted the authors to classify the spectral type as B0.5 IV–V, which is typical for an optical counterpart to a Be HMXB system.

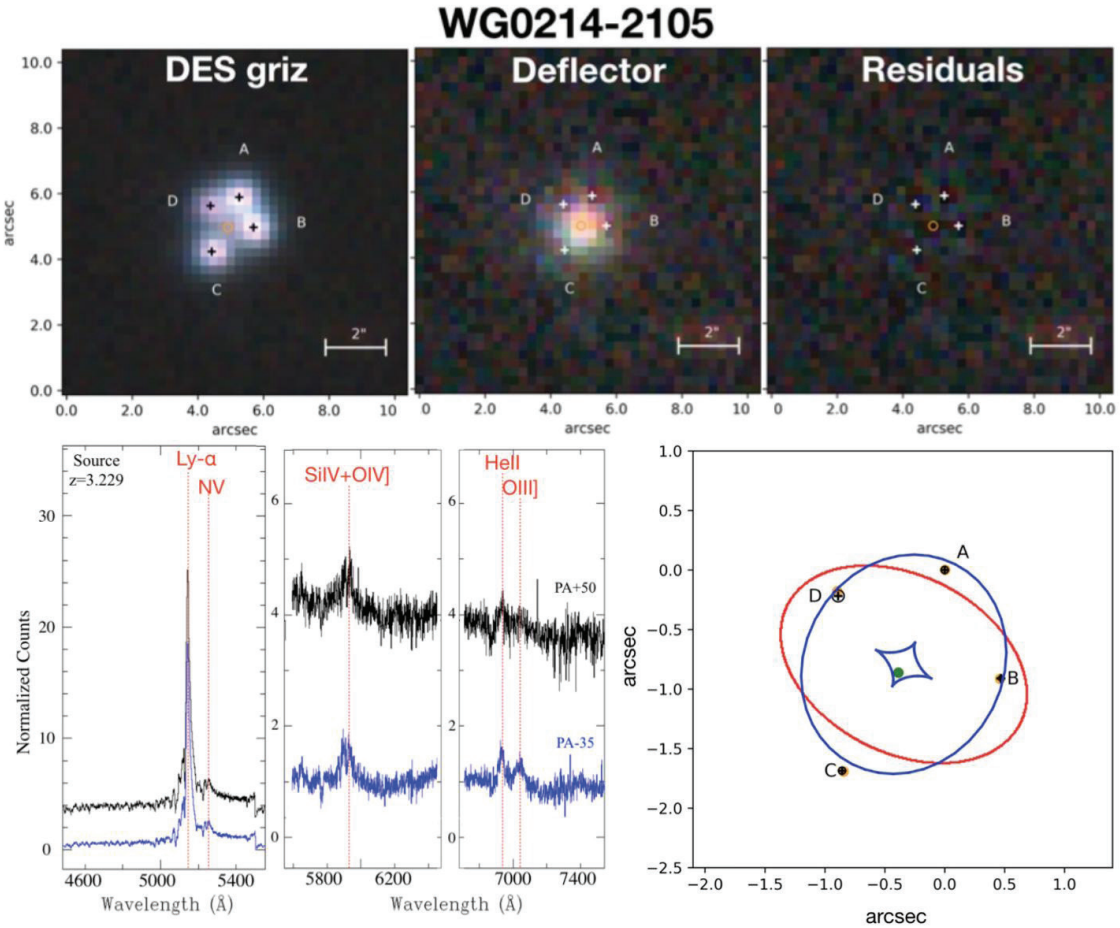


Hα line profiles during the current outburst; the top three were obtained with HRS, and the rest with RSS. The bottom spectrum is from the earliest observation, taken approximately 3 months before the current outburst, demonstrating the long-term disc stability.

Monageng, I. M., et al., 2019/06, MNRAS 485, 4617: The SMC X-ray binary SXP4.78: a new Type II outburst and the identification and study of the optical counterpart
Monageng, I. M., et al., 2019/10, MNRAS 489, 993: An X-ray and optical study of the outbursting behaviour of the SMC Be X-ray binary SXP 91.1

SALT detects two quadruple quasars in the Dark Energy Survey public footprint

Quadruply-lensed quasars (QSOs) are powerful cosmological tools though rare, requiring a closer alignment between source and deflector than for the more common doublet configuration. Only a few dozen are known in the whole sky. Thus, with the ongoing SALT programme "Gotta catch'em all", Lucia Marchetti from UWC and her team aim at confirming optically selected strong gravitational lensing systems candidates in the Equatorial and Southern hemisphere. Chiara Spiniello from INAF in Italy presents, on behalf of the team, the first results: Using SALT's RSS, the collaboration confirmed two new quadruplets (WG0214–2105 and WG2100–4452) within the Dark Energy Survey (DES) public footprint. For both systems, spectra for the sources and deflectors are presented that allow estimation of the source redshifts and unambiguous confirmation of their lensing nature. For the brighter deflector, WG2100–4452, they could also measure the stellar velocity dispersion from the SALT spectrum. They present simple lens models for both quadruplets which supply Einstein radii, singular isothermal ellipsoid (SIE) velocity dispersions, ellipticities, and position angles of the lens systems, as well as time-delay predictions assuming a concordance cosmological model.



The recently discovered lensing quadruplet WG0214–2105. Top left to right: combined *g*-, *r*-, *i*- and *z*-band DES image; the results after subtracting the multiple QSO images; the residuals obtained after also subtracting the deflector. Bottom left and middle: prominent emission lines of the source spectrum for two different position angles (PA); bottom right: the mass model fit obtained assuming a SIE profile matter distribution with critical (red) and caustics (blue) curves of the model.

Spiniello, C., et al., 2019/06, MNRAS 485, 5086:
Spectroscopic confirmation and modelling of two lensed quadruple quasars in the Dark Energy Survey public footprint

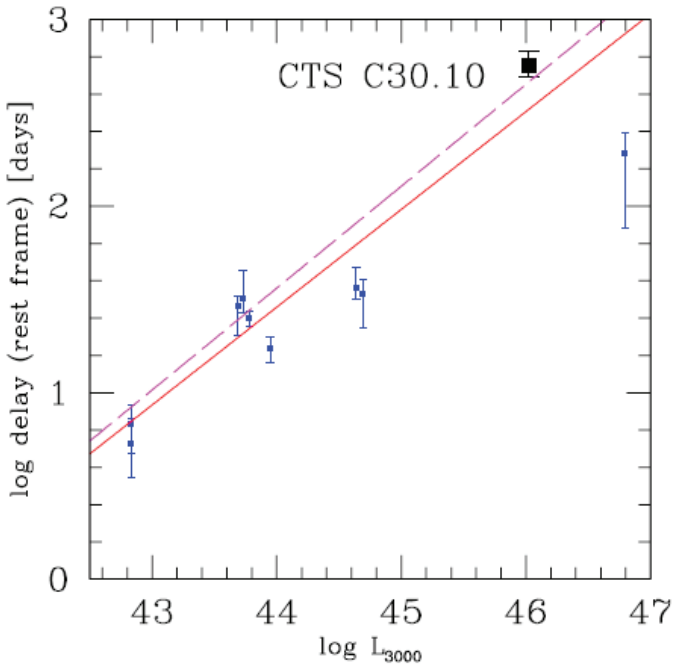
SALT measures the time delay of the Mg II line in the quasar CTS C30.10

The innermost region of the accretion flow in active galactic nuclei (AGNs), including the broad line region (BLR), is usually spatially unresolved. But the time variability of the emission lines allows insight into the structure of the nuclear region, provides a tool to measure the black hole mass, and contains a promise of possible cosmological applications. Time-delay measurements are time consuming, and, to determine the black hole mass, the strong correlation between the BLR size and the monochromatic luminosity can be used instead (using a single spectrum, which is especially useful for large surveys). The Hβ line is most useful for low-redshift AGNs, but intermediate-redshift (z ~1) AGNs only show the Mg II line in the observed optical spectrum. Scaling the relation from Hβ to the Mg II line has some limitations though, mainly because higher redshift sources frequently have higher masses and/or Eddington ratios. Direct confirmation of the scaling laws in lines other than Hβ using reverberation mapping is therefore important.

After six years of SALT monitoring, Bożena Czerny, from the Polish Academy of Sciences, and her team have finally succeeded in measuring the time delay of the Mg II emission line with respect to the continuum in one of their monitored quasars, CTS C30.10. The quasar is bright and has a redshift of z = 0.92005; the measured time delay is 1073 days in the observed frame, which is about three years. Thus, six years of monitoring was required to get the result. The reverberation campaign did not have to be very frequent, though: as expected, based on simulations prior to the start of the campaign, 25 spectra, well spread over the years, were enough to measure the time delay very accurately.

So far only one other high-redshift quasar had such a delay published (CTS 252 at z = 1.818), as well as several lower redshift sources observed by the SDSS–RM team. Combined with the new measurement, this allowed for the first time to plot the radius–luminosity diagram for the Mg II line. The authors conclude that the Mg II line time delay forms a radius–luminosity relation very similar to the one for the Hβ line. This result puts the determination of black hole masses in the intermediate-redshift AGNs on firmer ground. There are also hopes to apply the time-delay measurements to cosmology by direct application to the distance measurements.

The SALT monitoring campaign included two other quasars for which the results will be available shortly.



Radius–luminosity relation for the Mg II λ2800 line from a compilation of all available time-delay measurements, including SALT (black square and red line). The relation is similar to the well known relation for Hβ line (dashed line).

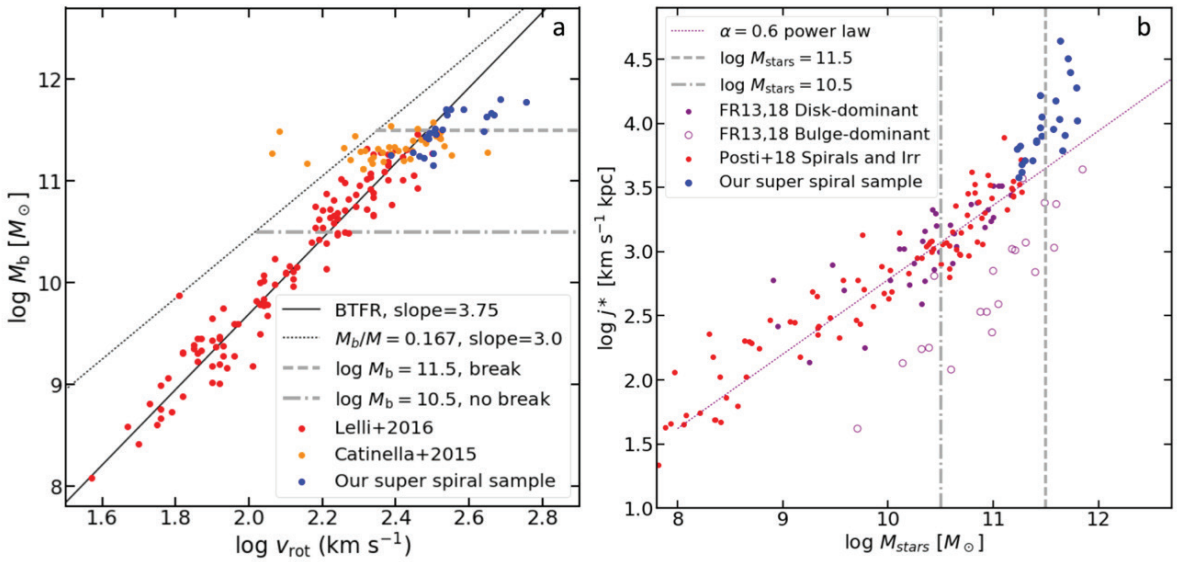
Czerny, B., et al., 2019/07, ApJ 880, 46: Time Delay Measurement of Mg II Line in CTS C30.10 with SALT

Super spirals rotate really fast and break from galaxy scaling relations

Super spirals are the most massive star-forming disc galaxies in the Universe. They represent a very rare population of massive disc galaxies in which star formation has not been quenched. As such, they provide a unique opportunity to extend studies of galaxy scaling laws into an entirely new regime.

Patrick Ogle from STScI, together with Tom Jarrett from UCT and other colleagues, observed 20 extremely massive, giant spiral galaxies with SALT/RSS. These super spiral galaxies were selected to have stellar masses (1 – 6) x 10^{11} times the mass of the sun. The long-slit spectra show unprecedented rotation speeds of up to 570 km/s that break from the baryonic Tully–Fisher galaxy scaling relation. These super spirals also break from the Fall relation between galaxy mass in stars and specific angular momentum, spinning up to a factor 10 faster than expected for their mass. Notably, the results are also inconsistent with the theory of Modified Newtonian Dynamics (MOND), which predicts a strict power-law relation between galaxy rotation speed and baryonic mass. Instead, the high rotational speeds of these spiral galaxies must be an indication of extremely massive dark matter halos.

The discovery of giant spiral galaxies that spin very fast has several implications for galaxy formation and evolution. First of all, it shows that spiral galaxies can form and survive in dark matter halos of up to 4 x 10^{13} M_{sol}, with stellar masses as great as an entire galaxy group combined. However, these super spirals are under-massive for their dark matter halos, obeying a strict limit to their stellar mass of 6 x 10^{11} M_{sol}. This is consistent with galaxy formation in a universe dominated by cold dark matter, where the maximum stellar mass is set by the maximum gas mass that can cool on dynamical timescales of approximately 1 Gyr. Remarkably, giant elliptical galaxies obey a similar limit, and can only grow by a factor of ~2 times larger by so-called 'dry' (gas-free) major mergers. As a result of the successful SALT campaign, the team obtained time with the IRAM 30-m and the GBT to observe CO 1–0 molecular line emission, so that they may determine the cold gas content and future star-forming potential of super spirals. Observing time with XMM–Newton will be used to measure the mass and temperature of the hot gas halo of the fastest-spinning super spiral. This will give an independent measure of its dark halo mass and complete the census of its baryons.



Super spirals (blue data points) break from the baryonic Tully–Fisher and Fall relations (dashed line); the dash-dotted line indicates the break in the galaxy stellar mass/halo mass relation. (a) Mass in baryons versus maximum rotation speed. (b) Specific angular momentum versus mass in stars.

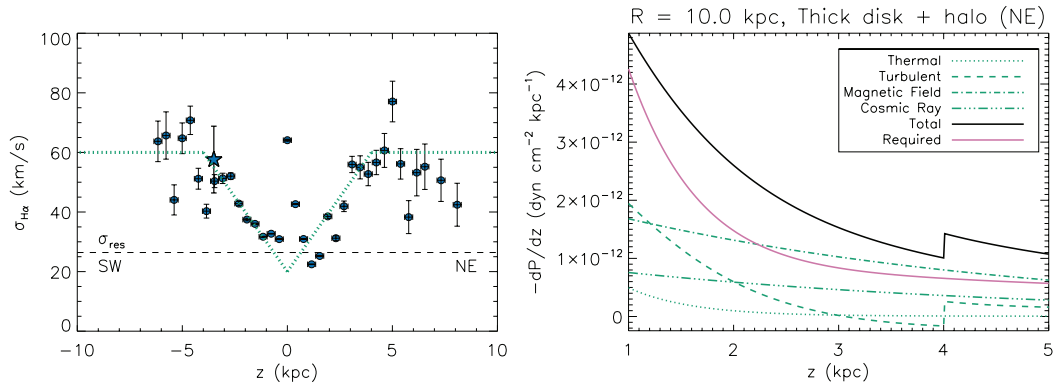
Ogle, P.M., et al., 2019/10, ApJ Letters 884, 11: A Break in Spiral Galaxy Scaling Relations at the Upper Limit of Galaxy Mass

A dynamical study of extraplanar diffuse ionised gas in NGC 5775

Erin Boettcher from the University of Chicago and her colleagues used SALT/RSS to probe the vertical structure and support of the gaseous, disc–halo interface of the nearby, edge-on disc galaxy NGC 5775. The gaseous, disc–halo interface is an important boundary in the baryon cycle: accretion and stellar feedback processes require gas to pass through this interface, imprinting its vertical structure, support, and kinematics with clues about the phenomena that drive galaxy evolution. Their warm, ionised phase presents a particular challenge to our understanding of these interfaces, as the observed exponential electron scale heights of the extraplanar diffuse ionised gas (eDIG) layers in the Milky Way and nearby, edge-on disc galaxies (~1 kpc) exceed their thermal scale heights (~0.2 kpc) by factors of a few.

The authors tested a dynamical equilibrium model for the eDIG layer in the interacting, star-forming galaxy NGC 5775. They asked whether additional sources of vertical pressure support — namely turbulent field, magnetic field, and cosmic-ray pressure gradients — can explain the eDIG density distribution in this galaxy. Using optical emission line spectroscopy obtained with RSS in long-slit mode, they measured the exponential electron scale heights of the thick disc and halo components of the eDIG layer on the northeast (0.6 and 7.5 kpc) and southwest (0.8 and 3.6 kpc) sides of the galaxy. Additionally, they obtained the highest spectral resolution measurements of the turbulent velocity dispersion of an eDIG layer to date using the Hα emission-line widths observed as a function of height above the disc along the minor axis of the galaxy. As shown in the left panel of the figure, this analysis yielded a turbulent dispersion of ≤ 70 km/s, a factor of a few higher than the thermal dispersion of ~10 km/s; it also produced the first clear evidence of an increasing eDIG velocity dispersion as a function of height above the disc.

Boettcher and her colleagues paired the SALT/RSS optical spectroscopy with radio continuum observations of the non-thermal halo of NGC 5775 from CHANG–ES (Continuum Halos in Nearby Galaxies: an eVLA Survey) to quantify the turbulent field, magnetic field and cosmic-ray pressure gradients in the eDIG layer. As shown in the right panel of the figure, the observed pressure gradients are sufficient to stably support the eDIG layer on the northeast and southwest side of the galaxy at a galactocentric radius of R = 10 kpc and R = 11 kpc, respectively. However, these are the minimum galactocentric radii at which both the thick disc and the halo are supported; at smaller R, the gravitational field becomes sufficiently strong that it is no longer countered by the thermal and non-thermal pressure gradients. As Hα imaging suggests that much of the gas is found within R < 10 kpc, the authors conclude that this dynamical equilibrium model is not a complete description of the dynamical state of the eDIG layer in this galaxy. The results suggest either that the eDIG layer is supported by a large vertical velocity dispersion that exceeds the horizontal dispersion measured here, or that the layer is shaped by bulk, disc–halo gas flows driven by feedback and/or accretion processes. This motivates further study of the vertical kinematics of eDIG layers in nearby, face-on disc galaxies to better understand the implications of these layers for the disc–halo connection at low redshift.



Left: Horizontal eDIG velocity dispersions determined from the Hα emission line widths along the minor axis of NGC 5775 provide the first evidence for an increasing eDIG turbulent velocity dispersion as a function of height above the disc. Right: The sum of the thermal and non-thermal pressure gradients in the eDIG layer on the northeast side of NGC 5775 (pink) is only sufficient to support the gas at its observed scale height at galactocentric radii $R \geq 10$ kpc (black), suggesting that the dynamical equilibrium model tested here is not a satisfactory description of the dynamical state of the gaseous, disc–halo interface.

Boettcher, E., Gallagher, J. S., III, Zweibel, E.G., 2019/11, ApJ 885, 160: A Dynamical Study of Extraplanar Diffuse Ionized Gas in NGC 5775

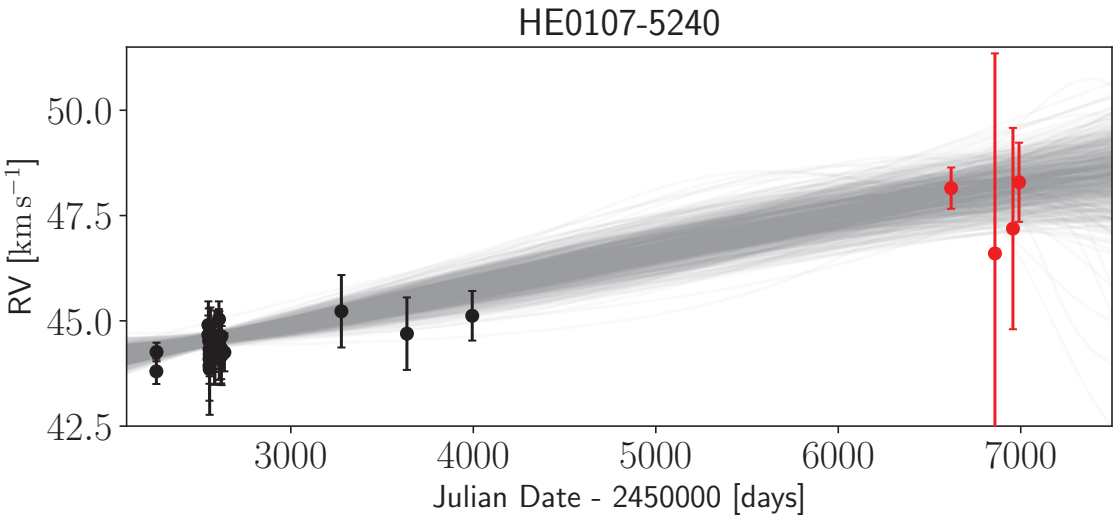

STELLAR AND GALACTIC ASTRONOMY
SCIENCE
HIGHLIGHTS

Binarity among the most metal-poor, carbon-enhanced stars

Extremely metal-poor stars are important tracers of processes in the early Universe. An interesting subclass of such stars are the carbon-enhanced metal-poor (CEMP) stars: these stars have a carbon-to-iron ratio that is enhanced by more than a factor of ten compared to a scaled solar abundance. For most of the extremely metal-poor CEMP stars (with iron abundance 1000 x less than that of the Sun, i.e., [Fe/H] < –3), the carbon is thought to come from the parent gas cloud out of which the CEMP stars formed and which was enriched through unique processes in the first stars and their supernovae. This subclass is called CEMP-no stars.

For her project, PhD student Anke Arentsen (AIP, Germany) together with Else Starkenburg (AIP, Germany), Matthew Shetrone (UTexas, USA) and colleagues have used SALT/HRS and CFHT/ESPaDOnS data to monitor the radial velocities of a sample of CEMP-no stars to investigate their binarity. They found a surprisingly large number to be in binary systems, especially among the stars that were particularly strongly enhanced in carbon. Their interpretation is that, possibly, binary mass transfer with a former AGB star companion could be an additional pathway to create or further enhance CEMP-no stars.

The authors also uncovered the most metal-poor binary system known, using the SALT/HRS data. The star HE 0107–5240 has an iron abundance [Fe/H] = –5.4 and did not show binary signatures in the past. The new data, taken roughly seven years after the last measurement, finally indicate that the radial velocities are changing slowly and the star is indeed a long-period binary system.



Radial velocities for hyper metal-poor star HE 0107–5240 from the literature (black) and SALT/HRS (red). They indicate that the star is in a long-period binary system, where the grey lines are possible orbital solutions with periods between 10,000 and 30,000 days.

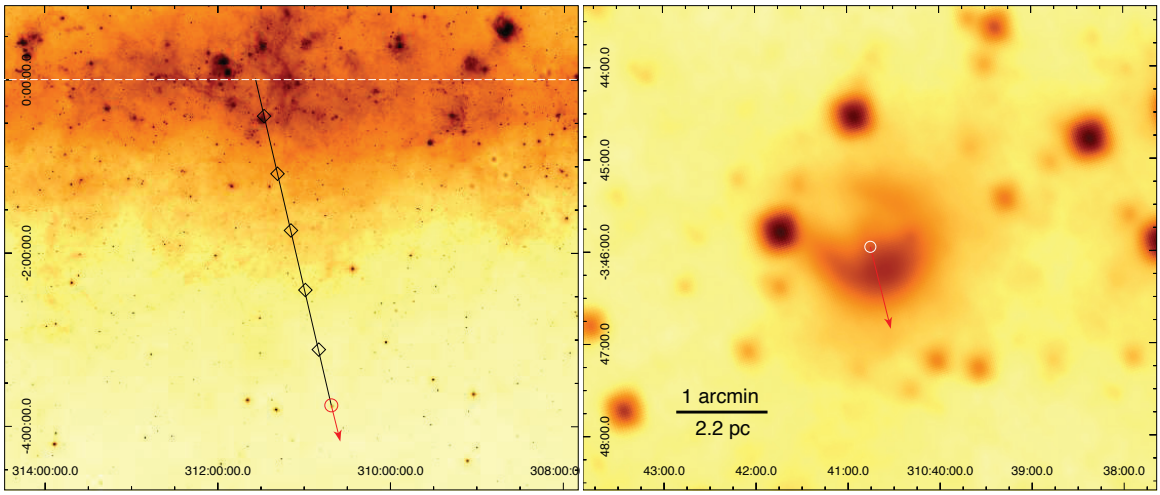
Arentsen, A., et al., 2019/01, A&A 621, 108: Binarity among CEMP-no stars: an indication of multiple formation pathways?

SALT discovers a massive spun-up and rejuvenated high-velocity runaway star

Observations show that the majority of massive stars are formed in binary and multiple systems. The mass-loss from these systems is defined not only by the (variable) stellar wind of individual companion stars, but also by various binary interaction processes, such as mass transfer or merger. In both cases, the system can lose a significant fraction of its mass (up to several solar masses) that slowly spreads into the circumstellar environment. After the thermal adjustment on the Kelvin–Helmholtz time-scale, the mass gainer or merger product might become a source of fast wind, which will blow a bubble in the surrounding medium. This bubble would be surrounded by a shell (nebula) if its expansion is supersonic. The shell will not form, though, if the binary interaction occurred within a larger hot bubble produced by winds of all massive stars of the parent star cluster. Thus, to produce a detectable nebula, the binary system should find itself far from the birth cluster and well prior to the beginning of the mass transfer or merger event, i.e., it should be a runaway star.

Observations also show that about 70% of runaway O-type stars are binary systems. Moreover, about 40% of O stars interact with a companion while they are still on the main sequence. This implies that many of the main-sequence O stars in the field could be the rejuvenated products of mass transfer or binary mergers (runaway blue stragglers), and therefore some of them could be surrounded by initially almost spherical nebulae, whose origin can hardly be explained within the framework of single star evolution. These nebulae, however, should be extremely rare because they rapidly transform into bow shocks when the forward edge of the wind bubble crosses the region occupied by the slow material lost during the binary interaction process and starts to interact with the unperturbed interstellar medium.

Vasilii Gvaramadze (SAI, Moscow) and Alexei Kniazev (SAAO/SALT) with their colleagues discovered a horseshoe-shaped nebula around the high-velocity (~160 km/s) runaway star CPD–64°2731, using WISE data. Spectroscopic observations with SALT/HRS showed that CPD–64°2731 is a fast-rotating main-sequence O5.5 star with enhanced surface nitrogen abundance. The derived projected rotational velocity of CPD–64°2731 of about 300 km/s is extremely high for this spectral type, while the kinematic age of the star of about 6 Myr, assuming it was born near the Galactic plane, exceeds its age derived from single star models by a factor of two. These properties suggest that CPD–64°2731 is a rejuvenated and spun-up binary product. The geometry of the nebula and the almost central location of the star within it argue against a pure bow shock interpretation for the nebula. Instead, the authors suggest that the binary interaction happened recently, thereby creating the nebula, with a cavity blown by the current fast stellar wind. This inference is supported by 2D numerical hydrodynamic modelling.



Left: WISE 22 μm image of CPD–64°2731 and its surrounding nebula (marked by a circle). The arrow shows the direction of the peculiar transverse velocity of CPD–64°2731, derived using the Gaia DR2 proper motion measurement and adopting a distance of 7.5 kpc. The solid, black line shows the trajectory of CPD–64°2731, and diamonds mark the positions of the star 1, 2, 3, 4 and 5 Myr ago. The Galactic plane is indicated by a white dashed line. Right: WISE 12 μm image of the nebula. Coordinates are Galactic longitude and latitude. At a distance of 7.5 kpc, 1 degree and 1 arcmin correspond to approximately 130 and 2.2 pc, respectively.

Gvaramadze, V.V., et al., 2019/02, MNRAS 482, 4408: CPD-64°2731: a massive spun-up and rejuvenated high-velocity runaway star

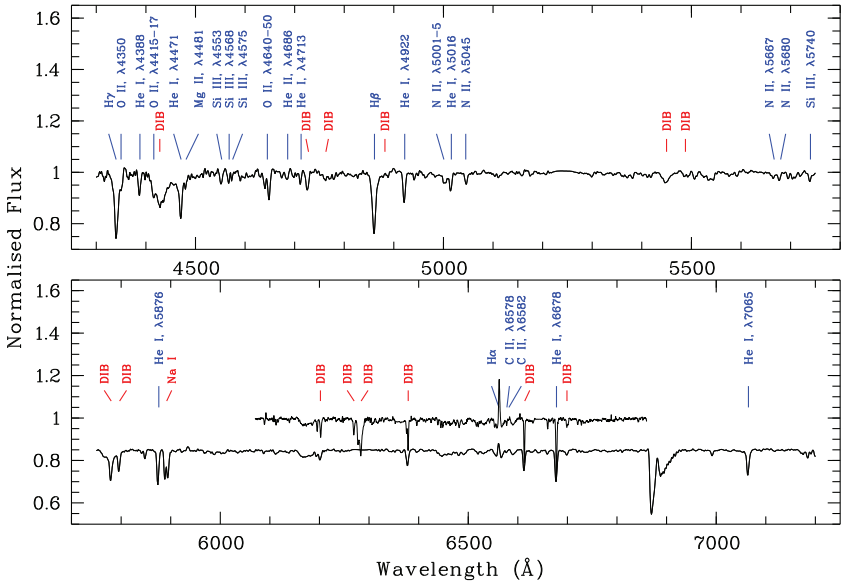
Two circumstellar nebulae and their massive central stars

Circumstellar nebulae around massive stars primarily originate from the copious mass-loss inherent to these stars at different stages of their life. For example, the compact (parsec-scale) nebulae around Wolf-Rayet (WR) stars of the late nitrogen sequence are produced in the course of interactions between the fast WR wind and the slow, dense material lost during the preceding red supergiant phase. The red supergiants themselves can also produce compact circumstellar nebulae, provided that their wind is confined by some external factors. Most often, circumstellar nebulae are found around (candidate) luminous blue variables, and it is believed that they are produced by either instantaneous mass ejections or by brief (maybe recurrent) episodes of enhanced mass-loss. Currently, more than 70% of stars of this type are known to be associated with nebulae of various shapes.

The bipolar morphology of some nebulae associated with massive stars suggests that their formation is somehow related to the (nearly critical) rotation of their underlying stars. The high rotational velocity of massive stars could be intrinsic to some of them from birth or could be achieved over the course of stellar evolution, e.g., because of the contraction of a single star during the transition from core-H to core-He burning, or because of mass transfer in a close binary system.

Since the majority of massive stars form in binary or multiple systems, binarity may actually be the most important factor for circumstellar nebulae. Indeed, the presence of a second star may not only spin up its companion, but it may also trigger various modes of mass-loss from the system, as has been proposed to explain the variety of shapes of planetary nebulae. Moreover, a significant fraction of massive stars are already subject to binary-interaction processes (including mergers) during the main-sequence stage, implying that circumstellar nebulae could be produced by relatively unevolved stars.

Vasilii Gvaramadze (SAI, Moscow) and Alexei Kniazev (SAAO/SALT) with their colleagues discovered two mid-IR nebulae using data from the WISE survey and identified their central stars with the early B-type stars BD+60° 2668 and ALS 19653. Optical spectroscopic observations of these stars with SALT (HRS and RSS) and the 3.5-m telescope at Calar Alto confirmed that they are massive stars, while the spectral modelling showed that both stars are either on the main sequence or have just left it. The results provide further support to claims that massive stars can produce circumstellar nebulae during the early stages of evolution. Since the origin of such nebulae can hardly be understood within the framework of single-star evolution, it was suggested that the formation of both nebulae is related to the binary nature of their central stars.



Normalised low-resolution RSS spectrum of ALS 19653. The principal lines and most prominent diffuse interstellar bands (DIBs) are indicated. The lower panel also shows the high-resolution HRS spectrum (upper curve).

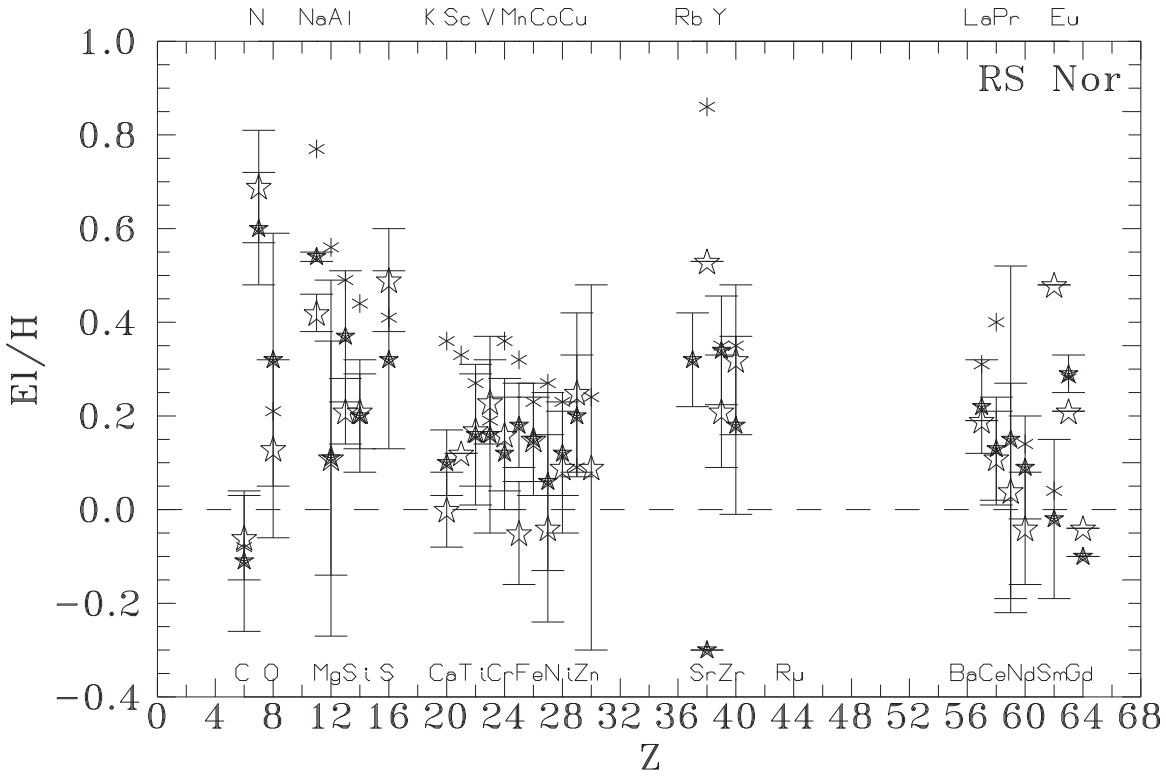
Gvaramadze, V.V., et al., 2019/02, AJ 157, 53:
Two Circumstellar Nebulae Discovered with the Wide-field Infrared Survey Explorer and Their Massive Central Stars

SALT's MAGIC project: Cepheid RS Nor as a test object

Observing at SALT is done in service mode to increase the observing efficiency, taking into account the reduced field of view of the telescope due to its fixed altitude. Alexei Kniazev, one of the SALT astronomers, and his Russian colleagues have analysed SALT specifications, capabilities of its current instrumentation and features of the astronomical conditions at Sutherland to propose a number of observing projects that, in their opinion, could use SALT with maximum efficiency. These projects are aimed at the spectroscopic study of various stellar subsystems of our Galaxy, including large samples of stars, and are grouped together under the large, single observing programme MAGIC — the Milky wAy Galaxy wIth SALT speCtroscopy.

The authors have now published a description of one of the sub-programmes of MAGIC, the high-resolution spectroscopic investigation of a large sample of Cepheids. Yellow variable supergiants called Cepheids are for a number of reasons known to be very convenient objects for studying the behavior of various chemical elements in the disc of our Galaxy. The authors have developed a unified reduction system for SALT échelle data taken in the medium-resolution mode (MR) and have tested it on observations of a single object, the well-studied Cepheid RS Nor.

Kniazev and his colleagues verified that data obtained for Cepheids using SALT's HRS spectrograph can be reduced in accordance with the described technique and allows the element abundances for these stars to be studied with an accuracy that is at least as good as that of earlier determinations carried out on similar échelle spectrographs.



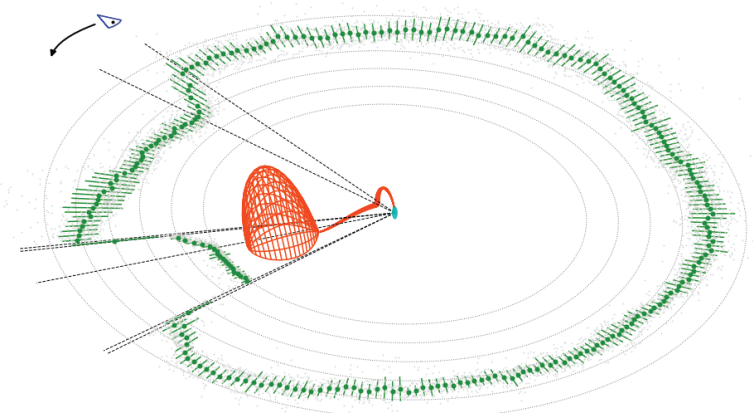
Comparison of the element abundances for RS Nor, obtained with SALT/HRS using a new reduction method, and the corresponding abundances reported in previous publications. The open and filled pentagrams show the results obtained using the modified and the standard method, respectively, and the stars show the estimates from previous publications.

Kniazev, A.Y., et al., 2019/04, Astrophysical Bulletin 74, 208:
The MAGIC Project. I. High-Resolution Spectroscopy on Salt Telescope and the Cepheid RsNor as a Test Object

Discovery, observations, and modelling of a new eclipsing polar

Amongst the plethora of interesting astronomical transients, the population of cataclysmic variables (CVs) form a fascinating and enigmatic subclass. Cataclysmic variables are close, semi-detached, binary stars consisting of a white dwarf (WD) accreting material from a low mass, red or brown dwarf companion. The subclass known as polars (or AM Her stars) have strongly magnetic white dwarf primaries that are usually tidally locked with their companions in synchronous orbit. In polars, the strength of the white dwarf's magnetic field, coupled with the short orbital period — and therefore close proximity of the two stars — leads to accreted material from the inner Lagrangian point, L1, being injected in or very near the magnetosphere of the primary. In the presence of such strong magnetic forces, the accreting material is constrained to flow along the magnetic field lines, forming an accretion column near the white dwarf surface before eventually settling near the magnetic poles of the star. As material impacts the surface of the WD at supersonic velocities, a deceleration shock is produced in the flow at ~10 km above the WD surface. In passing through the shock, the bulk kinetic motion of the gas becomes thermalised, producing a hot (~10^8 K) settling flow in the post-shock region. Most of the light, and indeed the variability, seen in these kinds of systems emanates from this small but significant region. As such, polars are a unique probe into the physics of accreting plasmas in strong magnetic fields. Amongst the population of polars, a small number are also eclipsing sources. Eclipsing systems are valuable systems in terms of studying the spatial extent and configuration of the accretion flow. As the stars orbit each other, the occulting limb of the secondary star systematically cuts off the light from the various luminous components in the system, allowing measurements of the positions and dimensions of the accretion regions (the 'hot-spots'), the accretion stream, and the interaction/threading region in the magnetosphere.

Hannes Breytenbach from UCT and SAAO and his colleagues report on the discovery of a new eclipsing polar, MASTER OT J061451.70–272535.5 (in short J0614–27), detected by the MASTER-SAAO optical transient survey. Follow-up time-resolved photometry showed the system exhibiting a deep, sharp eclipse, and a pre-eclipse 'dip', likely due to obscuration of the accretion spot(s) by the accretion stream. Key spectroscopic observation from SALT/RSS revealed a spectrum characteristic of a polar, allowing the team to confirm the identity of the star. Following the positive identification of the object as a polar, a larger photometric campaign involving high time resolution observation from SALTICAM on SALT and SHOC on the SAAO 1.0-m and 1.9-m telescopes allowed them to study the accretion geometry of the system in unprecedented detail. To investigate the physical origin of the unusual eclipse light curve, the team modelled the accretion stream using a swarm intelligence based approach employing "fireflies" (emission points of equal brightness) that are allowed to move freely within the Roche lobe of the primary. The firefly model was able to accurately reproduce the light curve of J0614-27, allowing Breytenbach and his colleagues to constrain the inclination and to estimate the physical parameters of the system. J0614-27 serves as an interesting example amidst the ever increasing number of newly discovered transient objects observed by SALT.



A 3D view into the system geometry. Central in the figure are shown the WD (cyan), the donor star (orange, upper half only) and the accretion stream (solid orange). A radial projection of the average phase-folded light curve of J0614–27 is plotted in green. In the co-rotating reference frame of the binary, the observer would move in a counter-clockwise direction around the centre of mass. This figure shows how the features in the light curve correspond to the physical components of the system.

Breytenbach, H., 2019/04, MNRAS 484, 3831: Discovery, observations, and modelling of a new eclipsing polar: MASTER OT J061451.70-272535.5

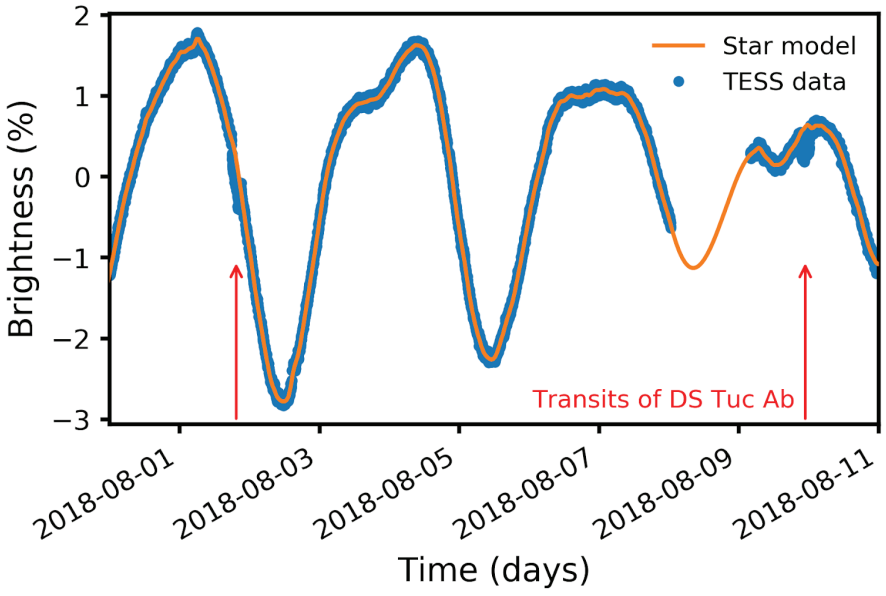
SALT confirms a young exoplanet found with TESS

How do planets form and evolve? This and related questions drive the current research in exoplanets: How and when do planets migrate to short orbital periods? How does atmospheric mass-loss result in the population of exoplanets that we observe around older, field stars (with ages of roughly 2 – 10 Gyr)? One approach to answering these questions is to study exoplanets around young stars; these still-maturing systems provide a window into the era when planet migration and atmospheric evaporation might still be underway. Planetary systems in young stellar clusters are a particularly important benchmark, since their ages are well-determined through their association with the cluster. NASA's Transiting Exoplanet Survey Satellite (TESS) mission, with its wide survey area, provides a unique opportunity to search for planets around nearby young stars, especially those in young moving groups.

In TESS's first month of observations, Elizabeth Newton from Dartmouth College and her colleagues detected a planet candidate around DS Tuc, one of the original members of the 45-Myr-old Tucana–Horologium Young Moving Group. DS Tuc is a binary star, and follow-up photometry from the Spitzer Space Telescope revealed that the signal comes from the solar mass primary star, DS Tuc A. Newton decided to use SALT/HRS for the first follow-up observations, which proved valuable both for ruling out false positive scenarios and for understanding the overall system architecture. They obtained four spectra of each of DS Tuc A and B over a week in November 2018 using a target of opportunity programme led by Dartmouth College.

The team first checked the spectra for close stellar companions to DS Tuc A and B and found none — this ruled out a claim in the literature that DS Tuc B is a spectroscopic binary. Using radial velocity (RV) measurements from the SALT/HRS and archival spectra, they then placed stringent limits on the mass of the companion to DS Tuc A, ruling out stellar companions and providing a key confirmation of the planetary nature of the signal. Next, they used the RVs to constrain the orbit of the DS Tuc AB stellar binary. Finally, they measured the rotational broadening. The SALT data confirmed the radial velocity component $v \sin(i)$ for DS Tuc A, and provided a measurement for DS Tuc B.

Putting everything together, Newton and her team were able to confirm that DS Tuc Ab is a planet with a size in between that of Neptune and Saturn, on an 8-day orbit around its 45-Myr-old host star. They also found that the stellar binary orbit, the spin of DS Tuc A, and the planetary orbit are likely close to aligned.



TESS photometry of DS Tuc AB (blue) and a Gaussian process model for the stellar variability (orange). The strong photometric variability is typical of young stars; the transits of the exoplanet are the small dips in brightness marked with red arrows.

Newton, E.R., et al, 2019/07, ApJL 880, 17: TESS Hunt for Young and Maturing Exoplanets (THYME): A Planet in the 45 Myr Tucana-Horologium Association

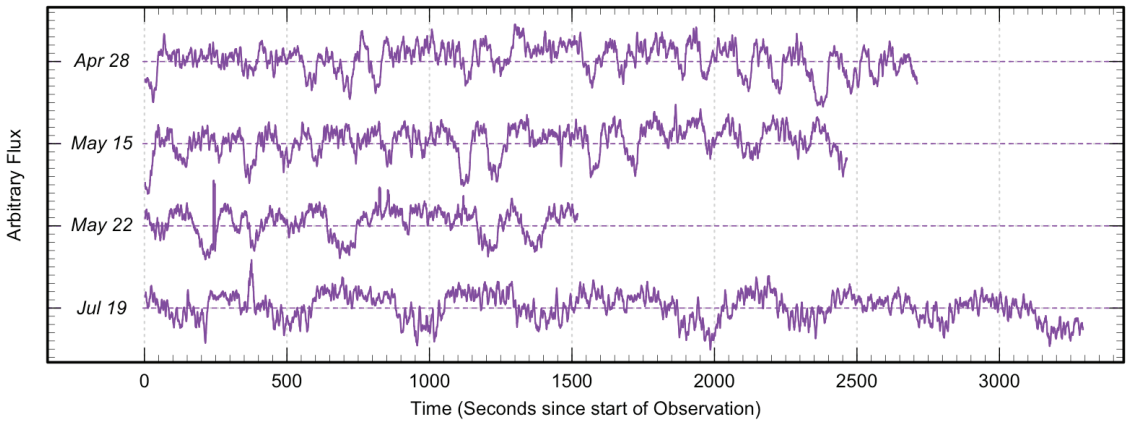
Puzzling blue dips in the black hole candidate Swift J1357.2–0933

Low-mass X-ray binary (LMXB) systems are the smallest black hole systems one can study in astronomy — which, by their very nature, makes them some of the fastest and most variable sources. With a black hole or neutron star feeding off an orbiting low-mass star, intriguing activity can happen, not just on second scales but even faster. Such activity is not yet fully understood, and many questions remain. John Paice from the University of Southampton and IUCAA and his colleagues asked a specific question: what is going on in Swift J1357.2–0933?

J1357 is one of the faintest black hole systems known and was only discovered due to a particularly bright outburst (for it) in 2011 and has been difficult to observe ever since — only adding to the plethora of enigmas present in the system. One of the biggest curiosities is the presence of dips in the optical light during outburst — dips which do not occur in X-rays and which become both longer and less frequent as the outbursts continue. To find out more about these dips and their cause was the driving point for a multiwavelength collaboration, of which SALT was a key part.

SALT's contributions involved tracking the evolution of the dips over the course of about three months during the 2017 outburst, using the RSS in slot-mode. The observations confirmed the similarity to dips observed in this source before. In addition, one of the SALT observations was organised to occur simultaneously with the X-ray telescope NuSTAR observation, confirming not only the lack of X-ray dips, but also providing an opportunity to see how the two wavelengths related. While the results were inconclusive (not a surprise for such a faint source), they became another piece of the incomplete puzzle: they hint at a particular pattern of lags between X-ray and optical emission that, when combined with a growing body of evidence, could indicate the presence of a jet in the source.

The question of what is going on in J1357 will likely remain one for years to come. Continued observations with SALT and other telescopes will add more and more pieces to this strange and fascinating puzzle.



SALT/RSS light curves from four different dates, showing the dips and their changing frequency and duration over time. The observations have been binned with a 50-s moving average function. The dashed lines show the mean of each observation.

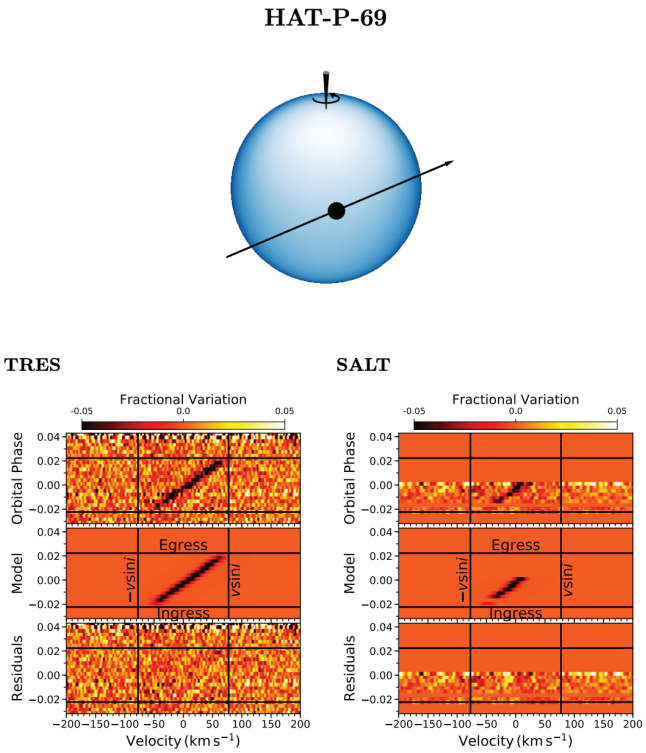
Paice, J. A., et al, 2019/09, MNRAS 488, 512:
Puzzling blue dips in the black hole candidate Swift J1357.2 - 0933, from ULTRACAM, SALT, ATCA, Swift, and NuSTAR

SALT's HRS investigates hot Jupiters

The properties of planetary systems are intimately linked to the stars they orbit. In particular hot Jupiters, close-in giant planets with periods less than 10 days, are test beds for nearly all of the techniques to measure the properties of exoplanetary systems. They are extreme examples of planetary migration, thought to have formed beyond the ice line and migrated to their present-day locations via interactions with the protoplanetary gas disc or via dynamical interactions with nearby planets or stars, followed by tidal migration.

HAT-P-69b is a hot Jupiter around an A star that was discovered by the HATNet survey and re-identified by NASA's TESS mission. George Zhou from the CfA (Harvard & Smithsonian) and his colleagues used SALT and other telescopes to map the spectroscopic transit of HAT-P-69b. When the planet transits its host star, it will successively block different parts of the rotating stellar disc, thereby inducing a sequential distortion to the rotationally broadened spectral lines of the star. For sufficiently rapidly rotating stars, one can spectroscopically resolve the rotationally-broadened line profile, and measure this line profile distortion directly via the Doppler tomographic technique. At the same time one can measure the orbital obliquity, that is, the angle between the stellar spin axis and the orbit normal of a planet, which is a key tracer of dynamical migration histories.

This measurement is part of a larger effort by the authors to confirm and characterise a series of hot Jupiters around intermediate-mass stars from TESS. By mapping the obliquities of these planets, the authors hope to infer the migration mechanisms that govern the observed demographic of hot Jupiters. As a result, they found a net hot-Jupiter occurrence rate of 0.41 ± 0.10% for their sample of AFG-type stars, consistent with the rate measured by Kepler for FGK-type stars. The authors conclude that they cannot discern any statistically significant trend in the occurrence of hot Jupiters with stellar mass.



Doppler transits of HAT-P-69b. Each Doppler map shows the intensity of the line profile as a function of both velocity (relative to the line center) and orbital phase. The ingress and egress phases are marked with horizontal lines. The top segments show the data from all of the observed transits, averaged into phase bins of size 0.003. The middle panels show the best-fitting model, and the lower panels show the residuals. Top: diagrammatic representation of the transit geometry of the system to scale; the gravity-darkening effect is exaggerated. Left: TRES (Tillinghast Reflector Echelle Spectrograph) transit observations. Right: partial SALT transit observations. Phases at which no data were obtained are colored in plain orange.

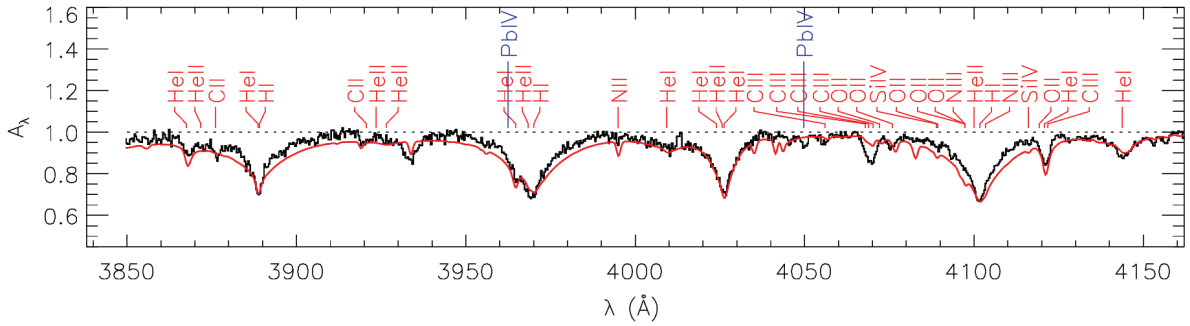
Zhou, G., et al, 2019/10, AJ 158, 141: Two New HATNet Hot Jupiters around A Stars and the First Glimpse at the Occurrence Rate of Hot Jupiters from TESS

SALT identifies a new lead-rich intermediate helium subdwarf

Lying somewhere between young main-sequence stars and old white dwarfs, hot subdwarfs are blue stars with about half the mass, a tenth the diameter and ten times the brightness of the Sun. They generally have surfaces which are either extremely hydrogen-rich or helium-rich. The former are probably due to chemical diffusion in the stellar atmosphere which encourages the heavier helium to sink. The latter are probably due to previous evolution, possibly the merger of two white dwarfs, which has led to the destruction of hydrogen. In between lies a small group of stars with intermediate helium abundances — that is, between 20% and 80% helium. In recent years, many of these have been discovered to show remarkable overabundances of certain iron-group and/or trans-iron elements, including zirconium and lead. The frequency with which these stars occur, the range of surface properties, and the reason for their extraordinary surface characteristics represent significant questions for subdwarf astronomy.

Over the past three years, Simon Jeffery (Armagh Observatory & Planetarium) and Brent Miszalski (SALT/SAAO) have been conducting a medium- and high-resolution spectroscopic survey of southern hot subdwarfs with SALT. They have discovered many unusual stars, of which EC 22536–5304 was the first SALT 'heavy-metal' subdwarf. SALT spectra show strong absorption lines of triply ionised lead. The HRS spectrum and a follow-up SALT/RSS spectrum show EC 22536–5304 to have surface properties (temperature, gravity, helium/hydrogen ratio) similar to other heavy-metal subdwarfs. With lead in the star's atmosphere being nearly 100,000 times more abundant than in the Sun, EC 22536–5304 is the most lead-rich intermediate helium subdwarf discovered so far. The atmosphere is moderately rich in carbon and oxygen, with the abundances of both exceeding that of nitrogen.

Analyses of EC 22536–5304 and other heavy-metal subdwarfs with SALT and other telescopes are ongoing. These aim to understand physical processes such as atomic diffusion currently at work in the stellar atmosphere, as well as the star's history which led to the reduced hydrogen abundance.



Part of the SALT/RSS spectrum of EC 22536–5304 (black) showing the locations of two lines of triply ionised lead. The line at 4049Å is clearly seen; neither Pb IV line is present in the model used (red). Other prominent lines are also labelled.

Jeffery, C. S. & Miszalski, B., 2019/10, MNRAS 489, 1481: EC 22536-5304: SALT identifies a new lead-rich intermediate helium subdwarf

SALT discovers a periodic, outflowing and very hot wind from close to a black hole

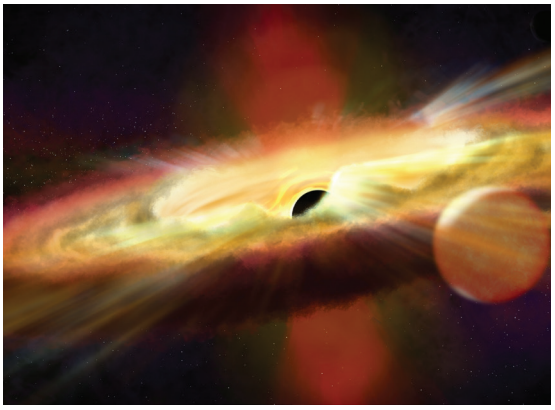
X-ray transients recur erratically on timescales of years to decades, and all consist of short-period binaries (orbiting each other every few hours to about a day) in which a low-mass star, not that dissimilar from our Sun, transfers material into a disc surrounding a compact object, which can be a white dwarf, neutron star or black hole. Massive X-ray outbursts then occur when material in the disc becomes hot and unstable, causing it to accrete onto the compact object, releasing copious amounts of energy, particularly at X-ray wavelengths. In the case of Swift J1357.2–0933, discovered as an X-ray transient by the Swift X-ray/gamma-ray satellite in 2011, the black hole compact object is at least 6 times more massive than our Sun.

Swift J1357.2–0933 is a really unusual object since its optical brightness displayed periodic dips in its output, and the period of these dips slowly changed from ~2 mins to ~10 mins as the 2011 outburst evolved. Indeed, such strange behaviour has never been seen in any other object. The orbital period is known to be 2.8 hours, which means that the cause of these dips had to be located somewhere in the inner accretion disc, close to the black hole. The cause of these remarkable fast dips has been a hot topic of scientific debate ever since their discovery. Phil Charles from the University of Southampton and his colleagues became very excited when a second outburst of this object occured in mid-2017, presenting an opportunity to study this strange behaviour in greater detail. SALT was ideal for this study as the key to getting the answer was to obtain optical spectra on the timescale of these dips, essentially studying how their colour changed with time, yet the object was relatively faint (16th magnitude) and the dip period short (~500 seconds when the authors observed it), so it required a very large telescope.

The results were stunning. The spectra showed ionised helium in absorption, which had never been seen in such systems before, indicating it must be both dense and hot (around 40,000 K). More remarkably, the spectral features were blue-shifted, implying an outflowing, very hot, very dense wind with speeds of about 600 km/s. But what really astonished Charles and his team was the discovery that these spectral features varied with the optical dips in the light-curve. They have interpreted this quite unique property as due to a warp or ripple in the inner accretion disc (at just 1/10 of its radius, very close to the black hole) that orbits the black hole on the dipping timescale.

What is driving this matter away from the black hole? It is almost certainly the radiation pressure of the intense X-rays generated close to the black hole. But it has to be much more luminous than we can see directly, and that requires us to be observing the binary almost edge-on to the disc, as shown in the schematic figure. That means we only see X-rays scattered into our line-of-sight, the true brightness being much greater. Interestingly there are no eclipses seen in either the optical or X-ray as might be expected, but this is explained by the companion star being very small, and constantly in the shadow of the disc. This inference comes from detailed theoretical modelling of winds being blown off accretion discs that was undertaken by one of the team, James Matthews at the University of Oxford, using supercomputer calculations.

This object has remarkable properties amongst an already interesting group of objects that have much to teach us about the end-points of stellar evolution and the formation of compact objects. A couple of dozen black hole systems in our Galaxy are already known, with masses in the 5 – 15 solar mass range, but the one at our Galactic Centre is around 4 million solar masses. They all grow by the accretion of matter, but a substantial fraction of the accreting material is literally blown away. When that happens from the supermassive black holes at the centres of galaxies, those powerful winds and jets have a huge impact on the rest of the galaxy. These short-period binary versions are a perfect way to study this physics in action.



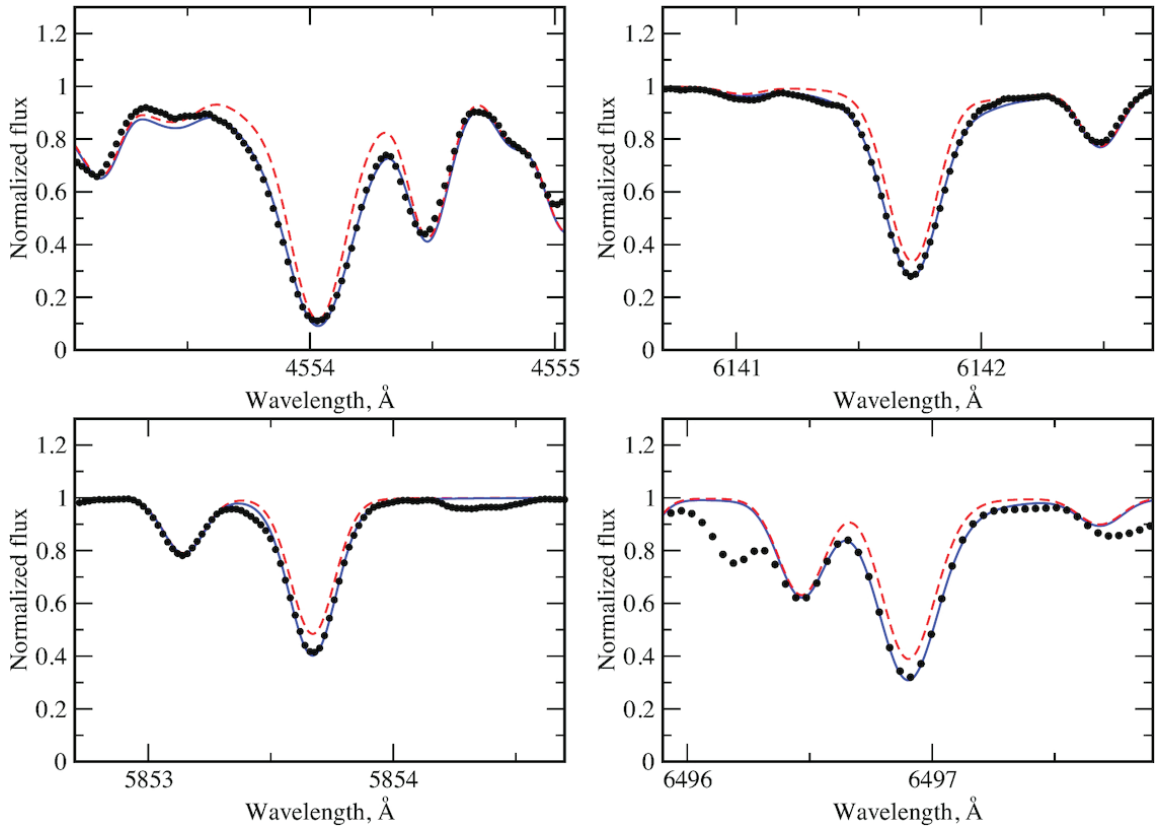
An artist's impression of Swift J1357.2–0933 showing a very hot, dense outflowing wind of material (ionised hydrogen and helium) from close to a black hole. Remarkably, the hot wind comes and goes with a period of around 500 seconds, behaviour that has never been seen before! -- Credit: John Paice (U Southampton/IUCAA)

Charles, P., et al. 2019/10, MNRAS Letters 489, 47: Hot, dense He II outflows during the 2017 outburst of the X-ray transient Swift J1357.2-0933

A mild barium star surrounded by the ejecta of a very late thermal pulse

While searching for rare types of massive stars through the detection of their infrared (IR) circumstellar shells, Vasilii Gvaramadze (Sternberg Astronomical Institute, Moscow) with Alexei Kniazev (SAAO/SALT) and their colleagues discovered a curious spiral mid-IR nebula using data from the WISE survey. Follow-up optical spectroscopy with SALT/HRS showed that the star associated with the nebula, TYC 8606-2025-1, is a G8 III mild barium star. Spectral analysis of TYC 8606-2025-1 along with the Gaia DR2 data allowed them to derive the luminosity of this star of $\log(L/L_{sol}) \approx 2$ and its initial mass of $\approx 3\ M_{sol}$. Moreover, an analysis of their own and archival échelle spectroscopic data has revealed radial velocity variability in TYC 8606-2025-1, meaning that this star is in a binary system and that its surface is polluted with barium (and other s-process elements) as a result of wind accretion from the more evolved companion star (now a white dwarf).

The authors did not find an optical counterpart to the spiral nebula in the available sky surveys in spite of the small distance and low reddening of the star, nor did they detect nebular lines in the long-slit RSS spectrum of the star. This non-detection was interpreted as an indication that the nebula is composed of hydrogen-poor material shed by the companion (primary) star after the very late thermal pulse (VLTP), and that metals in this material are at least triply ionised and therefore do not form nebular lines at optical wavelengths. The very likely binary status of TYC 8606-2025-1 implies that the formation of the spiral nebula around this star was induced by the orbital motion of the mass-losing post-VLTP star around the windless G-type star. From the shape and linear size of the nebula it was inferred that the nebula was formed during approximately one orbital period of ~100 yr, which is of the same order of magnitude as the duration of the post-VLTP phase.



Ba II lines of TYC 8606-2025-1. The observed spectra (black dots) are compared with synthetic NLTE spectra calculated from the derived atmospheric parameters for the solar abundances (dashed red line) and the final estimated abundances (solid blue line). The solar Ba abundance is not a good match to the observed spectrum, indicating that barium is overabundant.

Gvaramadze, V.V., et al., 2019/11, MNRAS 489, 5136: TYC 8606-2025-1: a mild barium star surrounded by the ejecta of a very late thermal pulse

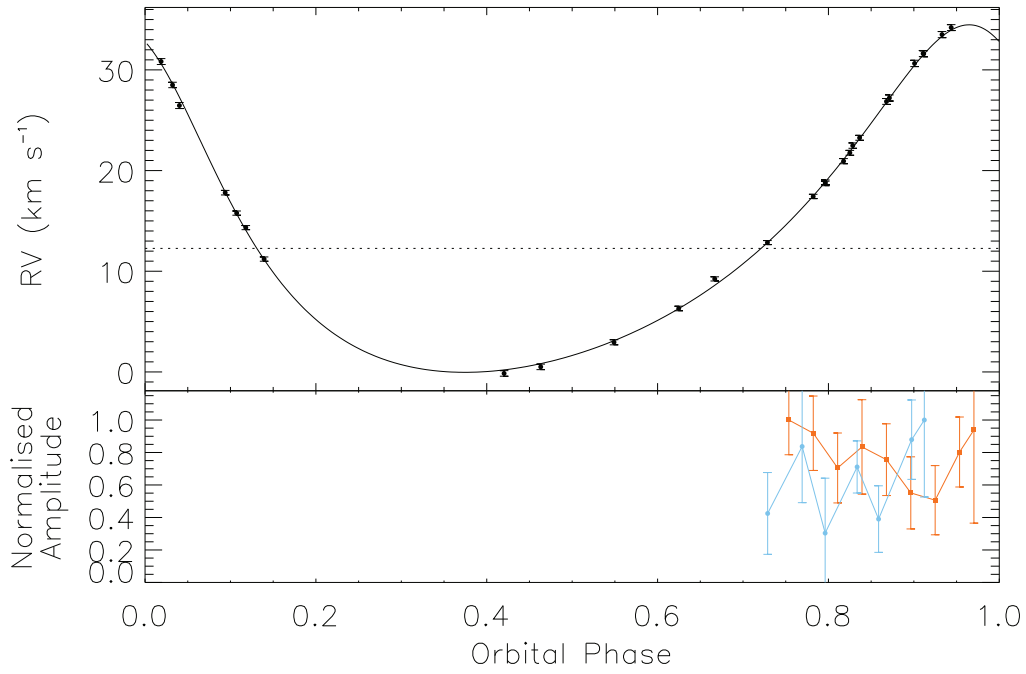
SALT observes the only known roAp star in a spectroscopic binary

A rare subclass of the peculiar A (Ap) stars are the rapidly oscillating (roAp) stars which were discovered at SAAO in 1978. They are chemically peculiar stars with kiloGauss-strength global magnetic fields. In the presence of such a magnetic field, chemical elements become stratified in the atmosphere, due to the suppression of convection leading to the presence of stable spots of predominantly rare-earth elements in the stellar atmosphere. These spots enable the determination of the stellar rotation period which can be anywhere between half a day and centuries.

In a very small number of Ap stars, rapid pulsations have been discovered. It is thought that these pulsations are driven by the κ-mechanism operating in the H1 ionisation zone, though in some cases pulsations driven through turbulent pressure is also a viable solution. The pulsation axis in the roAp stars is inclined to the rotation axis and closely aligned to the magnetic one, leading to oblique pulsation. In 1982, Kurtz formulated the oblique pulsator model to describe the roAp star pulsations. The unique way in which these stars pulsate allow for the determination of the mode geometry, as is otherwise only possible in the Sun, which is uniquely resolved.

Daniel Holdsworth from the University of Central Lancashire and his colleagues combined data from NASA's TESS mission, SAAO photometry obtained with SHOC on the 1.0-m telescope, and 27 high-resolution spectra obtained with HRS on SALT. For their study, they selected the only roAp star known to be in a spectroscopic binary. The HRS data were used to determine more precise orbital parameters of the system and to provide constraints on the secondary star. The SALT data were obtained simultaneously with the SAAO and TESS photometry, allowing the team to investigate whether the pulsation in the Ap star is influenced by its binary companion.

The authors found no significant correlation with amplitude and orbital phase, implying that the companion does not have an effect on the pulsation of this roAp star. Though the orbit is well sampled with the radial velocity (RV) measurements, additional photometric data around orbital phase 0.2 are desirable to fully investigate the pulsation amplitude–orbital phase question. It is also important to find more roAp stars in close binaries to characterise how binarity may affect the detection of roAp pulsations.



Top: phased fit of the binary model to the RV measurements. Bottom: normalised (to the respective maximum value) photometric amplitudes of the pulsation mode averaged over the rotation period. Blue circles represent the SAAO results and orange squares the TESS results. The zero-point for the phases is chosen to be the time of periastron passage.

Holdsworth, D.L., Saio, H., Kurtz, D.W., 2019/11, MNRAS 489, 4063: HD 42659:
the only known roAp star in a spectroscopic binary observed with B photometry, TESS, and SALT


ONGOING RESEARCH
SCIENCE
HIGHLIGHTS

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.

Currently, there are two active **Large Science Proposal** programmes:

Observing the Transient Universe 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. The programme started in the second semester of 2016 and was renewed to last to the first semester of 2021. The international team now comprises more than 50 Co–Is, and telescope time is being charged to five different partners (RSA, UKSC, POL, IUCAA and UW). Eighteen South African graduate students have been associated with this programme to date, with four completed and seven current PhD projects, as well as two completed and five current MSc projects. At least seven overseas-based graduate students have also benefited from the programme. Object classes observed in 2019 include LMXBs X-ray transient/black hole or neutron star binaries (21.6% of the time), nova optical/X-ray (20.0%), AGN gamma-ray flares (14.4%), Gaia/ASASSN/OGLE/ATLAS/Skymapper/Spitzer optical/IR, (10.7%), Supernovae optical (9.0%), CV optical/X-ray (8.8%), HMXBs X-ray (7.5%), MeerKAT radio (3.8%), others X-ray (2.6%), and GRBs (1.7%). Remarkable highlights of the last year include the discovery of the first MeerKAT transient (led by PhD student Laura Driessen) and of hot, dense wind outflows from an X-ray transient and candidate black hole binary, which resulted in two 2019 papers (led by Phil Charles and John Paice from U Southampton). In addition, another neutron star/black hole merger (S190814bv) has been discovered by LIGO and SALT was involved with the follow-up observations of potential optical counterparts. By the end of 2019, 1970 kiloseconds of observing time have been charged to the participating SALT partners, with 564 kiloseconds spent in the 2019 calendar year. The scientific progress, counted as published refereed papers, is even doubled: eleven publications in 2019, as compared to six in 2018 (bringing the total count up to 28), with many more publications in press or in preparation. Data from the project are also regularly presented at conferences and in Astronomer Telegrams.

BEAMS (Brightest cluster galaxy evolution with ACT, MeerKAT, and SALT), led by Matt Hilton from UKZN, started in 2019–1 and will run for four semesters. Brightest cluster galaxies (BCGs) are the most massive galaxies in the Universe and are found in special environments: the centres of galaxy clusters, which are in turn the most massive gravitationally bound structures in the Universe. In fact, clusters are so massive that they have 'atmospheres' of hot (10 – 100 million Kelvin) gas, which are detectable at X-ray and millimetre wavelengths. The BEAMS project aims to observe around 150 BCGs in galaxy clusters detected by the Atacama Cosmology Telescope (ACT) using the Sunyaev–Zel'dovich (SZ) effect. The target clusters cover the redshift range $0.3 < z < 0.7$, which corresponds to a 3.4 Gyr time period. BEAMS will measure the growth of BCGs over time through cannibalism of their neighbours, and the evolution of their stellar populations. BEAMS will also study the evolution of their star formation activity, and the impact of the supermassive black holes that they host on the surrounding cluster environment. This requires the combination of ACT and SALT data together with MeerKAT radio observations. BEAMS has got off to a good start, and, at the end of 2019, has observed 54 clusters out of the goal of 150. The BEAMS project is a collaboration between RSA (UKZN, SAAO, NWU), IUCAA, RU, and UW. South African students are welcome to work on the project.

In the two 2019 semesters, a total of 27 **Multi-Semester proposals** have been approved by the partner TACs, which is about the same as in 2018. Twelve of these proposals were carried over from 2018, and one from 2017 (*Galaxy pairs in the Hubble Frontier Fields clusters*, led by SALT Astronomer Rosalind Skelton). As in 2018, there is an approximately even split between extragalactic and Galactic astronomy topics, plus one project on exoplanets and their hosts and one project on probing Dark Energy. Two projects support each one of MeerKAT's Key Science Proposals (LADUMA and the Fornax galaxy cluster survey), and one probes the highest energy sources in the TeV range.

Since the second semester of 2018, a new proposal class for the follow-up of Gravitational Wave sources is available, which resulted in five **Gravitational Wave proposals** in the first semester 2019. This new proposal class is aimed at providing a simple framework to ensure openness and fairness across the SALT community. Similar to the Director's Discretionary Time proposals, one can submit such a proposal at any time, but they offer faster turn-around times since they do not require prior approval. Though none of the five observed objects proved to be a counterpart, two of the observed transients were interesting enough to merit GCN (GRB coordination network) notifications. One was observed in October as one of two candidate counterparts, which had been detected with MASTER-SAAO; it turned out to be clearly a CV. The second case was S190930t, classified as a neutron star/black hole event. SALT followed up on a transient identified by Swift (Swift J221951–484240), which was very blue. Evolving rather slowly, it was considered worthy of another follow-up observation: it could still be a GW counterpart because this GW class might have longer evolution times. Some weak spectral features were apparent in this spectrum, and the team now believes this is likely to be a QSO showing Mg II and Hβ emission as well as possible Ca-HK absorption. The object continues to be of high interest, being also a bright UV source, and the team has been recently granted time with the HST.

A number of individual projects have resulted in conference presentations or show interesting interim progress, of which we present a selection below.

Cezary Gałan from CAMK in Poland leads a programme on yellow symbiotic systems: while most symbiotic stars consist of a hot source (in most cases a white dwarf) and a cool M-type giant star, yellow type symbiotics involve a K-type giant star instead. Yellow symbiotic stars are useful objects for probing whether mass transfer has taken place in the past of these binary systems. Gałan and his team decided to monitor about two dozen of these systems with SALT/HRS to study changes in the radial velocities, to analyse chemical abundances in the giant components and to monitor the other symbiotic systems and related objects that experience some kinds of important and interesting manifestations of activity. Observations are still ongoing, and though most targets have orbital periods typically of order two years or longer and require more observations, first results on the outburst of the two symbiotic novae St 2-22 and V618 Sgr will be published shortly.

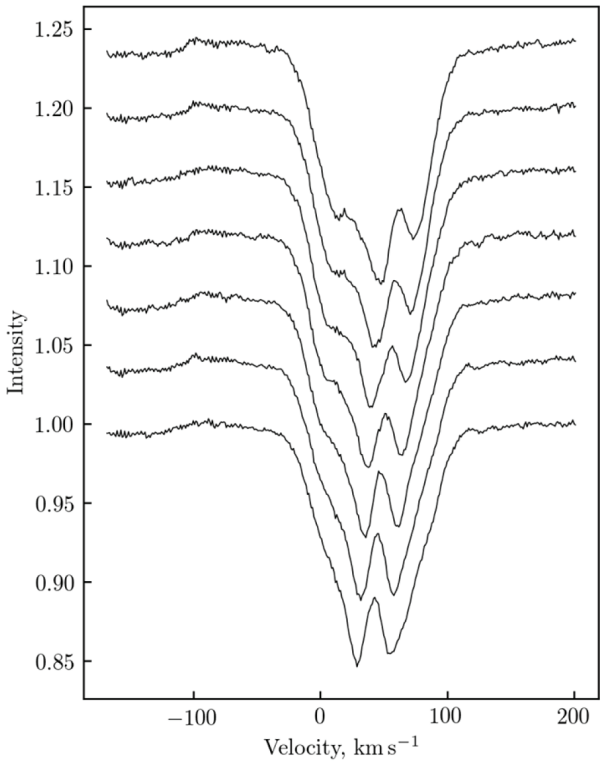
Thibault Merle from the Université Libre de Bruxelles in Belgium studies spectroscopic binaries (SBs) and has presented first results from his exciting multi-semester project at the EWASS 2019 meeting in Lyon, France, and the "Legacy of the Gaia–ESO Survey" meeting in Florence, Italy. He seems to have found a very rare hierarchical SB4 system in the Gaia–ESO Survey (GES), which is a ground-based large spectroscopic survey targeting a hundred thousand stars to obtain, among others, radial velocities. The bright A2 V star, named HD 74438, was detected with four radial velocity components in its cross-correlation function. The star belongs to the young open cluster IC 2391 and was already suspected to be a triple system since it lies 0.9 mag above the main-sequence. The GES spectra have revealed the physical nature of two pairs (SB2s) but the time coverage was insufficient to derive the orbital parameters. On-going follow-up observations of this star with SALT/HRS and MJUO/HERCULES allowed Thibault to derive an orbital solution of the fainter SB2 (P = 4.4 d, e = 0.16). The orbital elements of the brighter SB2 are more difficult to assess, possibly because of the interaction with the fainter SB2. A preliminary solution gives P = 27 d and e = 0.4. Long-term variation seems to show that the two SB2 systems are gravitationally bound.

Ewa Niemczura from the Wrocław University, Poland, and **Richard Monier** from the Observatoire de Meudon, France, are looking for new chemically peculiar stars (CPs) among southern slowly rotating late B-type stars. CPs usually are slow rotators, i.e., their projected equatorial rotational velocities ($v \sin(i)$) are less than 70 km/s. These stars represent an ideal laboratory to study a wide variety of physical processes that are at work in most stellar types, for example, radiation driven diffusion, differential gravitational settling, and magnetic fields. They have characteristic surface abundance patterns, strength and structure of the magnetic field, rotation, and multiplicity. The team's proposed strategy is to observe all southern late B-type stars with $v \sin(i) < 70$ km/s that have no archival spectra available. High-resolution, high signal-to-noise spectra covering a large wavelength interval are necessary to properly and reliably derive elemental abundances for these stars. Observations started in mid-2019 and 41 out of nearly 60 stars had been observed by the end of 2019. A publication is planned for a selection of five of the observed stars, where the team has analysed abundances for about 40 different chemical elements. In addition, they have found what appears to be two chemically peculiar HgMn stars — finding more of these will be the aim of a future proposal.

Pavana Muralimohan from the Indian Institute of Astrophysics (IIA) together with G.C. Anupama (IIA) and Ranjan Gupta (IUCAA) have obtained a high-resolution SALT/HRS spectrum of the nova ASASSN-18fv. They find that emission line profiles are structured with multiple peaks and are boxy. The velocity profiles of N III, He II, Hβ, He I were modelled to obtain the morpho-kinematic geometrical structures of the nova ejecta. The geometry of this nova ejecta is found to be asymmetric bipolar with equatorial rings.

Alexandra Wołowska from the Toruń Centre for Astronomy in Poland and her team study newly born radio AGNs that became radio loud only a few years ago. They have obtained SALT/RSS spectroscopy of three so-called changing-look AGNs that also have SDSS spectra from before transitioning into radio-loud sources. The comparison will help them to investigate how the ignition of radio activity influences their optical spectra.

Chris Engelbrecht (UJ, South Africa) & **David Mkrtichian** (NARIT, Thailand) are working on a project on asteroseismology of close binary systems with mass transfer, focusing on the spectroscopic search for and study of non-radial pulsations and orbits of southern Algol-type binary systems with mass-accreting pulsating components (oEA stars). These stars are semi-detached eclipsing Algol-type stars with mass transfer where the A- or F-type mass-accreting primaries lie in the instability strip of the δ Scuti (δ Sct) stars and show δ Sct-like pulsations. The unique property of oEA stars is the co-existence of oscillations with accretion. Non-stationary accretion keeps them in thermal imbalance and influences their pulsation properties and their evolution along the main sequence. Thus, in oEA stars one can simultaneously study the relationship between tidal interaction, mass transfer and the excitation of non-radial oscillations. During 2018, the team surveyed 12 Algol-type systems and got spectroscopic time-series (consisting of 6 – 30 spectra) sampling full orbital periods. From these, they discovered high-degree (> 4) non-radial pulsation (NRP) modes from the line-profile variations running in the direction of rotation. This is a very typical picture of the excitation of low- and high-degree non-radial modes in rapidly-rotating oEA stars. These high-degree NRPs have been discovered in AS Eri, WY Cet, VY Hya, GQ TrA, BD Vir, and UW Vir. A more detailed analysis of spectroscopic material for observed targets is in progress. For the 2019/2020 season, the team extended the project to oEA stars newly discovered by them from TESS light curves and obtained spectra sampling some orbital phases for the following targets: SU For, KP Eri, IQ CMa, RX Pic.



The time-series of line profiles of the primary components of VY Hya showing line profile variations due to high-degree pulsations. The blue-to-red running features are caused by prograde non-radial modes. The time axis is from bottom to top.


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 ongoing student projects or thesis submissions are presented here. Projects with publications in 2019 can be found in the research section.

Rutgers University has four students working with SALT data: PhD student **Yssavo Camacho–Neves** is working on SALT spectroscopy of SN 2014dt along with other type Iax supernovae. PhD student **Kyle Dettman** uses SALT spectroscopy of type Ia supernovae as part of the Foundation Supernova Survey. PhD student **Lindsey Kwok** is analysing SALT spectroscopy of SN 2014ad and other supernovae. Undergraduate student **Youssef Eweis** has worked on a SALT spectroscopy pipeline for the astronomy group at Rutgers.

Dartmouth College undergraduate **Joshua Perlmutter** is using SALT/RSS spectroscopy of low surface brightness galaxies for his honours thesis project, aiming to obtain an estimate for the luminosity function of these systems.

PhD student **Laura Rogers** from the University of Cambridge, USA, in collaboration with Mike Shara (AMNH, USA) uses SALT/HRS to characterise white dwarfs that are heavily "polluted with metals, probably via accretion of asteroids and dust.

Munira Hoosain from SAAO is using SALT for her MSc project which is part of the LADUMA (Looking at the Distant Universe with the MeerKAT Array) survey with MeerKAT. She uses galaxy positions and redshifts to map Cosmic Web filaments in the LADUMA field and wants to study the effect of filaments on galaxy evolution. To improve the spectroscopic completeness in the LADUMA field, Munira uses SALT/MOS, which will also be useful for future LADUMA science.

Kelebogile Bonokwane from SAAO is an MSc student and works on the monitoring of planetary nebula central stars, using SALT/HRS spectra. She determined radial velocities (RVs) of three objects (Hen3–1333, Hen2–113 and Hen2–47) using two methods: (a) through cross-correlation using the IRAF package RVSAO and the task `xcsao`, and (b) conducting Gaussian fitting of individual key emission lines with the Lomb–Scargle fitting technique using python. The time series of the RVs will help her to understand the behaviour of the objects and determine possible central star binarity.

While galaxy evolution is usually studied close to galaxy centres, it is governed by phenomena that extend far beyond the reaches of its stars, into the region known as the circumgalactic medium (CGM). The CGM is the place where fresh gas is accreted to fuel future star formation, and where galactic outflows powered by supernovae from recently formed stars escape and mix with the infalling gas. University of Wisconsin–Madison PhD student **Ben Rosenwasser** studies the enrichment levels of gas both in a galaxy's CGM and interstellar medium (ISM) to map how enriched gas travels through the CGM and mixes with inflowing, unenriched gas. While the CGM measurements come from space-based UV absorption spectroscopy, Ben uses SALT's MOS mode of the RSS to identify the galaxies responsible for launching the enriched CGM gas, and, if possible, to measure the galaxy's metallicity using strong emission lines. His CGM absorber/galaxy pairs will constitute the most direct way to measure the propagation of enriched gas in the outer haloes of galaxies.

Three undergraduate students at the University of Wisconsin–Madison (**Jalyn Krause, Lauren Laufman, Eowyn Yanyang Liu**) were involved in a project using SALT long-slit spectra to study ionised gas in the dusty early-type galaxy Zw049.058.

Krystian Iłkiewicz is a 5th year PhD student at CAMK, Poland, working under the supervision of Joanna Mikołajewska on evolved binary stars. His focus is the search for new symbiotic stars in the Magellanic Clouds, including SALT spectroscopy of promising candidates. Also from CAMK, **Daniel Pienkowski** is a 2nd year PhD student studying chemical abundances of symbiotic giants using SALT/HRS spectra under Cezary Gałan and Joanna Mikołajewska.

Perfect circles: A study of the scattering regions of Wolf–Rayet binary stars

Stella Yoos is an undergraduate student at the University of Denver with a strong interest in computational physics. For her project she uses time-dependent spectropolarimetric observations from SALT/RSS to construct new continuum polarisation curves for two Wolf–Rayet (WR) binary systems: WR 42 and WR 79. After subtracting interstellar polarisation estimates from the data for each binary, she fitted a theoretical model to each intrinsic polarisation curve, and from these fits derived system parameters including orbital inclination and distribution of scattering material. She found that the model did not account for all polarisation variations, which suggests that both systems contain ionised gas outside the orbital plane. Further analysis using RSS spectropolarimetry will pinpoint this additional material, which contains clues to the mass-loss and mass-transfer processes occurring in WR+O binaries and will help illuminate their roles as progenitors of supernovae and gamma-ray bursts. The results are presented in the (locally refereed) DU Undergraduate Research Journal.

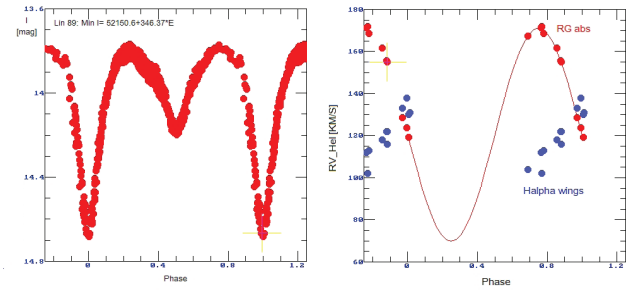
Stella Yoos, undergraduate student, University of Denver, USA

Lin 89 – an extreme β Lyr-type star

In 2019, Mradumay Sadh, an undergraduate student from the Sardar Vallabhbhai National Institute of Technology (SVNIT) in Surat, India, worked as an intern at the Nicolaus Copernicus Astronomical Centre (CAMK), Poland, under the supervision of Joanna Mikołajewska. His MSc thesis is based on the analysis of SALT/HRS spectra of Lin 89, an emission-line star in the SMC, combined with archival OGLE photometry.

Lin 89 is a very poorly studied emission-line star in the SMC that has attracted the team's attention as a possible symbiotic star. Based on OGLE II light curves, it was first classified as an ellipsoidal variable with an orbital period of 346 days. Subsequently, based on OGLE III and IV light curves, it was misclassified as a pulsating giant with a period of 173 days. Lately, it has been suggested that Lin 89 may be a Be or Ge star, based on an unpublished, low-resolution optical spectrum.

Mikołajewska and her team obtained and classified the first high-resolution spectra of Lin 89 using SALT/HRS, which Mradumay analysed in detail for his thesis. He found strong hydrogen Balmer lines with full widths up to about 1000 km/s and was able to establish the presence of a cool K-type giant in the spectra. The radial velocities of the red giant vary in antiphase with the width of the emission wings. Lin 89 has thus turned out to be an extreme Algol/β Lyr system including a Roche-lobe-filling K-type giant donor with strong hydrogen emission lines. The giant is eclipsed by a geometrically thick disc, which totally obscures the more massive, primary companion. Furthermore, no absorption lines could be detected from this component. The large amplitude of the radial velocity curves indicates that the system is a massive one, and the analysis of the light curves, together with radial velocity data, has resulted in preliminary mass estimates of ~ 3 M_{sol} for the K-type giant and ~ 8 M_{sol} for the primary.

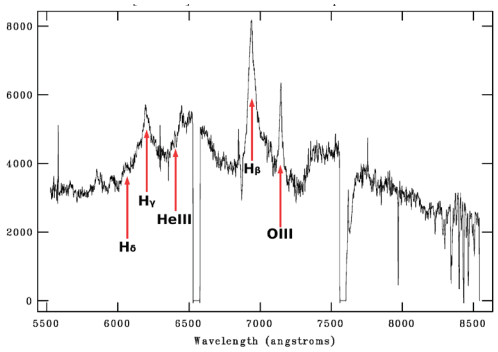


OGLE I light curves (left) and radial velocity curves for the K-type giant (right) for absorption lines as well as broad Hα emission line wings, phased with the orbital period of 346.37 days as derived from the light curve. The zero phase corresponds to the deeper minimum in the light curves when the giant is behind its invisible companion.

Mradumay Sadh, SV National Institute of Technology, India, MSc 2019

SALT multi-object spectroscopic observations of ULIRG candidates

Małgorzata Bankowicz, PhD student at the Astronomical Observatory of the Jagiellonian University, Poland, obtained SALT/MOS observations of ULIRG candidates, and presented the first results of her project at the Polish Astronomical Society Meeting in 2019. The main goal of this pilot programme of the project was to measure spectroscopic redshifts of galaxies around one of the ULIRGs from the AKARI Deep Field South (ADF-S), quasar HE 0435–5304. Małgorzata selected QSO HE 0435–5304 because of the ambiguity in its spectroscopic redshift value in the literature: z = 1.231 — mostly cited — and 0.425. She identified five strong emission lines in the SALT spectrum and was able to confirm the lower spectroscopic redshift of 0.4. In addition, the spectroscopic redshifts of the surrounding galaxies allowed her to ascertain their properties from spectral parameters and to estimate the local environment around ULIRGs.

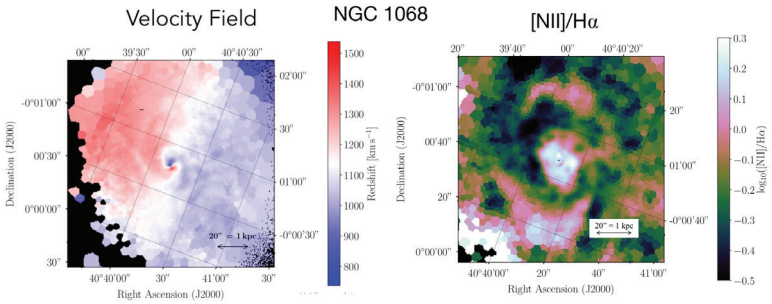


Spectrum of QSO HE0435–5304 with five identified spectral features.

Małgorzata Bankowicz, PhD student, Astronomical Observatory of the Jagiellonian University, Poland

Understanding the galactic scale effects of AGN with Fabry–Pérot spectroscopy from SALT

Active Galactic Nuclei (AGNs) are the most sustained radiator of energy in the Universe. Powered by accretion onto a supermassive black hole (SMBH) residing at a galaxy's centre, AGN have played a prominent role in understanding galaxy evolution, where SMBH fuelling and feedback processes have been proposed to influence the host on larger scales. Of particular interest are Seyfert II galaxies, characterised by their narrow emission lines, implying the high velocity gas near the SMBH is obscured. Supposing the obscuration is indeed from the nuclear region, these objects provide insight as to the fuelling process and large-scale galaxy connection. However, conventional spectroscopic techniques neglect spatial information and modern 2D Integrated Field Units (IFUs) only afford small fields of view, not suited to characterising the galactic scale effects of nearby, large solid angle, AGN hosts. However, Fabry–Pérot spectroscopy allows for large field-of-view spectrally resolved analysis of all relevant emission lines. Raphael Hviding from Dartmouth College presented in his Senior Honours thesis an analysis of nearby Seyfert II AGNs using Fabry–Pérot spectroscopy with SALT. He reduced the Fabry–Pérot data, applying an accurate wavelength calibration, and making use of multiple dithers to produce a data cube of his objects surrounding relevant emission features. He makes use of adaptive binning and nonlinear least square minimisation to characterise galaxy velocity and ionisation as a function of position. This culminates in the creation of diagnostic maps which connect the outer portions of the host galaxy to the core.



Velocity (left) and ionisation (right) maps from SALT/RSS Fabry–Pérot observations of the NGC 1068. The velocity map clearly illustrates the rotational structure of the galaxy, while the ionisation (N II /Hα) map indicates 'arcs' of high ionisation that may be the result of stochastic activity of the central AGN.

Raphael Hviding, Dartmouth College, USA, Senior Honours 2019


SALT CONFERENCE
SCIENCE
HIGHLIGHTS

SALT Mini Conference
13 – 14 November at IUCAA, Pune, INDIA

A two-day SALT Science meeting was held at the Inter–University Centre for Astronomy & Astrophysics (IUCAA) just before the SALT board meeting in Lonavala, near Pune, India. The main motivation for this meeting was to have talks on (i) the present status of and future plans for the telescope, (ii) new science coming out of SALT from different partners, including members from IUCAA, and (iii) to provide necessary exposure regarding SALT and its instruments to students and associates of IUCAA.

There were about 50 participants with about 20 representing different partner institutes from outside India. Participants from India included academic members from IUCAA, astronomers from Indian universities and some SALT users from other research institutions in India. In total there were 21 talks covering a wide range of topics, including stars and star forming regions in our Galaxy, optical and X-ray transients, galaxies at low and high redshifts, distant quasars and the intergalactic medium. In addition, there were also talks on the present status of SALT, how to optimally use SALT, and future plans for next generation instruments. The typical duration of a talk was 20 minutes, and ample time was provided for discussions. Several exciting results (already published as well as those in preparation) based on SALT observations were presented. Participants also had the opportunity to interact with their SALT Astronomers and astronomers from other partner institutions to share their experiences on how to improve the efficiency of observing programmes with SALT.

SAAO Director Petri Väisänen

IUCAA Director and host Somak Raychaudhury


OPERATIONS

A NEW SALT OPERATIONS FOCUS:
THE "NO PHOTON LEFT BEHIND!" CAMPAIGN

Following changes to the SALT management structure, the trio of the SALT Observatory Scientist, Lisa Crause, and the heads of the Technical and the Astronomy Operations group, Paul Rabe and Encarni Romero Colmenero, respectively, joined forces in August to re-launch the combined SALT Ops team. This took the form of joint presentations (by the three of them) to the Ops team members in both Cape Town and Sutherland, to establish new ground-rules and adopt a unified SALT Ops focus. The rallying cry of "No Photon Left Behind!" encompasses the goal of increasing the scientific productivity of the telescope through a campaign centred on improving:

- Telescope and instrument throughput
- Observing efficiency
- Data quality

The need for good communication, professional demeanor and a team culture that embraces learning and cooperation (which includes accountability and honest feedback) was also emphasised. The discussions following the presentations yielded suggestions as to how the team could support and develop each other by sharing their broad array of skills. The overall response has been extremely positive and the less hierarchical organisational structure is encouraging more ownership, initiative and creativity. This, in turn, yields a whole that is greater than the sum of the parts, while the parts still get to contribute their individual skills and abilities.

OPERATIONS

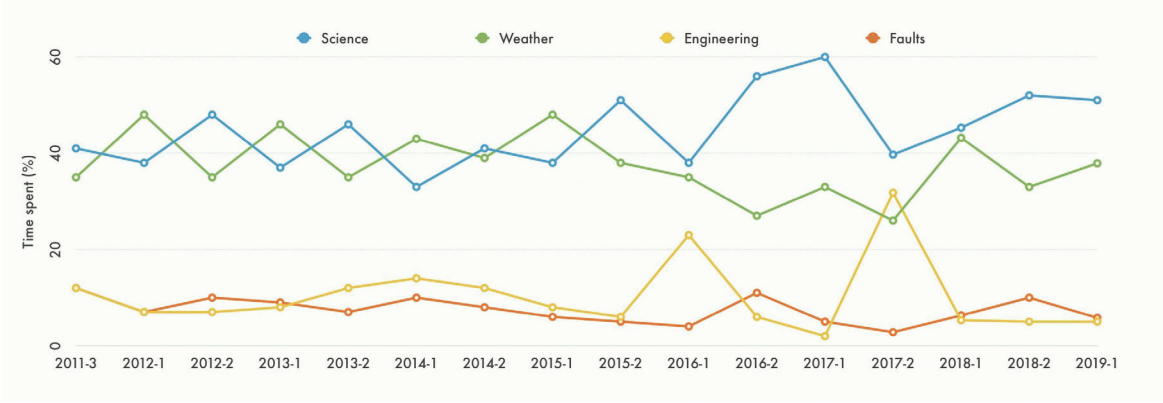
Semester statistics

The year 2019 has seen a large improvement in the time available for science as compared to the long-term average of 44%: 52% for the semester 2018-2 and 51% for 2019-1. This is due to favourable weather conditions during the year, combined with low engineering downtime.

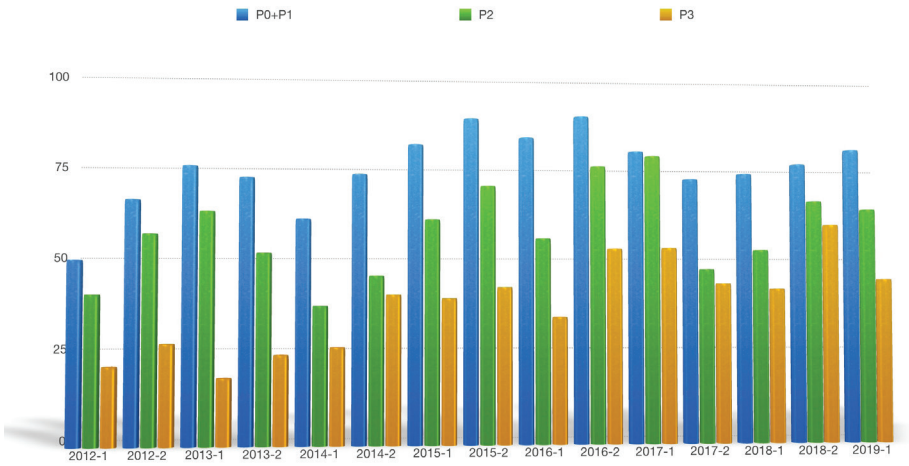
The completion levels were comparable to those of previous years, steadily improving from 71% in 2017-2 to nearly 80% in 2019-1 as the new RSS guider began living up to expectations and becoming the guider of choice for the SALT operators and astronomers. Unfortunately, a technical problem was discovered in August that affected all RSS linear spectropolarimetric observations taken during 2019, causing more technical downtime than expected. This fault was rectified in October and spectropolarimetric observations are now continuing successfully on SALT.

A significant effort was made during the 2018-2 and 2019-1 semesters to characterise the HRS high-stability (HS) mode, which led to an increase in engineering time. The results are encouraging: the HRS is capable of 3 m/s radial velocity precision when using the Iodine Cell on very bright (< 6th mag) stars, and 5 – 10 m/s for 7th and 8th mag stars. Further investigation is ongoing to establish the precision achievable when injecting ThAr light for simultaneous wavelength calibration into the HS calibration/sky fibre. The latter supports investigation into the feasibility of obtaining a laser frequency comb for the HRS. See the Instrument News section for more information.

The RSS Fabry–Pérot system went offline during 2019. The SALT Board approved the repairs of the MR and the LR etalons, together with support for this mode in the form of a 2 – 3 year SALT Postdoc position with a dedicated focus on Fabry–Pérot science and support.



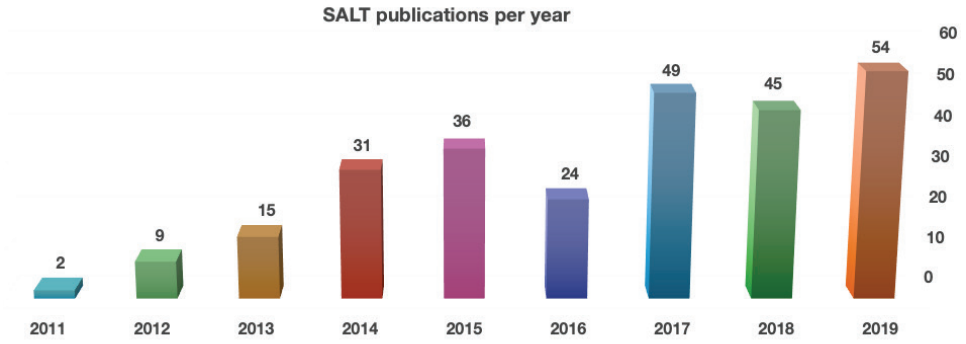
SALT time usage per semester



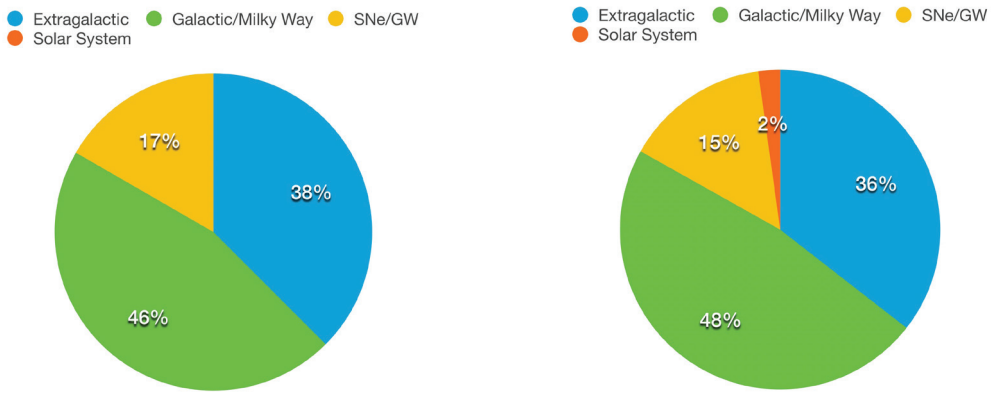
Completeness per priority in percent

Publication statistics

SALT is continuing on the publication trend expected for a telescope of its age and size, and broke the record for SALT refereed publications with 54 papers in 2019 (including two instrument papers and four generic science publications that do not refer to specific data). This brings us to 265 papers since the beginning of full science operations in 2011. As can be seen from the pie charts, Galactic astronomy papers (especially stellar ones) dominate our publications, closely followed by extragalactic astronomy, with a strong component from the supernovae and gravitational wave communities.

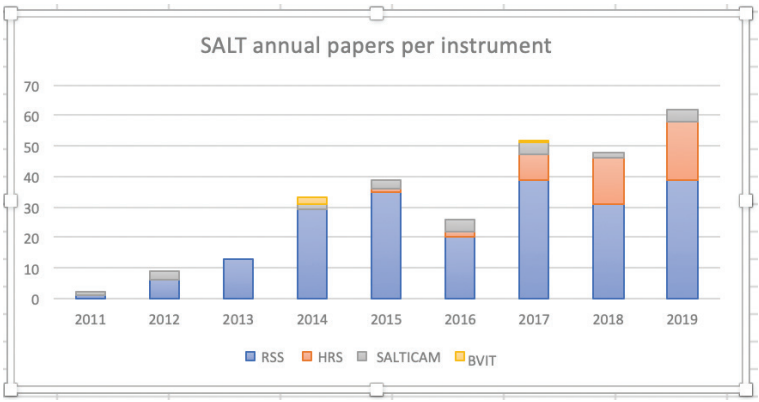


Refereed papers based on SALT science data and including instrument-related publications, from the start of science operations in 2011.



Distribution of science topics in all the SALT data papers (left) and, for comparison, in 2019 only (right).

Most of our papers to date come from RSS, which has traditionally been our main workhorse instrument, in particular its long-slit mode. However, the picture has been changing over the last few years. While RSS remains our most popular instrument during dark time and the best observing conditions, the HRS paper count is rising and it is now our main instrument for bright time and worse weather. It is also worth mentioning that although SALTICAM and BVIT are not as popular for science due to them not having autoguiders, they are both incredibly efficient in terms of publication outputs.



SALT paper count by instrument usage over the years, in percent.

User support

At the end of 2018, Astro-Ops issued a user support questionnaire to the SALT astronomical community. The feedback from the community was very positive in terms of our support and planning tools, while useful suggestions for improvement were made and are currently being addressed by the team. These include easier installation of the PySALT data reduction tools (this has now been achieved via Docker), updated documentation, a new SALT Data Archive which is almost ready for deployment, and better support for the pipeline, for which we now have a dedicated SALT Astronomer.

Notably, only 60% of the 50 responses received were from regular SALT users. The reasons to not use SALT included bad experiences in the past and not being able to find a suitable SALT project. A number of responses highlighted the fact that the application process takes longer and is more complicated than those at other observatories. To address these issues, (potential) SALT users are encouraged to start the proposal process early, and to use the helpdesk facilities or email the SALT Ops team with queries.

Responses on the usage of the instruments indicated that SALTICAM is used mostly in normal imaging mode, for RSS the long-slit mode is used four times more often than any other mode, and the three HRS resolution modes are used equally often. Regarding communication, most SALT users have contacted the SALT team at least once per semester, 93% of which rate our support very highly. Most of the suggested improvements concerned the websites (which are sometimes out of date) and the documentation (being overly complicated, especially for first-time users). On the software side, more than 75% of the participants rated the various software tools as "very good" or "excellent". The need for a SALT data archive and SALT data reduction tools were rated as extremely important by most of the user community. Because SALT is a significantly different telescope to most others, the data reduction process is more complicated, and one of our priorities is to continuously update and improve the data reduction tools.

To help SALT users publish more papers, clearer documentation on the reduced data products is required, as well as improvement of the pipelines that generate these products. The recently appointed new SALT Astronomer will specifically deal with the pipeline and all associated tools. The newsletter and other information provided by SALT is well received, and most of the SALT users are satisfied with the current level of support and information. Finally, the SALT conferences are extremely popular and the feedback on the structure and frequency of the SALT workshops has been most helpful.

Personnel

SALT Astronomer Éric Depagne's contract expired at the end of January 2019, with Enrico Kotze joining the ranks in April. Enrico's main focus is the SALT primary data reduction pipeline, which he re-developed in Python 3, making it more modular, incorporating some data quality checks, and removing IRAF dependencies.

SALT Astronomer Brent Miszalski's contract expired at the end of December 2019. The process to fill this vacancy was initiated in October but was not quite completed by the end of the year. Similarly, the SALT postdoc position that will focus on Fabry–Pérot science and support, that was advertised in October, has not yet been filled.

We have also initiated a process of training SAAO's postdocs and allowing them to take observations with SALT. This is a win-win situation, where the postdocs get training on one of the largest telescopes in the world and gain a better understanding of SALT, its capabilities and its instrumentation, while we get a wider, more diverse team of observers. Rajeev Manick, Jessymol Thomas and Solohery Randriamampandry have all received training in this manner during the year, with Rajeev also having had two observing weeks on his own.

In January 2019, we welcomed Sifiso Myeza back to Astro-Ops, now as a full member of Christian Hettlage's Astro-Ops software team. A new NRF intern, Lonwabo Zaula, joined Christian's team for the next 2 years. Lonwabo has also been heavily engaged in activities related to SAAO's Intelligent Observatory project.


TECHNICAL OPERATIONS
OPERATIONS

Technical downtime decreased from 5,5% in semester 2018-2 to 3.5% for 2019-1, with the target being 3%. This was mainly due to the improved functioning of the RSS Guider and assorted software fixes. It was noted in August, however, that the half wave-plate was not inserting at the correct position angle, resulting in all polarimetry blocks being rejected and thus bringing the technical downtime up to 7%. This has since been fixed and is now working as intended.

The Tech Ops team has been identifying and addressing issues that affect **night time operational efficiency**. While there are large projects that will take significant re-design and development of instruments, the team has been able to clear some of the smaller issues, especially on the software side.

Ever since the demise of the interferometer a number of years ago, focusing SALT has been a manual operation. That all changed when the new RSS guider was implemented in 2018, with a pyramid wavefront sensor that provides focus information. While this applies to all RSS science observations, it still leaves SALTICAM and the other instrument bays without automatic focus control. To improve holding the focus of the telescope, an investigation was launched to improve the **open loop focus model** of the telescope. This sets the telescope in focus at the start of a track, speeds up acquisition times, and subsequently requires minimal operator intervention during tracks. The focus information from the new guider provides all the information we need to characterise the focus drift over the complete range of the tracker and under varying environmental conditions. From this focus information, a number of systematic errors were discovered. A modeling effort is currently underway to eliminate these errors. The results look promising and implementation on the telescope will happen in early 2020. The investigation also uncovered a slow drift in segment focus. To correct this, an effort was launched to manually piston the entire primary mirror array, which dramatically improved the image quality of the telescope. To prevent this from happening again, the mirror swapping process was altered slightly to include more extensive segment piston checking, and an investigation is underway to see if it is possible to improve the CCAS instrument to a point where it can measure individual segment pistons and correct them during mirror alignment.

A lot of attention has gone into improving the efficiency of the CO_2 **cleaning of the primary mirror**. This required a re-design of the nozzle, which, after a couple of iterations and tests, has now significantly decreased the cleaning time for the full array from 8 hours to 1.75 hours. A new, single supplier was also sourced, resulting in 50% savings on all gases used at SALT. The mirror segment recoating schedule is on target for the average of 1.75 mirror segments per week.

As part of our **Asset Renewal** projects, two new general air compressors were replaced with additional air receivers, installed to ensure constant and efficient air handling for the structure and the louvres. The "Instrument Air" compressors are also scheduled to be replaced, pending the final confirmation of the NIR requirements to determine the capacity needed. The SPS (Segment Positioning System) controller replacement is in its final stages of development and implementation will take place during the February 2020 shutdown.

The year has also seen a number of **software improvements**, including upgrades to the technical web interfaces, issues that concern operational efficiency at night, some problems with the Windows operating system (a conversion to Linux is in progress), and a new collaboration with other NRF facilities, iThemba Labs and the South African Radio Astronomy Observatory (SARAO), on a data transfer project. In addition, the SALT software office in Cape Town received a revamp. The carpet and blinds have been replaced and the shelves and desks were altered to increase the usable space in the office.

Personnel

At the end of November 2019, Chris Coetzee, the Head of the Technical Operations team since mid-2009, retired. In his place we welcome Paul Rabe, who has been a SALT software engineer in Sutherland for the past eight years. The resulting vacant software position will be re-advertised, together with a second position caused by the resignation of Mark Wichman. These positions are available for both Cape Town and Sutherland.

The review and prioritisation of the list of projects for asset renewal, development projects and other tasks has led to the need to appoint more staff, to ensure that we remain operational, while also enhancing our science capabilities. While the recruitment process remains a challenge for Sutherland posts, we were able to appoint a mechanical engineer who grew up in Sutherland. The board has also approved a new position for a Systems Engineer from 2020.

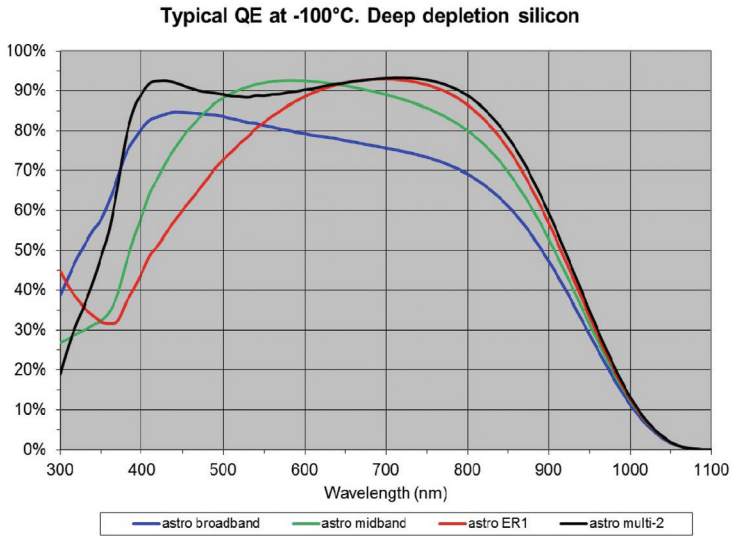
Health and safety

The SAAO flammable store was identified as a serious fire risk and is receiving attention to install a self-triggering fire hydrant system. Three safety incidents occurred at SALT during the year. A special report documented the findings of an investigation following an incident in which the dome drawbridge was damaged due to a lockout being bypassed for testing. In the second incident, contractors that were building a storm water drainage system around SALT left a shallow trench uncovered. One of the SAAO tour guides tripped and fell as a result and sustained minor bruising, but fortunately X-rays confirmed that there was no serious damage. In the third incident, an air handling unit in the electrical room sprang a leak and showered glycol onto the main UPS. This caused the UPS to burn out and take all of the telescope's critical systems down with it. The full team worked together through many long hours to temporarily restore the systems. The procurement department then managed to source a replacement, which ended up being delivered to Sutherland within just 24 hours. This was thanks to the company, for which the UPS unit was intended (Pyrotech), being kind enough to let SALT take their order, since their need was not as urgent as ours. Otherwise, we would have had to wait six weeks for a suitable replacement.


INSTRUMENT NEWS
OPERATIONS

Matthew Bershady has begun development of a new **fibre-optic lab** in the Technical Building at SAAO's Cape Town site. The lab will be furnished with state-of-the art equipment for the preparation and testing of fibre for astronomical instruments. This includes end-preparation (including polishing), lenslet-coupling, and calibration systems to measure throughput, scrambling and focal-ratio-degradation. One of the first instruments to be constructed in the lab will be an integral-field unit that fits inside a slit-mask cartridge for the RSS. The concept was developed by Michael Smith, in collaboration with Marsha Wolf, Matt Bershady and Joshua Oppor, at the University of Wisconsin–Madison. Sabyasachi Chattopadhyay will be joining Bershady in 2020 to work on this and other instrument projects for SALT and telescopes at Sutherland.

Astronomers and engineers from SALT and the SAAO Instrumentation group have been fleshing out details for the science and user requirements for a **new RSS detector system**. Following the MaxE concept change (from a separate stand-alone spectrograph to a new red channel for the RSS), the MaxE detector package will now be a near-identical copy of the RSS system that is being planned. The two projects therefore stand to benefit (both in terms of schedule and budget) from the shared development efforts and the opportunity to recycle hardware, such as the test cryostat and mechanical/electrical sample chips. The most likely choice will be a monolithic 6K x 6K device from CCD vendor e2v, employing the IUCAA Digital Sampling Array Controller (IDSAC) controller electronics and with the cryostat to be designed and built by the instrumentation team at SAAO. The new chip promises better quantum efficiency, less fringing and better gain stability compared to the current array, along with the significant benefit of not having any gaps. The estimated timescale for the delivery of the new system is of order 18 months.



Quantum efficiency curves for the various coating options available for a deep depletion 6K x 6K device from CCD vendor e2v. The "Astro Multi-2" coating (black curve) would be the most suitable for the new RSS detector, as well as for the MaxE system.

Equipping the High-Resolution Spectrograph for exoplanet science

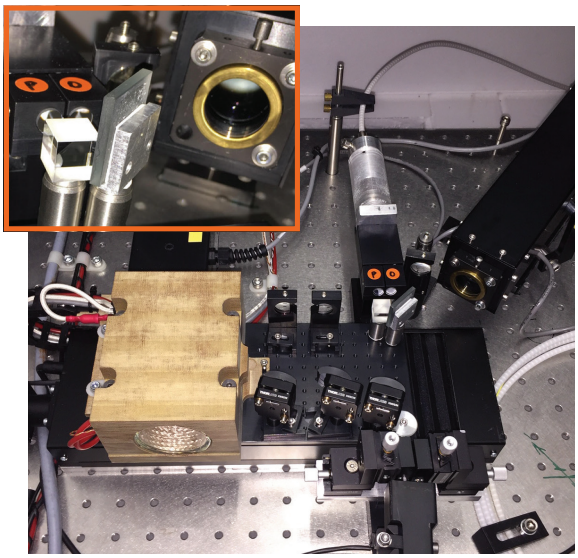
Work has been ongoing to investigate the suitability of the High-Resolution Spectrograph (HRS) for pursuing exoplanet science — see the flow chart. The spectrograph's high-stability (HS) mode has two specialised wavelength calibration options for precision radial velocity (PRV) measurements. These are known as the Iodine Cell (a gas absorption cell that superimposes a well-defined series of absorption lines onto the stellar spectrum) and the "simultaneous Thorium Argon" (ThAr) channel, whereby arc light is injected into the calibration fibre at the same time that starlight travels along the object fibre.

The new Iodine Cell that SALT obtained from Paul Butler was installed and commissioned earlier in the year. We have since established that the cell can deliver radial velocity precision at the 3 m/s level for very bright stars (5th and 6th magnitude), or at the 5 – 10 m/s level for 7th and 8th magnitude targets. The limitation is due to the overall throughput of the system. The Iodine Cell mode is the worst affected due to the dichroic split for the spectrograph's red and blue channels falling in the middle of the iodine spectral range, in addition to the combination of the 50-m long fibre cable, the fibre double-scrambler

unit, losses arising from the cell itself and the slicer optics that convert the relatively large (1.6" on the sky) HS-fibre into a narrow enough 'slit' to deliver R ~ 65k. There are options to explore in order to improve the throughput, but in the meantime the Iodine Cell setup is operational and available to observers.

The HRS's other PRV channel (using "simultaneous ThAr" arcs) is also being investigated to gauge its potential, particularly as it does not suffer all of the same losses as the Iodine Cell. The first step is to test the intrinsic stability of the instrument, for which we need to inject arc light down both the HS-mode fibres at once to see how the shifts measured in each compare. If the two fibres experience significant differential drifts (i.e., if they do not "fly in formation"), it is not worth investing further in this approach. If the stability is good (within a couple of m/s), it would serve us well to acquire a laser frequency comb to dramatically improve the HS mode's wavelength calibration system.

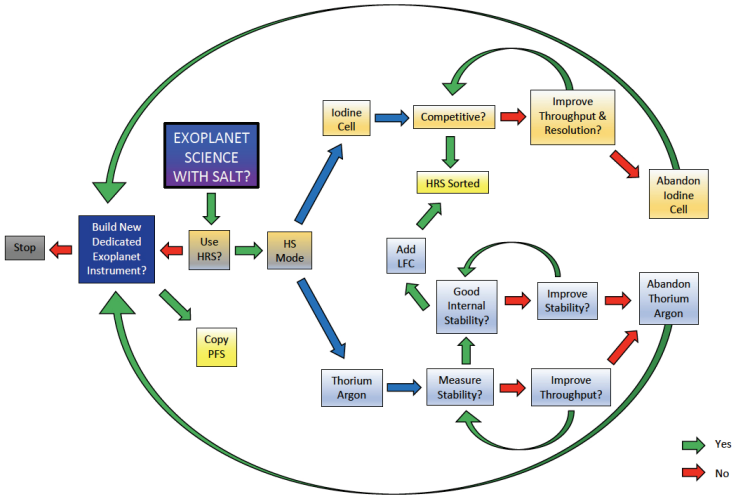
Since the ThAr lamp on the HS bench could only be fed into one or the other HS fibre at a time, we employed the ThAr lamp inside the payload (part of the telescope's calibration system) for our initial round of tests. Unfortunately, this setup could not deliver enough light to yield the required signal-to-noise, so a new optical feed was required on the HS bench. These new optics, consisting of a cube beamsplitter and a couple of fold mirrors, are shown in the figure below. The ThAr lamp on the HS bench is visible in the upper right of the figure. The arc light emerges from the brass-rimmed window and reflects off the right-hand fold mirror in the foreground, which directs it into the cube beamsplitter near the centre of the image. Half of the beam proceeds straight through the cube into the lens on the front of the P-fibre. The other half travels to the right, where it reflects off another fold mirror, sending that light into the lens on the front of the O-fibre. The single beam of ThAr light is thus split into two beams and directed into both HS fibres at once. This setup has now been used to obtain sequences of test arcs that span several-hour intervals. These data will now be analysed by simultaneous ThAr specialist Arpita Roy to characterise the stability of the HRS.



The high-stability bench showing the beige Iodine Cell housing on the left, and the black translation stage (that moves horizontally) configured to direct arc light from the ThAr lamp (top right) into both HS-mode fibres (labelled P and O in orange, see inset) for the ThAr stability tests.

The 3 m/s 'stability' measured with the Iodine Cell is different to what we are seeking with the ThAr tests. The Iodine Cell results are derived from forward-modelling each individual exposure, in which the calibration light is directly superimposed on the starlight. For the simultaneous ThAr approach, the results are dependent on the physical stability of the instrument itself, since the calibration light runs alongside the starlight, in a different fibre.

The main advantages of the ThAr system are that the calibration light spans the full wavelength range of the spectrograph (370 – 890 nm) — versus the Iodine Cell that only produces lines in the 500 – 600 nm range — and the fact that absorption within the gas cell consumes some of the starlight. If we eventually find that neither of the HRS HS options can deliver competitive exoplanet science capability, SALT would need to consider whether to pursue this field by investing in a new, dedicated instrument optimised for exoplanet work.



Flow chart describing the process of investigating the suitability of the HRS for exoplanet science. LFC = laser frequency comb and PFS = Planet Finder Spectrograph (on the 6.5-m Magellan II telescope).

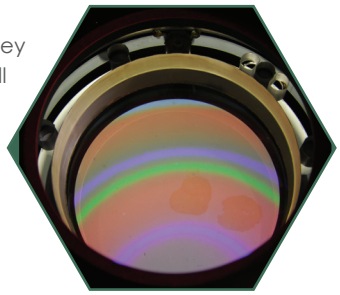
Fabry–Pérot etalon refurbishment

The RSS Fabry–Pérot system has been offline due to several problems, including degradation of the coatings and other operational issues. The FWHM of the lines were nearly double the original values, which were already broader than their design specifications.

In May, the SALT Board approved the refurbishment of the MR and the LR etalons. The associated plan includes:

- New coatings, designed to increase the spectral resolution of the etalons to their original specs and to reduce the number of regions required to calibrate them. This will simplify the calibration process and the number of scans required to cover a given wavelength range.
- New sealed housings for the etalons, which are expected to prevent the zero-points from wandering and tripping, and also to prevent future environmental degradation.
- The ability to operate the etalon controllers remotely from the control room, hence gaining the ability to automatically adjust their balance and prevent them from tripping.
- A new, sturdier mount with tip/tilt adjustments operable from the control room, to allow the adjustment of the dual etalon mode. It is hoped that the new housing will remove the need to operate the etalons at rho = 0, thus allowing PIs the flexibility to choose a suitable position angle.
- Funding for a dedicated Fabry–Pérot postdoc.

Both etalons are currently in the UK waiting to receive their new coatings. They are expected to arrive back in South Africa in the latter part of 2020. They will undergo calibration and re-commissioning in the lab in Cape Town, before being taken to the telescope for on-sky re-commissioning. If all goes to plan, the etalons could be available to the SALT astronomical community for the 2020-2 semester!



The original MR Fabry–Pérot etalon being inspected on a light-table in the lab. The two darker patches are coating damage caused by exposure to moisture.

SALT Mini-Tracker Feasibility Study Approved

SALT's spherical primary mirror array is 11-m across and has an enormous (35-degree diameter) uncorrected field of view. The prime focus corrector optics eliminate the debilitating spherical aberration over a 10-arcminute diameter field before feeding the light to the suite of instruments. But what about the rest of the ~960 deg^2 available at any given time? The extremely exciting opportunity to be explored is whether multiple mini-correctors could be made to range over the rest of the field, allowing SALT to observe a number of targets (distributed over a huge area of the sky) at once. This has remarkable potential given the deluge of transients that facilities like MeerKAT, the Large Synoptic Survey Telescope (LSST) and later the Square Kilometre Array (SKA) will uncover, the most interesting of which will require extensive spectroscopic follow-up.

This intriguing prospect was first described by Steve Crawford at the 2017 SALT conference in Poland. It raised enough interest that the former HET chief engineer, John Booth, investigated the concept and presented a paper at the 2018 SPIE conference on astronomical telescopes and instrumentation.

At the May 2019 SALT Board meeting in Wisconsin, the Board chair proposed that the mini-trackers be discussed at the next meeting, with the possibility of releasing funding to support a more detailed study. John was thus called upon to give an introductory presentation, based on his SPIE talk, at the November SALT Science conference, and then at the SALT Board meeting two days later. These two talks in India were well received and the Board approved a six-month feasibility study. John ended up giving a third mini-tracker talk to a much wider audience a few days later at SAAO in Cape Town.

We look forward to finding out more about what could turn out to be a truly revolutionary development path for SALT!

MaxE Project
PROGRESS

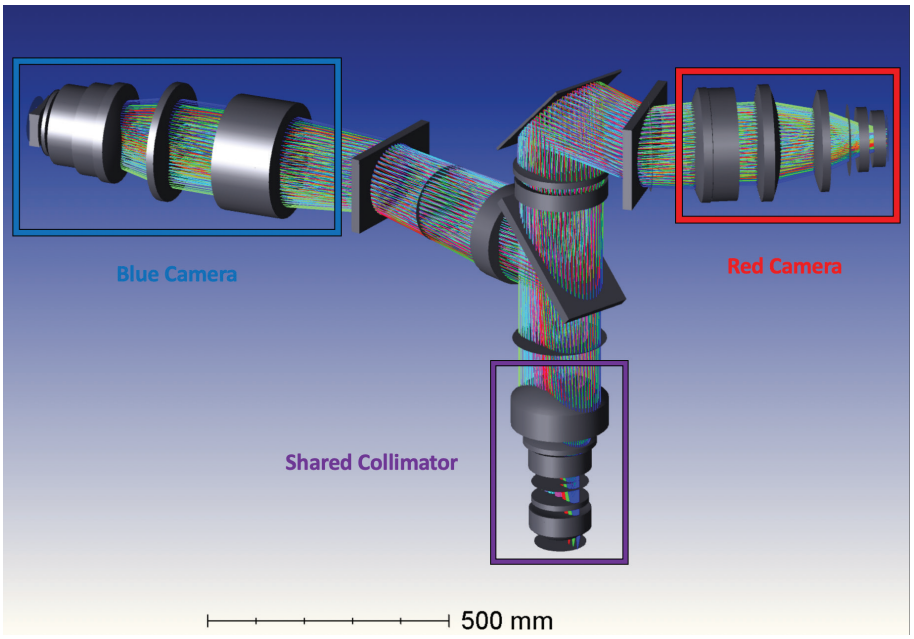
The project to build a simple, efficient, broad-band, low-resolution spectrograph, mainly for transient identification spectroscopy, has taken a new direction. The original concept for the design of MaxE was based on the spherical transmission grating spectrometer (STGS) proposed by Darragh O'Donoghue and Chris Clemens. This novel design can deliver high throughput, since the spectrograph itself in principle requires only two optics (a spherical VPH grating and a spherical relay mirror, although in this application there are also fore-optics and fibres). However, the design required a very narrow entrance aperture, leading to extreme fibre image slicing. The large number of fibres needed to sample even a point source, together with the simple optics that do not allow demagnification, would then lead to unacceptable oversampling on the detector. Furthermore, a wide wave-band is a key requirement for ID spectroscopy, which the single-band STGS design could not deliver.

Of the alternative concepts put forward and investigated, the most promising was the addition of a simultaneous red channel for the RSS. This requires a deployable dichroic/fold mirror assembly, allowing the RSS to operate as a dual-beam optical spectrograph, while maintaining all of the instrument's current functions when operated as a single channel system.

A new RSS red arm takes advantage of all the investment already made in the existing instrument, as well as planned RSS upgrades, to extend the RSS capability to better serve SALT's transient identification spectroscopy needs of the future. There are also various RSS upgrade projects lined up, such as replacing the current three-chip detector array with a monolithic 6K x 6K chip (with higher QE, better fringing performance and no chip gaps), parts of the RSS collimator are intended to be replaced and there are plans to acquire a new 700 lines/mm VPH grating.

The RSS red channel also supports exciting future developments, such as a payload upgrade that could introduce another deployable dichroic. That would allow RSS and the upcoming near-infrared (NIR) spectrograph to be fed simultaneously, yielding a 3-channel spectrograph with coverage from 360 nm to 1.7 microns in a single shot. Lastly, the RSS slit-mask IFU development would mesh extremely well with such a scheme, as the RSS and NIR IFUs would then offer matching area-spectroscopy coverage, simultaneously across this broad wavelength range.

The MaxE requirements review took place at the end of November. The next significant milestone in the project is the concept design review scheduled for the end of January 2020.



Optical layout for the new concept for the MaxE project:
the addition of a red arm for the RSS, thus converting the instrument into a two-channel spectrograph.


SOFTWARE UPDATES
OPERATIONS

While identifying and addressing issues that affect night time **operational efficiency**, the SALT software team has been able to resolve some of the underlying problems. One such example is the dreaded "payload silent deaths", which, by their nature, were wasting significant amounts of observing time. A module in the payload software would cause an exception in Windows, but would not affect the rest of the software so the operator would not immediately know there was a problem with the track. The software team is also addressing a number of pop-ups on SOMMI (the SALT Operator work-station), as their frequency causes frustrations by getting in the way of operating the telescope.

All of the computers associated with the HRS use Windows as a platform, and once the instrument went live during commissioning, a peculiarity was noticed where the **HRS detector machines** would appear to lose connection with the detector controllers. This was most noticeable when it happened during an exposure readout, as it would cause all of the data for that exposure on the affected detector to be lost. The symptoms were not isolated to a particular computer, hence it could not be attributed to a specific hardware problem on either the red or blue detector. The common denominator appears to be the Windows operating system, and the vendor-supplied control logic.

A mini-project is therefore currently underway to **port the detector machines from Windows to Linux**, using a custom-written software library to control the detectors on the Linux platform. On the Windows machines, the drivers and software library from the hardware supplier are used by the `LabVIEW` user-interface for hardware control (`LabVIEW` allows one to port the software between platforms seamlessly). On Linux, the same `LabVIEW` user-interface will be used, and the control layer on Linux is tailored to mimic the interface presented to the `LabVIEW` software on the Windows machine. This allows changing the operating system and the control library without touching any other part of the system. The work on the port is almost complete: the only activities that remain are testing of the hardware with the new software, and a mini-ATP (Acceptance Test Procedure) where all functionality of the new software layer is checked to confirm that no defects are introduced with the new logic.

The year has seen a number of **upgrades to the technical web interfaces**. The automated Software Log has been expanded to include all daytime operations, thereby becoming the SALT Daylog. This has reduced the burden of distributing daily updates to telescope staff and has become a repository for all technical changes made to the telescope. These changes are stored in a database, making them easy to retrieve and resulting in a decrease in time taken to diagnose operational issues. `WebELS`, the webpage from which all technical data such as weather, motor positions, temperatures, and control variables can be accessed, has also received an upgrade. The latest version includes substantially faster download times for large datasets, which will prove particularly useful for the SPS (Segment Positioning System) upgrade.

Some **other highlights** from the SALT Software department include the execution and analysis of the upgraded RSS guider's ATP. SALT Software is also working with the software teams at iThemba Labs and SARAO on the Callosal data-transfer project. The aim of this is to create a software-standard for moving large amounts of data, of any type, within and between organisations. When completed, this will be an essential tool for the Intelligent Observatory project, SAAO's new vision to tie all of the telescopes at Sutherland, including SALT, into one AI network that will substantially increase the observing efficiency of observing programmes through automated observations, predominantly of transients.

SALT data archive

To provide access to its hundreds of thousands of data files, SALT is developing a web-based data archive. It was scheduled to be published in mid-2019, but the project completion was delayed for various reasons. Beta testing on version 1 will now start in early 2020.

At the heart of the data archive is a search form which allows the user to specify general properties like target coordinates or a proposal title, as well as more telescope-specific details such as the detector mode, a polarisation mode or an RSS grating. The search results are presented in a paginated table whose columns can be customised by the user. Pages are preloaded so that wait times are minimised. The schema for the archive's database was inspired by the Common Archive Observation Model, which means a wealth of details about the observations can be stored. While not all of these can be queried via the current web frontend, future servers for accessing the database by means of standard astronomical query tools will allow more detailed searches for observations.

The data archive will distinguish between release dates for meta data and the actual data itself. Data or meta data is only displayed if they have been released to the public or if the user owns them. PIs will be able to set the release dates in the PIPT or the WebManager within the confines set by the SALT Board and the TACs. Data files from the search can be opened in JS9, DS9's browser-based equivalent. Alternatively, they may be added to a cart and downloaded at a later stage, optionally together with their calibration files. Data requests are stored, so that one can easily re-request data.

The web frontend is realised with `TypeScript` and `React`, the backend with `TypeScript` and `Node`. Communication is done with `GraphQL` and `REST-ful` queries. As a first for SALT, a `PostgreSQL` database is used for storing the data.

As a next step, the data archive will be extended to include observations obtained with all of the other SAAO telescopes.

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.

The SCBP team has performed well in fulfilling its mandate in 2019 as 44,723 people were reached through the unit's programmes and activities. These activities include open nights, Sutherland and Cape Town site tours, astronomy-based competitions, teacher training, support and development workshops, learner enrichment programmes, national and international exhibitions, public lectures and public stargazing activities. In summary, 634 teachers were trained through teacher development and support programmes, 17,170 members of the general public visited our sites and 26,919 learners were engaged in our various learner-based programmes and workshops.

TEACHER
TRAINING, SUPPORT AND DEVELOPMENT

SCBP as a unit is committed to contribute towards improvement and development of teacher quality and classroom practice in mathematics and science education. Training and supporting teachers has a positive, not to say even snowballing, effect on the science education system. By empowering and inspiring some teachers, we believe that ultimately their colleagues and learners will also benefit. Efforts towards realising this objective led to 634 teachers, drawn from the Western Cape, Gauteng, Kwa Zulu Natal (KZN) and Limpopo provinces, being trained, developed and supported during the year. The SCBP teacher training programme is geared towards providing relevant knowledge content, exposing teachers to innovative pedagogical approaches and sharing of modern and creative resources for their classrooms.

In collaboration with the KZN Department of Education and particularly working with the Lembe District, a one-week long training programme was held in April. This was based on the theme "Matter and Materials" of the national science curriculum and used an SAAO-developed kit consisting of mostly kitchen-based materials and easy to access and cheap resources for the teaching of the theme, including all the prescribed experiments. A total of 236 teachers, drawn from Stanger, Maphumulo and Ndwedwe areas, participated in these workshops.

A one-week long intervention programme was implemented with the Limpopo Department of Education and the Giyani Science Centre in September. The target audience was the Senior Phase teachers of natural science, with 124 teachers being reached. As in previous years, the programme focused on the theme "Earth and Beyond". Teachers were provided with relevant curriculum content and were exposed to creative pedagogical approaches to teaching the astronomy-based theme.

This included encouragement and support for naked-eye observations, use of astronomy software such as Stellarium and Celestia, hands-on activities, simulations and investigations.

Two teacher training and support workshops were held in Parow and Wallacedene, implemented in collaboration with the Western Cape Education Department (the Metro North and Metro East) and the Association in Educational Transformation (ASSET). A total of 88 teachers attended the workshops, which were also based on the "Earth and Beyond" theme, with a special focus on identifying and dispelling various misconceptions in astronomy learning and teaching. ASSET supported the workshop by supplying the teachers with various models, posters and teaching resources.

In partnership with the Gauteng Education Department, a one-day teaching development and support work was held in Bronkhorstspruit. A total of 29 teachers from the senior phase of the General and Training Phase participated in the programme. The teachers were supplied with memory sticks containing all relevant information and were also supplied with teaching resources. We also collaborated with the Primary Science Project (PSP) in the implementation of two teacher training workshops, again addressing the "Earth and Beyond" theme of the natural science curriculum. The first one was held at SAAO and was attended by six teachers, and the second one was held in Parow and was attended by 65 teachers. The annual SAAO/UCT School of Education teacher training workshop was held at SAAO and was attended by 18 Postgraduate Certificate in Education student teachers.

LEARNER ACTIVITIES

A total of 26,919 Learners were reached through curricular, co-curricular and extracurricular activities; these included the astronomy quiz, job shadowing, science expos and science clubs. Learners were also reached through participation in science festivals, exhibitions, public stargazing, learner workshops and school outreach activities.

The SCBP learner workshops continue to attract learners and schools to visit the Observatory both in Cape Town and at Sutherland, with over 6400 participants in 2019. All our workshops are based on the natural science school curriculum and are linked to the "Earth and Beyond" theme. These include topics such as the relationship between Earth, Moon and Sun, phases of the moon, the seasons, the solar system, exoplanets, galaxies, telescopes and the historical development of astronomy including indigenous/cultural astronomy knowledge. The workshops also offer hands-on activities that learners can take back home. This encourages learners to engage in conversations with each other and also with their family members. All our activities use simple, cheap and accessible materials. We also continue to use astronomy as a context for teaching mathematics, physics and chemistry for the higher grades.

Due to socio-economic challenges and distance, some schools are unable to visit the Observatory, and the SCBP staff strive to fulfil the wishes of the learners and teachers by visiting their schools. These school visits are linked to stargazing using small telescopes and the running of shows in our inflatable planetarium dome. The purchase of this planetarium has boosted our efforts at reaching out to historically disadvantaged schools. More learners and schools, who have never had an opportunity to visit a planetarium, have been exposed to it. The experience has served to inspire them to appreciate the night sky and stars and to start doing naked-eye observations.

Astronomy Quiz

The annual astronomy quiz for grade-7 learners remains very popular both in the Western and the Northern Cape provinces.

The use of the online version of the quiz is making it easier for the rural based learners and schools to participate. Teachers look forward to participating in the quiz as it not only improves the knowledge content, confidence of the learners and their interest in science but it also provides teachers with resources and exposure to modern discoveries and recent updates.

This year, 498 learners from the Western Cape participated in the national quiz. The provincial winner of the Western Cape, namely Park Laerskool Mossel Bay, was crowned 2019 National Winner in the national finals held in Johannesburg, where they had to compete with the winners from the other 8 provinces.

Though participation in the quiz is compulsory for all primary schools in the Western Cape, the greatest challenge remains the fact that many primary schools use Afrikaans as a medium of instruction and the quiz is currently only offered in English. SCBP with the help of Willie Koorts and the support of SAASTA have now begun the process of translating the astro quiz booklet into Afrikaans, which will encourage participation for learners in the Northern Cape and Free State where Afrikaans is used as the medium of transactions.

Robotics clubs and competitions

Thanks to SAASTA for providing training and support to the SCBP staff, we were able to guide and support the robotics clubs based at the three schools Thandokhulu, Vuyiseka and Luhlaza. Thanks also to UNISA who provided personnel support to our staff and to the learners from the three schools. The learners were able to use the SCBP robotics kits to develop their own projects and were able to participate in the SAASTA-led robotics competition. Coding, robotics and artificial intelligence are the main markers of the current industrial revolution, and our learners ought to be exposed to these areas of learning and be inspired to conquer their fear of and to engage with these new technologies.

Artificial intelligence girls camp

Building on the success of the robotics programme, a special camp focused on the fourth industrial revolution and artificial intelligence was held in Langebaan in July in collaboration with ASSET. A total of 44 grade-11 girl learners attended the camp. They were exposed to various young role models who hold qualifications in computer science, mathematics, applied mathematics, astronomy and data science. They were also given opportunities to do basic coding and robotics. The aim of this camp was the exposure of the learners to the changing world of work and the nature of skills and qualifications that will be required for jobs in the future.

The Telescopes in Education Project

In the past, we have managed to donate six 6-inch Dobsonian telescopes to schools. This was possible due to generous donations from staff from SAAO, SALT and SARAO, who prefer to remain anonymous. In 2019, we managed to acquire another 6-inch telescope, which will be given to one of the rural schools in the Eastern Cape. We wish to request that anyone interested in supporting this campaign contact SCBP staff.

There is a great need for schools, especially the township schools, to have a telescope for the teaching of the "Earth and Beyond" theme.

CAREER-BASED ACTIVITIES

The NSTF Brilliants

SAAO was fortunate to be chosen again to host the matriculants of the national Science and Technology Forum (NSTF) Brilliants Astronomy tour. The NSTF Brilliants are the top performing science and technology students, having obtained the best results nationally in the mathematics and science matric examinations in 2018. The 25 matriculants spent time at the Cape Town observatory grounds and visited the Sutherland Observatory on 23 June, including spending some time at SALT. They had many opportunities to interact with our astronomers, engineers and IT specialists.

Career exhibitions and expos

In an effort to disseminate information based on astronomy as a career, to share the pathway and institutions that offer astronomy and to spread information on astronomy opportunities and facilities, SCBP continues to participate in career exhibitions and expos. Working jointly with SARAO, a career exhibition was held in Villiersdorp in the Northern Cape and was attended by 269 learners. A mini career expo was also held in Touws River and it attracted 180 learners. SCBP also participated in the Eastern Cape based Careers Expo which was held in the Buffalo City Metro and Umtata municipality in April. A total of 1079 Grade-11 and 12 learners attended the careers expo in Umtata, 417 learners attended the Jongilizwe and 735 learners attended the St Johns career expo. SCBP staff also attended the UCT Eskom career expo and managed to interact and engage with 150 learners. These career expos provide us with an opportunity to share information on astronomy as a discipline and as a career; they also offer opportunities to popularise SALT, the work of SAAO, and astronomy as such in South Africa and in the world in general.

Job shadowing

As in previous years, two job shadow sessions were held in 2019. The first session, held on 2 and 3 July, was attended by 15 learners, and 13 learners came to the second one, held on 25 and 26 September. They were drawn from various high schools across the Western Cape and beyond to participate in this intensive, 2-day programme. The programme focuses on various careers at SAAO, thereby giving the learners a broad overview of astronomy-related jobs and better enabling them to make an informed decision regarding their potential studies and, ultimately, their future career choice. The holistic approach of the job shadow programme takes the learners not only through the experiences and job specifications of an astronomer (e.g., how they observe and collate their data) but also of other careers, such as engineering (mechanical and electrical), software development, information technology, librarianship, finance and supply chain management. Throughout the programme, the learners observe the role that all of these careers play at a national research facility and how they relate to each other. They are also supplied with information regarding the various institutions of higher learning that offer bursaries and scholarships. The programme is interactive and learners are encouraged to ask questions throughout their time at SAAO, with many making contacts and asking follow-up questions in the months to follow. The success of this programme lies in its diversity. Follow-up feedback emails between the coordinator Natalie Jones and the learners have revealed that since the implementation of this programme in 2014, over 15 learners chose to study astrophysics and many others selected fields in engineering and information technology for their studies.

Women's Day event

The annual Women's Day event was held on 9 August, which is celebrated nationally as a women's day. A total of 60 girl learners (30% more than last year) drawn from various schools across the Western Cape province were addressed by various female science and technology professionals. Astronomy, software development, and space physics were among the careers represented in the event. The learners had opportunities to interact with all the female scientists in an informal way where they were able to ask questions in a more relaxed environment. The learners were given packs consisting of various brochures and books based on different careers. Building on this annual project, we intend to continue to encourage girls in Cape Town and Sutherland in this manner. One important aspect of this project is for the girl learners to have an online (via email or social media) science mentor or role model to continue the conversation so as to sustain the interest aroused during the women's day celebrations.

ACTIVITIES FOR THE PUBLIC

A total of 17,170 members of the public were reached in 2019 through science clubs, science festivals or exhibitions, and tourism at the Sutherland Observatory. Open nights and star-gazing events also attracted a great number of people.

Science clubs

The SCBP unit continues to encourage the establishment of science clubs across this country. Science Clubs are vital in conservation and further development of interest in science inspired by a visit to an institution such as ours. A training camp for science clubs was held in Sutherland for 41 learners from the rural town of Vredenburg. The camp focused on training learners in how to establish and run their own science clubs. It also included coding, robotics, astronomy, physics and computer engineering. We are grateful to SAASTA for their generous funding for this project.

Science festivals

In an effort to popularise astronomy and science in general, SCBP continues to participate in national, provincial and regional science festivals. SALT remains the major attraction as a source for inquiries from participants at these festivals. With the building of the MeerKAT radio telescope, SALT has attracted more inquiries based on the difference between radio and optical telescopes and between the locations. Thousands of learners and members of the general public are reached through participation in these festivals. Also audiences from outside the Western Cape and Northern Cape provinces receive an opportunity to interact with the SAAO staff personally via these festivals.

In 2019, we participated in the Kirkwood Festival and managed to interact with about 4000 people via the inflatable planetarium and the astronomy exhibition. SCBP staff also participated in the Rural Education Development Festival (RedFest) in Tzaneen and Giyani, reaching 6840 learners. At the Eiding Science Festival we interacted with 1280 learners through workshops, lectures and exhibitions.

A highlight of the year was the National Science Festival (SciFest) in Grahamstown on 6 March. The team's activities consisted of astronomy-related workshops throughout the day and of public lectures which referred specifically to the future of astronomy in South Africa. Along with the exhibition stall, SAAO had a photo booth which was most popular. Also sought after was the use of iPads, which contained an astronomy quiz: learners were awarded certificates for answering a minimum of 10 out of 15 answers correctly. At the SciFest2019 prize-giving ceremony, SAAO carried away the day: the team was awarded "Highly Commended" for their exhibition stall, which was the highest award of all.

SCBP staff exhibited at SciFest and won the Best Exhibition in the category of "Highly Commended" exhibition.

National Science Week

South Africa has dedicated the first week of August of every year to celebrate the achievements of science and technology. It is also a time to inspire the youth to pursue science-based studies and to inform the public about the advances made through science and technology in South Africa. One of the main themes of the national science week is astronomy and space science.

We celebrated National Science Week in three provinces, namely the Northern Cape, the Western Cape and Kwa Zulu Natal (KZN), and various activities involving the general public and learners were implemented. In the Northern Cape, 5765 learners were reached through hands-on activities aligned to the theme of the National Science Week; this included activities based on climate change, astronomy and stargazing sessions. In KZN, in the rural towns of Dundee and surrounding areas including Msinga, 719 high school learners participated in week-long activities based on climate change and astronomy. In the Western Cape, an outreach programme to St Helena, Steenberg and Langebaan reached 1301 learners, and four public lectures on climate change were organised, attended by 100 members of the public.

Open nights at SAAO

Open nights at our Cape Town site are held on the second and fourth Saturday of every month (with the exception of December, with an open night on the second Saturday only). A total of 1736 people attended these events in 2019. Open nights include a public lecture, a tour of the Cape Town Museum and a stargazing session. Lectures were given by astronomers from SAAO, UCT, UWC, SARAO and overseas-based, visiting astronomers. The audience ranged from 20 to 140, depending on the topic of the lecture and the season. The historical McClean telescope remains the major attraction. Maintaining the telescope has proven difficult due to financial challenges. Last year's work concerned the hydraulic system that raises the floor. To fix the accumulator seal, the system underwent an overhaul under the supervision of SAAO's mechanical workshop. While the floor is now operational again, its system still suffers from a few small leaks and the hydraulic system needs to be topped up regularly. The open nights are one of the key attractions for local and international tourists and have made the SAAO site a popular place to visit. In a bid to reach public audiences from the disadvantaged communities, special open nights are planned to be held locally in townships and other places that are far from SAAO.

Cultural Astronomy project

The work in the collation and production of the indigenous astronomy knowledge, initiated in 2017, continues. A short, promotional video on indigenous astronomy has been produced and is available on SCBP's website and social media. Videos with interviews of individual African astronomy knowledge holders and black, South African born astronomers were also produced. All videos will form part of a DVD that will be distributed to the public. Posters based on African star lore are in the final stages. These will be printed and distributed nationally.

Following the success of cultural astronomy nights and storytelling workshops and as part of the bi-centenary celebrations of SAAO, we plan to host several cultural astronomy events in Cape Town in 2020.

SUTHERLAND: ACTIVITIES

Visitor centre

The Sutherland Tours remain very popular with steady numbers of visitors over the last couple of years. In 2019, 10,624 people visited the Sutherland Observatory. Astronomical events seem to spur interest and encourage people to visit the observatory. We have been advertising in various tourist magazines and sites, and SALT is in fact one of the greatest attractions for people to visit the Northern Cape province. Training for new tour guides is provided in conjunction with the Centre for Astronomical Heritage. We are continuously promoting astro-tourism to Sutherland, and tourism continues to contribute to the socio-economic development in the Sutherland area by way of providing jobs for the youth.

While working towards the celebration of the 200th anniversary of SAAO in 2020, plans are afoot to develop a new visitor centre in Cape Town and to improve the Visitor Centre in Sutherland. A new astro-tourism plan is being developed, involving, among many partners, SAAO, the Department of Science and Innovation, and the Department of Tourism.

French school visit

The grade-1 learners of the Cape Town French School in Cape Town, together with their parents, visited Sutherland. They met the grade-1 learners of Roggeveld Intermediate School at the community centre. They engaged in various activities and learned from each other in terms of languages and school culture. The activities also included a walk-and-talk on Freedom Day, 27 April, to the "ou lokasie" (old locality) to share a little bit of South African history. The school and parents also donated various educational materials to the Roggeveld grade-1 class. The day concluded with a social event between the French school parents and the teachers from Roggeveld Primary School, to share experiences and to build relations. Based on the success of this visit, we anticipate that this will become an annual activity and we hope to extend this to other schools.

Community Development Centre

The Community Development Centre continues to serve as a rallying point of development in the community of Sutherland and to facilitate improvement of the socio-economic well-being of the town of Sutherland. Various activities have been conducted all through the year, as follows.

Professor Dreizler and students from the University of Göttingen in Germany visited Sutherland in March. They engaged in physics classes in schools and at the community centre.

Youth Day, on 16 June, was celebrated as a community project in partnership with the South African Police Services (SAPS) and the Sutherland police forum at the community centre. All young people were invited to a "potjiekos" competition, that is, to prepare food that reflects and celebrates their heritage.

While they had a lot of fun with this engaging activity, information on the importance of the day was also shared.

The Mandela ("Madiba") Day celebration is an annual initiative in partnership with the local Intergovernmental forum of Sutherland. This year we reached out to the old age home in Sutherland and gave the elders cupcakes and a beautiful message to lift their spirits and to feel good again, to show how much we care for them.

Sutherland High School was chosen to paint a unique image as a part of a project by Keele University in the UK. The learners painted a huge image of the galaxy and of SALT.

Dr Vic Gibbon, an anthropologist at UCT, visited Sutherland and held a lecture at the community centre on forensic anthropology. She is a biological anthropologist, which is the study of the biological development of humans. Forensic anthropology is an applied science using biological anthropology methods to analyse human remains, primarily bones and teeth, from unexplained deaths for reconstructing information on and circumstances surrounding deaths. She also talked about medical anthropology, which is the relationship between health and culture.

Once a month, the Department of Labour and SASSA come to the Sutherland Community Centre. Their activities include, but are not limited to, registration of grant applications, information sessions and workshops for unemployed youth members.

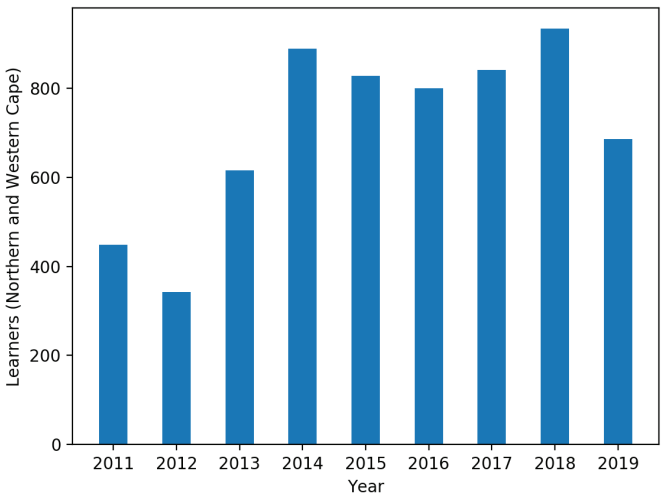
The Sutherland Community Development Centre is playing host to a skills-development intervention in Water and Waste Water Reticulation for a period of twelve months. Partners in this initiative are the Karoo Hoogland Municipality and the local government SETA (Sector Education and Training Agency). The target audience for this intervention is unemployed youths of the Sutherland community. The course consists of both theory and practicals. It is envisaged that these trainees will play a crucial role in assisting the municipality to save water and to use waste water more effectively in the future.

SAAO also partnered with the National Department of Tourism and the Northern Cape Provincial Department of Economic Development and Tourism to empower four unemployed young people as Tourism Safety Monitors over the period of one year. The monitors are paid a monthly stipend and are trained by the National Department of Tourism, with SAAO hosting them until the end of April 2020, giving them valuable work experience in a vibrant and busy tourism environment.

WORD OF
GRATITUDE AND AKNOWLEDGEMENT

We would like to thank our SALT partners for all their assistance in the execution of education and outreach programmes. We would also like to thank the SAAO executive and the Director, Professor Petri Väisänen for the support of the science engagement programmes. SCBP's manager, Sivuyile Manxoyi, wishes to extend words of gratitude to all SCBP staff members for all their contributions and hard work that has made this year a success. Thanks too to all SAAO staff and all astronomers that supported our efforts.

SCBP HIGHLIGHT:
ASTROQUIZ – MOST POPULAR COMPETITION



Participation of learners in the Astroquiz over the years.

Increasing the involvement of learners with science, technology, engineering or mathematics (STEM) subjects is of paramount importance in South Africa, and astronomy is a good way to spark interest in the natural sciences. This is particularly true if it is introduced by way of a competition. The South African Agency for Science and Technology Advancement (SAASTA) therefore is running an annual, nationwide Astroquiz for grade-7 learners. Apart from improving the awareness of basic astronomy, the Astroquiz aims to build appreciation for South Africa's astronomical achievements past and present, and to celebrate the contribution of women so as to foster interest of girl learners in career opportunities in astronomy.

The Astroquiz consists of four provincial rounds and national finals. In each round, the learners have to answer 30 multiple choice questions. Rounds 1 and 2 are done at the schools or at various centres, whereas Round 3 and 4 are taken on the same day at one institution in each province. The finals usually are held in Pretoria, giving the winning team of each province a good opportunity to explore this part of the country.

SAAO has been organising the Astroquiz on behalf of SAASTA in the Northern and Western Cape provinces since its inauguration in 2006. Traditionally, only one team per school could participate. In order to give more learners the opportunity to engage with astronomy, in 2013 the pen-and-paper version of the quiz was supplemented with an online quiz by SAAO, and schools are encouraged to take part with multiple teams. However, as internet and computer access can be an issue at some schools, the quiz can still be done offline if need be. In the last years, SAAO has also contributed to moderating and, in 2019, even setting some of its questions.

The Astroquiz reaches learners across the whole of a province. This is nicely illustrated by the fact that the 2019 national winners, who were from the Western Cape, came from a school in Mossel Baai, a good 4 hours drive from SAAO in Cape Town.


PARTNER ACTIVITIES
OUTREACH &
EDUCATION

SALT
ACTIVITIES

Every year, SALT (in addition to the SCBP's activities, though supported through their infrastructure) directly supplies funding to support Sutherland's community. In 2019, the major events were:

- Geysers were installed for the old age home;
- Medical supplies were handed over to the Sutherland Hospital;
- Jerseys and transportation were supplied for town and school sports teams.

In addition, SALT contributed towards the worthy efforts of the Sutherland community police forum in raising funds for the refurbishment of the South African Police Services reception area in Sutherland. The refurbishments included the painting and replacing of tiles of the reception area to make it more customer friendly and to lift the morale of staff who work in that environment every day.

SALT PARTNERS

Image poster created by the Sutherland High School.

UKSC — Keele University

PhD student Clara Pennock and Jacco van Loon from Keele University have started a project dubbed

"Inspiring the next generation"

to bring together young learners from the Sutherland High School and from the Thistley Hough Academy in Stoke-on-Trent in the UK. This was made possible with financial support from the Royal Astronomical Society in the UK. The project's instruction to each school was to select a non-famous galaxy from several images presented to them and to create a painting of it. Together the schools chose NGC 1809, which was subsequently imaged with SALT as part of the project, using extra-purchased SALT time.

The project led to two visits by the organisers to each of the schools with the aim to bring science and SALT to the classroom. This is also a good opportunity to foster mutual understanding of each other's background and culture and to tap into the learners' creative talents by helping them produce an artwork that will be part of an exhibition. Originally, Skype-sessions had been planned for the communication between the learners, but this proved not to be feasible due to exams and holiday time. Instead, the organisers gave detailed presentations of the partner school during their visits. Sutherland has finished their creation, and Thistley Hough are currently working on theirs. The exhibition at Keele University is under preparation; it will include artworks from a similar project with India. There is a possibility that the exhibition will go on tour afterwards.

Dartmouth College

Every other year, Brian Chaboyer, SALT Board member for Dartmouth College, visits South Africa for 10 weeks, bringing along students and other faculty to reach out to learners and astronomy students. In January 2019, the group comprised 14 undergraduate students, two graduate students and two faculty, visiting SAAO, SALT and UCT. During this educational tour, students learned about astronomy from the Dartmouth faculty. Highlights of the visit included observing at Sutherland (including visiting SALT), and participating in public outreach events organised by SAAO. During their visits to local schools, the Dartmouth students tutored young learners on astronomy and future careers in science, engineering or mathematics.

University of Göttingen

Like every year, Professor Stefan Dreizler and about six students from the Georg-August University at Göttingen, Germany visited Sutherland schools in March as part of the SCBP. The Georg-August University was a partner of the SALT consortium until the end of 2015 and decided to continue their outreach work with the SCBP thereafter. They engage in physics classes in schools and at the Sutherland Community Centre with the following activities:

- Paint-by-numbers of constellations in the Southern hemisphere;
- Paper planes, including test flights;
- Creation of a large mobile with some of these paper planes;
- Creation of a scaled solar system, including the calculation of distances and sizes;
- Model the Sun-Earth-Moon system to display the day/night cycle, seasons and eclipses;
- Demonstration of gravity with a table cloth and balls;
- Model Focault's pendulum and demonstrate the Earth's rotation;
- Phyphox smartphone experiments for (damped) oscillations including measurement of Earth's gravity;
- Oscillations of a rope, a spring, a big soap bubble, including a comparison to stellar oscillations;
- Light as a wave: creation of and experiments with a pinhole camera.


VISITING SALT
OUTREACH &
EDUCATION

MEDIA VISITS TO SALT

APRIL 2019 – Dorp van die Jaar, kykNET

This year, Sutherland, home of SALT, was featured on kykNET as a finalist in the "Dorp van die Jaar" kykNET Kwêla competition. Eligible in this competition are towns in South Africa and Namibia with less than 500,000 inhabitants. The winners are determined by popular vote. The show is targeted towards the Afrikaans-speaking market. Though Sutherland did not make the cut into the Top 3, the film is still available on YouTube. In addition to filming in town, they also filmed the inside and outside of SALT and interviewed SALT's Tech Ops manager Chris Coetzee and SALT Astronomer Rudi Kuhn. The film was shown in May 2019 on kykNET channel 144; Dorp Van Die Jaar is a segment in the programme called Kwêla.

MAY 2019 – X CON Films

X CON Films is an independent production house in Cape Town. Among others, they are producing a documentary called Forever Young, which airs on SABC 2. The show celebrates the heartiness of the forever youngs, through a nostalgic treatment of their heritage by the iconic old souls.

For one of their episodes, they were profiling Professor Patricia Ann Whitelock, a South African astrophysicist working at SAAO and a member of the Academy of Science of South Africa. Her research into stellar evolution, Galactic structure and the stellar content of the Local Group galaxies has helped to broaden the frontier of astronomy both in South Africa and internationally. The crew filmed at the SAAO facilities; next to an interview with Patricia, the episode shows cutaways of the facilities, including SALT, emphasising Patricia's work, most importantly because SAAO played a huge role in her career.

AUGUST 2019 – Voetspore

Voetspore is a hugely popular Afrikaans travel documentary series on SABC 2, featuring lesser explored tourist destinations all over Africa. In 2019, they decided to tour exclusively beautiful South Africa. ViSA (Voetspore in South Africa) is a normal Voetspore expedition of six guys in three 4x4's in an adventure documentary series. Emphasis is placed on the credibility of the journey and the choice of destinations. For the ViSA production, the team travelled all over South Africa, taking about thirteen weeks on a journey that is meant to introduce South African viewers to many of the less explored destinations in the country. The individual destinations represent the lesser-known yet equally beautiful and interesting destinations in South Africa. Many of these destinations are only reachable by 4x4, encouraging a growing market segment of holiday goers to visit these destinations. Viewers who have never camped and spent time in the great outdoors will be encouraged by the team's experience to do likewise, while viewers who are already part of this market segment will be introduced to new destinations. Guests and media, accompanying the team for the first time on production, will be used to showcase the attraction of this way of going on holiday. The series may also help to draw foreign visitors to our shores.

The team arrived in Sutherland on 9 August and stayed overnight in town. In the afternoon, Anthony Mietas, SCBP outreach manager for Sutherland, showed the film crew around the observatory's plateau. They also visited the SALT control room, talking to Marc Wichman and Timothy Fransman, before the night's observations started.

CORPORATE GOVERNANCE

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

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

Prof. Michael Shara (Chair)
American Museum of Natural History, USA

Prof. Matthew Bershady
(Appointed 01/12/2019)
University of Wisconsin–Madison, USA

Prof. Gerald Cecil
University of North Carolina at Chapel Hill, USA

Prof. Brian Chaboyer
Dartmouth College, USA

Prof. Phil Charles
United Kingdom SALT Consortium, UK

Dr Lisa Crause
National Research Foundation, South Africa

Prof. John P. Hughes
Rutgers University, USA

Dr Molapo Qhobela
National Research Foundation, South Africa

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

Prof. Marek Sarna
Nicolaus Copernicus Astronomical Centre, Poland

Prof. Eric Wilcots
(Resigned 31/11/2019)
University of Wisconsin–Madison, 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.

Operations contract

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

The Board Executive Committee (BEC)

The Board has delegated authority to the Board Executive Committee (BEC) to manage the Company during the period between Board meetings. The BEC typically meets once 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 four Board members. In this reporting period, they were: Prof. Michael Shara (Chair), Prof. Brian Chaboyer, Prof. Phil Charles, Prof. Eric Wilcots (until 31/11/2019), Prof. Jack Hughes (from 01/12/2019) and Prof. Somak Raychaudhury (from 01/12/2019).

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. Eric Wilcots (until 31/11/2019; Chair), Prof. Gordon Bromage, Prof. Jack Hughes (Chair since 01/12/2019) 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: Paul Groot, Matt Bershady, Hermine Schnetler, John Booth, Joanna Mikołajewska, David Buckley, Raghunathan Srianand and Lisa Crause (Chair).

Technical Operations Team 2019

Chris Coetzee (Head until 30 Nov 2019)

Paul Rabe (Head from 1 Dec 2019)

Richard Banda
Janus Brink
Keith Browne
Alrin Christians
Willa de Water
Timothy Fransman
Denville Gibbons
Johan Hendricks
Stephen Hulme
Nicolaas Jacobs
Anthony Koeslag
Jonathan Love
Deneys Maartens
Thabelo Makananise
Adelaide Malan
Paul Rabe
Etienne Simon
Ockert Strydom
Nicolaas van der Merwe*
Mark Wichman*
Eben Wiid

Astronomy Operations Team 2019

Encarni Romero Colmenero (Head)

Éric Depagne*
Danièl Groenewald
Christian Hettlage
Alexei Kniazev
Thea Koen
Enrico Kotze*
Marissa Kotze
Rudi Kuhn
Nhlavutelo Macebele
Fred Marang*
Brent Miszalski
Moses Mogotsi
Sifiso Myeza
Danny Sallurday*
Anja Schröder
Rosalind Skelton
Veronica van Wyk
Lonwabo Zaula*

SALT Observatory Scientist

Lisa Crause

Corporate Governance Team 2019

Lizette Labuschagne
Surayda Moosa

* part-time and/or part of the year

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** not complete

GLOSSARY & ACRONYMS

2D	two dimensional
3D	three dimensional
ACT	Atacama Cosmology Telescope
ADF-S	Akari Deep Field South
AGB	asymptotic giant branch
AGN	active galactic nucleus
AI	artificial intelligence
AIP	Leibniz Institute for Astrophysics Potsdam
ALS	Alma luminous star
AMNH	American Museum of Natural History
ASASSN	All Sky Automated Survey for SuperNovae
ASSET	Association in Educational Transformation
ATP	acceptance test procedure
BCG	brightest cluster galaxy
BD	Bonner Durchmusterung
BEAMS	Brightest cluster galaxy Evolution with ACT, MeerKAT, and SALT
BEC	board executive committee
BLR	broad line region
BVIT	Berkeley Visible Image Tube camera
CAMK	Nicolaus Copernicus Astronomical Center
CCAS	center of curvature alignment system
CCD	charge-coupled device
CEMP	carbon-enhanced metal-poor
CFHT	Canada–France–Hawaii telescope
CFO	chief financial officer
CGM	circumgalactic medium
CHANG–ES	Continuum HAlos in Nearby Galaxies: an EVLA Survey
Co–I	co–investigator
CP	chemically pulsating
CPD	Cape observatory, photographic Durchmusterung
CTA	Cherenkov Telescope Array
CTIO	Cerro Tololo Inter–American Observatory
CTS	Calan Tololo Survey
CV	cataclysmic variable star
DC	Dartmouth College
DDT	director's discretionary time
DES	Dark Energy Survey
DIB	diffuse interstellar band
DR	data release
DSI	Department of Science and Innovation
DU	Denver University
EC	Edinburgh-Cape survey
eDIG	extraplanar diffuse ionised gas
ESA	European Space Agency
ESO	European Southern Observatories
ESPaDOnS	an Echelle SpectroPolarimetric Device for the Observation of Stars
eVLA	extended VLA
EWASS	European Week of Astronomy and Space Science
FAC	finance & audit committee
FermiLAT	Fermi gamma-ray Large Area space Telescope
FP	Fabry–Pérot
FWHM	full width half maximum
GATS	Global Astrophysical Telescope System
GBT	Green Bank Telescope
GCN	GRB coordination network
GES	Gaia–ESO Survey
GRB	gamma-ray burst
GWP	gravitational wave programme
H2RG	HAWAII–2RG detector
HATNet	Hungarian-made Automated Telescope Network
HD	Henry Draper
HE	Hamburg–ESO survey
HERCULES	High Efficiency and Resolution Canterbury University Large Echelle Spectrograph
H.E.S.S.	High Energy Stereoscopic System
HET	Hobby–Eberly Telescope
HMXB	high-mass X-ray binary
HR	high-resolution (Fabry–Pérot)
HRS	high-resolution spectrograph
HS	high-stability
HST	Hubble Space Telescope
IAO	Institute Astronomical Observatory
IC	Index Catalogue
IDSAC	IUCAA Digital Sampling Array Controller
IFU	integral field unit
IIA	Indian Institute of Astrophysics
INAF	National Institute of Astrophysics, Italy
IR	infrared
IRAF	Image Reduction and Analysis Facility
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
KAT	Karoo Array Telescope
KZN	KwaZulu–Natal
LADUMA	Looking At the Distant Universe with the MeerKAT Array
LCO	Las Cumbres Observatory
LFC	laser frequency comb
LIGO	Laser Interferometer Gravitational wave Observatory
LMC	Large Magellanic Cloud
LMXB	low-mass X-ray binary
LOFAR	LOw Frequency ARray
LR	low-resolution (Fabry–Pérot)
LSP	large science programme
LSST	Large Synoptic Survey Telescope
MAGIC	Milky wAy Galaxy wIth SALT speCtroscopy
MASTER	Mobile Astronomical System of the TElescope–Robots network
MaxE	Maximum Efficiency spectrograph
MAXI	Monitor of All-sky X-ray Image
MDM Observatory	Michigan–Dartmouth–MIT Observatory
MJD	modified Julian Date
MJUO	Mt John University Observatory
MOND	Modified Newtonian Dynamics
MOS	multi-object spectrograph
MR	medium resolution
NARIT	National Astronomical Research Institute of Thailand

NASA	National Aeronautics and Space Administration
NCAC	Nicolaus Copernicus Astronomical Center
NGC	New General Catalog
NIR	near-infrared
NLTE	non-local thermodynamic equilibrium
NRF	National Research Foundation
NRP	non-radial pulsation
NSTF	National Science and Technology Forum
NuSTAR	Nuclear Spectroscopic Telescope ARray
NWU	North–West University
oEA	oscillating mass-accreting components of semi-detached Algol-type Eclipsing binaries
OGLE	Optical Gravitational Lensing Experiment
P0 … P4	priority 0 – 4
PA	position angle
PAS	Polish Academy of Sciences
PFS	Planet Finder Spectrograph
PI	principal investigator
PIPT	Principal Investigator Proposal Tool
PN	planetary nebula
POL	Poland
PRV	precision radial velocity
PSP	Primary Science Project
PyHRS	Python package for HRS data reduction
QE	quantum efficiency
QSO	quasi-stellar object
RedFest	Rural education development Festival
RINGS	RSS Imaging spectroscopy Nearby Galaxies Survey
roAp	rapidly oscillating Ap stars
RSA	Republic of South Africa
RSS	Robert Stobie Spectrograph
RV	radial velocity
RVSAO	Radial Velocity Package for IRAF
RU	Rutgers University
RXTE	Rossi X-ray Timing Explorer
SA	SALT Astronomer
SA	South Africa
SAAO	South African Astronomical Observatory
SAASTA	South African Agency for Science and Technology Advancement
SAI	Sternberg Astronomical Institute
SALT	Southern African Large Telescope
SALTICAM	SALT Imaging CAMera
SARAO	South African Radio Astronomy Observatory
SAPS	South African Police Service
SASSA	South African Social Security Agency
SB	spectroscopic binary
SCBP	SALT Collateral Benefits Programme
SciFest	National Science Festival
S–CUBED	Swift SMC Survey
SDSS	Sloan digital sky survey
SDSS-RM	Sloan digital sky survey Reverberation Mapping
SETA	Sector Education and Training Agency
SHOC	Sutherland High-speed Optical Cameras
SIDECAR	system image, digitizing, enhancing, controlling, and retrieving
SIE	singular isothermal ellipsoid
SKA	Square Kilometre Array
SMBH	supermassive black hole
SMC	Small Magellanic Cloud
SN	supernova
SNR	signal-to-noise ratio
SNR	supernova remnant
SOAR	SOuthern Astrophysical Research telescope
SOMMI	SALT Operator Man–Machine Interface
SPIE	Society of Photo–optical Instrumentation Engineers
SPS	(mirror) segment positioning system
SSP	single stellar population
SSWG	SALT science working group
STC	scientific and technical committee
STEM	science/technology/engineering/mathematics
STGS	spherical transmission grating spectrometer
STScI	Space Telescope Science Institute
SVNIT	National Institute of Technology in Surat (Sardar Vallabhbhai National Institute of Technology)
SXP	SMC X-ray Pulsar
SZ	Sunyaev–Zel'dovich
TAC	time allocation committee
TESS	Transiting Exoplanet Survey Satellite
THYME	TESS Hunt for Young and Maturing Exoplanets
TMT	Thirty Meter Telescope
TRES	Tillinghast Reflector Echelle Spectrograph
TYC	Tycho mission
U	university
UCLan	University of Central Lancashire
UCT	University of Cape Town
UFS	University of Free State
UJ	University of Johannesburg
UKSC	United Kingdom SALT Consortium
ULIRG	ultra-luminous IR galaxy
UNC	University of North Carolina – Chapel Hill
UNISA	University of South Africa
UPS	uninterruptable power supply
UV	ultraviolet
UW	University of Wisconsin–Madison
UWC	University of the Western Cape
VHE	very high energy
ViSA	Voetspore in South Africa
VLA	Very Large Array
VLBI	very long baseline interferometry
VLT	Very Large Telescope
VLTP	very late thermal pulse
VPH	volume phase holographic
WASP	Wide Angle Search for Planets
WD	white dwarf
WISE	Wide-field Infrared Survey Explorer
WR	Wolf–Rayet
XMM	XMM–Newton observatory
Zw	Zwicky

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

Editor

Anja Schröder, SAAO/SALT

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