Quest

SCIENCE FOR SOUTH AFRICA

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Our giant 'Eye in the sky'

Hidden galaxies

New life for old telescopes

Astronomy - reaching the people

A night in the life of SALT

ACADEMY OF SCIENCE OF SOUTH AFRICA

The Universe is right next door

The South African Astronomical Observatory (SAAO) brings the Universe closer to home.

We work with leading astronomers and scientists to unwrap the mysteries of the cosmos and continue to play an important role in new discoveries.

We also operate some amazing technologies such as SALT, the biggest optical telescope in the Southern Hemisphere.

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NRF National Research Foundation | SAAO South African Astronomical Observatory

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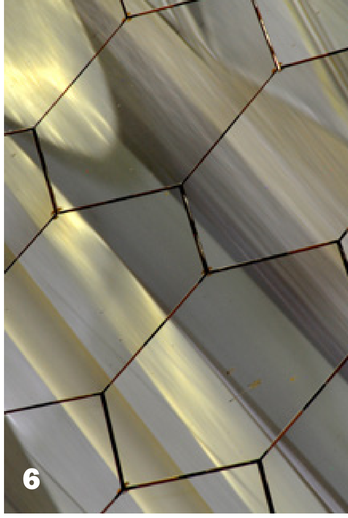
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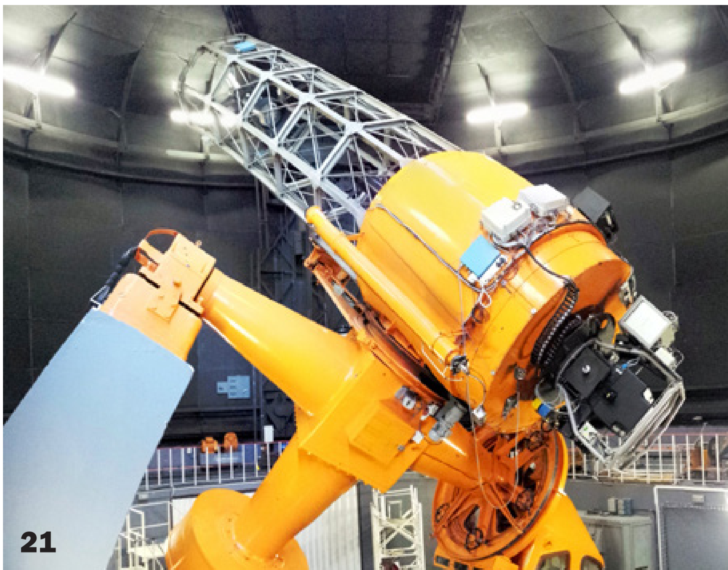
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Images: SALT, SAAO, NASA

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Eye in the sky...

South Africa has a long history of astronomy – right back to prehistoric times, when the early San people recorded astronomical events in their rock art, recording how they interpreted events in the world around them in terms of their known world. But this was not the only way that our early forebears used the skies. The stars and planets were used in their daily lives, with calendars based on phases of the Moon – giving the old African calendar 354 days – only 11 days short of our modern calendar, which is based on the movement of the Earth around the Sun.

Later in history there was massive exchange of knowledge between West Africa and the Islamic world that probably started over a thousand years ago when Muslim North Africa started trading with West Africa during the Ghana empire. The Ghana empire covered parts of Mauritania, Mali and Senegal and collapsed in the 11th century. It was during the Ghana empire that the culture of learning was established in West Africa. It is largely from this that cities such as Timbuktu (in the north of the Mali republic) benefited from the later movement of scholars. We do not know how far back astronomy was studied in Timbuktu, but there are astronomical documents that were definitely written by black West Africans in the early 1700s. One such scholar, Mohammed Baghayogo Gurdu, mentions that the teacher of Ahmed Baba (the most celebrated of the 16th century scholars from Timbuktu) studied under a Lybian astronomer in Egypt in the 16th century.

Closer to our own time, the South African Astronomical Observatory (SAAO) was founded in 1820 and is the national centre for optical and infrared astronomy in South Africa. The main telescopes for research are located at the SAAO observation station, 15 km from the small Karoo town of Sutherland in the Northern Cape. This is where the Southern African Large Telescope (SALT) is based and for the past five years South African astronomical sciences have had access to the SALT. During those five years SALT has steadily produced good quality data for both South African and international users – a true example of global collaboration in science. SALT is the largest single optical telescope in the southern hemisphere and among the largest in the world.

Why has South Africa had such wonderful opportunities for astronomical research? The answer is that South Africa is ideally situated to observe the skies. We have a relatively pollution-free atmosphere and lots of wide open spaces that are not polluted by light at night – death to sky watching. The Cape has also been on major sea routes for centuries – requiring astral observations to allow navigation. As a result, we have an enviable history of astronomical research and have, over the years, developed truly excellent research facilities.

These research facilities in turn, have allowed astronomy to grow as a major scientific discipline within South Africa and our research is world class. In fact, anyone with a gift for mathematics and physics should think seriously about a career in astronomy in South Africa. Along with SALT and the other telescopes in Sutherland, we have MeerKAT which is a precursor to the Square Kilometer Array (SKA) – a truly formidable set of research instruments to take us right to the forefront of research.

Astronomy and astrophysics are about big issues – life, the Universe and everything (to borrow from Douglas Adams). When you read about the history of the Universe, the life and death of stars and the research into extra-solar planets, you realise how small and insignificant we – and our Earth – are.

Bridget Farham
Editor – *Quest*: *Science for South Africa*

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

Petri Vaisanen explains how the Southern African Large Telescope is expanding our understanding of the Universe

Science with the Southern African Large Telescope (SALT)

SALT has been working in full science operations mode for five years now, since late 2011. Many technical upgrades have been completed during this time, and indeed the telescope is constantly being optimised for efficiency. During these five years SALT has steadily produced good-quality data with its instruments for both South African astronomers and its international users, with many exciting science results. This article gives an overview of what SALT is, how it operates and observes the Universe, and highlights some of the astrophysical objects it has studied.

SALT facts

The telescope

SALT is located in Sutherland, in the Karoo, some 400 km north east of Cape Town. The primary mirror of the telescope is 11 m across, making it currently the largest single telescope in the southern hemisphere, among the top few 10-m class telescopes in the world.

It is an unconventional design, however. It cannot point to any altitude in the sky, although it can freely move around the horizon. The moving part of the telescope during an observation, and technologically the most complex, is what is called a 'tracker'. This tracker is a metal structure carrying the science instruments above the primary mirror in the opposite way to how the sky is rotating. The extremely accurate high-tech machinery keeps astrophysical objects exactly stationary in the cameras and spectrographs, relative to everything that is moving.

The primary mirror is made of 91 identical 1-m hexagonal polished and coated glass segments. Because of nightly temperature variations, the steel structure behind the mirrors constantly tries to pull the mirror out of shape. To compensate for this, an ingenious system of sensors was recently installed in between all the mirror segments. These sensors keep track of the tiny movements and after solving a massive mathematical problem the system sends commands to every segment to compensate for these distortions, resulting in crisp images at any time. Even so the mirror is 'aligned' every week or so. This is done with the help of a laser shining down to the mirror from the tower standing next to SALT. The operators then make sure that the return spots from each segment of the mirror fall on top of each other.

Who owns SALT?

SALT is owned by an international consortium of about a dozen research institutes and countries. South Africa is the largest partner, with about a third of the ownership and observing time on the telescope. Other major partners come from Poland, the University of Wisconsin, Dartmouth College and Rutgers University in the United States, together with several smaller share-holders from India, UK, New Zealand and the USA.

SALT's mission statement calls for a world-class research facility provided cost-effectively for the astronomical community, and to lead the advancement of optical astronomy on the African continent, while training and educating young scientists and engineers.

How is SALT operated?

In traditional professional astronomy, an astronomer from a research institute or university would arrive at an observatory and use a telescope, gathering data, and then go back home to analyse these data. SALT operates differently. It is much safer and more efficient for dedicated staff to operate these giants of technology. The South African Astronomical Observatory (SAAO) is tasked with operating SALT. This SALT operations team is made up of about 30 people, of whom 10 are astronomers, and the rest engineers, technicians and software professionals.

SALT is an exciting work environment because of the constant need to innovate and come up with new and more efficient solutions to problems ranging from the mechanical and electronic, to optical and software engineering, and obviously astronomical. Professionals from these various fields, as well as trainees, students, and interns, work to keep SALT up and running every night of the year.

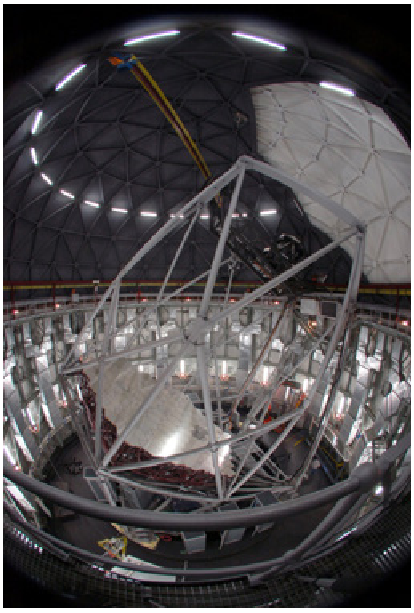
During the day the SALT dome and control room and offices are busy with many people undertaking development tasks to constantly improve the system, and to make sure the telescope is ready for the night of observing.

At night SALT appears to quieten down, at least superficially. The dome is dark and open under the vast and silent African sky. Only two people are left in the control room to do the actual observing, an astronomer and a telescope operator. The process of gathering faint light arriving from our own solar system, or from the farthest reaches of the cosmos, or anywhere in between, can be intense since the observers do not want to lose any photons or waste any time. But it is always fun and exciting, with music usually filling the room as they stay until the sun rises, and the day crew takes over again.

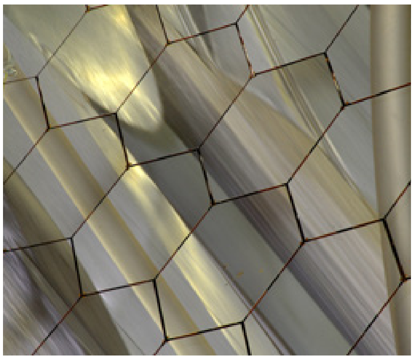
The spectacular southern Milky Way looms over the SALT dome on a beautiful, moonless Karoo night. Kevin Krause

A panoramic view of Sutherland and SALT. SALT

Members of the Technical Operations team look on with interest as the SALT astronomers resume science observations following an extensive overhaul of the telescope and instruments throughout the month of August. Lisa Crause



This wide-angle view of the inside of the SALT dome shows the 80 ton telescope at its fixed elevation of 37 degrees from the vertical. The white section of the roof is the dome shutter that slides open to allow starlight to reach the primary mirror array. The light is brought to a focus at the tracker (the black bridge at the top of the telescope), where the secondary optics and instruments are located. Lisa Crause



The hexagonal SALT primary mirror segments are a metre in diameter. Their individual mounting assemblies include three actuators, allowing each segment to be positioned to extraordinary accuracy to maintain the alignment of the entire 91-mirror array. Lisa Crause

On any given clear night the observers, who rotate through week-long night shifts, typically gather data from between 10 to 20 different astronomical sources. The observations of the night are saved on hard disks at multiple locations, transferred to Cape Town by the morning, and then processed with software developed by the team, and distributed. There are astronomers around the world studying particular astrophysical topics who ask for these SALT observations, and who get their data-sets on their laptops or desktops at their home institutes the morning after the observations without having to travel anywhere.

What does SALT see?

SALT is a large telescope. People often ask 'How far can it see?'. Well, that's always a bit tricky for an astronomer to answer in a simple way, since it depends on what you are looking at – you may be looking at a bright object far away, or a faint object closer by, and both would be equally challenging. Of course, the more distant a given type of an object is, the farther out you can still detect it with a progressively larger telescope. That's why our understanding of the size of the known Universe has essentially grown with the use of the large telescopes.

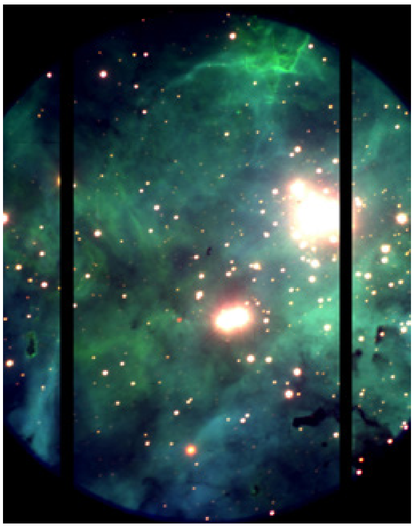
Because of the time it takes for light to travel, looking far into the Universe is also looking into the past. SALT has observed distant quasars, the light from which started to travel towards us when the Universe was just 2 billion years old, instead of the 13.7 billions years it is now. That is very, very far. For comparison, most of the stars you see on the sky every night are just tens or hundreds, sometimes thousands, of light-years away. If you know where to look for the Andromeda galaxy (easier the closer you are to the equator) this is the furthest away you can see with your naked eye – about 2.5 million light-years.

A light-year is a unit of astronomical distance that is equivalent to the distance that light travels in one year, which is 9.4607 x 10^{12} km (nearly 9 trillion km)

A more accurate question would be 'what are the most faint targets that SALT can see?'. The larger the telescope, the fainter the objects it can detect, since the more photons, or light particles, it can collect in a given time. In addition, with telescopes and their associated cameras you can keep collecting the light for long times, equivalent to leaving a bucket out in the rain of faint light. Your eye and brain cannot do it. You see the world instantaneously (or, in something like 10 – 20 millisecond chunks actually). Because of its size, *and* the long-exposure ability, SALT can see objects that are billions of times fainter than our naked eye can detect.

And there's still more to it. In astronomy *resolution* is essential. It is important that things can be resolved, or distinguished from each other, and this also depends on the size of the telescope. For example, with good eyes you would perhaps be able to say that the headlights of a car are two separate lamps from a 3 km distance. SALT could do it from 400 km away – and in fact that's just because of the annoying blurring effect of our turbulent atmosphere, something astronomers call the 'seeing'. If this blurring is corrected for (and many large telescopes are starting to have this capability, called adaptive optics), the distance to distinguish those headlights would be close to 10 000 km for SALT.

So far the discussion has been centred on images a telescope takes, but in fact the great majority of actual science done with SALT is in the form of *spectroscopy* (see 'How do we know what we know?'.) SALT has three instruments, one of which is an imaging camera (SALTICAM), which can also be used essentially as a video-camera to capture high-speed phenomena happening in very rapid timescales in Universe, typically around such exotic objects as black holes or neutron stars or white dwarfs. But the other two instruments are both spectrographs, the Robert Stobie spectrograph (RSS) and the high-resolution spectrograph (HRS), which both have various modes of operation. The spectrographs break up light, extremely accurately, to its different colours, or wavelengths – think of a raindrop and a resulting rainbow as a very crude spectrograph. Studying the resulting spectrum carefully, a huge amount of information can be gained, starting from the chemical composition of the target being observed, to its motion, mass, pressure, temperature, and so on. Most of the information obtained about the Universe, its size and what it is made of, and how stars work and evolve, over the past century and a half has been through spectroscopy. (See 'A night in the life ...)



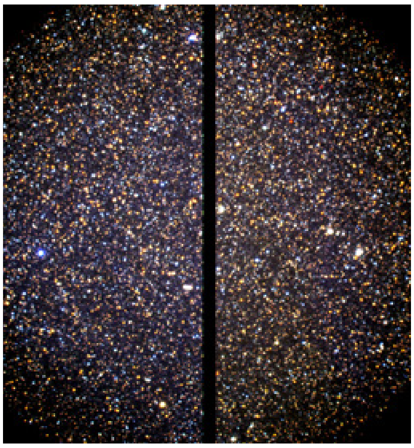
Colour composite image of the inner part of the Carina Nebula taken by the RSS instrument on SALT. The bright group of stars to the right is Trumpler 14, a young open star cluster inside the nebula. The hot stars in the cluster excite the surrounding clouds of gas, different colours coming from glowing hydrogen and oxygen. SALT

What has SALT discovered?

Over the past few years of science operations, astronomers both in South Africa and elsewhere have made a number of exciting discoveries. Often astronomers work in groups and also use other telescopes or instruments to study the same sources, putting together the information from the different angles in an effort to understand the nature and physics of the objects being studied. Below are just a few examples of studies and discoveries that have utilised SALT for their results.

Stellar neighbours and close shaves

Scholz's star is a small, dim red dwarf star in the constellation of Monoceros, about 20 light-years away. Its formal designation is WISE J072003.20-084651.2 but it is nicknamed 'Scholz's star' after the person who discovered it in 2013. A team of South African and international astronomers observed the star with SALT, and it was found to be a dim, red binary star system.



Colour composite image of a crowded star field in the Large Magellanic Cloud (one of our nearest neighbouring galaxies) observed with SALT's imaging camera, SALTICAM. The different colours of the stars indicate their relative temperatures, the blue/white ones being the hottest at tens of thousands of degrees and red indicating the coolest ones, at just a couple of thousand degrees. SALT

But its most remarkable characteristic turned out to be its past. Using its present motion determined from the SALT spectra, and images from elsewhere, the team found it had actually come close to our solar system only 70 000 years ago. At closest approach it was just 0.8 light-years away, showing that it travelled through the Oort Cloud of trillions of comets in the outer parts of our solar system at a velocity of 90 km per second.

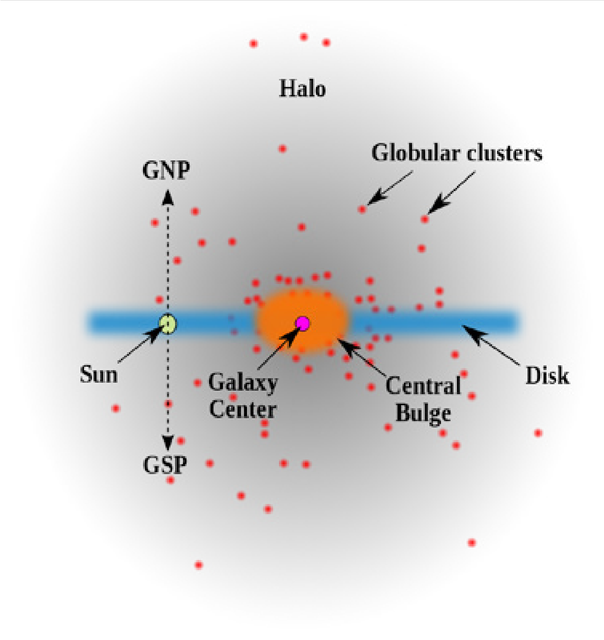
The Oort Cloud is a theoretical cloud of solid objects which is thought to surround the Sun to as far as between 0.8 and 3.2 light-years. The outer limit of the Oort cloud defines the cosmographic boundary of the solar system

This is the closest known stellar flyby to date. It is potentially very significant, since it is thought that perturbations of the Oort Cloud may trigger comet showers down to the inner parts of our solar system. These, in turn, can increase the probability of comet impact on Earth potentially causing extinction events as has happened several times in Earth's history. In this case, the group found from their calculations, that the perturbation is too small to result in comet showers. It remains a very interesting coincidence that a stellar object would visit us so recently. Statistics would have said it happens once in about 10 million years. Perhaps we do not understand the dim cool population of stars well enough yet and there might be others to be found.

Indeed, in a similar field of research, just the year before, a group of astronomers using SALT characterised a newly discovered object, and found it to be a pair of extremely red and cool objects called brown dwarfs. These are objects that have failed to light up as stars, because nuclear fusion reactions haven't started because they have too little mass. This object was just 2 parsecs away, or about 7 light-years, making it the third closest stellar neighbour to our solar system, after the Alpha Centauri system. This system contains Proxima Centauri, found 100 years ago from South Africa, and now featuring the closest known Earth-sized exoplanet and Barnard's star, also found a 100 years ago.

Flaring Milky Way

Using both SALT and a smaller infrared



A profile of the Milky Way showing the distribution of stellar bodies. Wikimedia Commons

An artist's impression of the record-breakingly powerful, superluminous supernova ASASSN-15lh as it would appear from an exoplanet located about 10 000 light-years away in the host galaxy of the supernova. Bejing Planetarium/Jin Ma

telescope, the IRSF in Sutherland, South African and Japanese astronomers discovered the very first known stars in the flared disk of our Milky Way galaxy. These stars are situated on the far side of our Galaxy, 80 000 light-years from the Earth and beyond the Galactic Centre.

This discovery is important because stars like these will allow astronomers to test theoretical ideas about how galaxies, like the Milky Way in which we live, formed. In particular these stars, which are close to the effective edge of the Milky Way, will help astronomers trace the distribution of the very mysterious dark matter. Dark matter is known to be an important component of all galaxies, but its nature and distribution remain elusive.

The five stars involved in this discovery are known as Cepheid variables, whose brightness changes regularly on a cycle time of a few days. These Cepheid variables have characteristics that allow their distances to be measured accurately.

The majority of stars in our galaxy, including our own sun, are distributed in a flat disk.

Early in the 21st century radio astronomers discovered that hydrogen gas, of which the galaxy contains a great deal, flared away from the disk at large distances from the Galactic centre, but until now no one knew that stars did the same thing. The study was published in the prestigious science journal *Nature*.

Brightest supernova

Stars are born, they live, and they eventually die. One of the spectacular ways stars die, is in a supernova explosion. Measuring distances to these supernovae is important for both understanding the life cycle of stars, and also because these explosions can be seen so far into the distant Universe that they can be used as measuring sticks to understand the fate and shape of the Universe itself.

One recent supernova explosion was special. A collaboration of telescopes, including SALT, unveiled a cosmic explosion about 200 times more powerful than a typical supernova, events which already rank among the mightiest outbursts in the Universe. It was more than twice as luminous as the previous record-holding supernova.

To prove the record-breaking nature of this supernova explosion, its distance had to be established. This was achieved with spectroscopic observations taken by RSS on SALT. At its peak intensity, the explosion, called ASASSN-15lh, shone with 570 billion times the brightness of the Sun. This level is approximately 20 times the entire output of the 100 billion stars comprising our Milky Way galaxy. ASASSN-15lh is among the closest superluminous supernovae ever found, at around 3.8 billion light-years away. Given its exceptional brightness and closeness, ASASSN-15lh might offer key clues in unlocking the secrets of this baffling class of celestial detonations. One of the best hypotheses is that superluminous supernovae's stupendous energy comes from highly magnetised, rapidly spinning neutron stars called magnetars, which are the leftover, hyper-compressed cores of massive, exploded stars. But ASASSN-15lh is so luminous that this compelling magnetar scenario falls short of the required energies. Instead, ASASSN-15lh-esque supernovae might be triggered by the death of incredibly massive stars that go beyond the top tier of masses most astronomers would speculate are even attainable.

Stellar evolution – LBVs and planetary nebulae

One sees supernovae after they explode. But to understand the physics going on, it is invaluable to also find stars that are likely to explode in the future. Out of the billions of stars mapped in our skies, only 16 are confirmed as luminous blue variables (LBVs) – and they are of interest to astronomers because they are stars which may soon die and blow apart in a supernova explosion.

A group of astronomers using SALT has recently found new, incredibly rare additions to this group of LBV stars. One of them is WS1, which the group identified as a possible LBV using the infrared Spitzer space telescope images, which showed that it is surrounded by a circular shell of material. This prompted them to make follow-up optical observations of the central star using SALT. They obtained a spectrum of the star and found features typically associated with LBVs. They then needed to observe the star over a long time period from 2011 to 2014 to confirm whether its variability in brightness and in its spectral features matched that expected from an LBV. This was done with both SALT and the SAAO 1.9-m telescope, and combined archival data spanning 40 years. They found that WS1 did indeed exhibit all the observational characteristics of a LBV-type star and concluded that WS1 is an incredibly rare LBV star.

Recently, it has become clear that some central stars of planetary nebulae, the hot stars responsible for keeping the lights on in these 'neon signs' of astronomy, are actually binary systems that have another hot star as a companion. Many of these systems cannot be found unless their influence on the companion is unveiled by monitoring the Doppler motions of the central star with repeated spectroscopic observations. The shape and movement of the nebula gas in NGC 5189 told the research group there was a high probability there was a binary present, so they set out to test the binary hypothesis once and for all. Over three months in 2014 SALT's giant eye was turned on the central star of NGC 5189 to see whether there was a stellar companion tugging the central star to and fro. A clear sign that a hot star orbited the central star every 4.04 days was found. Especially satisfying was the fact that this is only the second such binary in a planetary nebula where the visible central star belongs to a rare class known as Wolf-Rayet stars – stars renowned for their strong stellar winds (2 500 km per second in this case). The group plans to continue the search for similar binaries with SALT to help better understand how these unique stellar systems sculpt their surrounding nebulae.

How SALT is contributing to the world of astronomy

Overall, there are currently about 150 published articles in the international professional astronomical journals that have used data from SALT. Approximately half of these have been driven by South African astronomers. This trend in the rate of publications has been on par with other international large telescopes counting from the time that they have started science operations.

What is also interesting is that when compared with the operating costs of other large facilities, the SALT science productivity is extremely cost-effective, showing that even with a small team faced with many constraints, if motivated and talented, they can help output world-class science.

In addition to the science and new discoveries that South African and international astronomers produce and publish using SALT, its central mission is to provide a training ground for the development of a local community of scientists and engineers, and quite simply to participate in the development of the local South African community, scientists or not. This is done as part of numerous community and educational initiatives (see Astronomy and sustainable development). Q

Dr Petri Vaisanen is the Head of SALT Astronomy Observations, and his own research concentrates on galaxy evolution.

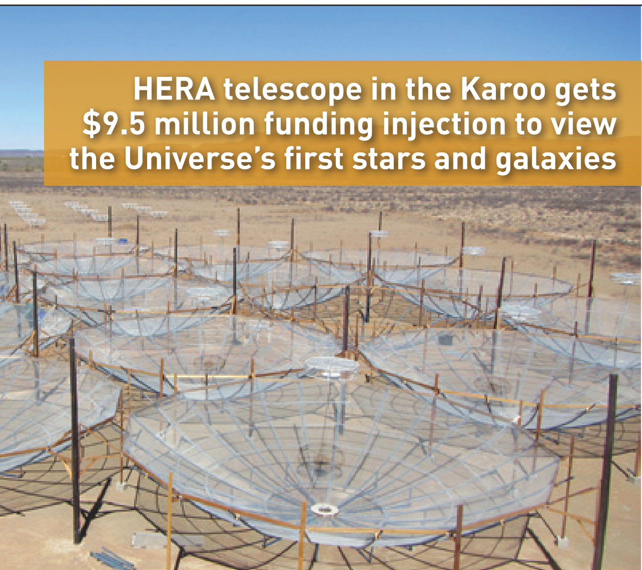
An example of a luminous blue variable, as seen by the Hubble Telescope. Hubble Telescope via Wikimedia Commons

Curriculum corner

Geography grade 10 – 12

Geographical information systems (Gis)

- GIS concepts: remote sensing, resolution
- Spatial and attribute data; and vector and raster data
- Data standardisation, data sharing and data security
- Data manipulation: data integration, buffering, querying and statistical analysis
- Application of GIS by government and the private sector
- Relate to all topics in Grade 12
- Develop a 'paper GIS' from existing maps, photographs or other records on layers of tracing paper



HERA telescope in the Karoo gets $9.5 million funding injection to view the Universe's first stars and galaxies

The Hydrogen Epoch of Reionisation Array (HERA) brings more international funding to South Africa with a $9.5 million investment to expand its capabilities, as announced by the US National Science Foundation (NSF) recently. HERA is located only a few kilometres from the MeerKAT radio telescope. The First Light image from the first 16 antennas of MeerKAT was announced by the Minister of Science and Technology Naledi Pandor in July 2016.

HERA, which was recently granted the status of a Square Kilometre Array (SKA) precursor telescope, currently has 19, 14-metre radio dishes at the SKA South Africa Losberg site near Carnarvon. These will soon be increased to 37. The $9.5 million in new funding will allow the array to expand to 220 radio dishes by 2018.

This innovative telescope aims to detect the distinctive signature that would allow astronomers to understand the formation and evolution of the very first luminous sources: the first stars and galaxies in the Universe.

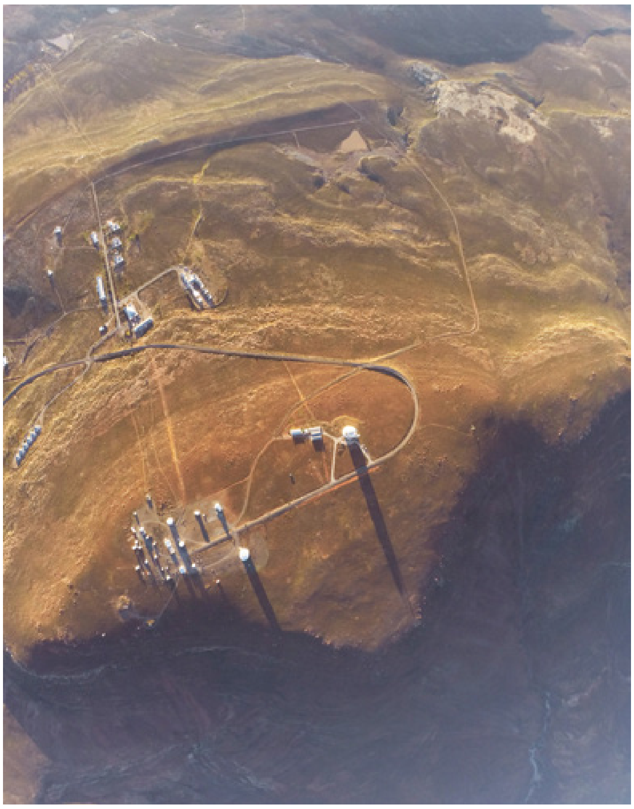
For more information on MeerKAT and HERA, visit www.ska.ac.za

science & technology
Department: Science and Technology
REPUBLIC OF SOUTH AFRICA
NRF National Research Foundation
SKA
SKA AFRICA

A night in the life...

Lisa Crause describes the instruments that allow SALT to explore the Universe

The Earth is revolving around the Sun and rotating about its axis as everything on the Earth's surface goes on. But all the while, light from every object in the Universe is streaking along at 299 792 548 metres per second and just waiting to be intercepted and analysed. So as darkness descends on our small scientific outpost in the Karoo, the SALT operator (SO) and SALT astronomer (SA) on duty open up the dome and prepare the largest optical telescope in the southern hemisphere for another night of science observations.

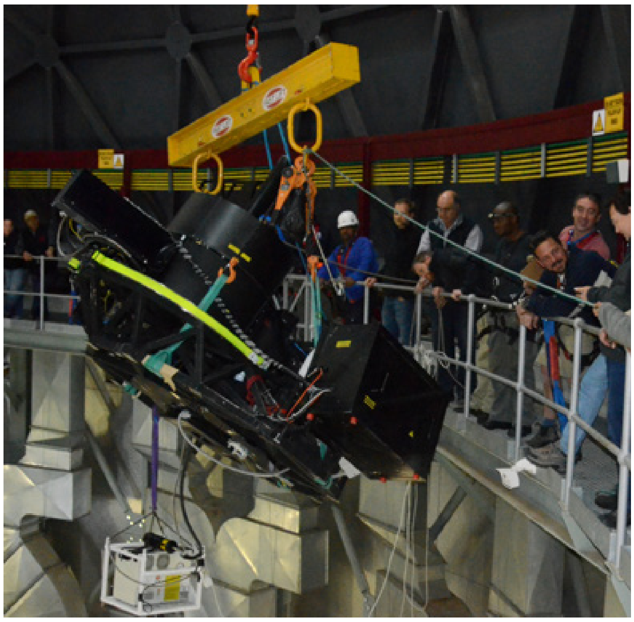


An aerial perspective of the observatory in Sutherland, showing the many facilities on the hilltop. Anthony Koeslag, taken with a GoPro camera attached to a small quad-copter.

A night's work begins

The building has been air-conditioned all afternoon so the telescope chamber is close to the outside temperature predicted for an hour after sunset. The crew point the telescope to the tall tower next to the dome to align the 91-hexagonal 1-m mirror segments that make up the 11-m primary mirror array. This alignment process used to be carried out several times a night before the new inductive edge sensors were installed a few months ago. These sensors are immune to humidity variations and so do a fantastic job of keeping the individual mirror segments optimally aligned. Consequently, SALT now produces beautifully sharp, stable images through the course of the night, and even for several consecutive nights before a re-alignment may be required.

Some calibration data are taken during twilight, but once the sun reaches 18 degrees below the horizon, the clock starts ticking – loudly! SALT's operating cost is approximately R100/minute, so there is no time to waste. The SA consults the database containing all the targets to be observed during the semester and decides which block (the smallest schedulable unit of an observation) will be the most appropriate based on various competing considerations like the sky conditions and what is accessible to the telescope. A target is selected and its celestial coordinates are sent to the SO, who commands the telescope to the appropriate right ascension (longitude) and declination (latitude) on the sky.



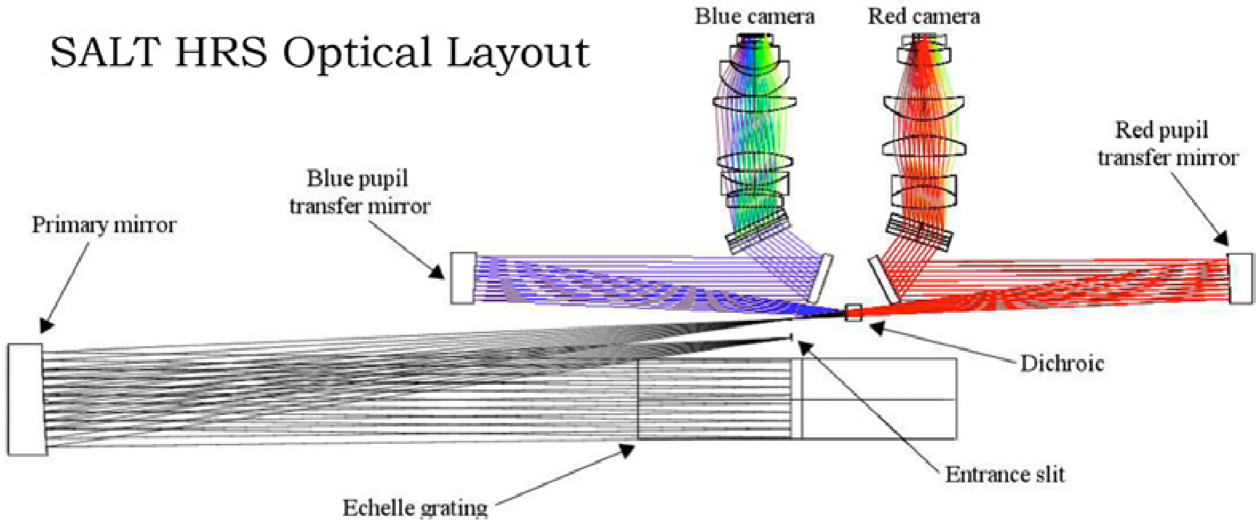
The SALT operations team watches the RSS being lifted back up to the tracker with the dome crane following the August overhaul of the instrument. Lisa Crause

The 85-ton structure lifts up – hovercraft-like – on a cushion of air and rotates to the required azimuth.

> In astronomy, the aszimuth is the direction of a celestial body from an observer – also called the 'bearing'.

Once the telescope has been positioned, the air is released and the structure is set down on the extremely flat and level concrete pier. It is then over to the tracker, the large bridge that spans the top end of the telescope and carries the payload, to follow the object as it arcs across the zone that SALT is able to observe in. The length of a track ranges from about one to three hours, depending on the location of the target in the sky. Regions in the south (with declinations around -70°) and near the celestial equator (declination 0°) in the north offer relatively long, single tracks. Intermediate declinations have two shorter tracks, one in the east and one in the west.

The payload, which carries the telescope's secondary optics,

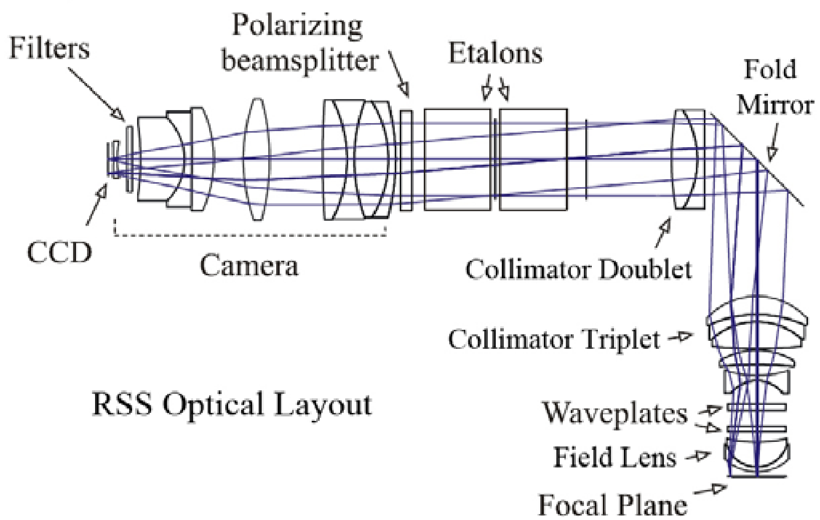


The optical layout of the HRS shows light entering the spectrograph at the slit, being collimated onto the grating by the primary mirror, then reflecting off the primary again en route to the dichroic. The dichroic splits the light into red and blue halves that proceed independently to their respective cameras. The two arms allow all of the optical elements and the detectors to be optimised for their respective wavelength ranges. SALT

most of the science instruments and various other critical subsystems is positioned where the light from the primary mirror comes to focus. The whole tracker bridge can move left/right (in the X direction) and the payload can be moved up and down the bridge, in the Y direction. The 1 400 kg assembly is supported by a hexapod that allows everything to be adjusted in tip, tilt and piston/focus (in the Z direction), while the rho stage allows the payload to be rotated clockwise/anti-clockwise. All of these degrees of freedom are necessary for the telescope to be able to follow the image of the target as the Earth's rotation carries the sky over from east to west.

Once the telescope has slewed to the required position and begun tracking, the SO and SA need to acquire the target. The photons entering through the open dome shutter strike the primary mirror segments (M1) and then reflect into the spherical aberration corrector (SAC), the 'optical washing machine' at the bottom of the tracker. There the light bounces off each specially figured mirror in turn: M2, to M3, to M4 and lastly to M5 in order to remove the spherical aberration introduced by the primary mirror segments. The next optic encountered is the atmospheric dispersion compensator (ADC) located just above the SAC, which corrects for the way the atmosphere differentially bends light depending on its wavelength (colour). Only after passing through the SAC and the ADC does the light arrive at the main intersection within the payload where its destination is decided. It can either be allowed to pass straight through to enter the telescope's main instrument, the Robert Stobie spectrograph (RSS), or be deflected in any of three directions by a pair of fold mirrors to either go to SALTICAM, the high-resolution spectrograph (HRS) or the Berkeley visible imaging tube (BVIT).

The acquisition process relies on SALTICAM, which is used to identify the object of interest by comparing an image of the



The Robert Stobie spectrograph (RSS) has an extremely complicated optical path. A beam of light needs to negotiate at least 21 optical elements (and typically a few more depending on which mode is being used) on its way through the spectrograph. The process begins at the lower right, at the telescope's focal plane, and ends at the upper left, at the RSS detector system. SALT

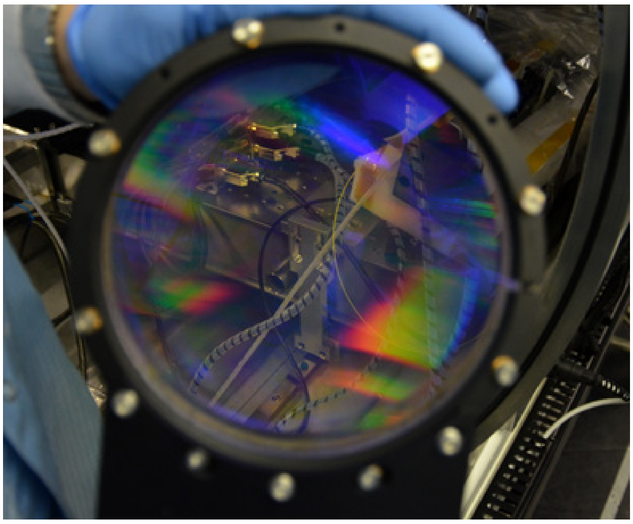
This collage shows various aspects of the high resolution spectrograph (HRS), including the 3-m long vacuum tank that encloses the optical bench, the red and blue camera units, the echelle grating and the numerous large mirrors and lenses. One needs to put on clean-room gear before working inside the tank as any contamination would compromise the integrity of the vacuum that shields the optics from thermal disruption. Lisa Crause

star field to a finder chart. The SO then positions the target on the relevant fiducial and the SA configures the required instrument using information for that specific observation from the proposal database. Once everything is correctly set up, the fold mirrors are flipped to direct the light to the instrument. For a spectroscopic observation, fine adjustments are made to accurately place the target on either the RSS entrance slit, or the HRS fibre face before a guide star is selected (to provide fine positional corrections to keep the telescope tightly locked on the target). The shutter is then opened to allow light from the object to pile up on the instrument's digital detector while the exposure time ticks down. When the shutter closes again, the image is read out and the data quality is checked, the necessary calibration frames are taken and the next target is cued. Summer nights are relatively short, but in the middle of winter this can go on for up to 13 hours a night – weather permitting!

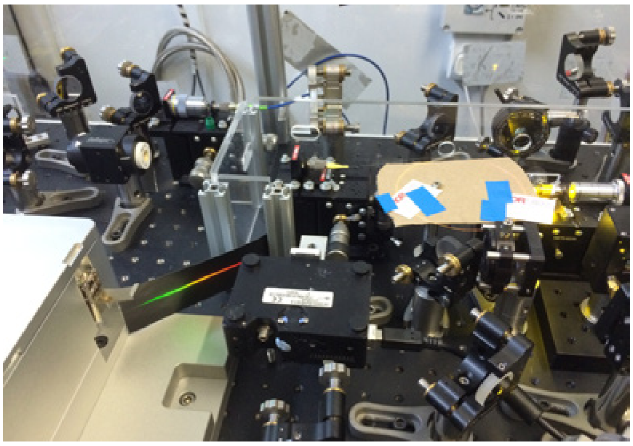
SALTICAM and BVIT are both imagers, but with very different operating modes. SALTICAM serves as the telescope's acquisition and imaging camera, since it has a field of view almost a third the diameter of the full moon. The data get recorded on two 2k × 4k charge coupled devices (CCDs) which are separated by a small gap. A range of filters allow light of specific wavelength ranges to pass through to the detector and colour images can be produced if frames are taken through different filters. The instrument also has two high-speed modes: frame-transfer and slot-mode. These allow high time resolution observations for studying rapidly varying objects such as pulsating stars and interacting binaries. BVIT has a much smaller field of view, but allows yet higher time resolution than SALTICAM. Although this instrument is not used often, it tends to yield significant results whenever a suitable target is available.

The workhorse SALT instrument is the RSS – the Swiss Army knife of spectrographs, which offers a wide variety of observing modes. The down-side to such an ambitious and hugely complicated instrument is that its complexity leads to operational and maintenance issues. Even the simplest mode of the RSS (long-slit spectroscopy) requires light to pass through 21 different optical elements, several of which consist of large crystals of exotic optical materials like calcium fluoride and even sodium chloride, before reaching the mosaic of three 2k × 4k CCDs. The more specialised modes like Fabry Perot spectroscopy and spectro-polarimetry involve yet more intricate optical assemblies such as etalons, a polarising beam-splitter and a set of waveplates. As a result, the SALT operations team had to get to grips with every aspect of this more than 650 kg problem child in order to tackle its many intricate and temperamental sub-systems. While this has presented its fair share of frustrations over time, it has also been enormously educational. The RSS now gets removed from the telescope and given an extensive overhaul every two years. This improves the performance and reliability of the many mechanisms and servicing the optics maintains the spectrograph's throughput. We also have a new addition to look forward to in years to come, in the form of a near-infrared arm for the RSS. This will allow SALT to do spectroscopy at longer (redder) wavelengths and will open up new research opportunities for astronomers in the international SALT partnership. Of course the new hardware will also bring new challenges, but we will learn from those as well.

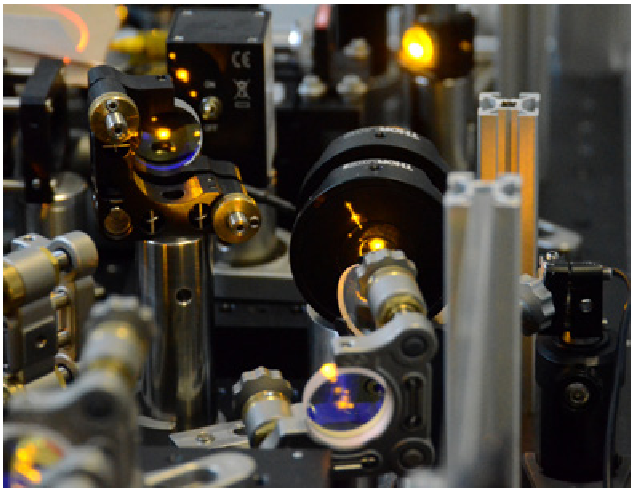
SALT's HRS occupies a totally different corner of parameter space. It is a relatively simple instrument in mechanical terms,



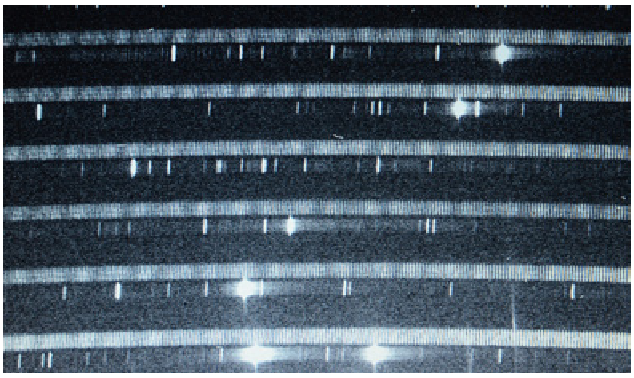
A glimpse of the HRS optical bench viewed through one of the volume phase holographic gratings used to split the light up on its way through the instrument. Lisa Crause



The laser frequency comb ultimately produces a super-continuum (the beautiful bright spectrum cast on the black strip) which actually consists of many thousands of individual laser spots. That light is directed into the HRS and dispersed by the spectrograph optics to produce an extremely comprehensive and superbly stable set of calibration features with which to map the wavelength scale of the HRS. Éric Depagne



A close-up view of the many optics that steer the laser beams around to produce the laser frequency comb. Lisa Crause



A calibration image taken with the red camera of the HRS, showing the comparison between the uniform laser frequency comb features and the thorium argon arc lamp lines that are sparse, irregularly spaced and variable in terms of brightness. Lisa Crause

with only four moving parts. But because the HRS stretches the light out far more than the low-resolution RSS does, the instrument's fundamental requirement is stability. HRS's stunning optics need to be shielded from the disruptive influence of temperature and pressure fluctuations, as well as vibrations and other mechanical perturbations, so that spurious signals do not swamp the impossibly small variations we seek in order to detect exoplanets, for example. This is similar to the difficulty of using a long zoom lens or high-power binoculars – to avoid blurred images, the camera and binoculars have to be held extremely still. So while the RSS can happily ride atop the tracker and not have its data be compromised, the HRS is nowhere near as adventurous. It needs to sit very quietly in a carefully controlled environment if it is to successfully complete its demanding assignments.

The HRS optics are bolted to a heavy optical bench that is kept under vacuum inside a 3-m long steel tank. The tank rests on pneumatic isolators to damp out any vibrations before they can reach the optics and disrupt the light path. An insulating igloo made of interlocking styrofoam bricks surrounds the tank and is itself located inside a temperature-controlled enclosure within the spectrometer room, below the dome floor. Light collected by the telescope is conveyed to the HRS via a 50-m long optical fibre cable that is safely routed from the tracker, along the telescope structure and down through a hole beneath the primary mirror truss to the spectrometer room below. The fibres are essentially long glass pipes, half a millimetre or less in diameter, that light bounces along by the process of total internal reflection. The cable consists of four pairs of individual fibres (+ a complete set of spares!) that feed different modes of the spectrograph, each of which has certain adaptations to suit specific science objectives.

Depending on the mode selected for a given observation, the star is positioned on the face of the appropriate fibre in the payload. The light pours out the other end (inside the vacuum tank) and passes through various small lenses that adjust the beam before it reaches the instrument's shutter. As the SA starts the exposure on the instrument control PC, the shutter opens and the diverging beam of light strikes the large collimator mirror. The parabolic shape of that mirror makes the light rays parallel after they reflect from the surface. That collimated beam then encounters the enormous (>70 kg) diffraction grating that splits the light into its component colours. The dispersed light leaves the grating and travels back to the collimator, which focuses the light just in front of the dichroic – an optic that splits the image into

The SALTICAM lens barrel showing reflections from each of the optical surfaces in the system. Lisa Crause

'red' and 'blue' components. Dividing the wavelength range in half allows the optics and detectors to be optimised to improve the instrument performance over the wide band-pass of the HRS. The red half is actually all of the spectrum redward of green and that light passes through the dichroic on its way to the red camera. The blue half consists of all the light blueward of green, which is reflected by the dichroic and sent in the opposite direction – towards the blue camera. Each arm of the instrument then has a pupil mirror to focus the light, a fold mirror to steer the beam, a volume phase holographic grating to cross-disperse the spectrum, a camera barrel consisting of several lenses (six for the red arm and eight for the blue) to form the image and a cryostat that houses the detector (a 4k × 4k chip for the red and a 2k × 4k chip for the blue). Each HRS exposure thus produces two frames.

While maintaining the stability of the instrument is the key operational requirement, the wavelength calibration process is critical. For the less demanding modes, the arc lamps that are typically used for this purpose (by comparing the emission lines from excited gas inside the lamps, to lists of characteristic wavelengths established in laboratories) suffice. But to take full advantage of the niche capabilities offered by the HRS's high stability mode, particularly in the field of planet-hunting, one needs specialised calibration options for higher-fidelity wavelength solutions. One approach is to obtain an arc spectrum at the same time as the target observation (instead of sometime before or afterwards), by injecting light from a thorium-argon arc lamp into what would normally be that mode's sky/background fibre. Another technique, widely employed in exoplanet studies, is to direct the starlight through an iodine cell. This is an evacuated glass cylinder that contains a small crystal of iodine. The cell gets heated up to sublimate the iodine and that gas results in a dense forest of absorption lines, with accurately established wavelengths, being superimposed on the target spectrum. This provides extremely good wavelength mapping, since the calibration is obtained absolutely simultaneously with the actual data, and using the same fibre.

These are popular methods for high-precision radial velocity calibration, but the state-of-the-art device for the most challenging applications is a laser frequency comb (LFC). This extraordinary instrument produces a spectacularly beautiful 'super-continuum', which visually resembles a continuous spectrum. However, when that comb light is fed into a HRS, the band of colour is stretched to reveal that it consists of thousands of uniquely defined laser spots, each with precisely defined wavelengths. This is superior in every respect to the calibration features from a conventional arc lamp, since it provides about 50 times as many lines, their brightness is fairly uniform and none of them are blended. This yields an incredibly comprehensive, stable and traceable wavelength solution, allowing minute velocity shifts to be measured from the spectra. Recently SALT was privileged to host an experimental LFC built by laser physics researchers at Heriot-Watt University in Edinburgh. That three-month field trial was the first time that such a system was deployed on a 10-metre class telescope and the results are hugely promising. We hope to pursue this collaboration and ultimately work with the Heriot-Watt team to develop a dedicated LFC for SALT's HRS.

SALT is a beacon for science and technology that serves as a fantastic catalyst for scientific, technical and human capital development in our country. We have much to be proud of and even more to look forward to, particularly as we begin planning and developing future instrumentation capabilities, and with new radio facilities like MeerKAT and SKA coming our way. **Q**

Lisa is a Staff Astronomer in the SAAO's instrumentation group, and one of the two South African Directors on the SALT Board. Lisa fell in love with the telescopes in Sutherland when she first visited the observatory during a high school work-shadow programme 23 years ago. She completed a PhD in Astronomy at the University of Cape Town before joining the SAAO in 2006. The practical aspects of building and working with astronomical instrumentation hold her fascination.

Dust lanes near the centre of the Milky Way rise behind the open 74-inch turret. Kevin Crause

Maintaining our second-largest telescope

Keeping Africa's second-largest optical telescope, the historic '74-inch', in business, by **Lisa Crause**

Since astronomers cannot visit stars or galaxies to explore them directly to collect samples to bring back to the lab for analysis, we have to be much craftier in order to extract the information we need to make sense of the Universe. This is why we have telescopes, which are essentially light buckets – designed with the simple purpose of catching more of the photons (the tiny bundles of energy moving at the speed of light) emitted by the countless astronomical sources scattered throughout the cosmos. The bigger the bucket, the more light can be caught and the fainter the objects that can be studied – or the shorter the timescales on which we can study them, to investigate the violent interactions that typically lead to rapid variability.

Africa's Giant Eye – the Southern African Large Telescope (SALT) – naturally commands most of the attention in terms of optical astronomy and the associated resources in the country. Having more than 25 times the collecting area of our next biggest telescope, SALT is unquestionably in a different, and extremely special, league as one of the world's largest optical telescopes. That said, our grand old 74-inch telescope – with its 1.9-m diameter primary mirror (which in its day was the largest in the southern hemisphere), has been in service for nearly 70 years and still has a significant role to play, both scientifically and by virtue of offering excellent student training opportunities.

The 'grand old 74-inch'

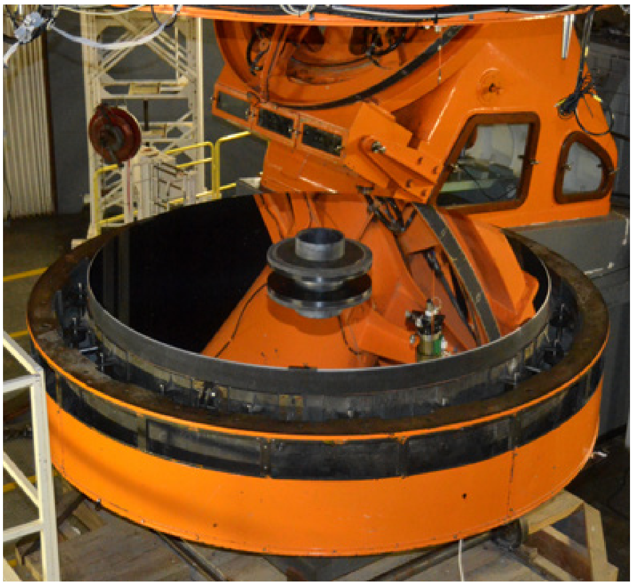
While the observatory's focus has centred on SALT and resolving the various technical challenges that characterised the telescope's early years, the 74-inch has been somewhat deprived of the care and attention it deserves. But with SALT now productively engaged in full science operations, the 74-inch has been able to claim its share of overdue attention and its scientific productivity is increasing as a result. Recent interventions to improve the performance, reliability and accessibility of the 74-inch have concentrated on re-aluminising the primary mirror, developing a new procedure to ensure optimal alignment of the primary and secondary mirrors, replacing the encoders for the drives and introducing a new control system to make the telescope remotely operable. The latter will make it possible for researchers to use the telescope without having to travel to the observatory's Sutherland field station to conduct their observations. This will allow for more flexible scheduling of the telescope and expand the potential user base, all of which will ultimately yield more interesting science.

Overhauling the primary mirror

Successfully aluminising the primary mirror required an extensive overhaul of the more than 50-year-old hardware (including the large steel vacuum tank and the two old diffusion pumps) housed in the aluminising lab below the telescope. The mirror stripping and washing procedures were also updated according to the effective techniques employed at SALT (where individual primary mirror segments are coated every week through the course of the year). Before and after reflectivity measurements on the 74-inch primary confirmed that the fresh coating was vastly superior to the old, severely degraded layer of aluminium – being about 35% more reflective than the old coating.

The new mirror alignment procedure ensures that the telescope delivers good image quality and thus does not waste

The freshly coated 74-inch primary mirror emerging from the aluminising tank. Lisa Crause



Installing the re-aluminised 74-inch primary mirror on the telescope. Lisa Crause

precious light. The improved alignment also ensures that each of the instruments that get attached to the telescope can perform optimally, without being degraded by any mismatches in their optical paths. Having a robust telescope alignment scheme also makes it easier to re-aluminise the downward-facing secondary mirror (which typically gets re-coated much less often than the primary) since it no longer has to serve as the reference for re-positioning the primary after re-coating.

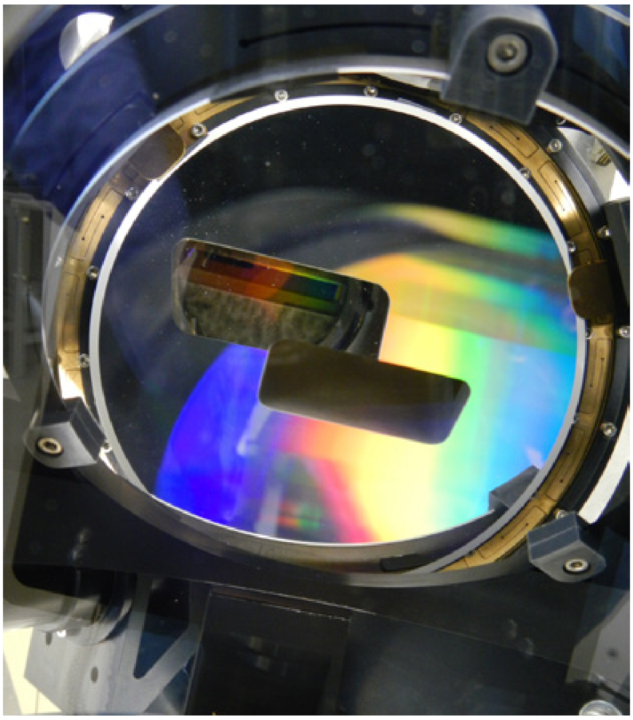
It's not all about collecting light

But merely collecting the light is not enough – the trick lies in then directing it through various types of astronomical instruments to interrogate (and attempt to understand) the celestial objects that produced those photons in the first place. To do the best we can with the light we receive, we need to continually develop more modern, scientifically competitive instrumentation that takes advantage of technological advances. If all we can do is patiently wait for astronomical photons to make their way to us, then we better be ready to make the most of them when they get here! So in astronomy – even more so than in normal life – technology drives progress, and leads to ever more intriguing discoveries. There simply is no other way for us to figure out how and why planets, stars, galaxies, super-clusters and the Universe itself got to be the way they are. Theorists can create models and carry out complex simulations to try to explain how things work, but they still need to check those results against actual observations in order to ensure that their theories remain grounded in some semblance of reality.

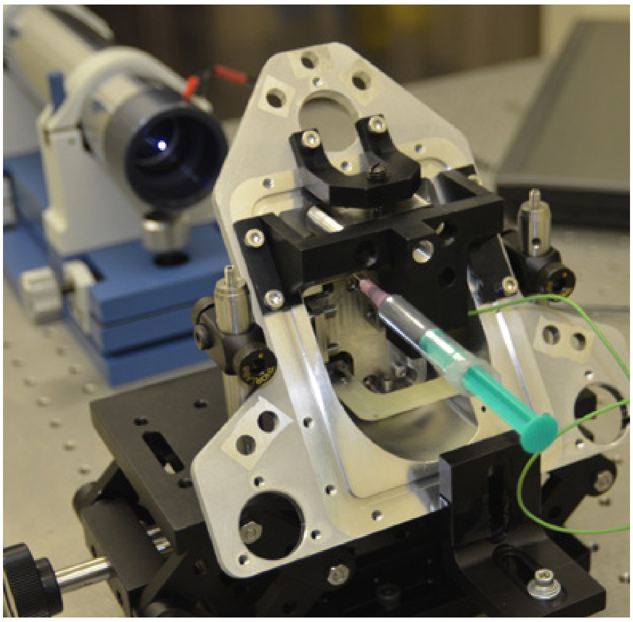
The most versatile tools of the observing trade are spectrographs – the astronomer's equivalent of a surgeon's scalpel. They come in many forms, offering different wavelength ranges, resolutions and data formats. Their design depends on the way in which the light is fed into the optics, and the optics themselves may work in different ways to disperse the light into its component colours. But in essence, a spectrograph takes white light and spreads it out into a band of colour that contains an extraordinary amount of information. That streak of light is captured on a digital detector that gets read out electronically in order to produce an image. The numbers associated with the image then get crunched and calibrated to produce a graph that plots the object's energy output as a function of wavelength – a spectrum. If a picture is worth a thousand words, then a spectrum is surely worth a thousand pictures! These endlessly fascinating graphs allow astronomers to measure all kinds of otherwise inaccessible properties of the objects we observe, like their compositions, velocities, temperatures, densities, pressures, magnetic fields and more. Those measurements in turn enable us to infer yet more remarkable information – such as distances, ages, evolutionary histories and most of the astronomical things that would seem impossible to know.

For four decades, the 74-inch telescope has hosted a low resolution spectrograph at its Cassegrain focus. This workhorse instrument underwent various incremental upgrades over time as detector technology progressed. The earliest version of the spectrograph employed an image intensifier that fed glass photographic plates! These plates would be exposed, typically for many hours, before being developed in a dark room located in the dome. For the past 20 years, the instrument has employed a CCD camera (a specialised digital detector optimised to perform in extremely low light-levels). But the spectrograph's CCD, the optical system and the various mechanical mechanisms inside the instrument were all growing long in the tooth and had become relatively inefficient. An extensive upgrade was sorely needed.

A new optical design for the instrument was developed in the late 1990s and the custom optics were manufactured in the UK. But the mirrors and lenses then hibernated in a cupboard at the observatory for more than a decade while we focused on SALT. Various mechanical and electronic design and manufacturing efforts continued in the background, but only in 2014 (once the other higher-priority tasks had been completed), could the Spectrograph Upgrade project (aka SpUp) command the full attention of the SAAO instrumentation group. The Cassegrain spectrograph was eventually taken out of service in October 2014 to allow refurbishment of the old components that were to remain, and to begin introducing the many new parts. The entirely new section that houses the replacement optics and detector first had to be assembled and optically aligned and tested in the lab in Cape Town before it could be incorporated into the rest of the instrument and the whole ensemble made to work.

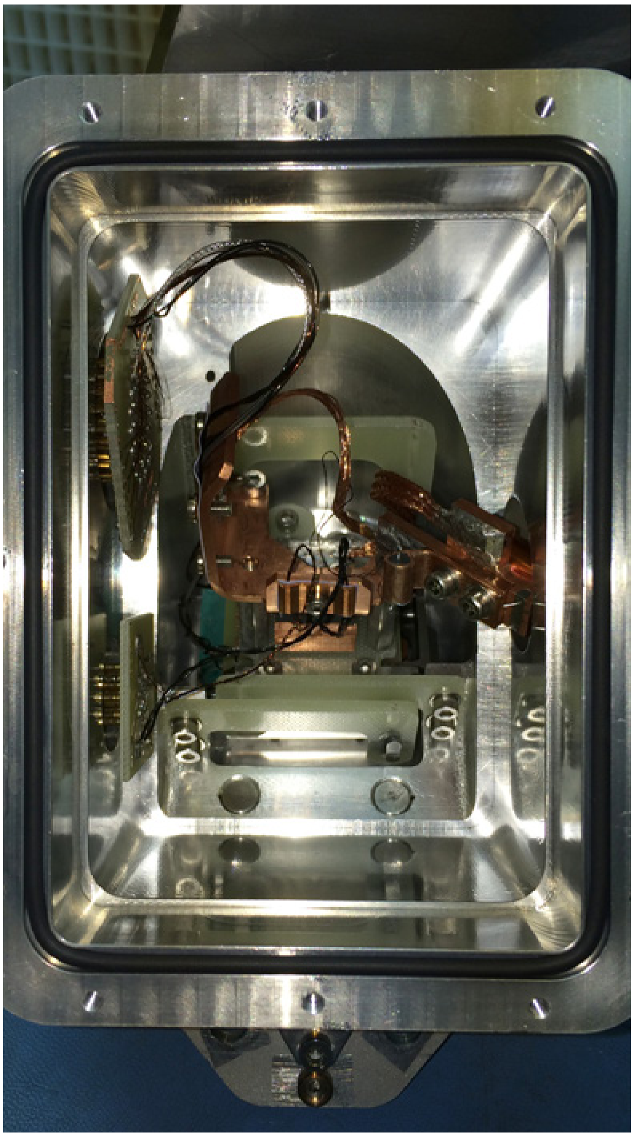


The SpUpNIC camera optics. Lisa Crause

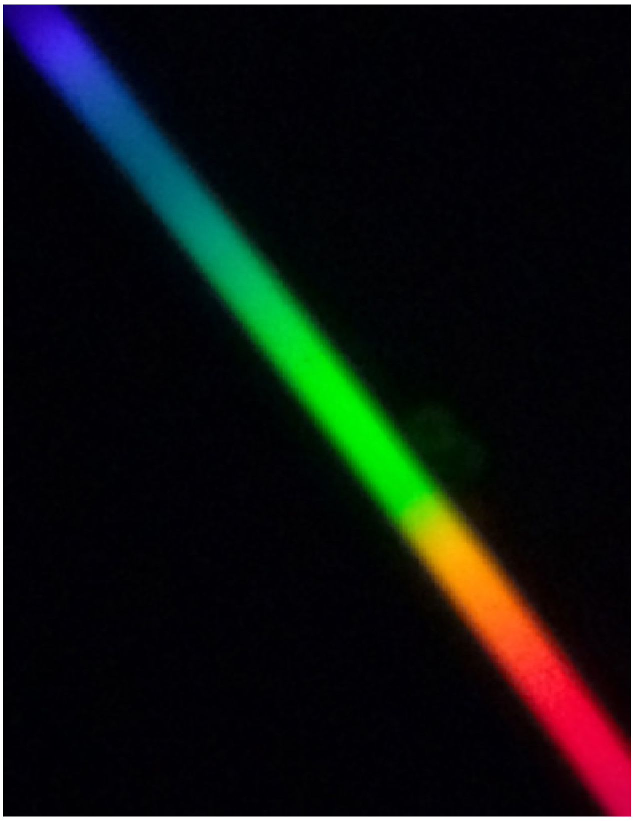


Injecting epoxy to bond the SpUpNIC detector-housing in position after optically aligning the CCD to the cryostat window. Lisa Crause

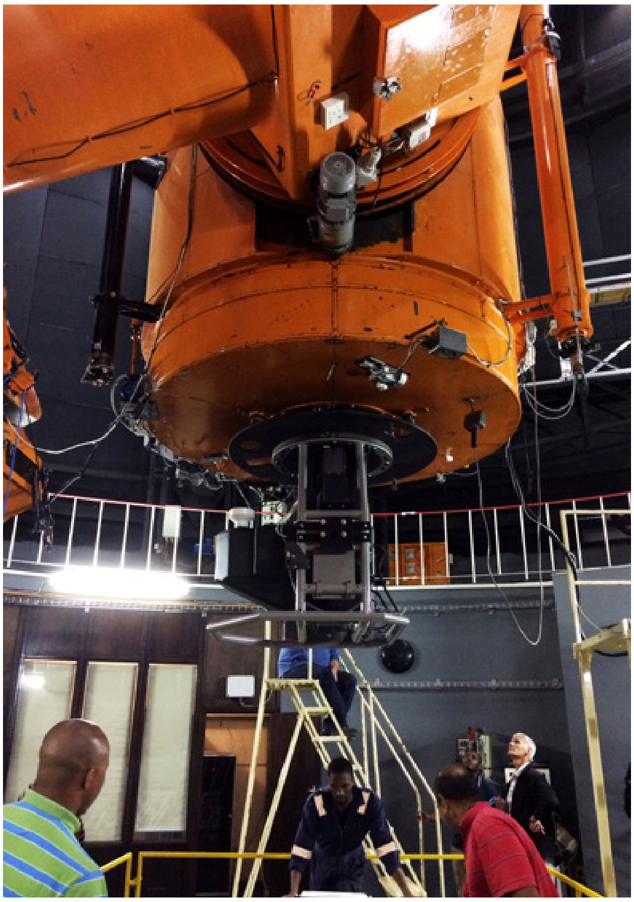
The SpUpNIC grating mechanism components prior to assembly. Lisa Crause



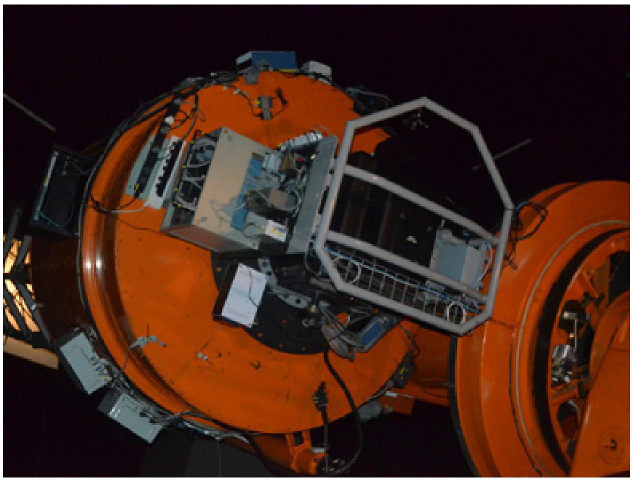
A view inside the cryostat that houses the digital detector (the CCD) for SpUpNIC. Lisa Crause



With the spectrograph optics aligned and white light injected through the slit, the new instrument produced its first spectrum. Lisa Crause



The upgraded Cassegrain spectrograph (SpUpNIC) being installed on the 74-inch on 21 October 2015 - first light was achieved that evening. Lisa Crause



Taking spectroscopic calibration frames with SpUpNIC mounted at the Cassegrain port of the 74-inch telescope. Lisa Crause

Building this 3D jigsaw puzzle was a daunting but amazingly rewarding task. It is misleading to think of a spectrograph as generating rainbows of light. Although beautiful, rainbows are inherently diffuse and untouchable. The blazing bright, rich colours that appear once white light is collimated, diffracted and then focused to yield a spectrum totally defy description – the intensely vivid colours are unbelievably striking and thoroughly mesmerising. Prior to the detector being installed, that ethereal image simply hovered in space above the instrument. Such a pure expression of physics is reminiscent of the fleeting, incomparable moments that define the crux of a total solar eclipse. Once you experience that thrill, you find yourself longing to chase down a few more minutes of totality, and itching to bring another spectrograph to light!

This latest incarnation of the spectrograph is effectively a brand-new instrument, with every sub-system having been extensively improved or completely replaced. The new software is also more robust and user-friendly, all of which contributes to greater observing efficiency and increased productivity. The system was installed on the 74-inch and achieved first light on 21 October 2015. Having confirmed that all was well, the spectrograph was renamed SpUpNIC, for Spectrograph Upgrade: Newly Improved Cassegrain. SpUpNIC has been in regular scientific use ever since and local and international users are delighted with the greatly improved performance of the instrument.

The combination of improving the optical and mechanical performance of the telescope and then equipping it with a productive new spectrograph breathes new life into our treasured Old Orange. Since we aspire to developing ever more powerful astronomical instrumentation, this approach will keep this wonderful telescope going for many years to come! **Q**

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Old telescopes, new software

Carel van Gend shows that old telescopes are still useful

The Karoo town of Sutherland is well-known for its cold winters and for its proximity to the South African Astronomical Observatory's (SAAO) remote observing station. If you had visited the SAAO site in the late 1970s, you'd have seen four domes rising above the arid plains. The telescopes inside had been moved here from their original locations in Cape Town, Pretoria and Johannesburg, to take advantage of the Karoo's dry, clear air and famously dark skies. The telescopes were themselves somewhat older; the main mirror of the 1.9-m telescope was cast in 1938. Throughout their lives the telescopes have been scientifically productive and helped put South African astronomy on the global map.

Visitors to the site today might be impressed by the number of newer domes and associated infrastructure that are now on the observing plateau. In addition to the SAAO's own telescopes, there are a number of hosted telescopes belonging to international research organisations, all taking advantage of what are still some of the world's darkest skies. Towering over the others is the dome of SALT, the Southern African Large Telescope, which stands as a landmark to South African engineering skill and resourcefulness. SALT is one of the world's foremost optical telescopes, and something of which all South Africans should feel very proud.

Old telescopes

But what of the ageing smaller telescopes? Should we abandon them, and concentrate our efforts on developing the newer instruments? Our answer is an emphatic no. The older telescopes remain useful: Sutherland is still an excellent site for astronomy, the optics of the telescopes are still good, and often a small and nimble telescope is preferable to a larger telescope. There are a great many interesting targets which are either too bright for, or inaccessible to, telescopes like SALT. Additionally, observing time on SALT is heavily oversubscribed, so the availability of the smaller telescopes makes them attractive to astronomers wanting to undertake extended

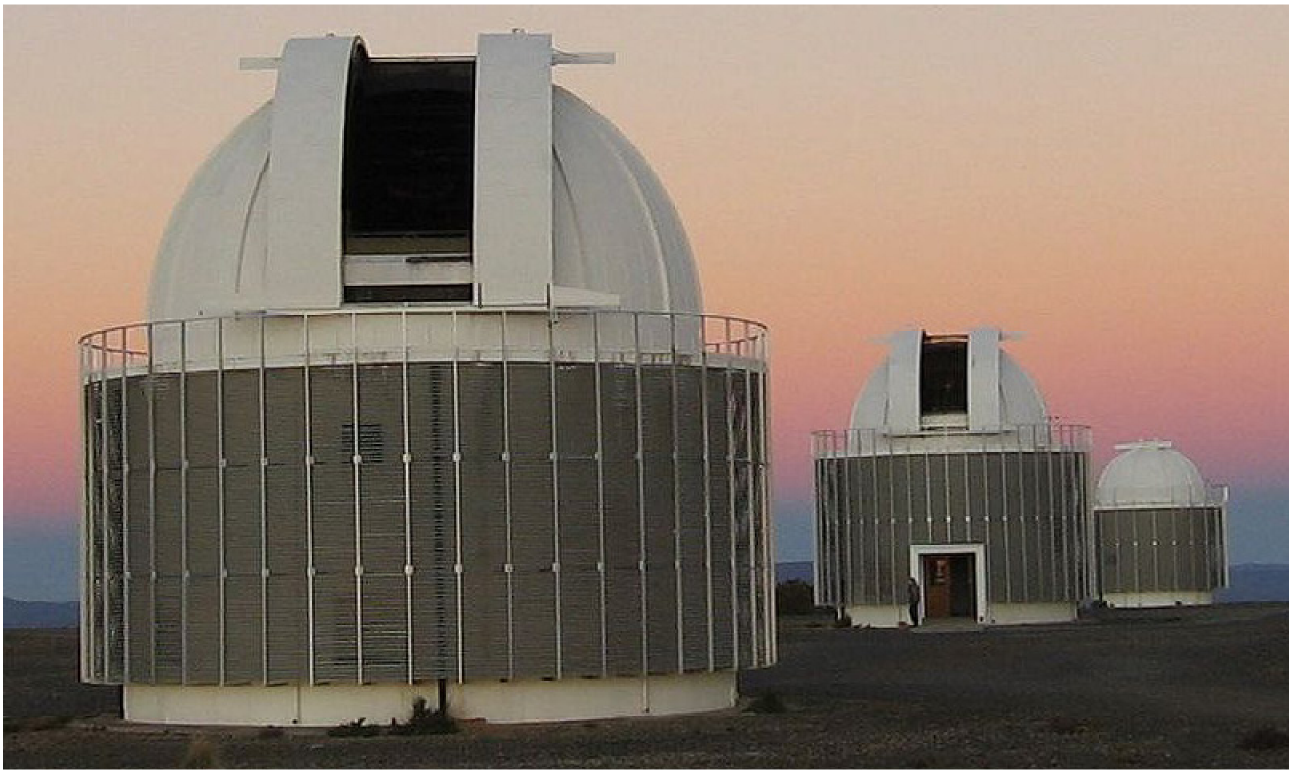
The name plate on the 1.9-metre telescope, showing the year the mirror was cast! SAAO

observations of their research targets.

So, how do we keep the old telescopes going? Well, the first thing that needs to be done is simply maintenance – there's a fair bit of mechanical upkeep required for an 80-year-old telescope. Gearboxes need replacing, domes need waterproofing, and the optical surfaces of the telescopes need from time to time to be cleaned or given a new, shiny aluminium coating.

However, we'd like to do more than just keep the old telescopes going. We'd like to make them first-choice options for astronomers, and ensure that they remain scientifically productive for years to come. The way we do this is by ensuring that the telescopes are equipped with a suite of modern instruments, and that the telescopes and instruments can be used efficiently.

A panoramic view of the observing plateau, showing some of the telescopes present today. SALT is in the centre of the frame; its distance makes it appear the same size as many of the other domes. The old 1.9-metre telescope is the turret-shaped dome, towards the right. SAAO



Three of the original four domes, pictured at sunset. SAAO

Useful instruments

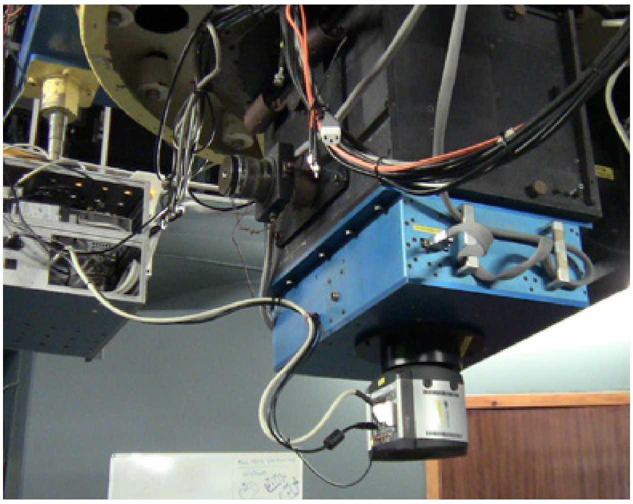
A telescope is primarily a means of collecting light. Of crucial importance is what you do with the collected light, and this is where instruments come in. We have built a number of different instruments for our various telescopes, fulfilling various roles.

One of the niche specialisations that the SAAO has established for itself is that of high time-resolution astronomy. Although many astronomical objects change only very slowly (compared with a human lifetime), there are also many interesting phenomena which happen much more quickly. To mention just two: variable stars can change their magnitude on very short time-scales, and occultations (where a planet passes briefly in front of a distant star) can happen in tens of seconds to a few minutes. For phenomena such as these, it is important to be able to gather data on a short time-scale, and also to have a very accurate record of exactly when the data were acquired. Two instruments we have built which are capable of this are the Sutherland high-speed optical cameras (SHOC), a pair of instruments which can be mounted on any of the SAAO's smaller telescopes. They each consist of a camera able to take high-resolution images every couple of milliseconds and a global positioning system (GPS) unit which can send very accurate timing signals to the camera. Usually SHOC is used in conjunction with a filter wheel, so that a particular frequency band of light can be selected.

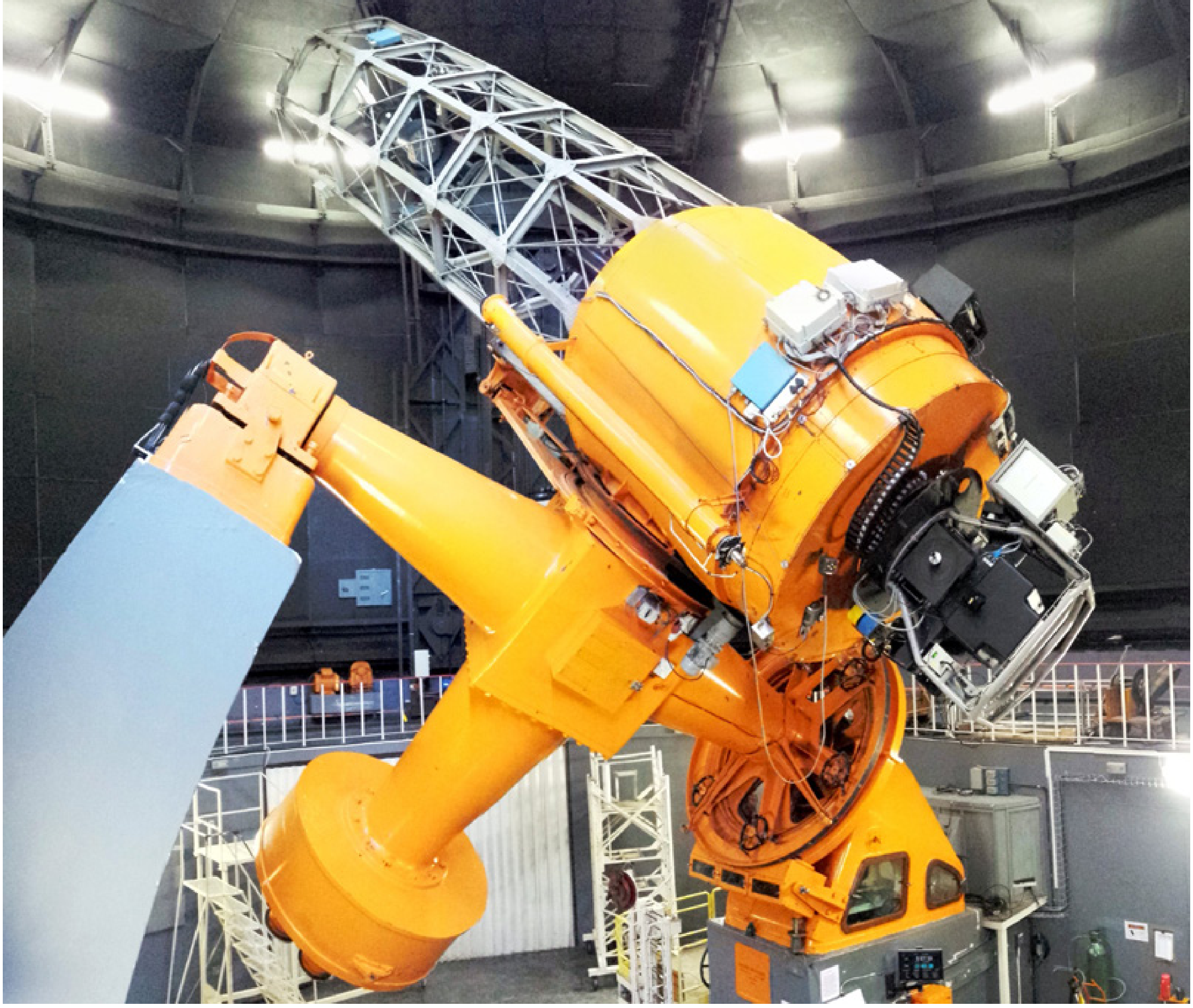
Spectrographs are often referred to as the workhorse instruments of astronomy, in that they are used very often and provide a wealth of information about their targets. By spreading the spectrum of light from an object across the spectrograph's detector, astronomers can deduce things like the chemical composition of the object, its temperature, and even the speed at which the object is approaching or receding from us! A major project the observatory recently completed was an overhaul of the spectrograph on the 1.9-metre telescope. In many ways this was more of a rebuild, with most of the moving components needing to be replaced. Fortunately, our in-house mechanical workshop was up to the task of machining the many precision components, and the resulting spectrograph is an exceptionally fine piece of engineering.

New software

Of course, an instrument needs efficient and well-functioning software to make it usable. Until recently, software at the observatory was a mixed bag of proprietary software supplied by hardware vendors, programs developed by astronomers, and other third-party applications. A mix of coding styles was used, source code was occasionally no longer available, and user interfaces were inconsistent. A particular disadvantage of this set-up was that the various pieces of software which were used to control instruments had no knowledge of each other. This meant that a lot of information had to be manually entered into the data files. To overcome these



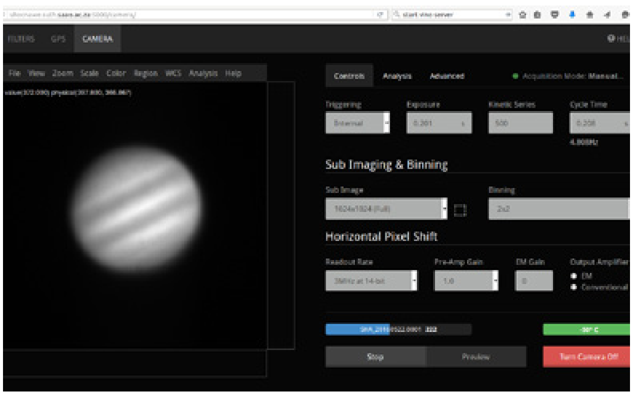
One of the SHOC instruments, mounted below the old 1-metre telescope. SAAO



The 1.9-metre telescope (affectionately known as 'Old Orange'). The newly refurbished spectrograph can be seen mounted at the bottom of the telescope. SAAO

problems, Briehan Lombaard and I took on the task of modernising the software which controls the various instruments and with which the astronomers interact. We had several goals in mind for this: we wanted to develop a standardised way of doing software at the observatory, incorporating modern design principles, with the aim of easing development and maintenance, promoting code reuse, and allowing practical user interfaces.

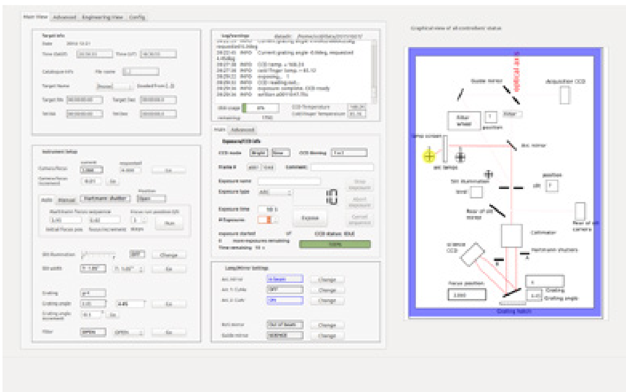
We considered various options, but eventually decided on using a distributed software architecture. This essentially means that the software for each instrument has several interacting but independent components, corresponding to each of the instrument subsystems. Some of the advantages of such an approach are that we can work on individual components without disturbing the rest of the system,



The SHOC web interface, showing the camera controls to the right, and the current image on the left. SAAO

we can choose the programming language most suitable for the specific task at hand, and we can easily reuse components in other instruments. For example, in the case of the SHOC instruments, we have filter wheel and GPS components written in the Python programming language, whereas for the more time-critical camera driver we have used the high-performance language C++. Both the SHOC and spectrograph instruments have modules which communicate with the plateau-wide weather service and with the telescope control system software, and thanks to the modularity of our design, we were able to re-use the same components for each of these.

A particular advantage of our software architecture is that we are able to develop different types of user interfaces for each instrument as appropriate, and can even replace the user interface without needing to make any changes to the underlying drivers.



The spectrograph graphical user interface. SAAO

So for example, all instruments are initially provided with a text-based interface. This is fine for initial development, and is still the preferred interface for running instrument diagnostics. For production use, however, a more intuitive interface is needed. Fortunately it's easy to swap out the text-based interface and replace it with a different one.

For the spectrograph, SAAO astronomer Dr David Gilbank has developed a traditional graphical user interface, running on the instrument control PC in the dome. From the interface, the user is able to view and control the various moving parts of the spectrograph, take exposures, and begin the data processing of these in real time.

For the SHOC instruments, we chose to forgo the conventional stand-alone graphical user interface, in favour of a web-based interface. Recent advances in network speed, web browsers and delivery technology have made it possible to develop interfaces which have the feel of a local application, but are in fact running on a remote server. There are several advantages to this: web interfaces are by nature streamlined and easy to use, require nothing more than a modern browser and a network connection, and do not need to be accessed from the same location as the server. In our case that means that the observer need not even be present in the dome to operate the instrument.

The user is nevertheless able to control all aspects of the instrument from the interface, and view the data as they are read out from the detector. Additional tools incorporated into the interface allow users to plot key characteristics of the data in real time and use this to tailor subsequent observations accordingly.

One aspect of observing astronomical targets is that there is sometimes quite a lot of repetition in the tasks which need to be performed. For example, an observer might move the telescope to a target, then take a series of exposures through different filters and for different times. Doing the same thing over and over is both tedious and error prone. The SHOC interface allows the observer to define scripts which then automate the observing program. The astronomer then only needs to point the telescope at the target, set the telescope to track that target, and set the script running.

In both manual mode and scripting mode, when the observation is complete the data are written to disk. Whereas previously the observers needed to keep detailed notes regarding the telescope pointing, the prevailing atmospheric conditions, and the particular filter in use, the new system integrates all this information and includes it in the data files.

Remote operation

Operating the instrument remotely is a great idea, but of limited practicality if the telescope is not similarly capable. The old telescopes were (unsurprisingly, given how old they are) not initially designed for remote operation, but required manual control by an operator inside the dome.

We'd like the telescopes to be as remotely operable as possible. Modern telescopes are usually designed from the get-go to be operated from afar, but for the older telescopes, quite a bit of work is needed. Chiefly, we need to modernise the telescope's tracking, pointing and control systems. This has been the task of Piet Fourie, a senior technician in the electronics division, and Dr Steve Potter, the head of the astronomy division. Piet Fourie has been replacing the old manual controls with electronic mechanisms, driven by programmable logic controllers (PLCs). The encoders (that tell the control system exactly where the telescope is pointing) have furthermore been replaced with newer, highly accurate ones. These changes have allowed Steve Potter to comprehensively overhaul the telescope control system (TCS). The TCS is essentially the brain of the telescope and enables astronomers to specify a target and have the telescope slew to that target and then track it as it moves across the sky. As a result of the changes, the 1.9-m telescope and dome can now be controlled by wire. Where before the astronomer needed to be in the dome to open the shutters and move the telescope about, this now can be done from a remote location. We should note that given the age of the telescopes, it's unlikely we will be able to eliminate entirely the need to have an operator present in the dome.

The hardware and software changes improve the user experience and ease of operation of the telescopes. Furthermore, with the possibility existing now of remote observing, it opens up the potential for more efficient scheduling and use of telescope resources. In the past, astronomers would be allocated a week's observing time, which then required travelling to Sutherland and spending long (and sometimes very chilly!) nights at the telescope. Often, this wasn't a problem, but for an astronomer who needed only a few hours' worth of data, this was overkill. Astronomers can now choose to access and operate the telescope and instruments remotely, without needing to travel to Sutherland.

The modernisation project is ongoing. The observatory recently acquired a new 1-m telescope, and we're building a large-format camera to take advantage of the telescope's wide field of view. There are also a number of other instruments which we will be upgrading as time and resources allow, and all of these projects will include an upgrade of the instrumentation software.

One of the mandates of the observatory is to help develop the country's technological skills base, through the provision of a world-class platform for astronomy. Our instrument-building team comprises astronomers, optical, electronic and mechanical engineers, machinists and software developers. We're excited to be working together and learning from each other. Along the way, we're taking instruments and telescopes older than many of us, and keeping them alive and thriving well into the 21st century. Q

Carel van Gend completed a PhD in Theoretical Physics at the University of Cape Town. His working life has mostly been spent in various branches of scientific computation, in medical physics, geophysics, telecommunications, biochemistry, immunology and now astronomy.

Curriculum corner

Life Orientation grade 10 - 12

Careers and career choices

Diversity in jobs: Economic sectors: primary (raw materials), secondary (finished products or goods) and tertiary (infrastructure and providing services). Work settings: workplace environment and conditions; indoors and outdoors (laboratory, mine). Activities involved in each job: designing, assembling and growing. Skills and competencies: information gathering or analysis and instruction Various facets of self and integration into the world of work: Opportunities within different career fields including work in recreation, fitness and sport industries: Research skills, salary package, promotion and further study prospects. Profitable use of time, how to use talents in working and career opportunities.

Hidden galaxies

Anja Schröder provides a multiwavelength view of galaxies hidden by our Milky Way

Figure 1: The 'Milky Way' stretches across the night sky from lower left. It is actually the next spiral arm of our own galaxy, while the individual stars over the whole sky are in our arm. The picture was taken in January 2007, when the Comet McNaught was visible. NASA

Our Milky Way is a pretty sight in the sky when viewed from a dark place far away from our bright cities. The 'milkiness' is caused by millions of small stars that form the disk of a great spiral galaxy that is our home. Intermixed with those stars are large dust clouds, like the Coalsack Nebula near the constellation of the Southern Cross. While this mix of dark and bright patches looks very beautiful in the sky (see Figure 1), it conceals a large fraction of our view of the extragalactic sky, that is, about 25%.

While a quarter of the sky is a really large fraction and affects our understanding of the local Universe, the good news is that how much is obscured by the dust depends on the wavelength – the absorption is smaller in the near-infrared and higher in the ultraviolet. We can see that when we view the sun through smoke it appears red, but this is not because the smoke 'colours' the sunlight but because the smoke (or dust) absorbs and scatters all the blue light so only the red light comes through.

Furthermore, at radio wavelengths the dust is fully transparent (for example, we can still use radios even in the thickest smoke of a forest fire!).

We therefore use such non-optical wavelengths to find our galaxies behind the Milky Way (see Figure 2). It is not only our own galaxy that looks different at these wavelengths, but every galaxy has a different look. This is because different objects emit light a different wavelengths (called a spectrum). For example, there are stars that are fainter and cooler than our yellow sun and they look red, and some are much brighter and hotter – they look blue-ish white. The pretty and colourful nebulae like the Orion nebula (see Figure 3) emit light only at certain wavelengths, like a Mercury lamp.

So, a galaxy in the near-infrared does not show the blue clumpiness of the gas in the spiral arms but the smoothness of the stars scattered about the disk. In the radio, on the other hand, we detect only the hydrogen gas from which stars are formed. That gas distributes differently to the stars. For example, the gaseous disk can be much larger than the disk formed by the stars. Also, only a certain type of galaxy has enough gas so that we can detect it – these are called star-forming galaxies. Most of these have a disk and show the pretty spiral arms. Some are less regularly built and form irregular blobs, like the Magellanic Clouds (see Figure 4).

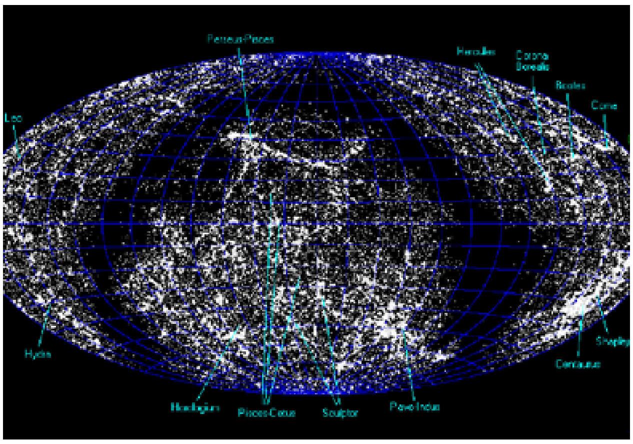


Figure 2: This shows a view of the extragalactic sky in the optical, that is, every point is a galaxy, found in all-sky surveys. The dark band with no points shows the area where the Milky Way prevents us from finding galaxies. http://people.virginia.edu

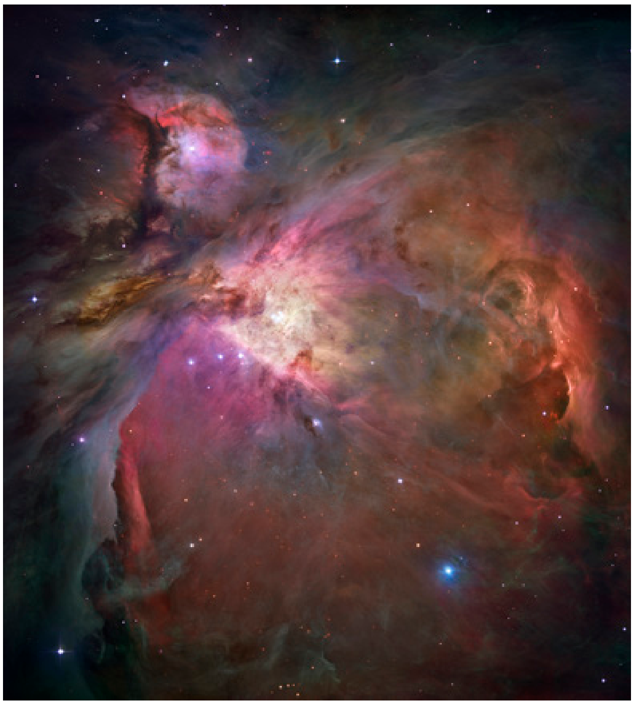


Figure 3: Thousands of stars are forming in the cloud of gas and dust known as the Orion nebula. More than 3 000 stars of various sizes appear in this image. Some of them have never been seen in visible light. NASA, ESA, M Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Project Team

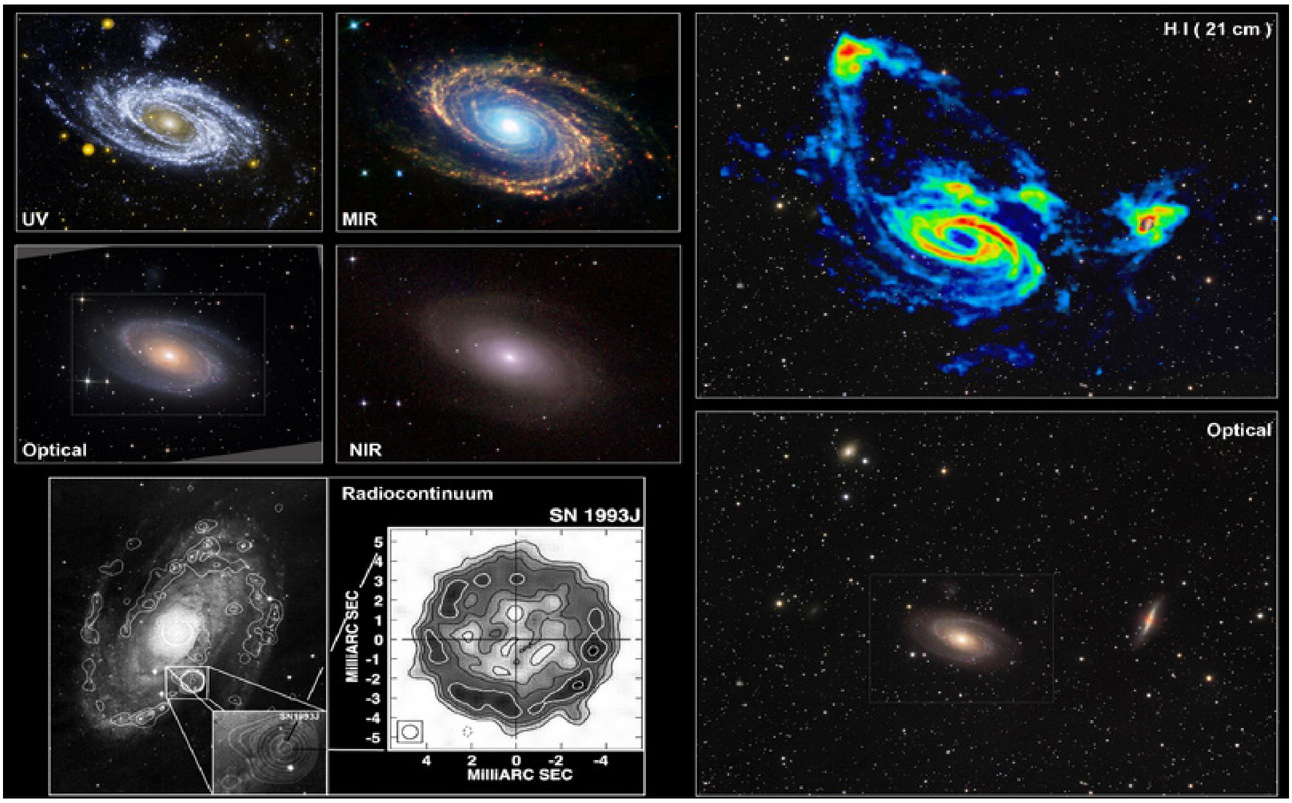


*Figure 4: 'A multiwavelength view of the spiral galaxy Messier 81.'*http://oldweb.aao.gov.au/local/www/alopez/multiwave

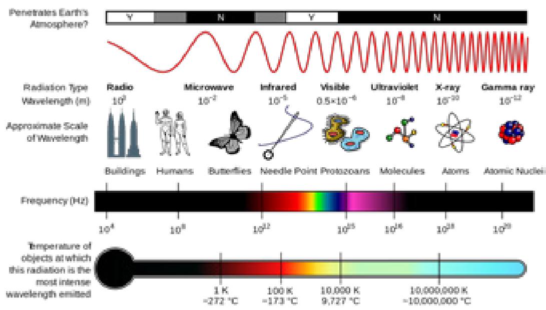
Figure 4 is a good example: The four panels to the top left show the same galaxy in ultraviolet (UV), mid-infrared (MIR; here the dust is made visible in yellow); optical and near-infrared (note the smoothness as compared with the other images). To the right is an image of the neutral hydrogen gas in the radio (called HI; the wavelength is 21 cm). Compare this image with the optical image just below: the hydrogen gas encompasses not only the big galaxy, but two smaller companions to the right and to the top as well. It means that the gravitation of the central galaxy pulls out the (lighter) gas from the companion galaxies, while the heavier stars are unaffected. We also have continuum emission in the radio, shown to the lower left, which mainly comes from nebulae in the spiral arms. http://oldweb.aao.gov.au/local/www/alopez/multiwave. Galaxies that don't form stars are called 'ellipticals' because they are so-called spheroids, that is, they can look like cigars or footballs, sometimes more elongated, sometimes more round. These galaxies have used up all their gas and can't form any more stars.

With this knowledge, we can now look through the Milky Way and detect all galaxies with either lots of gas (that is, spiral galaxies) using the 21-cm radio wavelength, or with lots of stars (that is, also the gas-poor elliptical galaxies) using the near-infrared wavelengths. There is one more difference of working at those two wavelengths, though: in the near-infrared we can easily survey large areas like the Milky Way or even the whole sky. In less than a minute one can already get deep images that show many galaxies between the stars. On the other hand, a survey at 21 cm is limited by the way the telescope sees the sky. In the near-infrared we use a CCD camera and get a picture of a part of the sky, in just the same way as we make pictures with our digital cameras. In the radiotelescope, however, we do not have a camera in the radio and the radio telescope sees the point in the sky it is looking at as a brighter or darker single blob. To make an image one has to move the telescope across the sky and make a 'scan'. That is much more tedious and requires complicated treatment of the data until one has an image.

On the other hand, in the radio we also get information on how far away the galaxy is, while in the near-infrared and the optical we simply get an image but do not know whether two galaxies next to each other are actually companions or at different distances.

To conclude our search for galaxies, we have combined the two wavelength regimes such that we used the existing all-sky near-infrared survey 2MASS to systematically select all galaxies above a certain brightness limit and to observe them with a radio telescope. We observed more than a thousand galaxies, and detected maybe a quarter of them. Those we did not detect either have no or very little gas or are further away than our radio telescope can see. In some cases, the spectrum is affected by man-made radiowaves, in particular from RADAR at a nearby airport, and we cannot tell if there is a galaxy in our data or not.

Our efforts in unveiling the galaxies behind our Milky Way continues, slowly filling in the gaps. The new radio telescope arrays like MeerKAT (currently being built here in South Africa in the Karoo) and the future Square Kilometer Array (SKA) will help by speeding up the surveys at radio wavelengths enormously so that we can find all galaxies that have gas at even larger distances than nowadays. **Q**



A diagram showing the electromagnetic spectrum. Wikimedia Commons

Glossary

Electromagnetic spectrum: a spectrum is the distribution of light over wavelengths. For example, the rainbow is a visible spectrum of our sun and goes from red (longer wavelengths) to the blue (shorter wavelengths). A full spectrum covers all possible wavelengths, that is, the longest wavelengths are the radio waves, then come the submillimeter waves, the infra-red (from the far-infrared at longer wavelengths to the near-infrared just next to the red in our visible spectrum). Beyond the blue in the rainbow comes the ultraviolet, then the X-rays and finally gamma-rays at the shortest wavelengths. There are two aspects to a spectrum – there is the continuum, that is a continuous coverage of the full spectrum, like the light from the sun (as, for example, seen in a rainbow). Then there are emission or absorption lines, made by particular atoms or molecules. Examples are fluorescent lamps or mercury vapour lamps.

Galaxies are star systems, formed by billions of stars, mixed together with gas and dust. Our Milky Way is such a galaxy. There are different kinds of galaxies: some look flat and disk-like and show beautiful spiral arms and colours; these are called spiral galaxies. Others are smooth and just look like a bright blob; these are called elliptical galaxies. Finally, some galaxies don't show any recognisable shape; they are called irregular galaxies.

Nebulae: as opposed to the pinpricks of light that are the stars, nebulae are extended objects. Some are colourful, like the Orion Nebula or the Ring Nebula in Lyra, others are just dark patches, like the Coalsack Nebula or the Horse-head Nebula. The colours come from atomic gas (e.g. hydrogen or oxygen) which is usually found near young stars. The dark nebulae are dust that blocks out the light of all the stars behind it.

Survey: a survey is an observation of a larger area of the sky with a particular telescope or at a particular wavelength. The idea is not to target a specific object but to make an image of a large region with lots of objects. Most astronomical catalogues are based on such a survey. For example, there is the 2MASS survey in the near-infrared that covers the whole sky (see http://www.ipac.caltech.edu/2mass/).

Radio telescope: a radio telescope works principally like an antenna though it can only see in one direction. It is much bigger than an optical telescope because the wavelength is so much longer. The biggest radio telescopes are the 300-m Arecibo telescope in Puerto Rico and the 500-m FAST telescope in China which is still under construction.

Anja Schröder obtained her PhD in astrophysics at the University of Basel, Switzerland in 1995. Her first postdoc position was at the National Central University at Chung-Li, Taiwan. She then spent two years at the Observatoire de la Côte d'Azur at Nice, France, as a Marie Curie Fellow. After working seven years at Leicester University, UK, for the XMM-Newton project, she moved to South Africa to join the KAT-7 project. In 2011 she joined SAAO to work for the SALT project.

The irregular galaxy NGC 1427A will not survive long as an identifiable galaxy, passing through the Fornax cluster at nearly 600 kilometers per second (400 miles per second). Galaxy clusters, like the Fornax cluster, contain hundreds or even thousands of individual galaxies. Within the Fornax cluster there is a considerable volume of gas lying between the galaxies. When the gas within NGC 1427A collides with the Fornax gas, it is compressed to the point that it starts to collapse under its own gravity. This leads to formation of the myriad of new stars seen across NGC 1427A, which give the galaxy an overall arrowhead shape that appears to point in the direction of the galaxy's high-velocity motion. The tidal forces of nearby galaxies in the cluster may also play a role in triggering star formation on such a massive scale. NASA, ESA, and The Hubble Heritage Team (STScI/AURA)

The galaxy Messier 101 (M101, also known as NGC 5457 and also nicknamed the Pinwheel galaxy) lies in the northern circumpolar constellation, Ursa Major (The Great Bear), at a distance of about 21 million light-years from Earth. This is one of the largest and most detailed photo of a spiral galaxy that has been released from Hubble. The galaxy's portrait is actually composed of 51 individual Hubble exposures, in addition to elements from images from ground-based photos. European Space Agency, NASA

Messier object 86 by Hubble space telescope – an elliptical galaxy. Wikimedia Commons

Horsehead Nebula (also known as Barnard 33 in emission nebula IC 434) is a dark nebula in the constellation Orion. The image is a frame mosaic taken with 5 different filters, standard Red – Green – Blue with details enhanced with narrowband data of hydrogen-alpha (Ha) and O III. The Ha was colour-mapped to red and the O III to teal, so it is a representative colour image consisting of over 900 minutes of exposure time. Ken Crawford

The history of the stars

Uncovering the history of star formation using the outskirts of nearby galaxies, by **David Gilbank**

Galaxies, or 'star cities', are the natural building blocks of the Universe. They consist of stars, dust and gas, and a large, unknown component known as 'dark matter' whose origins and properties are still a mystery, but whose effects are clearly observed via its gravitational influence on nearby visible matter. We live within a fairly typical galaxy known as the Milky Way.

In our current models, galaxies start off as small 'clumps' (smaller galaxies and proto-galaxies) and merge together over cosmic time to form progressively larger and larger systems. One way to verify and refine the ingredients going into this model is to observe the remnants of these past events. By looking at nearby galaxies with deep imaging we can probe the faint structures that surround them. These include streams of stars torn from the smaller satellite galaxies as they first orbit around, and later collide with, the main galaxy. Even if the dramatic signatures of tidal streams are not seen in a galaxy, the history of many small mergers can be read in its diffuse outer halo of stars.

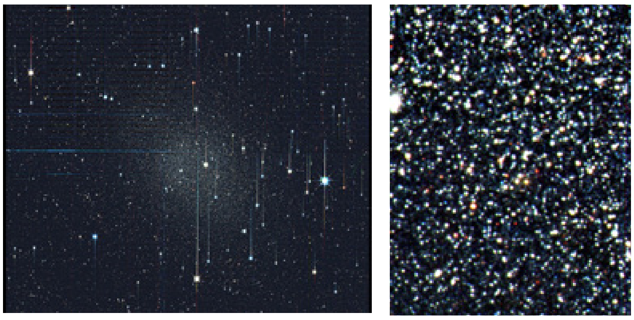
Deep imaging

In order to undertake such studies, deep imaging covering a wide field of view around the target galaxy is required. With the arrival last year of a new wide-field telescope, KMTNet, on the plateau at Sutherland, South African astronomers are just beginning such studies around a sample of nearby galaxies. KMTNet, the Korean Micro-lensing Telescope Network (http://kmtnet.kasi.re.kr/kmtnet-eng/), is a 1.6-m telescope sporting a massive $2^\circ \times 2^\circ$ field imaging camera. In a single shot, this camera images a region of sky four times larger on each side than the apparent size of the full Moon. This is achieved via an array of four CCD (charge coupled device) detectors, similar to the ones in your digital camera, but much larger. Each of these four arrays comprises 9 000 × 9 000 pixels, making it an approximately 300 Megapixel camera. As you might imagine, this large number of pixels means that each image coming from the camera requires a correspondingly large amount of disk space. In fact, each image is around 1 Gigabyte in size.

During the first South African observing time on KMTNet (October 2015–January 2016), astronomers led by a team at SAAO took imaging data of several galaxies as part of a pilot project to assess the data quality and the suitability of KMTNet for a study of the faint outskirts of nearby galaxies. Several other teams around the world have been conducting similar studies on larger telescopes (around 8-m class telescopes). However, despite KMTNet's relatively small (mirror) size, 1.6-m, it is potentially competitive with these larger telescopes thanks to the much larger size of its camera's field-of-view.

Imaging surveys

When conducting an imaging survey, there are two factors that matter: the size of the telescope's mirror (its ability to collect light); and the size of the field of view of the camera (the amount of sky it can image in a single shot). These two factors trade off of each other. For each factor it is the *area* which is important. A telescope mirror which is twice as large as another will collect *four* times the amount of light. Imagine two buckets left outside in the rain. If one is twice the diameter of the other, it will collect four times the amount of rain water in any given time. Exactly the same applies to telescope mirrors collecting 'drops' of light (photons). Similarly, a camera with a field-of-view twice as wide on a side can image four times as much sky in a single exposure. Since an 8-m telescope collects 25 times as much light as a 1.6-m telescope ($8^2/1.6^2$), but imaging cameras on the larger telescopes are typically about a fifth of the width of KMTNet's wide field camera (or 1/25 the area), these factors approximately cancel out. This means that while the larger telescope can reach faint limits relatively quickly, it must mosaic lots of individual exposures in order to cover a suitably large region around the target galaxy. On the other hand, KMTNet can image the regions around the galaxy in one exposure, but it must expose for much longer to reach the same faint limits as the larger telescope. The calculation above shows that the time to complete such a survey should be roughly the same in both cases. So, the diminutive size but massive camera makes the new 'small telescope' in Sutherland potentially competitive with some of the largest telescopes in the world.



A wide-field image of the Fornax Dwarf observed with KMTNet. The galaxy is the misty patch covering most of the centre of the field. The sheer number of individual stars is not noticeable until the image is zoomed in to show the exquisite detail. The vertical and horizontal lines are artefacts not completely removed from the data during the initial reduction process. David Gilbank

Target galaxies

Two of the targets of this initial 'pilot survey' shown here are the Fornax Dwarf Spheroidal (Fornax dSph) and NGC253 (also known as the Sculptor galaxy or 'Silver Coin' galaxy). Both Fornax and Sculptor refer to the constellations in which these objects are found. Both of these galaxies have South African connections.

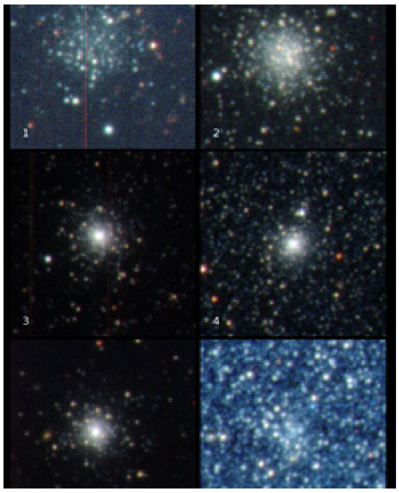
The Fornax Dwarf was discovered in 1938 by the American astronomer Harlow Shapley while he was in South Africa examining photographic plates taken by the 24-inch Bruce refractor at the Boyden Observatory. The 'dwarf' in the name refers to the fact that this diminutive system resides at the lower end of the range of galaxy sizes. In fact it is so small that we can only see it because it is right on our 'cosmic doorstep', and is a satellite galaxy of our own Milky Way (like the much larger and better known Magellanic Clouds). Interestingly, the brightest cluster of stars *within* this galaxy, known as a globular cluster, was discovered (also from South Africa) almost exactly 100 years before the galaxy itself. NGC1049 was discovered in the period 1834–1838 by John Herschel during his time in the Cape of Good Hope. It is bright enough to be seen in a small telescope. Because its light is concentrated into a much smaller region (a ball, as the name globular suggests) it has a much higher *surface brightness*, making it much easier to detect. Indeed, this nicely illustrates the difficulty in detecting low surface brightness structures, which is exactly the aim of our project, almost 100 years later.

The Sculptor galaxy was also well studied by John Herschel during his time in the Cape, after being discovered by his sister Caroline almost half a century earlier. Again, it is easily visible with a small telescope, or even binoculars. This particular galaxy was chosen for the KMTNet study because surveys on larger telescopes have recently identified structures around it, including low surface brightness dwarf satellite galaxies. Thus, it provides a good test to confirm that KMTNet can reach similar limits.

Long exposures – how to do it

One interesting complication of this first run with the new KMTNet telescope was the fact that the system had not yet been set up to take long exposures. In order to take long exposures of astronomical objects it is necessary to compensate for the rotation of the Earth, otherwise the object would quickly drift out of the camera's field of view, only returning there approximately 24 hours later. To ensure that astronomical images do not *trail* due to this motion, two methods are normally employed: tracking and guiding.

Tracking simply means that a drive on the telescope will move the telescope and instrument at the expected rate to compensate for the sky's motion due to the Earth's rotation (one rotation per day). However, in



Zoom-ins of the six globular cluster systems of the Fornax Dwarf. They are imaginatively called Fornax 1-6 (the numbers running left to right, top to bottom). Fornax 3 (centre left) is NGC1049, discovered 100 years before its host galaxy. David Gilbank

A wide field KMTNet image of NGC253, the Sculptor galaxy. As the remaining data are added to this, faint structures surrounding the brighter, obvious galaxy at the centre should begin to appear in the currently blank regions towards the edge of the field. David Gilbank

practice, if we wish to keep an object on the same pixel on the camera, this is not good enough. In KMTNet the pixels are approximately 0.4 arc seconds across (where an arc second is 1/60 of an arc minute, and an arc minute is 1/60 of a degree). The apparent size of the full Moon is half a degree across, and so this size corresponds to 1/18 000 of the diameter of the full Moon, or seeing a single grain of sand from 10 km away. Effects such as small imperfections in the telescope drive can easily cause the target to drift by several pixels and so an active method of *guiding* – monitoring a nearby bright star and forcing it to remain in the same location on the camera – is required.

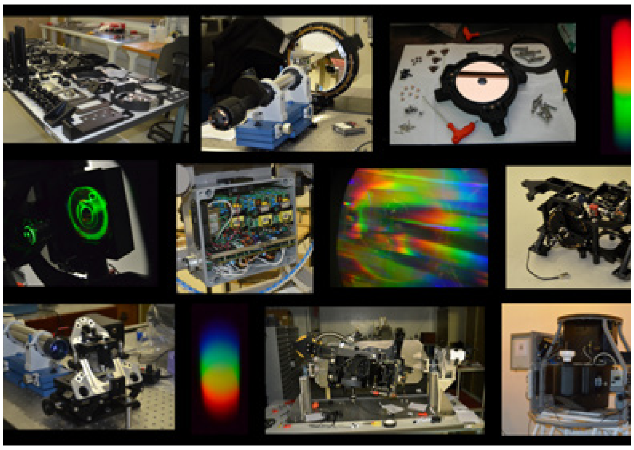
Since guiding was not available for the first KMTNet run, exposures had to be kept to a maximum of 2 minutes to avoid trailing. This meant that instead of taking half a dozen half-hour exposures, we had to take several hundred 2-minute exposures. Recall that these images are large file sizes. In fact, once calibration frames are included, a few nights of raw data easily exceeded 1Tb in storage! This also requires a large amount of computing time to process and align the many individual images. For this reason, the pictures shown here only show initial results from a small subsample of the images of each galaxy. Once all the data are added together, the resulting final images will be much deeper, allowing us to search the outskirts of these galaxies for the faint traces of past collisions. **Q**

David Gilbank is a research astronomer at SAAO. He holds a BA in Natural Sciences (Astrophysics) from Cambridge University, a PhD in Astronomy from Durham University, and worked as a postdoc at the Universities of Toronto and Waterloo in Canada before moving to South Africa in 2011. His main research interests are galaxy evolution, clusters of galaxies, and science with large surveys.

How we know what we know

Steve Crawford explains how astronomers use spectroscopy to unlock the secrets of the Universe

Astronomers will describe the composition of a galaxy or report the discovery of a planet around our closest neighbour or measure the temperature of a star – but how do they learn these things? How do astronomers carry out the experiments that allow them to explore and investigate even the most distant objects or objects far too faint to ever be seen by the naked eye? The workhorse instrument of astronomers is the spectrograph, which separates light into its different components and revealing the underlying physics of the Universe.



Assembling the new SAAO spectrograph in Cape Town. This instrument is to work with the SAAO's 1.9-m telescope – the Cassegrain spectrograph – and has undergone extensive overhaul to improve its efficiency. Every major sub-system has been replaced resulting in a brand new astronomical spectrograph – the first to be built in Africa. SAAO

Capturing dispersed light

Spectrographs are instruments that disperse light into its different components, allowing astronomers to measure the spectrum of objects. For anyone who has seen a rainbow, the basic phenomenon of spectra should be familiar to you: the light we see is composed of light at many different wavelengths and these wavelengths correspond to different colours. Red light has a wavelength around 700 nanometre, while blue light is around 300 nanometre. As sunlight is passed through water particles in the sky, light of different wavelengths is refracted (bent at different angles) and appears to be dispersed. Early spectrographs used prisms, that work on a similar principle, to make measurements of the spectra of different objects.

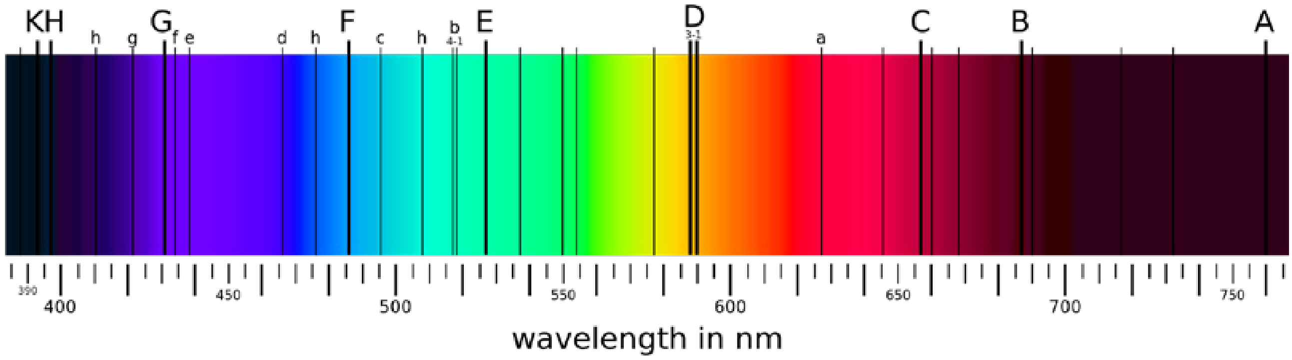
Today astronomers primarily use diffraction gratings to disperse the light: these are surfaces with small grooves in them (often hundreds of grooves per millimeter) that cause light of different wavelengths to reflect at different angles. The most modern spectrographs, like the Robert Stobie spectrograph on the Southern African Large Telescope, use volume phase holographic gratings, where the grooves are burnt into a gel by lasers.

In addition to the grating, a spectrograph usually includes several other components. Light from the telescope is fed to a slit or an optical fibre. This limits the amount of light being passed to the spectrograph and allows the astronomer to select the object they are targeting. Next, the light is collimated, which helps control how the light will be dispersed. The light is then passed to a prism or a grating where it is dispersed into its components. The highest dispersion spectrographs will resolve features in an optical spectrum to a hundred of a nanometer. This dispersed light is passed to a camera where it is then recorded electronically so it can be analysed.

Dispersed spectra can usually be broken into two components: a continuum and line component. From these different components, we can learn about the temperature, composition, and motions in different astronomical objects, which can lead us to know about the temperature, density, and size of these objects.

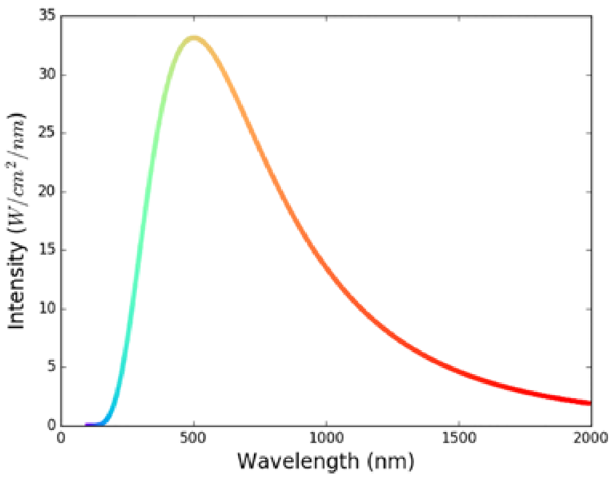
Continuum emission

For most objects, the continuum emission is dominated by blackbody radiation – the transformation of thermal energy into light. Essentially, any object that is opaque will emit blackbody radiation. The intensity of blackbody radiation peaks at a wavelength corresponding to a specific temperature. The peak wavelength is inversely proportional to the temperature. For example, the



Spectrum of the Sun with the absorption lines identified by Fraunhofer in 1814. Wikimedia commons

Sun with a temperature of 6 050° C peaks at 501 nanometres, whereas humans, with a typical temperature of 37° C, peak at 9.35 micrometres, corresponding to infrared light. Blackbody radiation becomes slowly less intense at wavelengths longer than its peak wavelength whereas the intensity diminishes rapidly at shorter wavelengths. The overall intensity depends on the temperature and surface area of the object.



Example of a blackbody spectrum with a temperature of 6 050° C, similar to our Sun. The peak of the blackbody occurs in the optical wavelengths around 500 nanometres.

The continuum emission from stars is primarily blackbody radiation. As such, the temperature of stars can be determined from the shape of its spectra. If the distance to the stars is known and the measured flux can be converted into an intensity, then an estimate of the size of the star can also be made.

In addition to blackbody radiation, there are also other sources of continuum emission such as Bremsstrahlung emission (caused by the de-acceleration of a charged particle) and synchrotron emission (caused by a charged particle rotating in a magnetic field). These typically dominate the emission seen in the X-rays or radio waves, respectively, whereas blackbody radiation is usually the main source of continuum emission in the optical and infrared. These different types of emission reveal different properties about the objects being studied, like temperature, density, or the strength of the magnetic field.

Line emission

When an electron moves from a higher-energy orbit to a lower-energy orbit in an atom, a photon will be emitted with an energy corresponding to the difference in energy between the two orbits. Likewise, an atom can also absorb a photon moving the electron from a lower-energy orbit to a higher-energy orbit. Due to the quantisation of energy at small sizes, only orbitals with certain energies are allowed around an atom. As the energy of a photon is inversely proportional to its wavelength, the photons will have distinct wavelengths corresponding to the energy difference between these levels. In a spectra, this transition of an electron will show up as lines at a given wavelength.

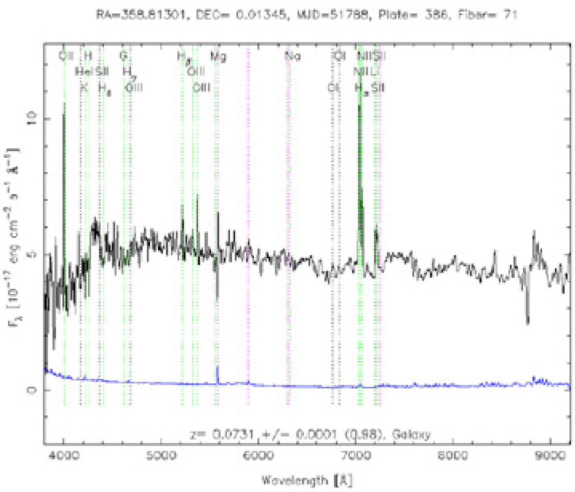
The allowed orbitals around an atom are set by how many protons, neutrons, and electrons the atom has. For example, the energy levels of an electron orbiting deuterium, a nucleus composed of one proton and one neutron, are slightly different to the ones around a hydrogen atom, which has only a single proton. Following the same principles, the energy levels of the orbits around helium, with two protons and two neutrons, are approximately four times that of hydrogen. However, the energy level of the orbitals of neutral helium, with two electrons orbiting around it, are different from previously ionised helium, with only one electron orbiting around it. So, each element, and different configurations of an element, has a unique set of spectral lines, and these spectral lines act as 'fingerprints', allowing an element to be identified. This is how astronomers can determine the abundance of different elements in an object from the lines in its spectra obtained from optical telescopes.

From measurements of the abundance of elements in stars, astronomers can trace the evolution of our galaxy. The abundance of different elements in a star is related to the fraction of those elements in the gas cloud from which that star formed. Heavier elements are formed in the cores of stars and are ejected into the interstellar medium when a star dies as a supernova – the abundance of heavy elements in the gas clouds increases with each generation of stars. Stars that have formed recently are rich in heavy elements like carbon, oxygen, and iron, whereas the oldest stars have only trace amounts of the heaviest elements. Astronomers are still looking for the very first stars, if any should still exist, as those stars should not have any heavy elements at all.

Temperature and density

The strength of spectral lines is determined by a number of different factors. Some are set by quantum mechanics, such as how likely a transition is to occur, while others are determined by the density and temperature of the gas. For example, the hotter a gas is, the more likely its atoms will be ionised, which will result in a different set of emission lines from a cloud filled with neutral gas. The denser the gas is, the more likely it is that transitions are caused by collisions between atoms and not by the emission of a photon.

For example, the ratio of different oxygen lines in a spectrum of a planetary nebula reveals its density and temperature. If the density of the gas is high, then the collisions between the particles would further excite the electrons so that the electrons would never make the transitions that cause these lines. In the same way, temperature can regulate the number of collisions that occur and how likely we are to observe certain lines, which will give an idea of the temperature.



Example of a spectra of a galxy from the Sloan Digital Sky Server. Different elements are labelled in the plot include hydrogen (H), oxygen (O), helium (He), nitrogen (N), and silicon (S). Sloan Digital Sky Survey

Motion of objects

Due to the Doppler effect, the spectrum of an object will shift with its velocity. For motions toward the observer, spectra will shift towards the blue and shorter wavelengths, while motions away from the observer will shift the spectra towards the red and longer wavelengths. By knowing the wavelengths of spectral lines to high precision and being able to measure their positions with high-resolution spectrographs, the velocity of objects can be measured to incredibly high precision. For example, the highest precision spectrographs today can measure velocities of objects to 1 m per second – comparable with walking speed.

The apparent motion of objects can be due to many different things – winds blowing material away from stars, outflows from the explosion of a supernova, the expansion of space – but for many objects this motion balances the force of gravity. For example, astronomers can measure the rotation of galaxies to measure the mass of the galaxy. For example, observations by Vera Rubin of rotating spiral galaxies were some of the first evidence for dark matter in galaxies: that galaxies were rotating far too fast for the amount of visible matter that could be observed.

One of the most exciting applications of spectroscopy is discovering new planets around other stars. Just as the Earth feels the pull of gravity from the Sun, the Sun feels the pull of gravity from the Earth. This causes a small wobble and the motion of this wobble can be measured using very precise, very stable spectrographs. Often kept in vacuum-sealed tanks to maintain a constant temperature and pressure and with resolutions of a hundredth or less of a nanometer, these spectrographs detect motions down to a level of centimeters per second. Recent radial velocity observations allowed the discovery of a planet orbiting around the habitable zone of Proxima Centauri, the nearest star to our own. The next generation of spectrographs will use even more advanced technology to provide even greater stability. This will allow the discovery of Earth-like planets around stars like our Sun.

Future of spectroscopy

These are just the some of the ways astronomers use spectroscopy to learn about our Universe. Future spectrographs and telescopes will further extend our knowledge by studying larger numbers of objects, fainter sources, higher resolutions, more precise velocities, and unlock wavelength regimes that have been unstudied. Currently, spectroscopy from SALT is helping to measure the mass of black holes, search for new planets, classify distant supernova, and measure the star formation in colliding galaxies. Future spectroscopy from the SKA will map even the farthest reaches of the Universe. While imaging produces some of the most beautiful images of our Universe, it is spectroscopy that lets us understand what we are seei ng. **Q**

Steve Crawford completed his PhD at the University of Wisconsin in 2006, after which, he took up a research fellowship at the South African Astronomical Observatory that led to his current post as the SALT Science Data Manager. His research interests include galaxy evolution, observational cosmology, and developments for improving astronomical research. His early work has focused on observations of different populations in galaxy clusters. Currently he is working on a variety of different projects but most of his recent work has focused on the Southern African Large Telescope. He is also interested in site testing and adaptive optics, spectrograph design, and software development for astronomy.

Curriculum corner

Physical Sciences grade 10–12

Transverse pulses on a string or spring (pulse, amplitude superposition of pulses), Transverse waves (wavelength, frequency, amplitude, period, wave speed, Longitudinal waves (on a spring, wavelength, frequency, amplitude, period, wave speed, sound waves), Electromagnetic radiation (dual (particle/wave) nature of electromagnetic (EM) radiation, nature of EM radiation, EM spectrum, nature of EM as particle−energy of a photon related to frequency and wavelength)

The transient Universe

Things that go bump in the night. **David Buckley** explains how we are observing the transient Universe in South Africa

When you look at the night sky it seems that, other than for the Moon, planets and occasional comets, it is essentially unchanging. The same stars are there from night to night and we see little change, at least by eye. Of course those early astronomers who began to observe the sky in a scientific manner learned that some stars do indeed change, at least in their brightness, and from time to time new ones appear and then fade away.

With the advent of modern astronomy, using bigger telescopes, better detectors and launching satellites that can observe at those higher energy wavelengths (X-rays and γ-rays) unobservable on the Earth's surface, we have learned that the Universe is anything but unchanging. Astronomers can detect the changes in motion and brightness of many different types of objects, both in our own Milky Way galaxy and in other galaxies. We have come to learn that there are a range of objects which undergo catastrophic eruptions, increasing their brightness by huge amounts, in some cases, for example gamma ray bursts (GRBs), out-shining, for a short time, the entire galaxy in which they reside. Such objects are often referred to as 'transients', since they seem to appear randomly and quickly and then fade away over timescales ranging from seconds to months.

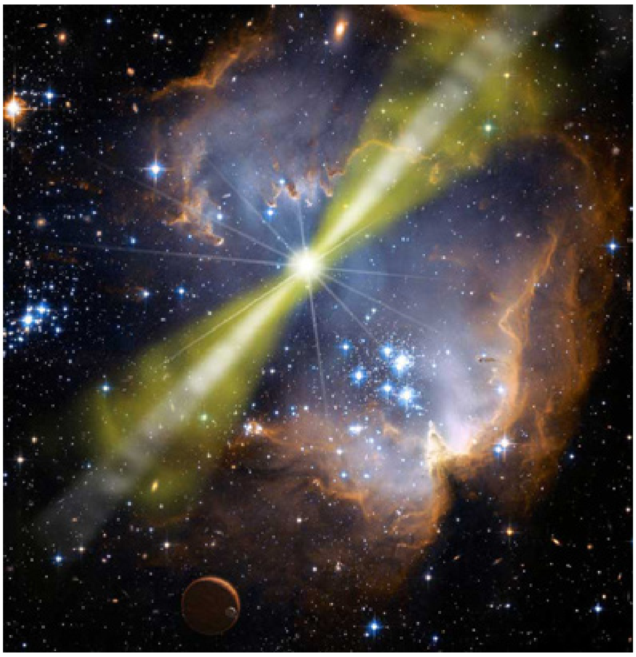
Finding transients

There is a continuing and growing interest among South African astronomers in studying astrophysical transients, particularly those related to energetic events, like X-ray outbursts, GRBs, active galactic nuclei (AGN) and optical outbursts associated with accretion process in binary stars with compact companions, called cataclysmic variables (CVs; with white dwarfs) and X-ray binaries (XRBs; with neutron stars or black holes). The study of astrophysical transients has entered a new era with the establishment of a number of robotic ground-based facilities, established over the last decade or so, used in both optical (i.e. wavelengths from ~350-900 nm) transient detection and follow-up programmes (e.g. for alerts from X-ray or γ-ray satellites).

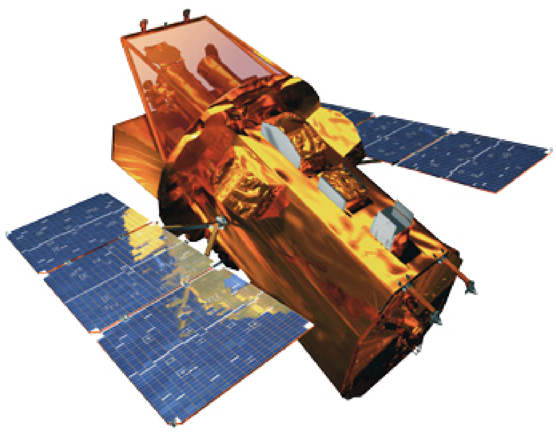
Some of these have targeted specific classes of transients, for example supernovae, e.g. the *Palomar Transit Factory* (*PTF*) and the *All-Sky Automated Survey for Supernova* (*ASAS-SN*) and Gamma Ray Bursts, e.g. *Robotic Optical Transient Search Experiment* (*ROTSE*) and *Watcher*. Other optical transient detection systems currently operating include the *Catalina Real-Time Transient Survey* (*CRTS*) and *MASTER*, which have been successful in detecting a variety of transients, including CVs, flare stars, long period variable stars, out-bursting blazars (a class of AGN) as well as supernovae and GRBs. In addition, both surveys are also discovering Solar System transients, namely comets and minor planets. With the development of recent facilities (e.g. *PanSTARRs*, *SkyMapper* and *Gaia*) and those in the future (e.g. the *Large Synoptic Survey Telescope* (*LSST*)), the opportunity to study the transient Universe will be unprecedented. Indeed the volume of alerts will mean the traditional manner of conducting follow-up programmes will become unmanageable and machine learning techniques will need to be employed in order to sift the wheat from the chaff.

Local transient detections in South Africa: MASTER-SAAO

Until very recently (late 2014) all optical transient alerts came from ground-based facilities on other continents, or from satellite missions. For prompt optical identification and follow-up, it is often



Artist's impression of a gamma ray burst (GRB), where a massive star collapses into a black hole, releasing a huge amount of energy. NASA



The NASA Swift satellite used for the detection and rapid follow-up observations, at X-ray and ultraviolet wavelength, of energetic transient events. NASA

Location of the MASTER optical transient network nodes.

Source: David Buckley

imperative to observe such events as close to the initial alert time as possible. This is particularly the case for GRBs, whose optical counterpart fade to non-detection in a matter of ~1 000 s.

Late December 2014 saw the establishment of the first comprehensive optical transient detection and follow-up system in South Africa, at the Sutherland observing site of the South African Astronomical Observatory, namely *MASTER-SAAO*. The *MASTER* project, aimed at the detection of optical transients, was first established in Russia in 2002 and the network has since expanded to include nodes across Russia, extending ~80° in longitude, Argentina, the Canary Islands and South Africa.

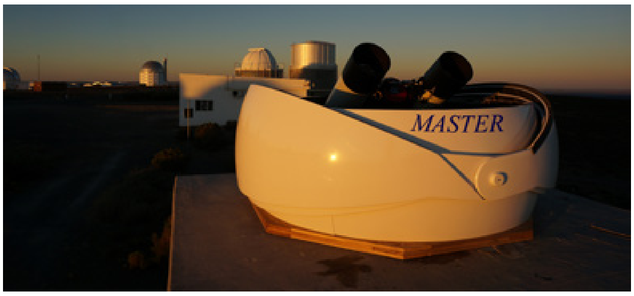
The main goal of the *MASTER* project is to produce a continuous fast and wide sky survey for optical transients. The survey is detecting the whole range of transients classes mentioned in the introduction. All *MASTER* telescopes can also be guided by alerts to conduct follow-up observation of transients detected by other facilities (e.g. X-ray or γ-ray satellites), and have been used for the detection of prompt optical emission from GRBs or other fast transients, including the attempts to search for optical counterparts from gravitational wave and neutrino sources. With the establishment of *MASTER-SAAO*, the southern hemisphere sky from Africa began to be routinely monitored as part of the *MASTER* programme for the first time.

Six of the *MASTER* nodes consist of identical dual 0.4 m diameter telescopes on a common mount, with CCD cameras. The telescope can either be co-aligned, each surveying an identical $2° \times 2°$ field with two different filters or polarisers (for detecting polarisation), or they can be misaligned to allow twice the sky coverage using identical filters. The latter is the default mode for surveying for optical transients.

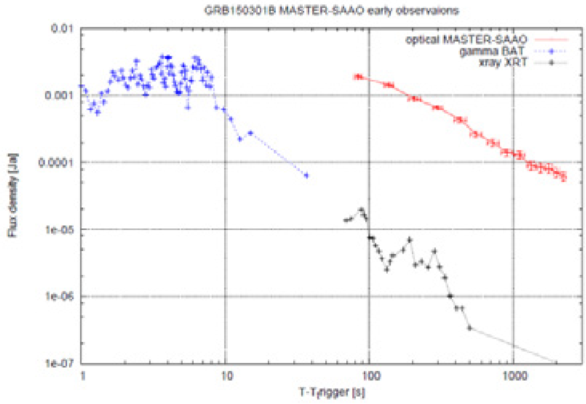
The impact of *MASTER-SAAO*

All *MASTER* optical transient discoveries are immediately published online as Astronomers Telegrams (ATels), on the *MASTER* website (http://observe.pereplt.ru/MASTER_OT.html) and other websites specialising in different transient classes. *MASTER* has been one of the most successful transient detection systems, as evidenced by the fact that up to 2014 it was responsible for ~25% of all ATel transient alerts, second only to *Swift* and the most of any ground-based optical alerts.

In the period since *MASTER-SAAO* has been operational (since late December 2014), over 300 optical transients have been detected, while follow-up optical observations have also been undertaken by MASTER-SAAO of dozens of transient alerts from other sources, particularly GRBs and blazar outbursts.



The MASTER-SAAO facility at Sutherland, with its two telescope tubes. David Buckley



Light curves of the GRB 150301B, showing the rapid decline in brightness, including Swift X-ray and γ-ray observations and the optical after-glow measurements from MASTER-SAAO (red line), which declined to below detection in ~1 000 s.

David Buckley

Follow-up observations of transients with SALT

Most transient discoveries require further follow-up observations to confirm their nature and to allow for more probing astrophysical observations. SALT is playing a large role in such studies. Being a 100% queue scheduled telescope, it is a lot easier to arrange rapid, so-called 'target of opportunity (ToO)' follow-up observations of transients than with conventionally scheduled telescopes. So far about 20 SALT programmes have been devoted to the observations of transients and ToOs, across all object classes.

Since May 2016, a large SALT programme has begun aimed at comprehensively observing compelling new optical counterparts of various transient objects. The programme involves astronomers at several institutions in South Africa (SAAO, University of Cape Town, University of the Free State, University of Johannesburg and North-West University) plus several SALT partner institution in India, Poland and the United Kingdom. The sources for these transients have come from a variety of alerts systems, provided by both space- and ground-based detection systems. The former include the X-ray and γ-ray satellites *Swift, Fermi* and *MAXI*, an experiment on the *International Space Station*, plus the *Gaia* satellite. Ground-based alerts come from facilities like ASAS-SN, CRTS, OGLE and MASTER-SAAO.

Future transient facilities and programmes

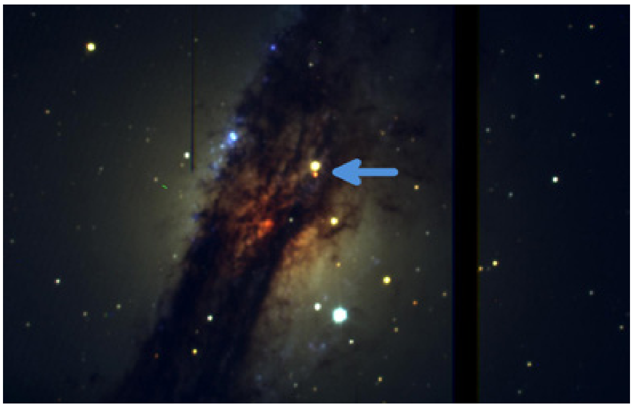
MASTER-SAAO, the first local optical transient detection system to be installed at the Sutherland station of the SAAO, will be joined in 2017 by another transient detection facility, namely

MeerLICHT (http://www.ast.uct.ac.za/meerlicht/MeerLICHT.html). This 0.65-m telescope with a 2-square-degree field is dedicated to simultaneously observe the same fields being observed by the *MeerKAT* radio telescope, once it begins operations in 2017. The aim is to have simultaneous optical images of *MeerKAT* fields to allow for the potential detections of the optical counterparts to any radio transients which *MeerKAT* may detect during its various observing programmes.

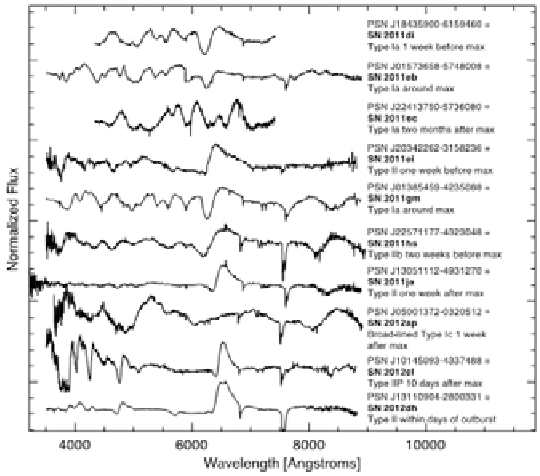
In addition, optical transient follow-up observations will be possible using other robotic 1-m class telescope facilities at SAAO, namely the *Las Cumbres Observatory Global Telescope* network (*LCOGT*), *MONET-South* and the newly installed SAAO 1.0-m robotic telescope. The science goals for these telescopes include regular monitoring of variable objects (stars and AGN), on a variety of timescale (hours to years), plus follow-up observations of transients and ToOs.

The recent decision for South Africa to become involved in the *Large Synoptic Survey Telescope* (*LSST*) programme will have a huge impact on transient studies of the Universe. This 8.4-m diameter telescope, with its ~10 square degree field of view, will survey most of the southern sky (~18 000 square degrees) continuously for 10 years, with ~800 observations of each 10 degree field over the duration of the survey, or on average one field every ~5 days. The deep imaging of *LSST* will allow the study of many faint objects in a single exposure, with repeat exposures made with up to five filters. Although the search for transient objects is just one of the many science drivers for *LSST* (others include probing dark energy and searching for near earth objects), it will also have a major impact on studying the time-varying Universe. With the expectation of at least a million transient alerts each night, only a very small fraction of these could ever be followed up on. Thus machine learning techniques and statistical analyses will be needed to sift through the enormous amounts of data to pick out the 'gems' for further study. The experiences we gain in the current transient research endeavours, with manageable data numbers (typically several transient alerts per night), will help to inform how to conduct larger-scale SALT and SAAO transient follow-up campaigns in the *LSST*, *MeerKAT* and *SKA* eras. **Q**

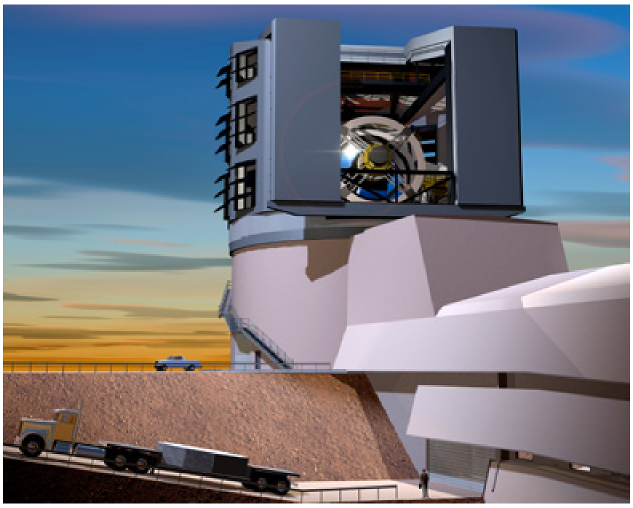
David Buckley has been an astronomer at the SAAO since 1992 and from 1998–2005 was the SALT Project Scientist during the construction phase and then from 2005–2015 held the positions of SALT Astronomy Operations Manager and SALT Science Director. He has an MSc from the University of Canterbury, New Zealand, and a PhD from the Australian National University, where he studied at the Mt. Stromlo and Siding Spring Observatories. His research has mostly focused on compact accreting binary stars and X-ray binaries, particularly magnetic cataclysmic variables, which he studies with both ground-based (e.g. SALT) and space-based telescopes (e.g. for X-ray observations). His recent research has expanded to include optical studies of transient objects of various classes and he is Principal Investigator for a multi-institutional/multi-partner SALT Large Programme on transient follow-up studies. Over his career David has been an author or co-author on over 720 publications, 180 in refereed journals. David is a recognised international researcher, and is, or has been, Principal Investigator for a number of joint international projects with astronomers in India, Kenya, France, Russia and Germany. He is also an expert on optical telescopes, instrumentation and site testing and characterisation. In recent years David has also assisted in astronomy capacity development in Africa, particularly in Kenya and Ethiopia.



An example of transient follow-up observations, namely the image of a supernova discovered in the galaxy Centaurus A. The galaxy is well known for its peculiar and prominent dust lane and for hosting one of the closest active galactic nuclei with massive radio jets. SALT was the first major telescope to take a spectrum of the supernova just hours after its discovery on the night of 8 February 2016. David Buckley



Another example of transient follow-up observations, namely supernova spectra taken with SALT as part of a ToO program lead by Dartmouth College, a SALT partner. The regular monitoring of the absorption and emission features in such spectra allows astronomers to probe the evolving physical conditions of these explosions. David Buckley



Artist's concept of the LSST, currently under construction in Chile and due to begin surveying the southern skies in ~2021. LSST Corporation

SALT – astronomy for the benefit of the people

How astronomy can contribute to sustainable development in southern Africa. By **Sivuyile Manoxoyi**

Ms Buzani Khumalo observing the partial solar eclipse with a group of teachers at the University of Limpopo. Sivuyile Manoxoyi

The southern African people have always had a rich and profound history and relationship with the heavens and stars. This relationship always extended beyond the romance of mere observation of the skies and stars for recreation and found practical applications in their everyday life by using stars for creating calendars, navigation and regulation of ceremonies. The construction and subsequent operation of the Southern African Large Telescope (SALT), located in the rural town of Sutherland, not only transformed the methods of data collection and analysis but also set an excellent example of how research infrastructure can be used for the benefit of broader society in areas of socioeconomic development and education.

From the construction to the current operational phase of SALT, consistent efforts have been made to maximise industrial, public awareness, educational and socioeconomic benefits for the southern African people and in particular for the residents of the Karoo Hoogland areas which cover the towns of Sutherland, Fraserburg and Calvinia.

The greatest benefits of SALT are socioeconomic and educational. Before the construction of SALT, Sutherland was not known as a tourist town, with fewer than 250 people visiting the town each year. The construction of SALT ushered in a new era of astro-tourism and has led to the development and opening of 45 guest houses and bed and breakfast businesses, 18 guest farms, five restaurants and a hotel, creating employment and entrepreneurial spirit. National and international tourists appreciate Sutherland's beautiful skies and enjoy visiting the observatory and take part in informative and memorable tours of SALT. An average of 13 000 visitors visit Sutherland each year. Arts and craft businesses supported and inspired by SALT target the tourists with astronomy-inspired art works. Through the SALT Collateral Benefits Programme (SCBP), SALT contributed to the training of young unemployed members of the community as tour guides. Five are now permanently employed by the observatory and have completed astronomy courses at SALT partner universities. Others have initiated their own informal town and township tours.

To cater for the tourist's interest in astronomy, SCBP operates a Sutherland visitor centre. This is an astronomy-based science centre which hosts astrophysics, geology and cultural astronomy exhibits. Visitors are able to view the beautiful Sutherland night sky and appreciate the celestial jewels through 14- and 16-inch visitor telescopes. Some of the workers at the guest houses have also been trained and they offer star-gazing nights at their guest houses. Day, night and hourly tours are offered in Sutherland.

Through support from the Department of Science and Technology, an old unused building was identified by SCBP and was converted into the vibrant Sutherland Community Development Centre (SCDC). The centre hosts 35 internet-linked computers, books and a reading section and also a section for very young children. The centre is used to provide training for the community in computer literacy, email, internet and social media. Members of the community have free internet access via the centre and have been able to acquire business and job opportunities. Learners also use the centre for school-based projects and research activities.

The centre is also used to host various specialised training and development workshops, such as e-banking and website development for individuals in the community and businesses in the area. Social development workshops in CV writing, anti-substance abuse, business development and operations have been held. Learners from the local schools have used the centre for a project based on a remotely operated telescope, Las Cumbres Global Telescope, California, USA, taking pictures and analysing data from the telescope.

SCBP also provides high school and university bursaries and scholarships. Through collaboration with university-based SALT partners such as University of Central Lancashire, the University of Southampton, Dartmouth College, Rutgers University and the University of Wisconsin (Madison), SCBP has assisted several students through PhD degrees in astrophysics, as well as offering undergraduate bursaries to 22 students to complete their astronomy- or physics-based studies.

Schools are hosted both in the Sutherland and Cape Town observatories. An average of 32 000 learners visit both sites per year and learner-based workshops that are curriculum related are offered, as well as extra-curricular enrichment programmes. Job-shadowing opportunities in astronomy, information technology and engineering are offered to Grades 10–12 learners during school holidays. Learner-based workshops and outreach programmes are extended to schools, which need to be booked in advance as the activities are popular with both learners and teachers.

SCBP has also contributed to teacher training, development and support. Few South African teachers are exposed to astronomy at school and during their teacher training studies, but they have to teach the topic 'Earth and Beyond' which includes astronomy, geology and oceanography. Working with universities such as Stellenbosch, Cape Peninsula University of Technology and University of Cape Town, teacher training workshops have been offered to thousands of pre-service teachers. Through collaboration with provincial departments of education and science centres based in various provinces, teachers in all nine provinces have been trained to teach Earth and Beyond, using hands-on and electronic resources distributed and offered free of charge. Working with the national department of education and the Mark Shuttleworth Foundation, training of all natural science curriculum advisers was conducted over a two-year period. The South African Physical Science and Mathematics high school curriculum requires teachers to use astronomy as a context for teaching science and mathematics. Through collaborations with Ithemba Labs and the Square Kilometre Array (SKA), SCBP has been providing teacher training workshops for high schools in the areas of gravity, optics, data analysis and mathematics.

Through Universe Awareness, a project that focuses on early childhood development and that uses astronomy as medium for inspiring interest in science and technology, training and resources have been distributed in all nine provinces. A 'Universe in box' (a science resource for higher primary school) has been distributed to all science centres and also to teachers who attended the UNAWE workshops.

Collaborating with Hartebeesthoek Radio Astronomy Observatory and SKA, SCBP has been a constant feature and presence at Scifest Africa, Techno X and all provincial science festivals. Astronomy presentations, exhibitions and hands-on workshops are facilitated at these festivals. Stargazing sessions are held in the evenings. Generally SCBP hosts stargazing sessions at schools and in communities on request and we are also willing to lend telescopes to schools and organisations

Learners looking through the telescopes at Sutherland. Willem Prins that are interested in hosting their own stargazing sessions.

Day tours are offered in Cape Town on request. There are two open nights, every second and fourth Saturday. These consist of a public lecture, tour of the site and a stargazing session. Members of the public and schools can also invite members of SCBP to offer presentations and stargazing sessions at various sites and schools.

SCBP provides information on astronomy to the public via the SAAO website and in hard copies. There is a monthly sky guide , called 'What's Up' – a description of the Sun, Moon, planets, meteor showers , morning and evening stars – that can be printed off our website. SCBP also distributes an Astro DVD consisting of all free educational materials, basic astronomy texts, films, videos, animations, simulations, posters and free astronomy software.

The multi-million dollar SALT is an inspiration to us all. It has not only delivered in terms of scientific output but has contributed tremendously educationally and socioeconomically. It is not surprising that South Africa managed to win the bid to host SKA as SALT has served as a demonstration of what our potential and capabilities are. SALT has inspired a generation of African astronomers and has served to inspire the youth to explore science and technology-based careers and is Africa's pride and joy. **Q**

For more information: Contact SAAO, 021 447 0025
Websites : www.saao.ac.za, www.salt.ac.za, www.unawe.org

Sivuyile Manoxoyi works as a Manager of SALT Collateral Benefits Division, which is responsible for communicating the power, beauty and relevance of astronomy. He oversees the socioeconomic development associated with SALT and astronomy in general and also leads all astronomy education, communication and awareness programmes. He serves as National Co-ordinator of Universe Awareness in South Africa. He studied at UCT, Australian National University and Stellenbosch University and has a BSc in Physics and Apllied Mathematics, a BEd with Honours in Science Education, a Higher Diploma in Education, a Certificate in Science Communication, a New Managers Certificate (UCT), a Certificate in Science Centre Management (ANU), a post-graduate Diploma in Theory and Practice of Science Centres (ANU) and did a Management Development Programme (SU). He is passionate about astronomy and believes that science teacher development can contribute towards changing our society.

Ms Buzani Khumalo presenting to teachers at a teacher training workshop in Polokwane in Limpopo. Sivuyile Manoxoyi

Young learners at a stargazing session led by SCBP members in Stellenbosch. Cedric Jacobs

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Sprites over South Africa

The South African National Space Agency recently recorded the first ground-based observations of sprites over South Africa

The South African National Space Agency (SANSA) recently recorded the first images of sprites from Sutherland on 11 January 2016. Triggered by lightning, sprites are optical gas discharges from the top of convective thunderstorm clouds at an altitude of typically 50 – 100 km.

Impact of research into sprites

Research into the Earth's atmosphere and ionosphere is crucial for understanding our universe and the interconnected processes and dynamics that govern our natural environment and the technologies we rely on. Space weather is an area of research that is equally relevant to developed and developing nations due to our increasing reliance on space-based systems and the continued use of high-frequency long-range communications.

'Despite being easily visible, nobody has ever reported seeing sprites over southern Africa. We are extremely excited to have finally captured the first images of sprites over South African skies' says Prof. Michael Kosch, Chief Scientist at SANSA's Hermanus office in the Western Cape and the principal investigator on the sprite project. Using an NRF-funded night-vision TV camera the sightings were made possible from the South African Astronomical Observatory (SAAO) in Sutherland, one of the world's darkest astronomical sites.

The other team members involved in this exciting first sighting were Mr Stanislaus Nnadih, a Masters student at the University of Cape Town (UCT), who operated the night-vision camera that captured the sprite images and his supervisor, Prof. Peter Martinez of the UCT SpaceLab in the Department of Electrical Engineering.

'It was an amazing experience; seeing in real-time what has never been recorded over southern Africa. I felt like a hunter!' says Stanislaus.

Sprites occur in the upper atmosphere and are very bright but brief flashes of light lasting between 1–10 milliseconds. They are almost always initiated by large positive cloud-to-ground lightning strikes during major thunderstorms. Predicted in 1925 by Nobel Laureate, Prof. Wilson, they were first observed by chance in 1989 over the USA and have subsequently been observed frequently from spacecraft, aircraft and the ground. Given the millions of lightning strikes that occur annually, the rarity of the reported sightings is surprising.

'These observations pave the way for more comprehensive observations at multiple wavelengths to improve our understanding of how sprites are triggered and their effects on the upper atmosphere,' says Martinez.

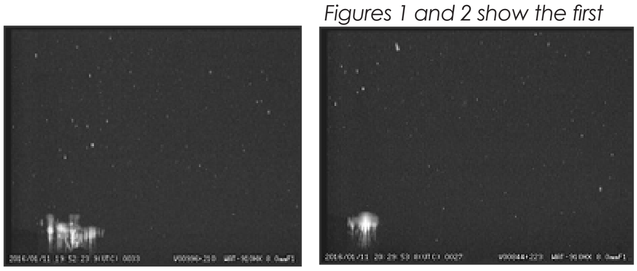
The geographic location and infrastructure of the SAAO facilities in Sutherland have been identified as one of the most suitable sites to provide the ideal visibility conditions for recording sprites in South Africa. SAAO has entered into a four-year agreement with SANSA to host a state-of-the-art optical space research (OSR) Laboratory which will be used for further research into sprites as well as new research in atmospheric gravity waves using a night-vision airglow imager and Fabry-Perot interferometer to remotely observe the waves and measure high-altitude winds and temperatures. In addition, a co-located optical telescope will be able to track space junk and debris greater than 10 cm.

'We will be using the OSR initially to study atmospheric gravity waves that will provide us with greater insight into the dynamics of the Earth's middle atmosphere,' says Prof. Kosch. 'Such knowledge is important because the middle atmosphere couples space weather from above to terrestrial weather below.'

The unique capabilities of the OSR laboratory will provide crucial space science data to meet national and international obligations, raise the standard of South African research, supply information about unanswered scientific questions and enhance scientific development.

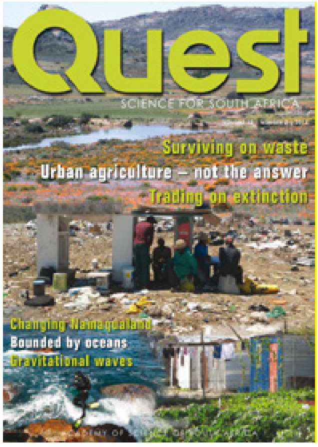
During the upcoming sprite season (December to February 2017), SANSA will deploy multiple night-vision camera systems in an attempt to capture the sprite colours, mainly the red and blue emissions of nitrogen, as well as in the near-UV.

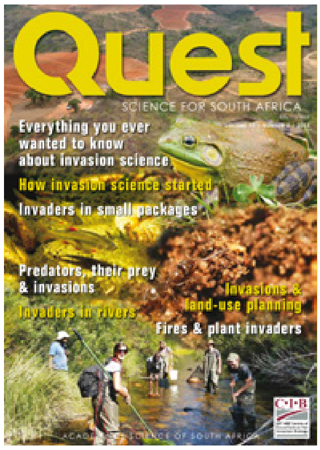
Issued by Catherine Webster, Communications, SANSA Space Science. **Q**



Figures 1 and 2 show the first South African image of a cluster of sprites, probably initiated by a series of lightning strikes. These thunderstorms occurred approximately 550 km north-east of Sutherland. The dark square is another telescope building at SAAO. SANSA

Stanislaus Nnadih, a Masters student at the University of Cape Town (UCT) who operated the night-vision TV camera that captured the first images of sprites in South Africa. SANSA





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Science of little fish leads to big award for NMMU prof

Prof. Nadine Strydom – winner of Nelson Mandela Metropolitan University's Researcher of the Year Award – is Africa's leading expert on 'little fish', and a regular pioneer of new technologies in her field. Her speciality is identifying fish larvae so tiny they can only be seen under a microscope. She tracks the early life stages of fish – monitoring their movement from the sea (where fish spawn) to the surf zone (where fish larvae are part of the plankton) to estuaries (where they grow into juvenile fish) and even up-river (where marine fish make use of unique nursery areas). She also monitors the age and size at which fish start reproducing.

An understanding of fish larvae can help with predictions about the size of future fish populations. 'It's a well-known scientific phenomenon that the success of any fish population is underpinned by the success of the larval phase,' says Nadine Strydom. Fisheries worldwide use eggs and larvae to predict the number of adult fish they are likely to catch two to three years down the line.

Her research on fish reproduction and early life history stages is necessary to help conservation authorities and policymakers make decisions regarding fish protection and management. In South Africa, this is critical, given that many coastal fish stocks – the kind targeted by shoreline and small boat anglers – are collapsing.

'We only have 3% of the entire population of Dusky Kob left. This is because of misaligned size restrictions related to the size at which reproduction starts (most are fished out before they have even reproduced once); unregulated fishing in estuary nursery areas; and poor angler education on [both] the biology of the species they are fishing and the poor state of many coastal fish stocks.'

Nadine Strydom has adapted a technique used at GEOMAR, which is typically used for fisheries research in the Northern Hemisphere, for ecological purposes in estuaries in South Africa.

"This technique uses RNA:DNA ratios to determine whether fish larvae are in good condition or not. The healthier the larvae, the better their survival rates will be. I'm using the technique in new ways to figure out how good the different estuaries are, in terms of serving as feeding and nursery areas for the baby fish, and to test it as a pollution-monitoring tool.'

Much of Strydom's research is also coupled to marine spatial planning. Because estuaries in South Africa are typically used as nurseries by many linefish species, caught recreationally and commercially, issues like industrial and sewage pollution are critical.

She is passionate about nature – marine and terrestrial – and its conservation. She recently co-authored a book on the identification of the larval stages of fish in east African coastal waters. With the funds raised as a spin-off from the book, she hosted training courses for academically-deserving students working in fields such as aquaculture and fish ecology in a number of African countries. 'The more people we can get to work in this research field, the better they can serve ecology, fisheries and aquaculture.'

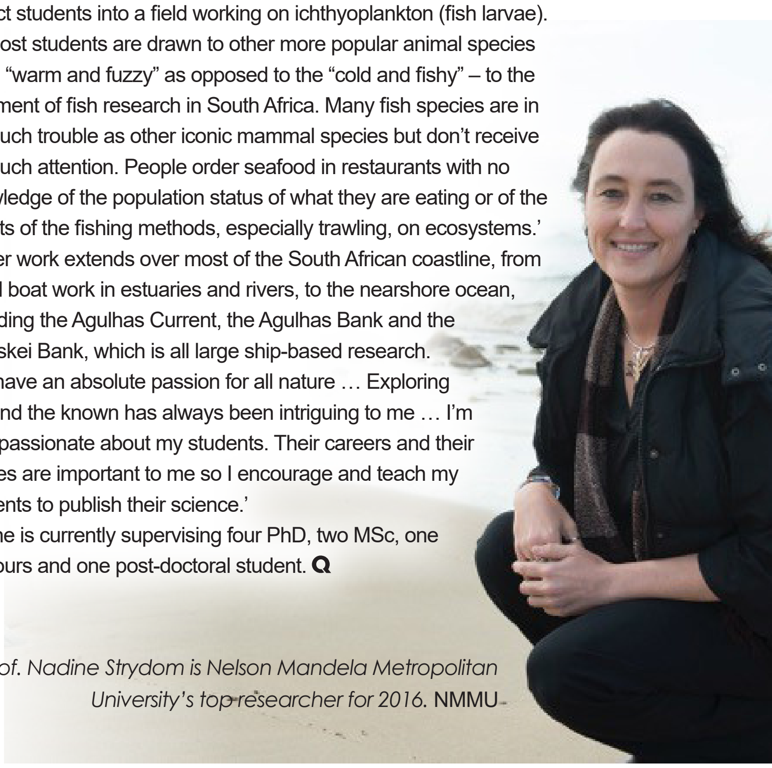
Despite her groundbreaking work, she says it remains a struggle to attract students into a field working on ichthyoplankton (fish larvae).

'Most students are drawn to other more popular animal species – the "warm and fuzzy" as opposed to the "cold and fishy" – to the detriment of fish research in South Africa. Many fish species are in as much trouble as other iconic mammal species but don't receive as much attention. People order seafood in restaurants with no knowledge of the population status of what they are eating or of the effects of the fishing methods, especially trawling, on ecosystems.'

Her work extends over most of the South African coastline, from small boat work in estuaries and rivers, to the nearshore ocean, including the Agulhas Current, the Agulhas Bank and the Transkei Bank, which is all large ship-based research.

'I have an absolute passion for all nature … Exploring beyond the known has always been intriguing to me … I'm also passionate about my students. Their careers and their futures are important to me so I encourage and teach my students to publish their science.'

She is currently supervising four PhD, two MSc, one Honours and one post-doctoral student. **Q**



Prof. Nadine Strydom is Nelson Mandela Metropolitan University's top researcher for 2016. NMMU

Back page science

UCLA scientists use ultrasound to jump-start a man's brain after coma

A 25-year-old man recovering from a coma has made remarkable progress following a treatment at UCLA to jump-start his brain using ultrasound. The technique uses sonic stimulation to excite the neurons in the thalamus, an egg-shaped structure that serves as the brain's central hub for processing information. The researchers targeted the thalamus with low-intensity focused ultrasound pulsation.

The technique used a device about the size of a coffee cup saucer, which creates a small sphere of acoustic energy that can be aimed at different regions of the brain to excite brain tissue. Before the procedure began the man showed only minimal signs of being conscious and of understanding speech but the day after the treatment, his responses had improved measurably. Three days later, he had regained full consciousness and full language comprehension, and he could reliably communicate by nodding his head 'yes' or shaking his head 'no.'

The researchers cautioned that the procedure requires further study on additional patients before they determine whether it could be used consistently to help people recovering from comas. UCLA

Orion's ionised carbon atoms

The dusty side of the Sword of Orion is illuminated in this striking infrared image from the European Space Agency's Hershel Space Observatory. This immense nebula is the closest large region of star formation, situated about 1 500 light years away in the constellation of Orion. The parts that are easily observed in visible light, known alternatively as the Orion nebula or Messier 42, correspond to the light-blue regions. This is the glow from the warmest dust, illuminated by clusters of hot stars that have only recently been born in this chaotic region.

The red spine of material running from corner to corner reveals colder, denser filaments of dust and gas that are scattered throughout the Orion nebula. NASA

Orion's dusty side. NASA

Competition may have killed off largest shark ever

Is there anyone who doesn't know *Jaws*, the film about the great white shark and the devastation it wreaked? But there have been bigger and more dangerous sharks in the past.

The largest known shark species ever, *Carcharocles megalodon*, reached lengths up to 18 m – that's about the length of a bus – but the ancient beast, thought to have fed on marine mammals during its terrifying existence between 23 million and 2.6 million years ago, died out. Thank goodness! Scientists have usually blamed climate changes for the disappearance, but a new study concludes that the shark perished because the diversity of its prey shrank and new competitors appeared. Researchers from the Paleontological Institute and Museum of the University of Zurich in Switzerland and colleagues examined the animal's geographical range and abundance over time.

For scale, the man next to the replica of the Carcharocles megalodon *jaws is 1.78 m tall.* Wikimedia Commons

They found that its fate seems to have been intertwined with other species. When megalodon's range shrank, many smaller marine mammal species disappeared and new predators appeared such as the ancestors of the killer whale and the great white shark. The results suggest these species could have competed for increasingly scarce food, the researchers said.

The findings are published in *The Journal of Biogeography*. World Science, http://www.world-science.net

New class of fuel cells offers increased flexibility, lower cost

A new class of fuel cells based on a newly discovered polymer-based material could bridge the gap between the operating temperature ranges of two existing types of polymer fuel cells, a breakthrough with the potential to accelerate the commercialisation of low-cost fuel cells for automotive and stationary applications.

Researchers have discovered that fuel cells made from phosphate-quaternary ammonium ion-pair can be operated between 80°C and 200°C with and without water, enhancing the fuel cells usability in a range of conditions.

Current fuel-cell vehicles need humidified inlet streams and large radiators to dissipate waste heat, which can increase the fuel-cell system cost substantially. Two main classes of polymer-based fuel cells exist. One is the class of low-temperature fuel cells that require water for proton conduction and cannot operate above 100°C. The other type is high-temperature fuel cells that can operate up to 180°C without water; however, the performance degrades under water-absorbing conditions below 140°C.

The prototype fuel cells made from the ion-pair-coordinated membrane demonstrated excellent fuel-cell performance and durability at 80 – 200°C, which is unattainable with existing fuel cell technology. Los Alamos National Laboratory

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