National Research Foundation

SAAO
South African Astronomical Observatory
200 YEARS

BEYOND 200 YEARS OF ASTRONOMY

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MESSAGE FROM THE SAAO DIRECTOR

The year in review, April 2020 to March 2021, began in a national Level 5 hard lockdown in South Africa. What followed was one roller-coaster of a year, including the 200 year Anniversary of our Observatory celebrated amidst the COVID-19 pandemic.

Operationally, what turned out to be a highlight of the year in SAAO, was also spurred by the otherwise devastating global situation. Pushed by the lockdown, our technical, software, and astronomy operations teams managed to convert SALT and SAAO telescopes to be fully remotely controlled from Cape Town in a very short time. SALT in particular was a matter of pride for us, as it turned out to be one of the least affected large telescopes on the whole planet, losing just a handful of weeks of on-sky time. And all this was done absolutely safely both in terms of people, the most important aspect, as well as equipment. What helped in the latter was also our government's special permission, for which we were grateful, for us to move across Provincial borders at all times to be able to safeguard equipment with required maintenance.

Hence, while most of us became very accustomed to Zoom meetings from our homes, this year our astronomers and operators also became very familiar with successfully running, say, a 10-m class optical telescope, hundreds of km's away, from their lounges, kitchens and beds. These developments are also intentional stepping stones to SAAO's core vision for the decade, the Intelligent Observatory initiative (see p.16, and article **).

Another source of pride was the part our SAAO mechanical Workshop with SALT & SAAO engineers played in providing the nation with non-invasive ventilators in the fight against the worst effects of the pandemic. With our capability of very high precision mechanical engineering, SAAO produced the prototypes of the oxygen blenders for the National Ventilator Project, coordinated by our sister-organisation SARAO, all during the time of the mentioned hard lockdown.

A major aspect of the year of course was the 200th Anniversary in October, with the theme of "Beyond 200 Years of Astronomy". By it we mean that while conveying the excitement of exploring our amazing universe, we also wish to highlight the benefits that science brings to society, and look to a future full of opportunity and pride in the excellence of decidedly

African astronomy at the forefront of a cutting-edge global pursuit. While party plans had to be scaled back, it nevertheless was a memorable event with the Unveiling of Observatory site as a National Heritage Site, followed by a very well-attended SAAO 200 Symposium, and a Virtual Festival, and also a string of community events under the 200 Days of Astronomy banner. The month also featured the premier of our first full-dome Planetarium film, the Rising Star. You can read more about all these events and activities in this Review.

Science-wise, the year was no slacker either. Staff and students continued publishing at pre-COVID rates, with 125 refereed papers in the year. And, in fact, papers based on SALT-data by all its users hit an all-time high to-date, with 64 per year. Several science highlights on black holes, accreting pulsars, gamma-ray bursts, galaxies, and the like, are featured in this Review. Excitingly, these also include a new comet being discovered by, and named after, one of our astronomers: C/2020 S3 (Erasmus). I note that many results come from multi-wavelength and multi-facility studies, including simultaneous observations between SALT and MeerKAT. Using multiple wavelengths is often extremely important for in-depth understanding, and being able to successfully leverage our national facilities also demonstrates the courageous South African foresight in investing in these cutting-edge facilities.

I hope you will get a taste of the excitement of activities at SAAO from this Annual Review, from science to operations, to student projects and supervision, and to the wide range of science engagement activities. I am extremely proud of the SAAO staff and students for putting in such an effort during this tough year of global anxiety in particular. Thank you!

*** https://physicstoday.scitation.org/do/10.1063/PT.6.1.20210204a/full/*

Prof. Petri Väisänen

SAAO 200

THE SOUTH AFRICAN ASTRONOMICAL OBSERVATORY
200 VIRTUAL SYMPOSIUM

The South African Astronomical Observatory (SAAO), formerly The Royal Observatory Cape of Good Hope, celebrated 200 years of existence as an astronomical observatory on 20 October 2020 and is the oldest scientific institution in South Africa.The Royal Observatory Cape of Good Hope was founded on 20 October 1820, and for much of its history, it was the major contributor to positional astronomy in the southern hemisphere. The SAAO is not only known for its rich history and various contributions to science, its buildings are also of special architectural significance. Consequently, on 21 December 2018, the South African Heritage Resources Agency (SAHRA) officially declared the SAAO a National Heritage Site and on 20 October 2020 it was formally unveiled.

HISTORY OF THE OBSERVATORY

At the time of its foundation, the Royal Observatory was formally controlled by the British Admiralty and was initially intended for the improvement of navigation. Its main duty was to chart the southern skies and provide a time service for passing ships in Cape Town Harbour. The work of the Observatory, however, soon moved into scientific inquiry and discovery.

Indeed, only a few years after the completion of the Royal Observatory in 1832/1833, Thomas Henderson made the first measurements to find the distance to a star. The Royal Observatory found its forte in the late 19th century by leading the way in astronomical photography and the cataloguing of stars. For this, it gained a global reputation. The 20th century saw research move into the more fundamental physics of stellar dynamics and evolution, including the development of spectroscopy with the donation of the Victoria Telescope by Frank McClean. This led to further breakthroughs such as the discovery of oxygen, silicon, and europium in stars. In 1951, the Observatory gained access to the 1.9-metre Radcliffe telescope in Pretoria which remained the largest telescope in South Africa until 2004. In 1971, a decision was taken to amalgamate the major facilities for optical astronomical research into one body, which became known as the South African Astronomical Observatory. There was a new beginning in South African optical astronomy in 1972 with the foundation of the SAAO's Sutherland Observatory, situated far from the Cape Town city lights, wet winters and air pollution. The Sutherland site offered ideal conditions for astronomy being at high altitude with cold, clear air and a steady atmosphere. One of the primary telescopes at the new Sutherland site was the 1.9-metre telescope from the Radcliffe Observatory in Pretoria which was moved to Sutherland following the closure of the Radcliffe Observatory, and it became operational again in January 1976. The South African astronomy community began considering the idea of acquiring a new telescope towards the late 1980s and had initially envisaged a rather modest 4-metre instrument.

However, these dreams were far surpassed when, in 1998, South Africa became the leading partner in the Southern African Large Telescope (SALT), which was to become the largest optical and infrared telescope in the southern hemisphere. It is designed to provide maximum collecting area for minimum cost and is especially suited for spectroscopy of faint objects.SALT comprises 91 hexagonal mirrors arranged to form a combined diameter of over 10 metres and was additionally backed by a consortium of international partners. The SALT consortium involved institutions from nearly a dozen countries in Europe, the USA, Britain and New Zealand, with South Africa constituting the largest partner. Based on the Hobby-Eberly Telescope in Texas, this facility has provided South African astronomers with outstanding capacity in the fields of optical photometry and high-speed spectroscopy with South African scientists having access to one-third of the observing time.The South African National Research Foundation stated in 1999 that SALT's 'two primary missions' were (1) to provide a state-of-the-art facility for local and international astronomers and astrophysicists and (2) to overcome and redress past government policies that 'dislocated the majority of South Africans from science, engineering and technology education'. From 2011, after a period of commissioning and performance verification, SALT started full science operations, coming into its own as Africa's 'giant eye' on the universe, with significant contributions to global astronomy.

One of the most notable and dramatic discoveries in recent years came in August 2017 when four telescopes at Sutherland contributed to a global effort to detect the first visible counterpart of a gravitational wave source. Gravitational waves were predicted by the theory of General Relativity but are extremely difficult to detect as they are ripples in the structure of space–time and are not like electromagnetic radiation. Gravitational waves were observed from a source in a known galaxy 130 million light years away on 17 August 2017. SAAO observed the aftermath of this neutron star merger with four telescopes: SALT, MASTER-SAAO, the 1.0-m and the Infrared Survey Facility, with SALT obtaining the first spectrum of the source.Today Sutherland is home to more than 20 telescopes of various shapes and sizes with SALT remaining the flagship and the 1.9-m telescope still fully operational.

SAAO 200 **CELEBRATIONS**

To celebrate the bicentenary of the Observatory, various events were arranged including the unveiling of the SAAO as a National Heritage Site, the SAAO 200 Astronomy Symposium, and the SAAO 200 Virtual Astronomy Festival.

SAAO Managing Director Prof. Petri Väisänen stated:
This occasion is an opportunity to recall some great scientific achievements. But more than that, it is an opportunity to celebrate our country's and continent's rich heritage in an attempt to understand the universe and our place in it. In particular, we want to convey the pure excitement of exploring the amazing universe we are part of, and also highlight the many benefits that science brings to society. The theme of our event is 'Beyond 200 Years of Astronomy', and we see this future full of opportunity, inspiration, and pride in the excellence of decidedly African astronomy at the forefront of a cutting-edge global pursuit.

UNVEILING OF THE SAAO AS A NATIONAL HERITAGE SITE

The formal 'virtual' unveiling of the National Heritage Site was held on the 20 October 2020 and was attended by a limited number of dignitaries including Director-General of the Department of Science and Innovation (DSI), Dr Phil Mjwara, and CEO of SAHRA, Adv. Lungisa Malgas.

The unveiling included pre-recorded addresses by the Minister of Sports, Arts and Culture, the Honourable Nkosinathi Mthethwa, and the Minister of Higher Education and Training, Science and Innovation, the Honourable Dr Blade Nzimande.The programme included interviews with SAAO staff, and the premiere of a new animation of indigenous Khoesan starlore, 'Moons Message', which was very well received by dignitaries, the community, and the media. The livestream of the unveiling was viewed by over 1000 people.

SAAO 200 VIRTUAL **SYMPOSIUM**

The SAAO 200 Symposium was planned as an in-person symposium due to take place from 20 to 22 October 2020. Owing to the COVID-19 pandemic, the decision was taken to shift from an in-person symposium to a virtual one.

The symposium was then extended to become a 4-day event, starting with the unveiling of the SAAO as a National Heritage Site, followed by the SAAO 200 Symposium. The original target was set at 300 attendees for an in-person symposium. Shifting to virtual allowed for more participants and complimentary registration fees.

The symposium kicked off on 20 October with the number of registrations at 575. In total, 626 attendees registered and, at any given stage, an average of 127 viewers were engaged.In terms of participants, 75.6% were from South Africa. The Western Cape represented 52.5%, Gauteng 12.8%, Eastern Cape 3.2%, KwaZulu-Natal 2.2%, Mpumalanga 1.5%, Free State 1.4%, North West 1.3%, and Limpopo 0.9%. Participants from other countries included those based in Britain, Mauritius, Nigeria, India, USA, Turkey, Japan, Uganda and Zimbabwe.

The virtual symposium provided an ideal opportunity to incorporate some leading international speakers without incurring exorbitant travel costs. This helped to develop a very strong programme.

SAAO 200 **VIRTUAL FESTIVAL**

During the same week the SAAO hosted, in collaboration with Scifest Africa, a joint Virtual Festival to celebrate Astronomy and Space Sciences.

The SAAO Virtual Festival saw a series of small events each week in October culminating in the online virtual festival from Tuesday to Friday 20-23 October 2020. Some highlights of the public programme were virtual storytelling hosted by Dr Gcina Mhlope who dazzled us with beautiful narrations of the African night sky, live evening talks, presentations and lectures on astronomy and space science, workshops for learners, parents and educators. In total 13 events were held with an estimated attendance of over 1500 individuals

Finally the Virtual Festival came to a close with a night of live virtual stargazing and good music hosted by Master KG of the hit single Jerusalema.

ASTRONOMY FOR SOCIETY

The SAAO 200 Virtual Symposium saw presentations covering a wide range of topics, including current and future science, the history of astronomy on the continent, as well as the cultural and sociological aspects of astronomy.

The opening session of the Symposium included keynote addresses focusing on a wide range of astronomy-related topics. The President of the International Astronomical Union (IAU), Prof. Ewine van Dishoeck, addressed the IAU's role in development, outreach and education including its Office Astronomy for Development (OAD) at SAAO in Cape Town. Prof. Vanessa McBride provided further details of the excellent work being done by the OAD to utilise astronomy to achieve the United Nations Sustainable Development Goals. One highlight of the Symposium was the address by the SAAO Manager of Collateral Benefits in Sutherland, Mr Anthony Mietas, who delivered a stirring account of the remarkable achievements of the programme over the past decade. Through this work, Sutherland has become an astro-tourism hub and has created 302 jobs directly and, indirectly, a number more. SAAO/SALT remains the single largest employer in the town of Sutherland, and SALT and SAAO continue to utilise the Sutherland-based local companies for various projects.The SAAO and the National Research Foundation have refurbished both the primary and high schools' laboratories and SALT purchased school desks for the intermediate learners in the Roggeveld Primary School. Additionally, the Sutherland Community Development Centre is an initiative from the SAAO, with support from SALT, the local community, and various partners, in particular the DSI as the main sponsor. The centre provides connectivity, childcare and several cultural, artistic, sports and social events throughout the year, enhancing the life of the community.

Various talks at the symposium addressed critical societal issues within astronomy such as transformation, human capital development and successful outreach initiatives across South Africa and the rest of Africa. Teams such as the SAAO Outreach department, the Astronomical Society of Southern African and the African Astronomical Society presented on their efforts to engage with the community.

A RICH HISTORY

The Symposium featured a variety of presentations on the diverse history of the Observatory and of astronomy in Africa, including presentations on indigenous knowledge and ethno-astronomy and efforts to better communicate this valuable knowledge and the efforts of astronomers at the Cape before 1820.

Dr Ian Glass delivered his keynote address on 'The Cape Observatory from 1820 to 1972', highlighting the myriad scientific achievements during those years and this was complemented by more detailed discussions of some of the key figures involved, such as Sir David Gill, as well as the role of the Royal Astronomical Society in South African astronomy.More recent developments in African astronomy, such as the advent of SALT and the genesis of the Square Kilometre Array, were presented by Dr David Buckley and Dr Bernie Fanaroff, respectively, illustrating the tremendous advances in astronomy facilities on the continent in recent decades. The SKA Director-General, Prof. Phil Diamond, addressed some of the challenges and opportunities arising from one of the largest science experiments in his talk entitled 'SKA: Building an Observatory to Study the Dawn of Time and the Origins of Life'.

A BRIGHT FUTURE

The bright future for African astronomy would not be possible without the development of African astronomers.

Prof. Patricia Whitelock gave an overview of the hugely successful National Astrophysics and Space Science Programme (NASSP) founded in 2003. Hosted at the University of Cape Town, the University of KwaZulu-Natal and North-West University, the programme has seen over 300 students graduate with honours degrees and more than 140 with master's degrees. In addition, since 2011, 87 students who were trained at SAAO and SALT have graduated – approximately 40% with honours, 30% with MSc and 25% with PhD degrees. Of these students, 63 (72%) were people of colour. Students at NASSP and SAAO represent the rich diversity and culture of our continent, coming from a range of countries including Rwanda, Uganda, Ethiopia, Mauritius, Sudan, Burkina Faso, Lebanon and Madagascar.Many of these students were represented in the Symposium schedule, both in oral and poster presentations, with talks covering observational and theoretical aspects of stellar and extragalactic astronomy, astronomical instrumentation, and computer modelling. Many projects involve combining and analysing data from different wavelengths, e.g. optical data from SAAO/SALT with radio data from MeerKAT and/or X-ray measurements from spacecraft.Astronomy is expanding across the African continent, with the newly revitalised African Astronomical Society. On the horizon is the largest meeting in the astronomy calendar, the General Assembly of the International Astronomical Union. This meeting in Cape Town in 2024 will be the first General Assembly held on the African continent since the establishment of the Union over 100 years ago – securing the recognition of Africa's contribution to global science.

Cunnama D. The South African Astronomical Observatory 200 Virtual Symposium. S Afr J Sci. 2021;117(3/4), Art. #9392. https://doi.org/10.17159/sajs.2021/9392

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THE SOUTH AFRICAN ASTRONOMICAL OBSERVATORY IN THE 21ST CENTURY

by Vanessa McBride & Petri Vaisanen

Looking to the future of the South African Astronomical Observatory.

The commemoration of the bicentenary of astronomy in South Africa offers us an opportunity to look to the future and the exciting scientific and technical developments on the way. But it's also a moment to consider our past: how it has shaped the South African Astronomical Observatory (SAAO) into the institution it is today, and how we can both build on it and escape it to realise the future of the SAAO.

The Royal Observatory at the Cape of Good Hope, as established in 1820 by the British, was founded on colonial and imperialist ambitions. Before it served the scientific community, it was a naval observatory, with the focus on timekeeping and navigation. Out of these roots grew a scientific institution that would become the South African Astronomical Observatory (SAAO) in 1972. New astronomical discoveries have been ubiquitous during this time, ranging from a measurement of the distance to Alpha Centauri in 1842 to observations of the first optical counterpart to a gravitational wave event in 2017. While bound by apartheid laws of the time, the SAAO, situated in the suburb of Observatory, Cape Town, was also embedded in a 'grey' suburb - one of the few areas where South Africans of all races lived together.

Today, just like its home suburb, the SAAO is an eclectic juxtaposition of the old and the new. A beautiful, wood-panelled library houses the first volume of the Monthly Notices of the Royal Astronomical Society. Behind it, a state-of-the-art workshop manufactures, to micrometre precision, bespoke components for cameras and spectrographs. The observing station is located 360km away, just outside the Northern Cape town of Sutherland.

The Southern African Large Telescope (SALT) stands as a sentinel on the observing plateau, a working monument to the audacious vision of the South African government and science community.

While the town of Sutherland has been reshaped by astro-tourism, its ongoing development challenges are also a stark reminder of the realities of poverty, unemployment and inequality that face South African society.

Science and the society in which it is embedded are inextricably intertwined. History has left us with a legacy that pervades the very fabric of our society: we must unlearn decades of discrimination. **As we take stock of the immense leaps forward in our astronomical knowledge over the last two hundred years, we see also how science in South Africa must diversify its workforce.** Over the last decade, the SAAO, while delivering world-class scientific research, has been at the heart of training programmes designed to address the inequalities faced by women and black scientists.

This work is far from done. South Africa's historically disadvantaged institutions are stepping forward to claim their places on the stage of blue-sky science, and a network of astronomers is burgeoning across the African continent, consolidating in the newly revitalised African Astronomical Society. On the horizon is the biggest meeting on the astronomy calendar, the General Assembly of the International Astronomical Union. The meeting in 2024 will be the first General Assembly held on the African continent since the establishment of the Union over 100 years ago - securing the recognition of Africa's contribution to global science. This is a pivot point for the South African Astronomical Observatory. It's an opportunity for both science and society. Bring on the next 200 years!

This article first appeared in the October 2020 special astronomy edition of the NRF's Science Matters magazine, produced in celebration of the 200th Anniversary of the SAAO.

ABOUT THE AUTHORS:

Prof Petri Väisänen obtained his PhD from the University of Helsinki, and after spells in USA and Chile, he joined SALT and SAAO in 2004. He currently serves as the Director of the SAAO, while his own research is on colliding and interacting galaxies and violent star formation.

Assoc Prof Vanessa McBride is an astronomer at the IAU's Office of Astronomy for Development and Head of Research at the South African Astronomical Observatory. She is also an adjunct associate professor in the Department of Astronomy at the University of Cape Town.

THE INTELLIGENT OBSERVATORY AND THINGS THAT GO BUMP IN THE NIGHT

By Steve Potter, Zwido Khangale & Vanessa McBride

Leading the way for the next generation of observatories

Advances in telescope technology over the last decade have made it possible to monitor the entire night sky on almost a continuous basis. Coupled with affordable computational power and storage, astronomers across the globe are poised to enter a new era of exploring astrophysical transients or, in other words, things that go bump in the night.

Some astronomical objects vary slowly while others merge or explode in rapid, bright cataclysmic events which are often detected across the entire electromagnetic spectrum from the radio to the visible to X-rays and even as gravitational waves or neutrino events.

Many sky surveying telescopes are already in operation, with the newest and most ambitious of these, the Legacy Survey of Space and Time (LSST) on the Rubin Observatory, currently under construction in Chile, set to go online in 2024. With so many wide eyes on the sky, the number of these so-called transient events is enormous, perhaps reaching millions per night when LSST comes online. This means that the potential for new discoveries is enormous. Understanding what's behind these transient events requires more detailed follow-up multi-wavelength observations. For example, exploring their spectral signatures or taking high-speed measurements of the more rapid and explosive events.

However, with so many transient events, it is impossible to follow-up even 1% of those expected from LSST alone. Instead the transient events have to be intelligently filtered, classified and the most potentially interesting ones selected for more detailed observations. The South African Astronomical Observatory (SAAO) has embarked on a drive to upgrade all of the telescope facilities on the plateau at the Sutherland observing station to do exactly that.

The new programme, called the Intelligent Observatory (IO), involves the development of software algorithms to filter and to intelligently decide what to observe, and also requires upgrades of the telescopes' hardware so that they become more autonomous and capable of "talking" to each other. Then, given a live-stream feed of alerts from surveys like LSST, the IO will be able to make real-time decisions and subsequently execute a course of follow-up observations that will allow scientists to maximise their understanding of the most interesting objects.

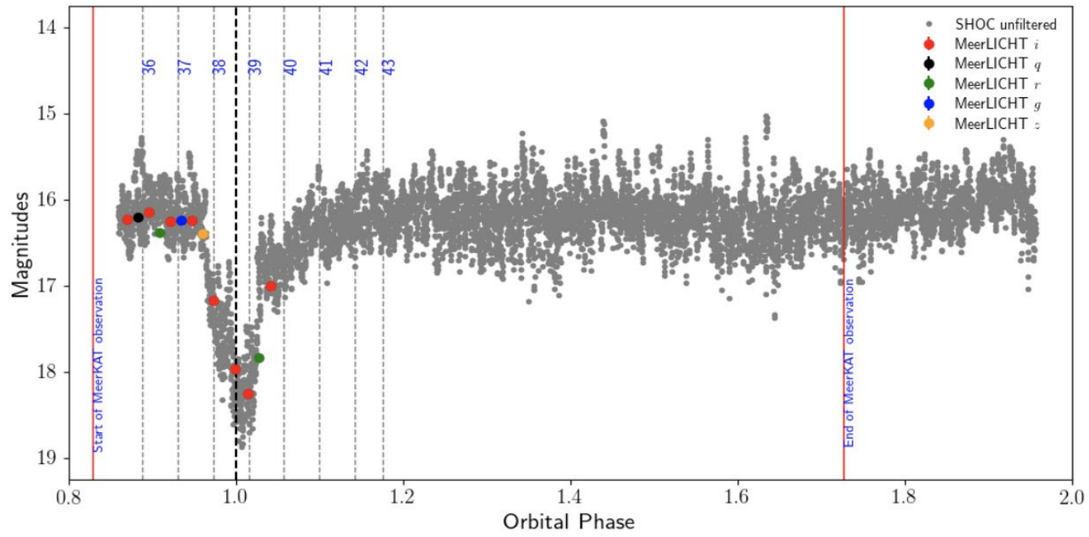
This approach catapults a 200-year old observatory squarely into the 4th industrial revolution, with humans and machines working in combination to uncover new results and push the boundaries of our understanding of the Universe.

One such multi-wavelength observation was performed on 06 November 2018 to observe a well studied eclipsing binary system in the constellation of Fornax, known as UZ For. We used four telescopes - three in Sutherland: the Southern African Large Telescope (SALT) in spectropolarimetry mode, SAAO 1.9-m telescope and MeerLICHT in photometry mode, and the MeerKAT radio telescope.

UZ For was discovered in 1987 as a strong source of X-rays and subsequently classified as a "polar". Polars consist of two stars orbiting each other typically every few hours. The more massive star is the compact remnant core of a sun-like star that has exhausted its hydrogen fuel supply (the white dwarf) and the companion is a low-mass sun-like star. In this setup, the low-mass companion is constantly transferring material to the white dwarf via a ballistic stream.

The white dwarfs in polars are strongly magnetic with field strengths ranging from 10 to 230 million Gauss (the Earth's magnetic field is typically about 0.5 Gauss). Therefore, the transferring material is directed along the magnetic field lines to eventually crash onto the surface near the magnetic poles of the white dwarf, releasing vast amounts of energy seen as X-rays, visible and radio emission.

The two stars in UZ For orbit each other every 126 minutes and the system is fortuitously aligned, from our perspective, such that the stars eclipse each other once every orbit. Studying eclipses is very useful for determining basic parameters such as masses and sizes etc, especially because these systems are too far away to resolve the individual stars.



The brightness variation of the eclipse of UZ For, as seen by four different telescopes in South Africa: SALT, MeerLICHT, MeerKAT and the SAAO 1.9m telescope.

The high-speed measurements of the brightness variations (using the SAAO 1.9m telescope) shows the eclipse of the white dwarf by the companion in UZ For. Additional colour information was obtained with the MeerLICHT telescope and is overlaid around the eclipse (see Figure below). The SALT observations (dotted grey lines) as well as the start and end-time of the MeerKAT radio observations (red lines) are also shown. Analysis of the SALT spectropolarimetric observations revealed that the light from UZ For is circularly polarised, a typical characteristic of light that is produced in regions of strong magnetism. Detailed modelling of the SALT spectrum suggests that the magnetic field strength of the white dwarf in UZ For is 57 million Gauss. The MeerKAT radio observations also confirmed the presence of radio emission, the origin of which is still under debate.

This was the first time that these four South African telescopes were used in conjunction to observe an astronomical target. It required months of planning and communication to organise such synchronous observations. In future, the IO will make observations like these a more common occurrence.

The IO will set a new benchmark for efficient follow-up of things that go bump in the night, one that is led by South Africa and will likely be emulated by observatories across the world.

This article first appeared in the October 2020 special astronomy edition of the NRF's Science Matters magazine, produced in celebration of the 200th Anniversary of the SAAO.

ABOUT THE AUTHORS:

Originally from the UK, Prof. Stephen Potter obtained his PhD from University College London. His career with SAAO began in 1999 where he is now Head of Astronomy and holds a visiting professorship with the University of Johannesburg. His research expertise is in observational astronomy particularly of high-energy galactic objects.

Mr Zwidofhelangani Khangale is a doctoral student at the University of Cape Town (UCT) and the South African Astronomical Observatory (SAAO). His PhD research focuses on understanding various emission mechanisms found in magnetic cataclysmic variable stars.

Assoc Prof Vanessa McBride is an astronomer at the IAU's Office of Astronomy for Development and Head of Research at the South African Astronomical Observatory. She is also an adjunct associate professor in the Department of Astronomy at the University of Cape Town.

HIGHLIGHTS OF ASTRONOMY IN SOUTH AFRICA BEFORE 1972

By Ian Glass

Some of the most exciting scientific achievements in South Africa's Astronomical research

Astronomical research in South Africa began in the mid-18th century with the visit of the French Academician Nicolas-Louis de La Caille in 1751-1753. La Caille undertook a careful examination of every square degree of the Southern Sky, resulting in the first truly comprehensive sky survey ever made (in either hemisphere!)

His pioneering work was followed by the establishment of the Royal Observatory, Cape of Good Hope, in 1820.

For much of its history this, the first permanent observatory in South Africa, was the major contributor to positional astronomy in the Southern Hemisphere.

Over subsequent years, this work, though laborious, led to important scientific discoveries.

Observations made by the Cape astronomers include the first measurement of the distance to a star; the first photographic sky survey; the accurate measurement of the distance to the Sun; developments in stellar spectroscopy; the determination of the shape of the Earth in the Southern Hemisphere; and the first accurate geodetic surveys of Southern Africa.

MEASURING STELLAR DISTANCES

A consequence of Nicolas Copernicus's assertion in 1543, that the Earth orbits the Sun, was that we should be able to observe the apparent shift in the position of the nearest stars from different points in the Earth's orbit. This, however, had not been observed in the centuries following. The reason was, of course, that even the nearest stars are incredibly far away and the effect being looked for is very small.

When the Royal Observatory was founded in 1820, it was equipped with the most accurate star position measuring devices available. The first believable measurements of this effect, known as "parallax", were made from the Cape in 1831-1833 by Thomas Henderson. By observing the angular "movement" of Alpha Centauri, and knowing the size of the Earth's orbit, this gave the distance to the star by simple trigonometry. Alpha Centauri is still the second-closest star known.

STAR SURVEYS BY PHOTOGRAPHY

A major occupation of all observatories in the 19th century was making precise observations of star positions one by one and publishing catalogues of these. In 1882, the head of the Royal Observatory, David Gill was surprised by receiving a letter from Mr Simpson, an amateur photographer in Aberdeen, Cape. Simpson had managed to photograph a bright comet that had just appeared but, incredibly, his photographic plates were sensitive enough to register stars in the background.

This led to a "light bulb" moment for Gill as he realised that the positions of stars could now be recorded in quantity on a permanent medium, more reliably than any visual observer could ever hope to do.

He accordingly set up a special photographic telescope using the largest lens that he could find and set about making the first photographic star catalogue. This was called the Cape Photographic Durchmusterung after its much more laboriously compiled Northern Hemisphere equivalent compiled in Bonn, Germany.

PROXIMA CENTAURI

In 1903, the Johannesburg Observatory was established and it achieved its greatest success in 1915 when its Director, Robert Innes, discovered a very faint star near Alpha Centauri. On various grounds he claimed it to be the nearest star to Earth but it took many years of investigation before this could be verified.

The new discovery was named "Proxima Centauri", meaning the nearest in the constellation Centaurus. Not only was it the nearest star but at that time of discovery, it was the least luminous star ever discovered. Other dimmer stars have been found since but Proxima still retains its nearest status and its distance has since been thoroughly verified from space satellites.

DOUBLING THE SIZE OF THE UNIVERSE

In 1948 the private Radcliffe Foundation in the United Kingdom set up in Pretoria what was for a time the largest telescope in the Southern Hemisphere and joint fourth largest in the World. Coincidentally this is a title currently held by the Southern African Large Telescope (SALT). Early on in the Radcliffe's existence, the then Director, David Thackeray and Adriaan Wesselink, discovered in the Magellanic Clouds a number of RR Lyrae variable stars that astronomers using smaller telescopes could not detect.

By measuring their average apparent brightnesses they determined that the cosmic distance scale originally determined two decades before by Hubble and others was underestimated by about a factor of two.

In effect, they doubled the size of the Universe! This result was announced to great acclaim at the triennial meeting of the International Astronomical Union in 1952.

The South African Astronomical Observatory in Cape Town has played a highly significant scientific role over time as the oldest permanent observatory in the Southern Hemisphere. With more than 200 years of history, it still retains its prominence in the international astronomical community.

This article first appeared in the October 2020 special astronomy edition of the NRF's Science Matters magazine, produced in celebration of the 200th Anniversary of the SAAO.

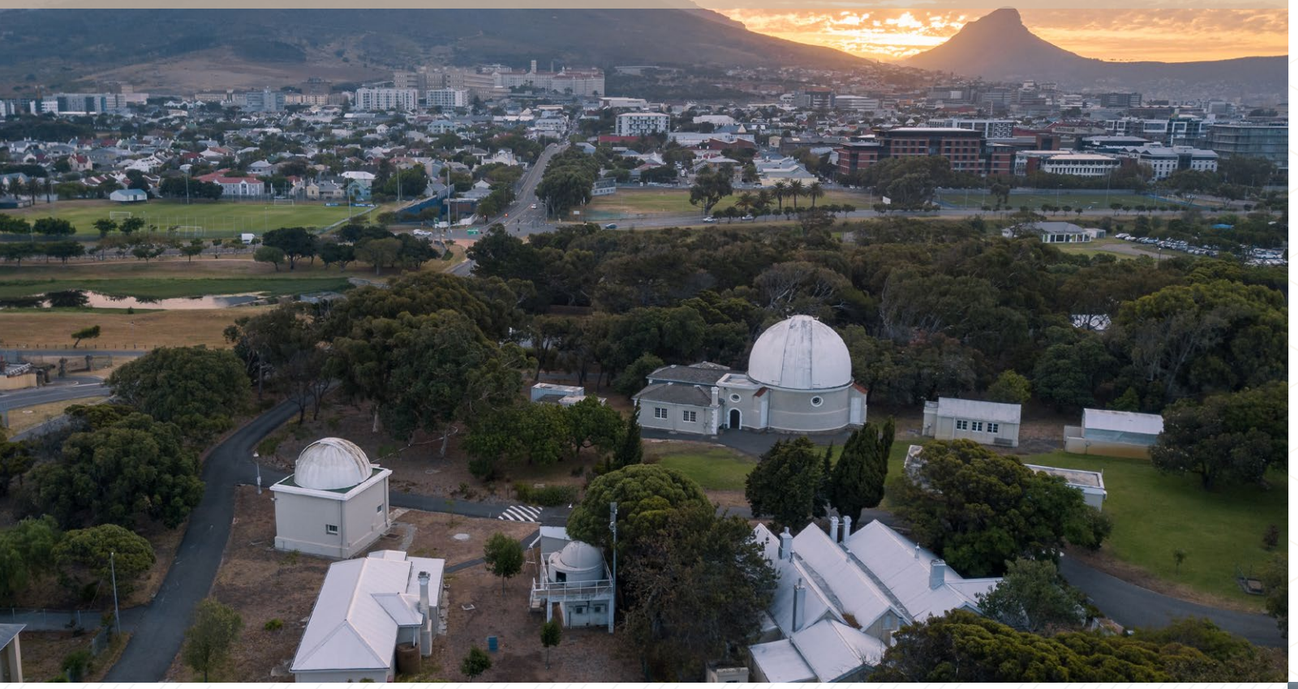
ABOUT THE AUTHOR:

Dr Ian Glass was born in Ireland and has a BA from Trinity College Dublin and a PhD from MIT. His career in various countries involved X-ray, visual, infrared and radio astronomy. Associated with SAAO since 1971, he has written 6 books and about 220 scientific papers, with over 9000 citations.

ABOUT SAAO

ABOUT **SAAO**

The South African Astronomical Observatory (SAAO) is a business unit of the National Research Foundation(NRF) and a National Research Facility which operates under the mandate of the Department of Science and Innovation (DSI).



The SAAO is the national centre for optical and infrared astronomy in South Africa. It is also the premiere facility for optical astronomy on the African continent, and operates the Southern African Large Telescope (SALT), the largest optical telescope in the southern hemisphere. **The primary role of SAAO is to provide modern ground-based observational facilities for astronomers across the nation and the world, as well as conduct world-class astronomical research itself.** The SAAO makes key contributions to the National System of Innovation (NSI) through its basic research, by providing the infrastructure to support research by astronomers at South African universities, and by developing new technology for astronomical instrumentation. SAAO astronomers participate in a wide variety of international research projects and host a number of international facilities at our Sutherland site. The dissemination of our research results through publications and conference presentations spurs innovation across the nation and throughout the world.

science & innovation
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

OFFICE OF ASTRONOMY FOR DEVELOPMENT

National Research Foundation

SAAO
South African Astronomical Observatory
200 YEARS

The SAAO also promotes astronomy and astrophysics in Southern Africa, by sharing research findings and discoveries and participating in outreach activities to enthuse citizens about physics and astronomy to sow seeds of innovation by future generations of South Africans. SAAO hosts the International Astronomical Union's Office of Astronomy for Development (OAD), which coordinates projects across the globe to improve people's lives through astronomy. SAAO also hosts the secretariat of the African Astronomical Society (AfAS). Our astronomers supervise the education of numerous post-graduate students, and students trained at the SAAO are now leading researchers and educators throughout South Africa and across the African continent.

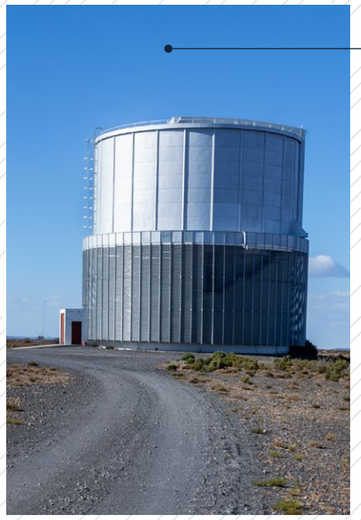
SAAO's headquarters are located in the eponymous suburb of Observatory in Cape Town within the Two Rivers Urban Park, at the confluence of the Black and Liesbeek Rivers. Its history dates from 1820 when the establishment of the observatory was authorised, making it one of the oldest permanent structures in Cape Town. Owing to light and air pollution in the city, research observations take place at SAAO's Sutherland site in the Karoo semi-desert region. Nevertheless, some of the historical telescopes in Cape Town are still used for outreach and public events. Open nights are held every second and fourth Saturday each month and comprise a public lecture, a tour of the SAAO Museum and a stargazing session. The Cape Town site is also one of the last remaining places close to the city centre where the original ecology of the area is preserved. Its low-lying portions are subject to occasional flooding and support a wide range of bird and animal life as well as a variety of flowering bulbous plants. The grounds mark the northern limit of the Western Leopard Toad (Amietophrynus pantherinus), an endangered species, and it is the only remaining habitat of the rare iris Moraea Aristata.

SAAO's main research telescopes are located at the observing site 15 km from the small Karoo town of Sutherland in the Northern Cape, a 4-hour drive from Cape Town. On a hill-top, 1800 metres above sea level and far from Cape Town's city lights, stand 24 telescopes of various sizes and forms, some owned by SAAO and some hosted for international research institutes (see table). They give astronomers in South Africa and all over the world access to our exceptionally dark skies. The site is ideally placed in longitude between the other large optical observatories of the southern hemisphere (in Chile and Australia) and allows continuous coverage for time-critical observations.

SAAO **TELESCOPES**

SALT (Southern African Large Telescope)

Size: 9 x 11 m
Spectrographs (low and high resolution), CCD camera, Spectro-polarimeter
Start of science operations: 2011



1.9-metre

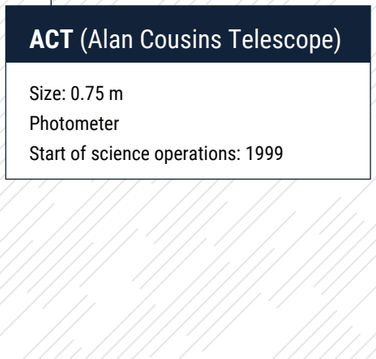
Size: 1.9 m
Spectrographs, CCD cameras, Polarimeter
Start of science operations: 1938-1948

Lesedi

Size: 1.0 m
CCD cameras, spectrograph coming soon
First light: 2016

1.0-metre

Size: 1.0 m
CCD cameras
Start of science operations: 1964



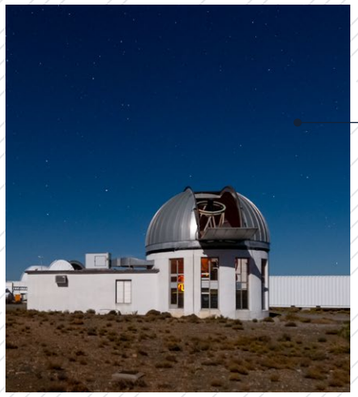
ACT (Alan Cousins Telescope)

Size: 0.75 m
Photometer
Start of science operations: 1999

DIMM

Sky monitor, part of SALT

SAAO **CO-OWNED FACILITIES**



IRSF (InfraRed Survey Facility)

Size: 1.4 m
Nagoya Univ, Kyoto Univ, NAOJ (Japan), and SAAO

IRSF has been a fruitful collaboration between Japan and SAAO since 2000 and offers a near-infrared camera (SIRIUS) and polarimeter (SIRPOL).

MeerLICHT

Size: 0.65 m
Six institutes in South Africa, the Netherlands and the United Kingdom

MeerLICHT -- Dutch for 'MORE LIGHT' -- is fully robotic and provides a simultaneous, optical view of the radio sky as observed by MeerKAT to help identify and classify transient events.

BiSON (Birmingham Solar Oscillations Network)

Size: 0.5 m
Birmingham University (UK) and SAAO

BiSON is a cooperative programme between SAAO and Birmingham University, UK, to study the 5-minute oscillations of the Sun. Its Sutherland station is one of six networked solar telescopes spread around the world.

KELT-South (Kilodegree Extremely Little Telescope)

Size: 4.2 cm / 7.1 cm, telephoto lenses
Ohio State University, Vanderbilt University, Lehigh University, SAAO

KELT consists of two robotic telescopes: KELT-North in Arizona, USA, and KELT-South at Sutherland. They are conducting a survey for transiting extrasolar planets.

HOSTED FACILITIES

KMTNet (Korea Microlensing Telescope Network)

Size: 1.6 m

Korean Astronomy and Space Science Institute (KASI)

KMTNet is a Korean network of three identical 1.6-m telescopes situated in the southern hemisphere (Chile, South Africa, and Australia), conducting a wide-field photometric survey. The network's main scientific goal is to discover earth-mass planets using the gravitational microlensing technique.

MONET (MOnitoring NEtwork of Telescopes)

Size: 1.2 m

University of Göttingen, Germany

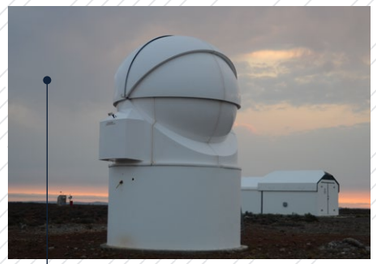
MONET consists of two fully automatic telescopes located at the observatory sites of partner institutions in Texas and South Africa. A large fraction of observing time is available to schools.

LCO (Las Cumbres Observatory)

Size: 3 x 1.0 m and 1 x 0.4 m

Las Cumbres Observatory

The Las Cumbres Observatory is run by a private operating foundation; it consists of a global network of telescopes and operates as a single facility. LCO is used for professional research and citizen investigations. Sutherland is the location of three 1-metre and one 0.4-metre telescopes.



Solaris-1 and Solaris-2

Size: 2 x 0.5 m

Poland

Solaris is a Polish scientific initiative to open a new frontier in the hunt for extrasolar planets. It consists of a global network of fully autonomous telescopes: two at SAAO and one each in Australia and in Argentina.

OSR (Optical Space Research)

Size: 0.5 m

SANSA, DLR (the German Aerospace Centre)

The OSR laboratory is a space debris tracking telescope (part of the Small Aperture Robotic Telescope Network, or SMARTnet), to enable activation of collision-avoidance measures, to ensure the safe operation of satellites.

ASAS-SN (All-Sky Automated Survey for SuperNovae)

Size: 0.4 m

Las Cumbres Observatory, Ohio State University

The LCO's Aqawan hut hosts both the ASAS-SN as well ast the 0.4-m LCO telescope. The network comprises five ASAS-SN telescopes. The network comprises five ASAS-SN telescopes.

MASTER-SAAO (Mobile Astronomical System of the TElescope-Robots Network)

Size: 2 x 0.4 m

MASTER-Net

MASTER-Net is a network of optical transient alert twin-telescopes distributed in longitude over Russia, Argentina and South Africa (MASTER-SAAO). It is a fast survey system, covering more than 2000 square-degrees of sky per night.

bRing Project (ß Pic b ring)

Size: 2 x 2.4 cm f/1.4 wide field lenses

University of Rochester, USA; NASA Jet Propulsion Laboratory; Leiden University, Netherlands

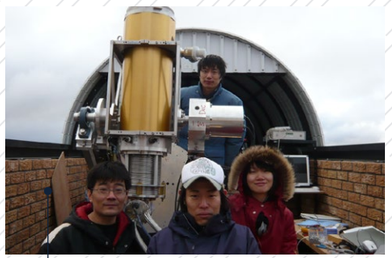
The bRing experiment consists of a twin/two-camera telescope, monitoring the bright star β Pictoris for signs of obscuration from circumplanetary dust associated with the young gas giant exoplanet β Pic b.

Xamidimura

Size: 2 x 0.4 m

Keele University, UK

Xamidimura (meaning "Eyes of the Lion") is a new installation in the enclosure formerly housing SuperWASP, dedicated to following up eclipsing binary discoveries.



WFTC II (Wide Field Cryogenic Telescope)

Size: 0.22 m

Nagoya Univ, Kyoto Univ, NAOJ (Japan)

WFTC II is a special infrared telescope whose interior is under vacuum and cooled to cryogenic temperatures. It has not been used much in recent years. The roll-off roof building was named Semi-hut for the Sumitomo Foundation that supplied funding.

ASTMON 2 fish-eye photo lenses

All-Sky Monitor; used to determine the sky brightness in magnitudes.

SANSA facility

SANSA

The SANSA container comprises several instruments (airglow imager, night-vision video cameras, extremely low-frequency receiver, mesospheric temperature mapper and satellite-based augmentation system receiver) to study the Earth's atmosphere and ionosphere, including research into how sprites are triggered and their effects on the upper atmosphere.

SAGOS (South African Geodynamic Observatory Sutherland)

German Research Centre for Geosciences (GFZ)

The SAGOS seismograph is a semiconducting gravimeter providing continuous high-resolution monitoring of changes in the Earth's gravity field.

SAAO NEWS

KAVLI–IAU TRANSIENTS 2020 WORKSHOP PRODUCES MULTI-MESSENGER AND TRANSIENT ASTRONOMY WHITE PAPER

In February 2020 a Kavli–IAU Workshop took place at the South African Astronomical Observatory in Cape Town, South Africa. Its focus was the future of multi-messenger and transient astronomy and the importance of international coordination in this context. A White Paper has now been drawn up summarising the discussions that took place and the resulting recommendations for how to fulfil the full scientific potential in the 2020s and beyond.

Many remarkable astronomical discoveries having recently been made through the coordinated detection of electromagnetic waves, gravitational waves and neutrinos, the use of multi-messenger and transient astronomy to explore the Universe has flourished. Additionally, the ongoing development of new and existing astronomical facilities will offer even greater capacity for such exploration.

To fully capitalise on the continually-improving technology available, a new level of international coordination will be essential. In light of this, the IAU Executive Committee Working Group on Global Coordination of Ground and Space Astrophysics convened a five-day workshop on this theme with the generous support of the Kavli Foundation. 50 people from 18 countries participated in the discussions, which centred around existing and potential bottlenecks for transient and multi-messenger astronomy. Eight broad areas of concern were identified, and they are set out in this White Paper.

Some of them are very similar to the challenges faced by many astronomers engaging in international collaboration, such as data-access policies, funding, theoretical and computational resources and workforce equity. Others, including alerts, telescope coordination and target-of-opportunity implementation, are strongly linked to the time domain and are therefore particularly challenging for astronomers responding to transients. To address these bottlenecks the White Paper offers thirty-five specific recommendations, some of which are simply starting points and require development. These recommendations are aimed not only at collaborative groups and individuals, but also at the various organisations that are essential to making transient collaborations efficient and effective, including the International Astronomical Union, observatories, projects, scientific journals and funding agencies. The recommendations are intended to help those involved in transient research to develop collaborations with greater impact and more inclusive teams.

Most of the recommendations in the White Paper are associated with one or more named IAU Divisions, Commissions and/or Working Groups. The authors of the paper ask those named to consider whether drafting an IAU Resolution, involving one or more of the recommendations, is desirable. If it is, they should, in liaison with other stakeholders, draft the appropriate wording, for consideration by the next IAU General Assembly (to be held in Busan in the Republic of Korea in August 2021). Note that these drafts should be submitted to the General Secretary six months before the General Assembly (assuming the resolution has no budgetary implications for the IAU).

MORE INFORMATION

The IAU is the international astronomical organisation that brings together more than 14 000 professional astronomers from more than 100 countries worldwide. Its mission is to promote and safeguard astronomy in all its aspects, including research, communication, education and development, through international cooperation. The IAU also serves as the internationally recognised authority for assigning designations to celestial bodies and the surface features on them. Founded in 1919, the IAU is the world's largest professional body for astronomers.

THE PREMIERE OF NEW PLANETARIUM FILM 'RISING STAR'

19 October 2020, saw the premiere of the highly anticipated locally produced planetarium film 'Rising Star' at the Iziko Planetarium and Digital Dome nestled in the heart of Cape Town, South Africa. The film was supported by the South African Astronomical Observatory (SAAO) and the South African Radio Astronomy Observatory (SARAO) and was produced by the South African based company VR Capture. This 24-minute full-dome film offers the viewer an engaging and fully immersive 360-degree glimpse into the world of South African Astronomy.

Rising Star takes you on an astronomical journey from our beginnings through the development of astronomy research in South Africa and looks at what the future of astronomy holds for the country. In addition to introducing multi-wavelength and multi-messenger astronomy, it highlights the many remarkable facilities hosted in South Africa along with some of their latest results. This includes unrestricted views of the Southern African Large Telescope and the most powerful radio telescope in the Southern Hemisphere, MeerKAT.

The film is accessible to all ages and aims to excite both South African and International audiences about South African astronomy and inspire the next generation of astronomers in the country.

As the first of its kind to be produced in Africa, Rising Star hopes to stimulate the production of many more locally produced planetarium films from multidisciplinary fields, with the goal of popularising Africa's numerous scientific achievements.

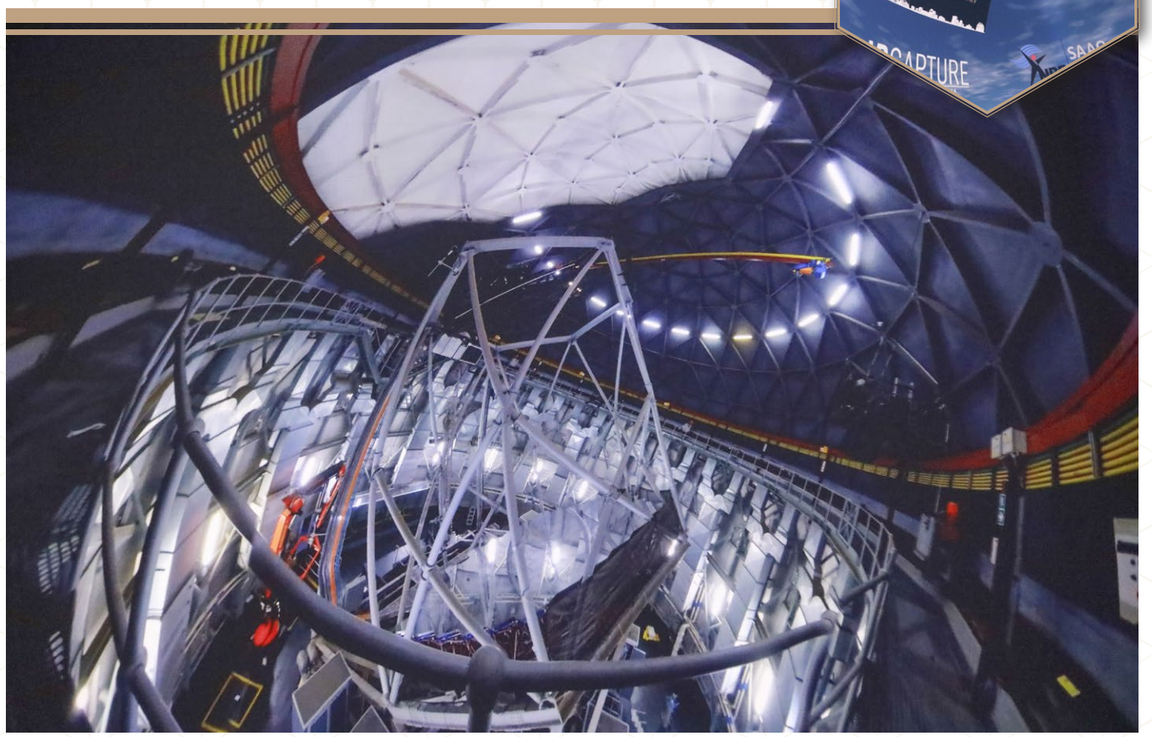
Keep an eye on your local planetarium's show schedule as Rising Star will be shown to the public in South Africa from November onwards. The film (in both fulldome and full VR format) will also be made freely available via online channels for international audiences to download where language translations will be encouraged for greater global accessibility and exposure.

IZIKO PLANETARIUM **AND DIGITAL DOME**

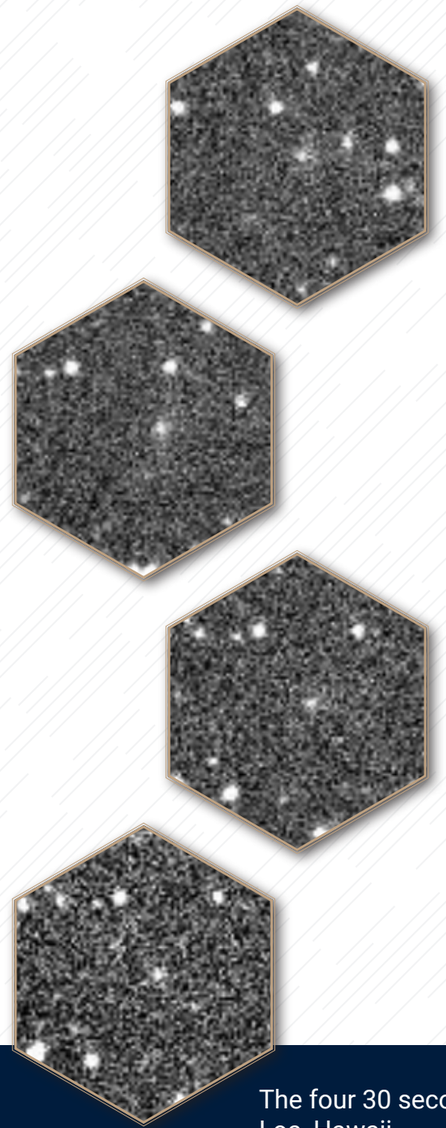
The Iziko Planetarium and Digital Dome (IPDD, https://www.iziko.org.za/museums/planetarium) stands side-by-side with the Iziko South African Museum overlooking the Company's Gardens in Cape Town.

With its 15.2-m dome and capacity for 144 viewers, it is currently one of the four major planetaria in South Africa and caters to around 100 000 people a year. After being established in its current location in 1987, the digital dome underwent a major 8K digital upgrade in mid-2017.

Since then, it has catered to a wide range of audiences, with a public show program, a dedicated schools' program (adapted to the national school curriculum), an experimental art film festival, and an active research program. Indeed, it is one of the few planetaria in the world that is actively involved in research visualisation, lead by a consortium of local universities and the IDIA Visualisation Laboratory (https://vislab.idia.ac.za/).



SAAO ASTRONOMER DISCOVERS **NEW COMET C/2020 S3 (ERASMUS)**



On Sunday 20 September 2020 the International Astronomical Union (IAU) Minor Planet Center announced the discovery of a comet (magnitude ~18.5) by SAAO Astronomer Dr Nicolas Erasmus. The discovery was made from four 30 second exposures taken on Sep 17 UT by ATLAS-MLO at Mauna Loa, Hawaii, in the course of the "Asteroid Terrestrial-Impact Last Alert System" (ATLAS) search program. In general, comets are named after their discoverer and thus the new comet has been designated C/2020 S3 (Erasmus).

The discovery images were taken at around 16:40 SAST (close to sunrise Hawaii time) and ATLAS's automated algorithms initially flagged it as a potential near-Earth asteroid. This was because the initial orbit calculation showed that the orbit came close to Earth's orbit. The automated software then posted the images on the nightly discovery page of ATLAS's internal system. At this point, a scientist stepped in to monitor and vet the observations before making the final submissions to the Minor Planet Centre (MPC). The algorithm generates many false-positives every night and the human eye and brain are still the best "asteroid detector".

Dr Erasmus, talking about the discovery said, **"While doing the nightly vetting (which I do every ~3 weeks, a duty shared with two others) I noticed that the object in the discovery images had a faint coma and after double-checking with my other ATLAS colleagues that they also see a coma (our agreed procedure) I notified the MPC around 18:30 SAST that this was a potential comet discovery."**

The MPC confirmed the discovery on Sunday 20th September 2020. The comet will reach perihelion (the closest approach to the Sun) around 12 Dec 2020 and will be at its brightest at that point. How bright it becomes will depend on how much it starts outgassing as it approaches the sun but it will most likely not visible to the naked eye.

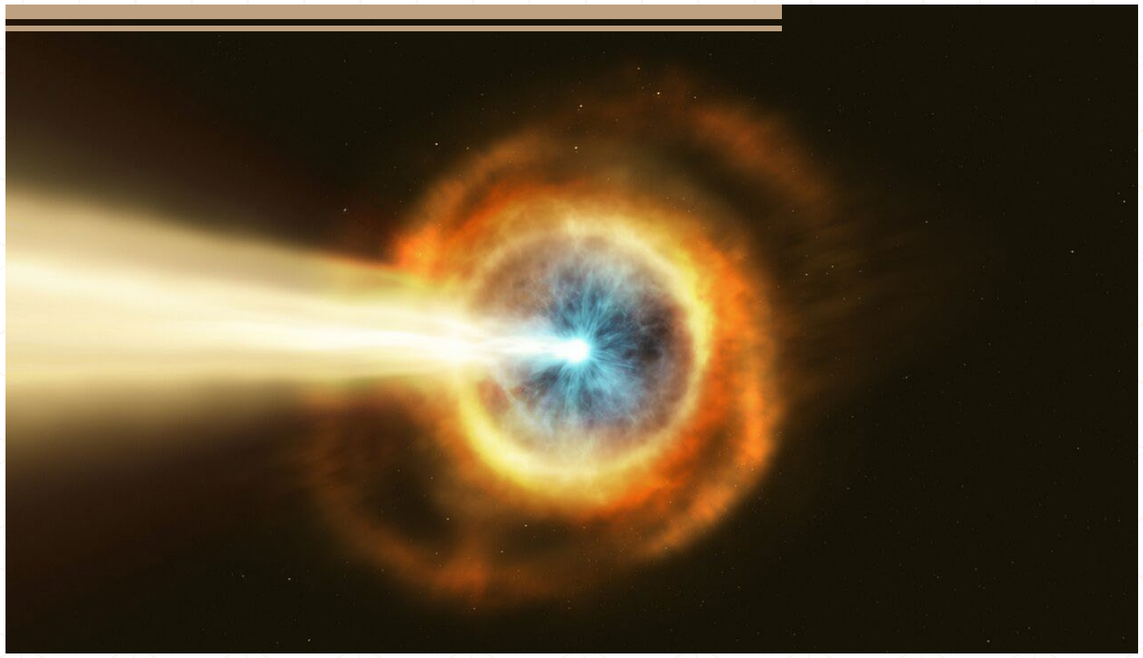
In 2021, the SAAO will be installing a new ATLAS telescope in Sutherland. The ATLAS is a NASA-funded automated system of telescopes designed for searching for incoming Near-Earth asteroids (that is, asteroids on a trajectory towards an impact or close approach with Earth). The ATLAS project is a collaboration between the University of Hawaii ATLAS Project and SAAO. The telescope will be similar to the two 0.5-m ATLAS telescopes currently in operation in Maunaloa and Haleakalā in Hawaii.

The four 30 second exposures taken on Sep 17 UT by ATLAS-MLO at Mauna Loa, Hawaii,

SCIENCE HIGHLIGHTS

SAAO MASTER TELESCOPES OBSERVE **GAMMA-RAY BURST AFTERGLOW**

The MASTER-SAAO Robotic telescopes contributed to the observation of an unusually energetic gamma-ray burst (GRB) which has prompted astrophysicists to rethink the role of magnetic fields in these enormous stellar explosions. Observations made in the burst's immediate aftermath show that key features of its associated magnetic field mysteriously vanished – a phenomenon that cannot be explained by current theories of how such fields form and evolve.



On 14 January 2019, NASA's early-warning Swift satellite spotted a flash of gamma rays from an exploding massive star in a galaxy 4.5 billion light-years away. Such flashes occur when a star's iron core collapses into a stellar-mass black hole, producing two relativistic beams of strongly-magnetized particles. These beams generate gamma rays through synchrotron radiation, and as they shoot outwards from the collapsing core, the particles in them collide with circumstellar material shed by the star in the run-up to its explosion.

The resulting shock creates an optical afterglow that can linger for months.

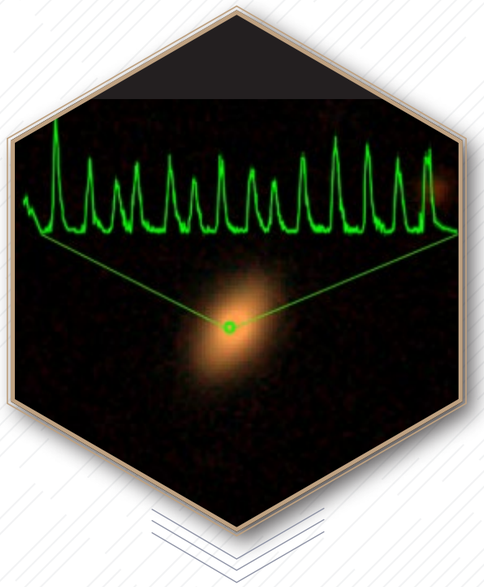
As soon as Swift detected the burst, which was designated as GRB 190114C, it automatically alerted a host of telescopes on the ground. Within 32 seconds, the MASTER telescopes in the Canary Islands and South Africa were in position and recording the burst's afterglow.

The MASTER-SAAO Telescope is part of the Russian Mobile Astronomical System of Telescope-Robots. It consists of two paired 0.4-m telescopes.

Read more at the original article: https://physicsworld.com/a/titanic-stellar-explosion-scrambles-magnetic-fields/

eROSITA AND SALT WITNESS **THE AWAKENING OF MASSIVE BLACK HOLES**

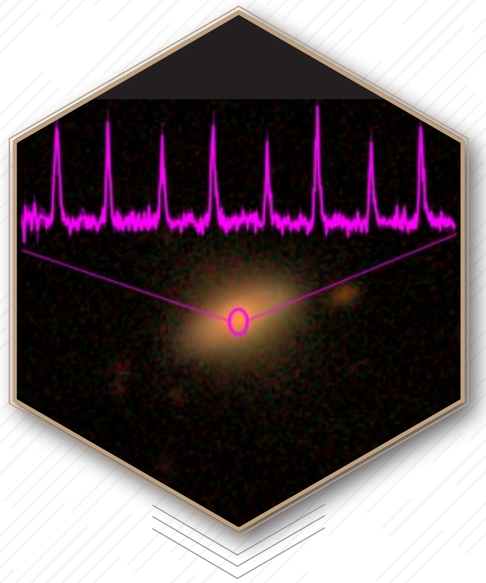
Combined observations by eROSITA, the main instrument aboard the Spectrum-Röntgen-Gamma (SRG) satellite, and the Southern African Large Telescope (SALT) have led to an important discovery. Two apparently normal galaxies observed by eROSITA during its all-sky survey show quasi-periodic X-ray eruptions, despite them appearing to be dormant and inactive. The nuclei of these galaxies light up in X-rays every few hours, reaching a peak brightness comparable to that of the entire galaxy. This pulsating behaviour might be due to a stellar object orbiting the central black hole, possibly quite massive. As these galaxies are relatively close and small, this discovery could help scientists to better understand how black holes are activated in low-mass galaxies.



Optical image of the first galaxy found with quasi-periodic eruptions in the eROSITA all-sky data, the NICER X-ray light-curve is overlayed in green. The galaxy was identified as 2MASS 02314715-1020112 at a redshift of z~0.05, determined by SALT. The peak-to-peak separation of the X-ray outbursts is about 18.5 hours. Credit: MPE; optical image: DESI Legacy Imaging Surveys/D. Lang (Perimeter Institute)

Quasars or "active galactic nuclei" (AGN) are often called the lighthouses of the distant universe. The brightness of their central region, where a very massive black hole accretes large amounts of material, can be thousands of times higher than that of a galaxy like our Milky Way.

"In the eROSITA all-sky survey, we have now found two previously dormant galaxies with huge, almost periodic sharp pulses in their X-ray emission," says Riccardo Arcodia, PhD student at the Max Planck Institute for Extraterrestrial Physics (MPE), who is the first author of the study now published in Nature. These kinds of objects are fairly new: only two such sources were known before, found either serendipitously or in archival data in the past couple of years. "As this new type of erupting sources seems to be peculiar in X-rays, we decided to use eROSITA as a blind survey and immediately found two more," he adds.



Optical image of the second galaxy found with quasi-periodic eruptions in the eROSITA all-sky data, the XMM-Newton X-ray light-curve is overlayed in magenta. The galaxy was identified as 2MASX J02344872-4419325 at a redshift of z~0.02, determined by SALT. This source shows much narrower and more frequent eruptions with a mean peak-to-peak separation of only about 2.4 hours. Credit: MPE; optical image: DESI Legacy Imaging Surveys/D. Lang (Perimeter Institute)

The eROSITA telescope currently scans the entire sky in X-rays and the continuous data stream is well suited to look for transient events, such as these eruptions. Both the new sources discovered by eROSITA showed high-amplitude X-ray variability within just a few hours, which was confirmed by follow-up observations with the XMM-Newton and NICER X-ray telescopes. Contrary to the two previously known similar objects, the host galaxies of these new sources found by eROSITA show no signs of previous black hole activity.

"These were normal, average low-mass galaxies with inactive black holes," explains Andrea Merloni at MPE, principal investigator of eROSITA. "Without these sudden, repeating X-ray eruptions we would have ignored them." The optical observations of the two galaxies concerned were obtained with SALT through a collaboration between the German eROSITA Consortium and SALT transient follow-up teams. "This is an exciting new result", says David Buckley of the South African Astronomical Observatory, principal investigator of the SALT transient programme. "It shows that energetic X-ray emission from black hole interactions is not just confined to the nuclei of active galaxies."

Scientists now have the chance to explore the vicinity of supermassive black holes with relatively low masses of 100 000 to 10 million times the mass of our Sun.

Quasi-periodic emission, such as the one discovered by eROSITA, is typically associated with binary systems. If these eruptions are indeed triggered by the presence of an orbiting object, its mass has to be much smaller than the black hole's – maybe of the order of a star or even a white dwarf, which might be partially disrupted by the huge tidal forces close to the black hole at each passage.

"We still do not know what causes these X-ray eruptions," admits Arcodia. "But we know that the black hole's neighbourhood was quiet until recently, so a pre-existing accretion disk, as present in active galaxies, is not required to trigger these phenomena." Future X-ray observations will help to constrain or rule out the "orbiting object scenario" and to monitor possible changes in the orbital period. This scenario could also make these kinds of objects observable via both electromagnetic and gravitational wave signals, thus opening up new possibilities with multi-messenger astrophysics.

"This is the first major result from the SALT-eROSITA collaboration", says Buckley. "Due to the unprecedented sensitivity of eROSITA, coupled with its repeated scanning of the entire sky, we are continuing to make new discoveries. These help to reveal the nature of variable X-ray sources in our Universe".

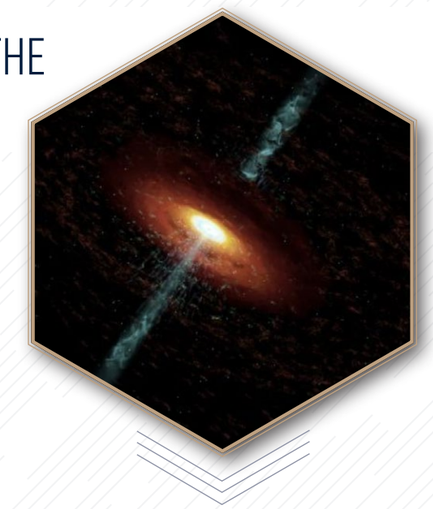
Original publication: *X-ray Quasi-Periodic Eruptions from two previously quiescent galaxies*
1. Arcodia, A. Merloni, K. Nandra, et al.
Nature, published 29 April 2021
Link / DOI: https://dx.doi.org/10.1038/s41586-021-03394-6

ROBOTIC REVERBERATION MAPPING OF THE **BROAD-LINE RADIO GALAXY 3C 120**

Hlabathe et al. 2020, Monthly Notices of the Royal Astronomical Society 497, 2910

> Michael Hlabathe led this project to infer the properties of the supermassive black hole located in radio galaxy 3C 120.

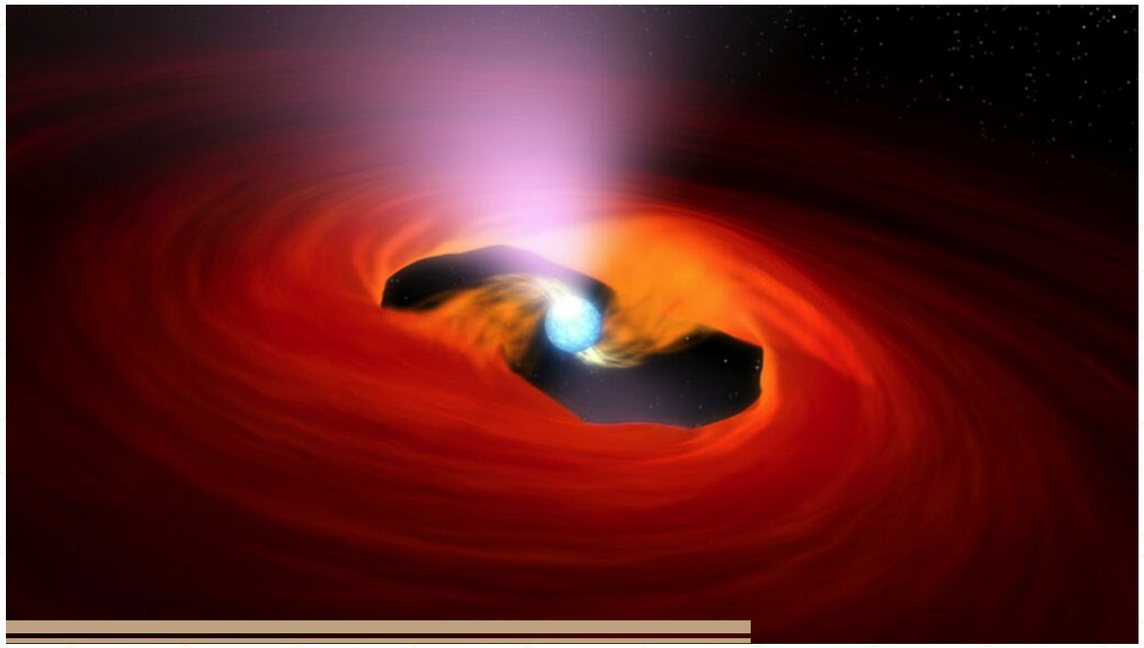
He is a PhD student at the University of Cape Town and his research work was supervised by Encarni Romero-Colmenero, who is head of SALT operations at SAAO. Supermassive black holes are thought to drive the formation and evolution of galaxies that host them. In order to measure their influence, astronomers need an estimate of their masses. Michael used observations from the Las Cumbres Observatory, which has a 1.0m telescope hosted at the SAAO's observing station at Sutherland, and used a technique called reverberation mapping to measure the mass of the black hole in 3C 120. The method uses time delays between light coming from the disk of material around the black hole and light coming from clouds of cooler material further away. Michael's work produced a measurement of the black hole mass consistent with previous measurements, but with smaller error bars. He is working on applying this method to observations of other galaxies.



An illustration of a radio galaxy, similar to 3C 120. Image credit: (Cosmovision led by Dr. Wolfgang Steffen) that illustrates the discovery discussed in our paper "Observational Evidence for the Accretion-Disk Origin. for a Radio Jet in an Active Galaxy" in the journal Nature (Marscher, A.P., et al., 2002, vol. 417, pp. 625-627, 6 June 2002 issue).

ACCRETING PULSAR CAUGHT IN THE ACT OF POWER UP

Goodwin et al. 2020, Monthly Notices of the Royal Astronomical Society, 498, 3



Observations across a range of wavelengths (optical, ultraviolet and X-rays) made in 2019, including those from the Southern African Large Telescope (SALT) have captured – for the first time – the powering up of the outburst from an accreting neutron star. It took 12-days for the accreted material to spiral onto the neutron star, triggering an X-ray outburst thousands of times brighter than our Sun.

The scientists observed an 'accreting' neutron star as it entered an outburst phase in an international collaborative effort involving five groups of researchers, seven telescopes (five on the ground, two in space), and 15 collaborators.

The telescopes involved include two space observatories: the Neil Gehrels Swift X-ray Observatory, and the Neutron Star Interior Composition Explorer (NICER) on the International Space Station; as well as the ground-based Las Cumbres Observatory network of telescopes and the Southern African Large Telescope (SALT).

"Optical spectra obtained with SALT were crucial in demonstrating the powering-up," said the SALT Transient programme lead, Dr David Buckley. "We observed on 6 occasions during August 2019. The first two observations showed it was very faint, while by the time of the third observation, on 6 August, is was clearly in outburst. This demonstrates the importance of flexible telescope scheduling that can quickly react to changing circumstances," he concluded. SALT has made many advances in the study of compact objects, like neutron stars and black holes, including studies of the most energetic events in the Universe, like gamma-ray bursts and gravitational wave events.

It is the first time such an event has been observed in this detail – in multiple frequencies, including high-sensitivity measurements in both optical and X-ray.

The physics behind this 'switching on' process has eluded physicists for decades, partly because there are very few comprehensive observations of the phenomenon.

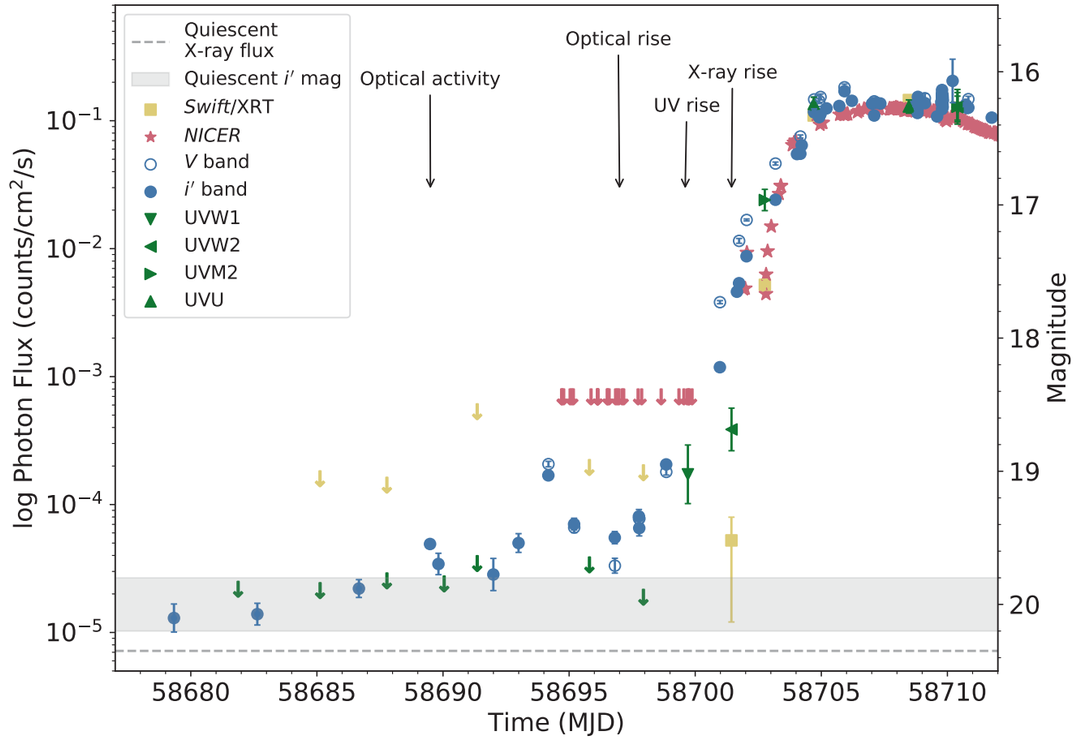
The researchers caught one of these accreting neutron star systems in the act of entering outburst. They witnessed the onset of the outburst, from the first sign of optical activity to the beginning of X-ray emission, all the way to the end of the outburst.

The observations revealed that it took 12 days for material to swirl inwards and collide with the neutron star, substantially longer than previously thought.

"These observations allow us to study the structure of the accretion disk, and determine how quickly and easily material can move inwards to the neutron star," said study lead PhD candidate Adelle Goodwin from the Monash School of Physics and Astronomy in Melbourne, Australia.

"Using multiple telescopes that are sensitive to light in different energies we were able to trace that the initial activity happened near the companion star, in the outer edges of the accretion disk, and it took 12 days for the disk to be brought into the hot state and for material to spiral inward to the neutron star, and X-rays to be produced," she said.

This image shows the time evolution of different wavelengths observed in the powering up of SAX J1808.4-3658, with arrows indicating significant changes. ***Figure from Goodwin et al. 2020.***



In an 'accreting' neutron star system, a pulsar which is a dense remnant of an old star, strips material away from a nearby star, forming an accretion disk of material spiralling in towards the pulsar, where it releases extraordinary amounts of energy – about the total energy output of the sun in 10 years, over the period of a few short weeks.

This is so energetic that most of the radiation is released in the highest energy portion of the electromagnetic spectrum: in X-rays.
Some accreting neutron stars are not always active and can spend years in a quiet state, known as quiescence, where they emit barely any light at all and accrete at a very low rate. They can suddenly go into an outburst and become extremely bright in X-rays for around a month.

The pulsar in a binary system is named SAX J1808.4–3658, and spins at a staggering rate of 400 times per second.

What the researchers saw was unexpected: it took 12 days from the first sign of increased optical activity before any high energy X-ray emission was observed.

This is longer than anyone thought it would take, with most theories suggesting there should be only a two- to three-day delay.

"This work enables us to shed some light on the physics of accreting neutron star systems, and to understand how these explosive outbursts are triggered in the first place, which has puzzled astronomers for a long time," said New York University researcher, Dr David Russell, one of the study's co-authors.

Accretion disks are usually made of hydrogen, but this particular object has a disk that is made up of 50% helium, more helium than most disks. The scientists think that this excess helium may be slowing down the heating of the disk because helium "burns" at a higher temperature, causing the "powering up" to take 12 days.

The research, led by PhD candidate Adelle Goodwin from the Monash School of Physics and Astronomy in Melbourne, Australia, was featured at the recent 236th virtual meeting of the American Astronomical Society meeting (1-3 June 2020), before it is published in Monthly Notices of the Royal Astronomical Society. Adelle leads a team of international researchers, including her supervisor, Monash University Associate Professor Duncan Galloway, and Dr David Russell from New York University Abu Dhabi and Dr David Buckley from the South African Astronomical Observatory.

The preprint of the submitted paper is available on the Astro-PH arXiv here: ***https://arxiv.org/abs/2006.02872***
Goodwin 2020/month

MEERKAT AND SALT COMBINE TO SOLVE **MYSTERY STELLAR EVENT**

Scientists using the MeerKAT radio telescope and the Southern African Large Telescope have combined forces for the first time to discover and identify a unique and previously-unseen flare of radio emission from a binary star in our Galaxy.

South Africa has already demonstrated its excellent science and engineering skills by designing and building the MeerKAT radio telescope – as a pathfinder to the SKA. IThe 64-antenna array is located at the SKA site at Losberg in the Karoo, about 90 kilometres from Carnarvon. Credit: SARAO (South African Radio Astronomy Observatory).

The MeerKAT radio telescope in the Northern Cape of South Africa discovered the object which rapidly brightened by more than three times over a period of three weeks. This is the first new transient source discovered with MeerKAT and scientists hope it is just the tip of an iceberg of transient events to be discovered with the telescope in future.

Astronomers call an astronomical event "transient" when it lasts only for a short time, it may appear or disappear, or become fainter or brighter over seconds, days, or even years. These events are important as they provide a glimpse of how stars live, evolve, and die.

Using an assortment of telescopes around the globe, the researchers determined that the source of the flare is a binary system; where two objects orbit each other approximately every 22 days. While the cause of the flaring and the exact nature of the stars that make up the system is still uncertain, it is thought to be associated with an active corona – the hot outermost part of the brighter star.

The source of the observed activity is located in the Southern constellation of Ara and was found to be in the same place as a giant star about 2 times as massive as the Sun. The star's orbital motion was discovered and measured using optical observations with the Southern African Large Telescope (SALT). Fortuitously, the star is sufficiently bright to have also been monitored by optical telescopes for the last 18 years and is seen to vary in brightness every three weeks, matching the orbital period.

"This source was discovered just a couple of weeks after I joined the team, it was amazing that the first MeerKAT images I worked on had such an interesting source in them. Once we found out that the radio flares coincided with a star, we discovered that the star emits across almost the entire electromagnetic spectrum from X-ray to UV to radio wavelengths," said Laura Driessen, a PhD student at The University of Manchester who led this work.

The Southern African Large Telescope (SALT), the largest optical telescope in the Southern Hemisphere Credit: SAAO (South African Astronomical Observatory).

Patrick Woudt, Professor and Head of the Astronomy Department at The University of Cape Town said: "Since the inauguration in July 2018 of the South African MeerKAT radio telescope, the ThunderKAT project on MeerKAT has been monitoring parts of the southern skies to study the variable radio emission from known compact binary stars, such as accreting black holes.

"The excellent sensitivity and the wide field of view of the MeerKAT telescope, combined with the repeat ThunderKAT observations of various parts of the southern skies, allows us to search the skies for new celestial phenomena that exhibit variable or short-lived radio emission."

Dr David Buckley from the South African Astronomical Observatory, who leads the SALT (Southern African Large Telescope) transient follow-up programme, which followed up on the discovery, commented: "This is a perfect example of where coordinated observations across different wavelengths were combined to give a holistic view of a newly discovered object.

"This study was one of the first to involve coordination between two of South Africa's major astronomy facilities and shows the way for future such work."

Professor Ben Stappers from The University of Manchester said: "The properties of this system don't easily fit into our current knowledge of binary or flaring stars and so may represent an entirely new source class."
The MeerKAT telescope is sweeping the sky for sources that vary on timescales from milliseconds to years, and will significantly improve human understanding of the variable radio sky. The discovery of this new transient with MeerKAT demonstrates how powerful this telescope will be in the search for further new transient events.

Rob Adam, Managing Director of the South African Radio Astronomy Observatory (SARAO) said: "Once again we see the potential of the MeerKAT telescope in finding interesting and possibly new astrophysical phenomena, as well as the power of the multi-wavelength approach to the analysis of observations."

SALT CONTRIBUTES TO **A NEW UNDERSTANDING OF NOVAE**

An international team of researchers, led by Dr Elias Aydi, a former SAAO and University of Cape Town PhD Student, now at Michigan State University (MSU), have discovered a new cause for the incredible brightness observed when a star explodes. The discovery used high-resolution optical spectroscopy from different telescopes including SALT to better understand the stellar explosion or nova.

Animation of the Nova Carinae on 30 July 2018 (credits: W. Paech & F. Hofmann, Chamaeleon and Onjala Observatory, Namibia)

A nova is an explosion on the surface of a star that can produce enough energy to increase the star's brightness by millions of times. Sometimes a nova, which occurs in stars called white dwarfs, is so bright it appears as a new star to the naked eye. A white dwarf star strips material from its companion star that piles up on the dwarf's surface, eventually triggering a thermonuclear explosion.

While for many years astronomers have thought that nuclear burning of material on the surface of the white dwarf directly powered all the light from the explosion, more recently astronomers started debating that "shocks" from the explosion might power most of the brightness.

The research is detailed in a paper published in the journal Nature Astronomy titled "Direct evidence for shock-powered optical emission in a nova."

"This is a new way of understanding the origin of the brightness of novae and other stellar explosions," said Elias Aydi, a research associate in MSU's Department of Physics and Astronomy, who led an international team of astronomers from 40 institutes, across 17 countries. "Our findings present the first direct observational evidence, from unprecedented space observations, that shocks play a major role in powering these events."

The SALT observations were taken under the transient follow-up programme, with Dr David Buckley at SAAO being the Principal Investigator. Nova became an important class targeted by the programme since 2016, led by Dr Aydi, who was a graduate student at the time. It now involves a number of different co-investigators from 3 of the SALT partners (South Africa, USA and Poland) plus many other international collaborators. Astrophysical shocks form in a similar fashion to those formed by a supersonic jet aeroplane. When the jet exceeds the speed of sound, it produces a shock which leads to a loud sonic boom. In a nova explosion, the shocks produce light rather than sound. When material blasts out from the white dwarf, said Aydi, it is ejected in multiple phases and at different speeds. These ejections collide with one another and create shocks, which heat the ejected material producing much of the light.

Another side effect of astronomical shocks are gamma-rays, the highest-energy kind of electromagnetic radiation. The astronomers detected bright gamma-rays from the star, known as nova V906 Carinae, whose explosion in the constellation Carina was first detected in March 2018.

Using NASA's Fermi Gamma-ray Space Telescope, they showed that V906 Car had the brightest gamma-rays ever observed for a nova, proving that it hosts energetic shocks.

But the real surprise came because an optical satellite – one of the six nanosatellites that make up a collection of satellites operated by an international consortium called the BRITE constellation of cube-sats – just happened to be looking at the part of the sky where the nova occurred. Comparing the gamma-ray and optical data, the astronomers noted that every time there was a fluctuation in gamma-rays, the light from the nova fluctuated as well.

"We observed simultaneous fluctuations in both the visual and gamma-ray brightness, meaning that both emissions are originating from shocks," said Kirill Sokolovsky, a research associate at MSU and a co-author on the paper. "This led us to the conclusion that shocks are indeed responsible for most of the brightness of the event."

"We were lucky that members of our team were observing that part of the sky with these special satellites and were able to collect this unprecedented set of data," Aydi said. "This allowed for continuous monitoring of the nova for 65 days, producing an unprecedented dataset."

The team estimates that V906 Car is about 13,000 light-years from Earth. This means that when the nova was first detected in 2018, it had actually happened 13,000 years ago.

This new information may also help explain how large amounts of light are generated in other stellar events, including supernovae and stellar mergers, when two stars collide with one another.

Original paper:
https://www.nature.com/articles/s41550-020-1070-y)

Adapted from:
https://msutoday.msu.edu/news/2020/seeing-the-light-msu-research-finds-new-way-novae-light-up-the-sky/

SAAO OPERATIONS

TECHNICAL OPERATIONS REPORT

The technical department comprises the instrument section, the mechanical and electronic workshops and a dedicated CCD lab. Apart from the necessary maintenance, new instruments, or parts thereof, are developed here for our telescopes. Our engineers also research more efficient ways to run these instruments and the telescopes.

ASTRONOMY OPERATIONS

SAAO TELESCOPES REPORT

SAAO's observing station near Sutherland is home to an array of instruments and telescopes , which support a range of observing modes from spectroscopy, through polarimetry to wide field imaging.

Observing time on SAAO's Lesedi, 1.9-m and 1.0-m telescopes is available on a competitive basis to astronomers world-wide, and all observing applications are vetted by a time allocation committee. Highlights for 2020 include:

- Regular remote observing has been carried out with Lesedi, and it was included in the normal scheduled observing rota for the first time during 2020.
- Adoption of remote observing modes on Lesedi, the 1.9m and 1.0m telescopes during 2020/21 (accelerated by the constraints imposed by the Covid-19 pandemic)

The Telescope Operations (TOPS) division is responsible for operating all the SAAO telescopes on the Sutherland plateau, excluding SALT, and also liaising with the (co)-owners of the hosted facilities regarding their operations.

As a result of COVID-19, the SAAO telescopes were temporarily shut-down during the national lockdown Level 5. The telescopes were re-opened in early May, and they have been operated remotely from Cape Town throughout 2020/2021. The SAAO and SALT boardrooms were repurposed as additional remote control rooms. In addition, remote observing from SAAO astronomers' homes was commissioned, and a few astronomers have successfully observed, and continue to observe, from their homes. However, load shedding is currently a challenge when observing from home.

We recently worked with one of our regular and most experienced international observers to remotely operate the 1.0m telescope from their office at the University of Central Lancashire, UK. That was a successful process, paving the way to develop a new enhanced service for researchers to access our facilities not only from Sutherland and current remote stations at SAAO headquarters, but widely from anywhere in the world. On the 1.9m telescope, a new flatfield screen on the dome roof has been successfully installed and programmed into the TCS. This is to ensure that remote observers are able to take their own flatfields remotely, without needing someone to be at the telescope to drive it into the software limits. The Dec drive fast motion motor gears were also replaced, dome slip rings refurbished and the weight plate was modified to allow SpUpNIC on the 1.9m telescope to rotate 180 degrees. A physical presence is required at the telescopes, when working remotely with the 1.9m telescope and the spectrograph, to change gratings and arc filters.

An issue at the 1.9m and 1.0m telescopes has been broken wind blinds, this makes observing difficult in moderate wind speeds. The 1.9m telescope wind blinds were fixed earlier in the year, and no issues were reported with them for the past few months. However, in late November 2020 the wind blinds came off its tracks and were severely damaged, and had to be disabled, and we are still looking at possible short-term fixes, as well as long term fixes, including the possibility of sourcing a new wind blind system on the 1.9m telescope. For the 1.0m wind blinds, the necessary purchases have been made. Safe installation, however, requires new ladder and anchor systems which a contractor will be installing simultaneously to other domes as well. Another issue on the 1.0m telescope recently has been the telescope wobbling in RA (East-West) at some Hour Angles (HAs), which over time seems to have disappeared on its own. Initially we added weights, which only moved the problem from one pointing position to the next.

Regular remote observing has been carried out with Lesedi too, and it was for the first time included in the normal scheduled observing rota during 2020. The in-house browser-based TCS has been released, and several observers have already been trained to use it, who will in turn train other observers. A report on the image quality found that the final performance specification for which the supplier is responsible, is met. The internal review panel therefore agreed to release the final payment to APM, thus finally concluding the long-term contract. Throughout Q2 to Q4, Lesedi has been used: (i) to carry out remote service observations for PIs who had time scheduled on the 1.0m telescope and were not able to travel due to lockdown; (ii) for commissioning of Sibonise; (iii) for training of local PIs who have then observed their own programmes in week-long blocks; iv) preparing for installation of Mookodi, one of the new instruments on Lesedi, and (iv) for carrying out ad-hoc service requests that had been scheduled on telescopes elsewhere affected by lockdown, including a fee-paying comet monitoring programme, and recently a quasar monitoring programme from a group in Germany that also has observing time on SALT as part of a reverberation mapping programme. Several publications have been submitted and others already published incorporating recent results from our telescopes, including those from Lesedi and the 1.0m telescopes in discovery of exoplanets. A safety platform was designed, manufactured and installed on the Lesedi observing floor, to ensure that people working on the floor do not risk falling off the edge.

Training of astronomers and students on remote observing continues for those who have observing time allocated, so that they can do their own observations remotely. This is necessary to maintain a reasonable pool of observers that can help support observers that are not able to come to SAAO during their allocated observing time. In 2020 new observers were trained at the SAAO telescopes, including a student on the 1.9m telescope, using the SpUpNIC. We already have a group of local observers who have helped keep all telescopes (1.9m, 1.0m and Lesedi) in use ~100% of the time, either observing for themselves or helping national and international astronomers who are not able to visit SAAO.

The average uptimes on the SAAO telescopes for Q4 (Jan-March) was an excellent 99.3% indicating minimal technical issues.

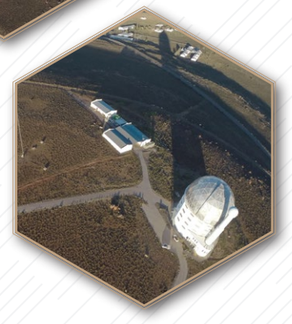
Subscription levels in the table below are given as the average fraction of weeks applied for relative to the number of available weeks per trimester. The subscription levels include all the applications received before the deadline as well as subsequent applications for the unallocated observing time after the deadline and applications for occultation observing time (which requires only a small fraction of a night).

Table: Observing time subscription levels on the 1.9-m and 1.0-m telescopes for 2019.

Trimester (2019)	1.9-m(%)	1.0-m (%)
Trimester I (Jan - Apr)	129	94%
Trimester II (May – Aug)	122	100
Trimester III (Sep - Dec)	100	122
Average (2019)	117	105

SAAO's observing station near Sutherland is home to many optical and infrared telescopes, ranging from the very large (SALT) to very small with a large field of view (KELT), to those having very large CCDs (e.g. KMTNet with its 18k x 18k CCD). They allow a range of observing modes from spectroscopy (both low and high resolution), photometry (including high-speed, optical and IR imaging) and polarimetry. Observing time on SAAO's Lesedi, 1.9-m and 1.0-m telescopes is available on a competitive basis to astronomers world-wide, and all observing applications are vetted by a time allocation committee. Lesedi, and some of its instruments, is being commissioned, and observing time is available on a shared-risk basis to experienced observers. Observing time on SAAO's co-owned IRSF is available to South African and Japanese astronomers and their collaborators.

Observing time on the 1.9-m and 1.0-m telescopes is traditionally given in blocks of weeks. This was as a result of logistical requirements relating to transporting observers from Cape Town to Sutherland, as well as instrument changes requiring some technical efforts that can only be done during the day. With the Covid-19 pandemic making it difficult to travel to Sutherland, it is now possible to operate all the SAAO telescopes (SALT, Lesedi, 1.9-m and 1.0-m telescopes) remotely from Cape Town, and therefore the need to allocate observing time in blocks of weeks is no longer a requirement on SAAO telescopes.



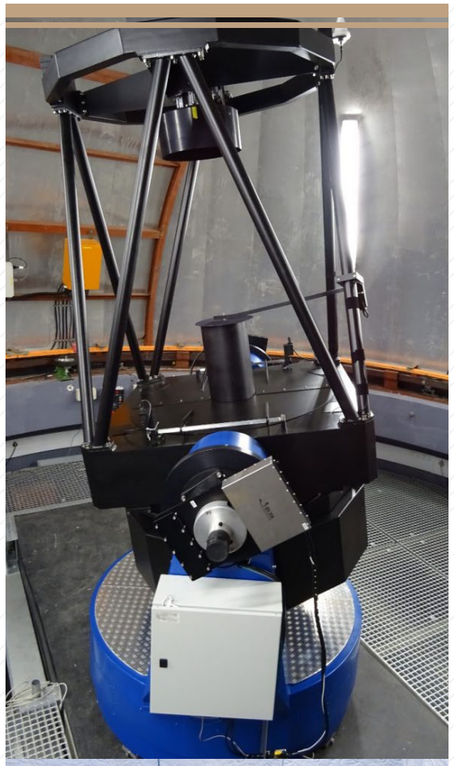
REMOTE OBSERVING

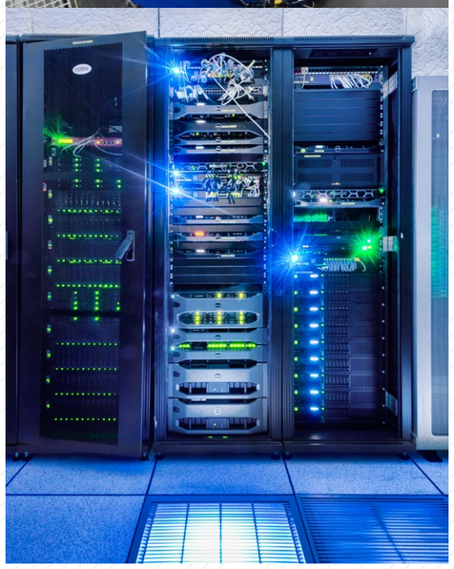
The three largest SAAO telescopes (1.9-m, 1.0-m and Lesedi) are now remotely operable from Cape Town with the following instruments: The Sutherland High-Speed Optical Camera (SHOC; available on all three telescopes) and the spectrograph SpUpNIC (Spectrograph Upgrade – Newly Improved Cassegrain, on the 1.9-m).

Lesedi has been remotely operable right from the beginning and has a suite of instruments that are easily selectable without the need for an instrument change. The 1.0-m and 1.9-m telescopes have been equipped for remote observing, although instrument changes still require considerable manual effort and can only be done during the daytime. During the national lockdown, it was decided that we would have limited instrument changes on the telescopes, and that priority would be given to instruments that can be operated remotely. The priority, therefore, is to have SHOC on Lesedi and the 1.0m telescope, and SpUpNIC on the 1.9m telescope.

SHOC is frequently used remotely without any issues. Remote operation observations with SpUpNIC work, but still require some of the operations to be done manually at the telescope, for example; taking dome flats (which involves the telescope being pointed into the software limits) and changing gratings and filters. The next priority is to reduce the number of manual operations on the 1.9m telescope when operating remotely. For example, we are exploring the possibility of putting the flat field screen on the telescope dome roof, this will allow the telescope to point without moving into the software limits. With the remote observing modes on the SAAO telescopes becoming available, it will no longer be necessary to offer observing time in blocks of weeks.

The temporary remote control rooms in Cape Town are in the East Wing of the Main Building, the SAAO Boardroom and the SALT Boardroom. The 1.0-m telescope is operated from the SAAO Boardroom, SALT from the SALT Boardroom and the 1.9-m telescope from the Main Building. We are in the process of determining the minimum requirements of operating the telescopes from home, and this is being trialled with Lesedi. The requirements include internet speed, availability of computer monitors to display all the required telescope and instrument controls and the weather display.





HOSTED FACILITIES

SAAO not only provides research platforms for South African and international astronomers, but it also hosts many national and international research facilities at Sutherland. These include both telescopes and geophysical facilities. Most of the hosted facilities pay what is called an annual site or facility fee. Those that require a larger bandwidth, that is, above the 1.5 Mbps provided as part of the facility fee, also pay for internet bandwidth. Facilities that are co-owned by SAAO or where SAAO is part of the collaboration, currently do not pay facility fees (e.g., MeerLICHT and IRSF).

Some facilities give the South African astronomy community access to observing time. These include KMTNet, which allocates four blocks of 10 nights between October and February to SAAO usage, constituting about 10% of the total observing time; and the LCO, which allocates 10% equivalent time for each of the telescopes hosted at SAAO over their entire network, that is, with the three 1-m telescopes and one 0.4-m telescope at Sutherland, SAAO's 4 x 10% observing time can be taken at any of the LCO telescopes in the world-wide network of equivalent telescopes at Sutherland (nine 1-m telescopes, and seven 0.4-m telescopes at six astronomical observatories).

Other telescope facilities usually have a clause in their agreement indicating that they will give SAAO users access to their database, usually for science that is not related to the main scientific objective of the facility. For example, some South African astronomers make use of the data from the SuperWASP database for their scientific publications on non-exoplanet related studies.

FUTURE TELESCOPE PROJECTS

Three telescopes will be constructed at Sutherland in the near future:

- The ATLAS (Asteroid Terrestrial-impact Last Alert System) is a NASA-funded automated system of telescopes designed for searching for incoming Near-Earth asteroids (that is, asteroids on a trajectory towards an impact or close approach with Earth). The ATLAS project is a collaboration between the University of Hawaii ATLAS Project and SAAO. The telescope will be similar to the two 0.5-m ATLAS telescopes currently in operation in Maunaloa and Haleakalā in Hawaii.
- The second planned telescope is PRIME (or PRime focus Infrared Microlensing Experiment), a 1.8-m IR telescope dedicated to a project called "Infrared Gravitational Microlensing Survey". PRIME is a collaborative project between SAAO and the University of Osaka in Japan.
- Solaris-5, a 1.0m telescope similar to the two Solaris telescopes at Sutherland, owned by Nicolaus Copernicus Astronomical Centre (NCAC) of the Polish Academy of Sciences is planned in the near future. The SAAO and NCAC signed an MoA for the construction and operation of Solaris-5 earlier in 2020.

RESEARCH GROUPS

SAAO's astronomers have formed three research groups to stimulate research between people who share common scientific interests. These groups can be cross-disciplinary and involve members of multiple institutions.

SAAO not only provides research platforms for South African and international astronomers, but it also hosts many national and international research facilities at Sutherland.

STELLAR ASTROPHYSICS GROUP

The stellar astrophysics group meets for weekly discussions (virtual at present) organized by Kelebogile Gasealahwe and Anke van Dyk on Fridays at 11 am. Non-SAAO based researchers are most welcome to join us! Regarding this or any other queries, contact us at bang@saao.ac.za .

Over the past year, time domain astronomy has remained a major research focus area for our group, involving a large number of collaborators from South Africa and abroad.

The multi-semester SALT transient programme (PI David Buckley) was once again awarded a sizeable allocation of observing time that has resulted in several high-profile results and important discoveries, for example: Novae have been an important class targeted by the programme since 2016, led by Elias Aydi (researcher at Michigan State University), who was a graduate student at SAAO at the time. It now involves a number of different co-investigators from 3 of the SALT partners (South Africa, USA and Poland) and many other international collaborators. A nova is an explosion on the surface of a white dwarf that can produce enough energy to increase the star's brightness by millions of times (they can be so bright that they appear as a "new star" to the naked eye - hence their name). For many years the nuclear burning of accreted gas on the white dwarf surface was thought to power all the light from the explosion, however, more recently it has been suggested that shocks from the explosion might be the main source. In research published in Nature Astronomy, data at optical and gamma-ray (NASA's Fermi Gamma-ray Space Telescope) wavelengths of nova V906 Car was used to demonstrate direct evidence for shock-powered optical emission in a nova. When material blasts out from the white dwarf it is ejected at different phases and speeds, the internal collisions that result create shocks which heat the ejected material producing much of the light. Comparing the gamma-ray emission (which is produced by the shocks) and the optical data, the astronomers noted that every time there was a fluctuation in gamma-rays, the light from the nova fluctuated as well. This new information may also help explain how large amounts of light are generated in other stellar events, including supernovae and stellar mergers, when two stars collide with one another. **Original paper: https://www.nature.com/articles/s41550-020-1070-y**

The ability of SALT to conduct fast turnaround spectroscopy of high-energy sources discovered by the X-ray instruments eROSITA (a Russian-German X-ray satellite) and PART-XC onboard the Spectrum Röntgen Gamma satellite (Russian Space Research Institute, IKI) has enabled optical characterization and detailed studies of typical stellar transients like X-ray binaries and cataclysmic variable candidates, but also tidal disruption events, changing look active galactic nuclei and Quasi Periodic Eruptions (QPEs) in galactic nuclei. Published in Nature was the discovery of dramatic quasi-periodic soft X-ray bursts (QPEs), repeating on a few hour timescales, emanating from the nuclei of two normal non-active galaxies, as revealed by their SALT spectra. Two previous examples of QPEs were known prior to these discoveries, but both were associated with active galactic nuclei. The two QPEs discovered by eROSITA show no nuclear activity, and are thought to be driven by a black hole of M < 104 MO orbiting a relatively low-mass nuclear super-massive black hole of 105 – 107 MO. This is in contrast to QPEs associated with active galactic nuclei, where current models invoke radiation-pressure driven accretion disk instabilities. The binary black hole scenario could make QPEs a viable candidate for the electromagnetic counterparts of the so-called extreme mass ratio inspirals, with considerable implications for multi-messenger astrophysics and cosmology. **Original paper: https://dx.doi.org/10.1038/s41586-021-03394-6**

These selected highlights demonstrate the very productive synergies between SALT and high-energy facilities in studying transients. At longer, radio wavelengths, MeerKAT is also opening new windows into time-domain astronomy. For example, Danté Hewitt published the results of his Msc research on MeerKAT radio observations of 11 nearby nova-like cataclysmic variables, including four detections. Nova-likes are a type of cataclysmic variable (outbursting accreting white dwarfs) that are non-magnetic and have by-and-large stable, bright accretion discs. The systems were observed as part of the ThunderKAT (The Hunt for Dynamic and Explosive Radio Transients using MeerKAT: PIs Rob Fender and Patrick Woudt) programme, and together with multi-wavelength data in the literature, were used to place constraints on the mass-accretion rate of these binaries. The radio emission of nova-likes is not well understood - from this study there is some evidence that the ratio of their X-ray to radio luminosities follows a similar relation to that observed for non-pulsating neutron star low-mass X-ray binaries. **Original paper: arXiv:2006.07918**

Research on other variables, e.g. pulsating red giants such as Miras, and the period-luminosity relation for distance scales and tracing galactic structure, has also featured prominently.Caroline Huang, together with 9 others, including Patricia Whitelock published Hubble Space Telescope observations of Mira variables in NGC 1559, the host galaxy of a type Ia supernova (SN Ia). This is the first dedicated search for Miras in an SN Ia host, and subsequently the first calibration of the SN Ia luminosity using Miras in a role historically played by Cepheids. They identified 115 oxygen-rich Miras with periods less than 400 days, based on their light-curve properties. Comparing these with similar Miras in NGC 4258, which has a distance derived from its mega-maser, resulted in a distance modulus for NGC1559 of μ1559=31.41±0.050 (statistical) ±0.060±0.060 (systematic) mag. Combining the various available distance measurements from Miras results in a value of the Hubble constant that is in close agreement to that derived via Cepheids. This validates the approach of using Miras calibrators in the numerous places where Cepheids are not found. **The paper has already been cited >80 times as of July 2021, see: https://ui.adsabs.harvard.edu/abs/2020ApJ...889....5H/abstract.**

In addition to the science produced, there have been additional organizational activities and developments that promise to further strengthen stellar astrophysics research at the SAAO and beyond. Following the Kavli–IAU Workshop held at the SAAO at the beginning of 2020, A White Paper (2020arXiv200705546C) articulated the recommendations from the workshop on "International Coordination of Multi-Messenger Transient Observations in the 2020s and Beyond". Co-chaired by Brad Cenko (NASA) and Patricia Whitelock (SAAO/UCT), this covered existing and potential bottlenecks for transient and multi-messenger astronomy, identifying eight broad areas of concern. Some of these are very similar to the challenges faced by many astronomers engaging in international collaboration, for example, data access policies, funding, theoretical and computational resources and workforce equity. Others, including alerts, telescope coordination and target-of-opportunity implementation, are strongly linked to the time domain and are particularly challenging as we respond to transients. To address these bottlenecks they offer thirty-five specific recommendations, some of which are simply starting points and require development. These recommendations are not only aimed at collaborative groups and individuals, but also at the various organizations who are essential to making transient collaborations efficient and effective: including the International Astronomical Union, observatories, projects, scientific journals and funding agencies. They expressed the hope that those involved in transient research will find them constructive and use them to develop collaborations with greater impact and more inclusive teams.

Major awards and excellent results obtained by staff and students were also celebrated. Patricia Whitelock was conferred a Doctor of Laws (LLD) (honoris causa) from Rhodes University at its 2020 virtual graduation ceremonies (**https://www.ru.ac.za/media/rhodesuniversity/content/graduationgateway/documents/Citation_for_Patricia_Whitelock.pdf**), and was also one of two South Africans elected to The World Academy of Sciences in 2021 (**https://twas.org/article/twas-elects-35-new-twas-fellows**). She was elected for contributions to the fields of Astronomy and Astrophysics, particularly Optical Astronomy and her distinguished research on the late stages of stellar evolution, Galactic structure and the stellar content of Local Group Galaxies.

Among the graduates from the University of Cape Town were: Naomi Titus, who was awarded her PhD for her work on neutron stars in the Magellanic Clouds (supervised at the SAAO by Vanessa McBride and David Buckley). She will continue as a postdoc working with Paul Groot (UCT/Radboud University) on MeerLICHT research. Orapeleng Mogawana completed his MSc research on "Meshless hydrodynamic simulations of young supernova remnants" (supervised by Shazrene Mohamed and Kurt van Der Heyden) and has also joined Paul Groot's group for his PhD, observing supernovae in the nearby universe with MeerLICHT. Danté Hewitt was awarded his MSc with distinction for his research on "MeerKAT observations of nova-like cataclysmic variables" (see highlight above) and was supervised by Margaretha Pretorius and Patrick Woudt. He has joined the Anton Pannekoek Institute at the University of Amsterdam for his PhD on FRB localisation under the supervision of Jason Hessels. Kelebogile Gasealahwe was also awarded her MSc for research on "The SALT-HRS and TESS monitoring of central stars of planetary nebulae" (supervised by Brent Miszalski, Shazrene Mohamed, Itumeleng Monageng and Rajeev Manick). She also won the SALT-SAAO PhD prize scholarship and will carry out her doctoral studies on neutron star X-ray binaries with MeerKAT under the supervision of Itumeleng Monageng, Rob Fender and Patrick Woudt. This is the second SALT-SAAO PhD prize scholar in the group - in 2019, Daniel Igbo was selected for the prize PhD award to work with David Buckley on transients.

PLANETARY ASTRONOMY GROUP

The SAAO has a small but active, professional planetary science research group. The group's work is primarily focused on small bodies in the Solar system. In particular, measuring rotational periods and colours of both near-Earth and main-belt asteroids, as well as activity in Centaurs through broadband photometry. There have also been observing contributions from our group to global observing campaigns like the recent 2021 planetary-defence exercise of the "re-discovery" and characterisation of Apophis, a large asteroid discovered in June 2004, which will make an extremely close encounter with Earth in 2029.

The group primarily makes use of the SHOC instrument, which is now available on the 1.0- m, 1.9-m, and Lesedi telescopes. The high-speed SHOC cameras are ideal for our nearEarth asteroid program as relatively short exposure times are essential because of the large sky-motion of these objects.

Through our collaboration with the ATLAS group at the University of Hawaii, we have also made extensive use of the large and existing ATLAS photometry dataset for several mainbelt asteroid studies. The data access has been possible through our partnership with ATLAS linked to a third node of the ATLAS network being installed in Sutherland which is expected to be completed by end of 2021.

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GALAXY GROUP

There is a wide range of research related to galaxies being done at SAAO. The current interests include star formation in galaxies, active galactic nuclei (AGN), feedback processes from supernovae and AGN, ultra-diffuse galaxies, the evolution of brightest cluster galaxies (BCGs), mergers of galaxies, and the dynamics and assembly of galaxy discs. The topics of interest are mostly explored from an observational angle, using optical, near-infrared and radio (continuum, HI and molecular gas) data from telescopes around the world. Some of our researchers also simulate galaxy formation using high-performance computer clusters at SAAO and elsewhere. Instrumentation for integral-field spectroscopy is also being developed at SAAO for observations at both optical and near-infrared wavelengths on SALT.

There are a number of postdoctoral scholars and postgraduate students working with SAAO researchers on extragalactic astronomy. We are particularly proud of Nazir Makda, Omphemetse Mputle and Munira Hoosain, who completed excellent Masters theses in 2020/2021, and Jamie Bok, who recently submitted her PhD thesis. We are also excited that two recent SAAO-SALT Prize Scholarship recipients: Petro van Rensburg and Sriram Sankar, have started their PhD and MSc projects on extragalactic astronomy.

Researchers at SAAO are involved in a number of projects that utilize the complementarity of SALT and MeerKAT for extragalactic science. This includes studies of galaxies in the LADUMA and MIGHTEE fields, MHONGOOSE galaxies, the MeerChoirs groups and a large science programme called BEAMS (BCG Evolution with ACT, MeerKAT and SALT), which has been using SALT since 2019 to measure the distances to BCGs and better understand their evolution. This collaboration between SALT partners in South Africa (led by Matt Hilton, UKZN), India and the USA, is following up BCGs identified by the Advanced Atacama Cosmology Telescope spectroscopically, looking back over more than half the Universe's history. Complementary multi-wavelength data from SALT and the MeerKAT radio array will allow us to measure the star formation histories and gas content of these galaxies, which will improve our understanding of how massive galaxies grow and change over time and how the most massive structures in the universe build up. Researchers are also involved in other projects such as the SALT follow up of the GLEAM 4-Jy sample, showing how SALT can be used to complement other radio telescopes. SALT is also being used to study very faint dwarf galaxies in nearby voids, galaxies in groups and clusters, star-forming rings around lenticular galaxies, kinematics and outflows from galaxies and black holes at the centres of galaxies.

STUDENT **SUPPORT**

With a view to (1) providing higher levels of support to both student and supervisor and (2) trying to get more students to completion on the prescribed timescale, the following measures have been put in place for those students who are primarily based at the SAAO:

- Each PhD student has a postgraduate advisory committee (PAC) which meets once a year, with and without the student and supervisor(s), to discuss progress. In the first year, they review the research proposal, and in subsequent years they attempt to identify any serious problems and make suggestions for additional support should it seem necessary. PACs can also be organised for MSc students if they and their supervisor consider it helpful.
- A student coordinator (astronomer) and a student administrator have been appointed to streamline the process of supporting students within SAAO.
- Top-up funding to bursaries/grants has been provided, so that all students supervised at SAAO receive the same funding, at a respectable level. In return for this, the students work 40 hours per year (i.e. approximately one hour per week) for SAAO. These duties include service observing, remote observing and helping with open nights and/or with school visits. This will help develop essential skills students will require in future.
- Two large offices, suitably furnished, have been set aside for use by the students.
- Students may elect to meet once a fortnight with a professional tutor to study English in a "writing circle". The emphasis is on writing scientific papers, but the students also use the opportunity to develop their spoken language and presentation skills.
- Students are encouraged to attend colloquia and journal clubs to broaden their general scientific knowledge.
- A system of mentors comprising young staff astronomers or postdocs, has been established. They meet their assigned student a few times a year, or when required, and offer advice and support on academic and other matters.
- An SAAO Student Representative (SSR) is elected from among the students and meets monthly with the Student Coordinator and Student Administrator to improve communications, to deal with matters of mutual interest and to ensure that any problems are dealt with timeously.

THE INTELLIGENT OBSERVATORY (IO) **PROGRAMME**

Design image of the remote observing station, showing the screen of the night sky above. Credit: Jonathan Green/Some Architects

SAAO's strategic plan for the next decade will move the observatory into the era of the Fourth Industrial Revolution (the combination of software with AI and advanced connectivity).

The SAAO Intelligent Observatory (IO) will substantially increase the efficiency of observing programmes through automated observations. The vision of the Sutherland Observatory is to eventually have all SAAO telescopes, in particular Lesedi, the 1.0-m, the 1.9-m and SALT tied into the IO network. Multiple hosted facilities are also anticipated to contribute, e.g. by providing triggers and/or follow-up observations. The primary science driver for the IO is time-domain and transient science. Critical to the success of the science is the rapid and intelligent use of the Sutherland telescopes to react to triggers/alerts from other ground- and space-based observatories. Triggers from LIGO/Virgo and MeerKAT will likely be the highest priority initially for the IO, with SKA, CTA and LSST providing opportunities in later years. To fully capitalise on time domain and transient science, intelligent algorithms will be developed to filter and prioritise the deluge of candidates and select only the most interesting and relevant targets for follow-up. For example, the determination of the magnitude of a target is done with optical imaging and identification of unknown-origin triggers are best done with a relatively low-resolution spectrograph.

In collaboration with the Liverpool John Moores University in the UK, a dual imaging/spectrograph is in the final stages of assembly and is expected to be delivered to SAAO in late 2021 for installation onto the Lesedi telescope. The instrument (Mokoodi) is designed to be optimised for auto-mated observations.

Before the IO can become a reality, the telescopes will have to be upgraded and adapted to become more autonomous. As of July 2021 developments on Lesedi, the 1.0-m and the 1.9-m are making this more possible. The COVID-19 pandemic has fast-tracked developments such that all three telescopes are now being operated remotely almost 100% of the time. Similarly SALT is now operated entirely remotely. Software developments have included the first release of a real-time systems monitoring dashboard and local control units (LCUs) for the 3 SAAO telescopes. The LCUs will replace many functions of an astronomer operating the telescope and instrument. This first release of the LCU has the ability to monitor the weather and force a shutdown of the telescopes if the weather goes outside of acceptable conditions. In addition, it has the ability to force a shutdown of the telescopes if contact with the remote user is lost.

In parallel, the TCS of the 40inch has been upgraded to permit observations through a web browser which was put into operations in May 2021. Operations through a web

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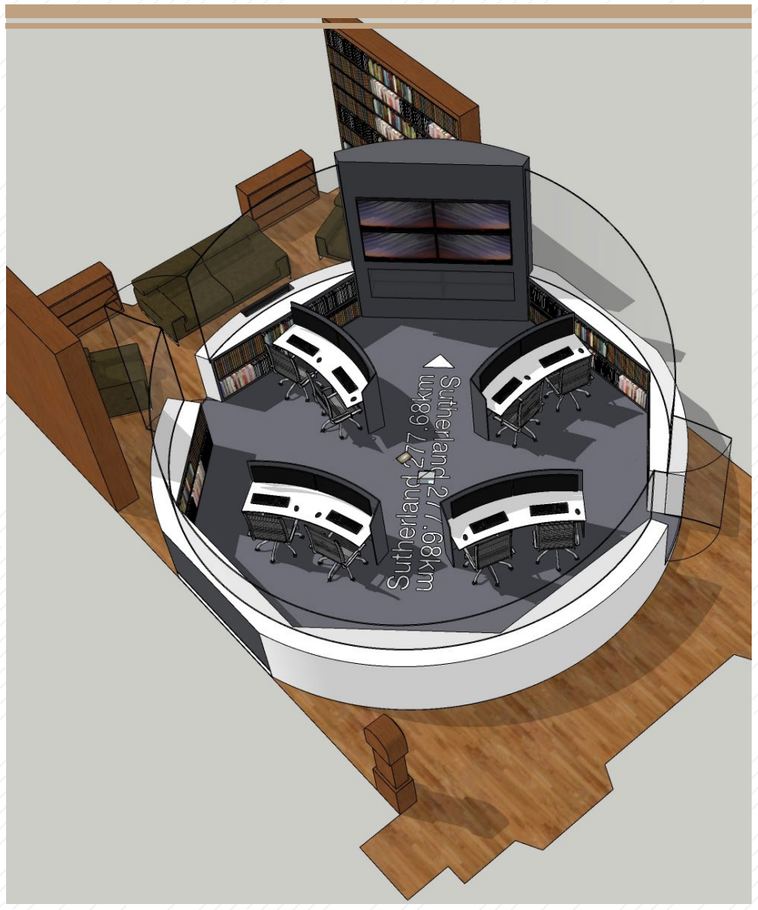
browser, rather than a VNC connection, significantly reduces the internet band width load required for remote operations. Users from the UK have now used both Lesedi and the 40inch in the past few months. In addition, the same software upgrade to the back end TCS's will provide the functionality for automated observations.

In mid 2020 a feasibility study was initiated to explore the possibility to upgrade the 1.9m telescope with a multi-instrument port. Currently only one instrument can be mounted on the telescope at any one time for several weeks at a time. As of July 2021, the project has matured to a final design with parts (mechanics and optics) on order. Once commissioned, the multi-instrument port will allow swapping between different modes of observations at anytime, e.g. between spectroscopy and imaging or polarimetry and imaging; and be under software control.

In June 2021, the IO team have begun upgrading the Observatory Control System (OCS). I.e. the system that manages and controls data base services, proposal management, schedulers etc. Rather than designing and developing an OCS from scratch, the team is investigating the OCS made available and supported by the Las Cumbres Observatory (LCO). Their OCS is already advanced with proven capability to manage multiple telescopes around the globe, providing data and proposal services for users as well as being software and data compliant for autonomous observations.

REMOTE **COMMAND ENTER**



To support the IO, a state-of-the-art control center was planned at the SAAO headquarters in Cape Town to be placed in one of the current library rooms and divided into a relaxation area and a circular platform for the observers with desks, computers and a bank of monitors.

The futuristic vision combines a high-speed, high-data-rate link with a virtual representation of the Sutherland site where the live night sky is projected on a screen above, and speakers on each desk project the live sounds from the relevant telescope domes to ensure immediate feedback when any equipment is moved. The command center will be encased in glass walls so that dignitaries and the general public can experience real-live action of astronomers at work. In addition to being a remote control room for observers, it will also ultimately be the command center from which all the autonomous functions of the IO will be managed and monitored. Construction began in 2020 and as of July 2021 the command center is complete and is currently waiting for the installation of work stations (desks and chairs).

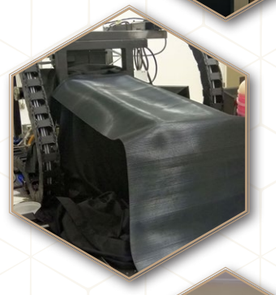
SUPPORTING DEPARTMENTS

LIBRARY & INFORMATION SERVICES

In 2020 we saw the journals room of the library make way for the Remote Operations Room with the journals being stored in the compactus installed in a side room.

This is warmly welcomed because it means that the Library and the Remote Operations Room will once again co-exist as it had from the start of the Observatory when astronomers kept their books and their telescopes/instruments together in the Main building before telescopes were moved to the dark skies of Sutherland in the 1970s. The library hosted a Library and Information Science intern who was able to learn about working in a special library such as the SAAO Library. Staff and students were provided with access to 850 e-books and 144 journals (both print and electronic) with over 12 000 full-text articles requested and downloaded. This is a significant increase for the year which is mainly due to the COVID-19 pandemic forcing staff to work virtually. The library continued to maintain an online publications database and to provide statistics for key KPIs on a quarterly basis. The library also procured a new library management system, GeniePlus, in collaboration with iThemba Labs and SARAO that will improve the circulation and access to library material.

INFORMATION & **TECHNOLOGY SERVICES**



2020 was a challenging year due to the COVID-19 pandemic. We moved to remote observing completely to limit contact with staff in Sutherland, the hostel was closed for visitors as well.

Remote observation areas were deployed in the auditorium, boardrooms and the main building. Observers were assisted over the internet (via VPN) with staff working from home. This allowed an observer to operate a telescope from the UK for the first time. This requires a reliable connection and in most cases we can depend on it. Due to frequent outages, due to extreme weather or vandalism, which can last for a few hours to a few days we contracted with VOX telecoms for a GSM backup link in Sutherland that provides us with a means into the network via the cellular networks. IT deployed a separate VPN server to provide a secure connection to the network and telescopes. This proved to be very useful for other departments as well who needed to gain access to the server in Sutherland during the non-observation periods.

The Cape Town site generator has been serviced and has proven to be more reliable. This was a major concern over the past year since sudden power outages could affect the lifespan of our equipment or cause immediate equipment failure.

IT assisted with the streaming and broadcasting of the 200 year anniversary for the Observatory. This was a great event that really showcased the various disciplines of the SAAO.

IT projects during 2020 included installing the network and IT equipment for the new remote observing room, planning and procuring equipment for Sutherland town wireless upgrade project and the development of a new backup system, Bacula, following the end of the old system, Arkeia. This was deployed at both Sutherland and Cape Town sites. Another major project involved working with engineering on a product called TeamCentre, this manages the drawing and licencing of the NX design application.

Over the last year the IT department took part in two workshops with SARAO and iThemba labs to find common areas for collaboration. The first of the workshops was dedicated to IT infrastructure and the second to computing for science. Teams have been identified to start skills sharing sessions in the near future. We also attended a cyber security workshop and this gave us the tools to better audit the current state of our environment.

OUTREACH & EDUCATION

2020 APRIL – 2021 MARCH:
SCBP EDUCATION AND OUTREACH REPORT

2020 has been a challenging year due to the outbreak of the Covid 19 pandemic which affected and limited some of our in person public outreach programmes. Despite all the challenges and limitations, we successfully implemented a number of programmes during the level 5 stringent state lockdown and during the relaxed state lock down period (level 1-3). We were compelled to utilize online and social media approaches in engaging our audiences.

THE COVID 19 – HIGH LEVEL RESTRICTIONS

Concomitant with the Covid 19 pandemic outbreak came a total lockdown with stringent Covid 19 prevention protocols and restrictions which rendered in person engagement activities and site visit impossible. To support the learning and teaching of Mathematics and Physical Science, SCBP staff acted as tutors and instructors using a 'WhatsApp' based programme geared towards supporting mathematics and science learners. This programme was implemented jointly with the Association in Educational Transformation.

A zoom based presentation followed by question and answers was organised to celebrate the International Asteroid Day. The session was addressed by Dr Nicolas Erasmus and was intended for school going youth.

A programme dubbed the "2020: Moments in the history of optical astronomy" initially intended to in person internal staff engagement was changed to be an online programme. This involved sharing videos on the history of astronomy in South Africa, the critical moments and discoveries, the professional astronomers experience, reflections from the SAAO and SALT staff and hopes and visions of the young astronomers, engineers and observers of the Observatory. The videos included the beneficiaries of our programmes in Sutherland and featured the schools and local clinic, they also included students who had previously participated in our successful job shadowing programme and are currently studying astronomy, physics, computer science or engineering at various universities.

Selected videos were shared via social media with the general public.

A series of crossword, search word and anagrams based on the history, telescopes and research conducted at SAAO and SALT were developed and these were shared with SAAO staff and with the public via social media.

To further engage the public, since the open nights and public tours were suspended, astronomers were encouraged to record themselves giving a talk and also provide a written summary of the talk. These were posted on the SAAO website and also shared via twitter and Facebook. The aim was to continue sharing the relevance of our institution and inform the public of the developments and discoveries.

A media training forum was organized for the astronomers. This was organized by SCBP staff and focuses on the media releases and media relations including handling of post media releases radio and television interviews.

The SCBP staff also participated in various online forums and discussions as panel members for the Africa Day celebrations, Science and science engagement for scientists and researchers, and career based discussions.

LEVEL 1-3 COVID RESTRICTIONS

With the relaxation of the lockdown conditions, we were able to roll out some programmes even though many were still online based, an attempt was made to encourage the public to observe the bright planets in our solar system, the annular and partial social eclipses and the great planetary conjunction of Jupiter and Saturn. In addition, a series of weekly zoom based seminars were held from the 27th of October to the 20th of December, and an astronomy quiz for Grade 7 learners was implemented jointly with SAASTA and ArcelorMittal.

ECLIPSES

The 21st of June 2020 annular eclipse was visible to the African continent. In support of this event, SCBP staff distributed solar filters and solar viewers to interested parties and organisations in various African countries. This was also done in collaboration with AfAS (African Astronomical Society).

Similar efforts were undertaken with the partial social eclipse of the 14th of December 2020. This was only visible to the northern and eastern regions of Africa. Solar viewers were distributed to science centres, amateur astronomers and the general public in Cape Town. The public was encouraged to observe the eclipse, the weather was not favourable for this event in many South African towns and cities.

THE GREAT PLANETARY CONJUNCTION

On the 21st of December we experienced and observed the great planetary conjunction of Jupiter and Saturn. SCBP staff and postgraduate staff volunteered to translate posters into various South African indigenous languages. These were shared and distributed via social media. The public was encouraged to observe the planetary conjunction, unfortunately the weather was not favourable for many towns and cities. SCBP staff and the science engagement astronomers fielded various radio interviews in a bid to communicate and share the relevance of the planetary conjunction.

ASTRONOMY QUIZ

An astronomy quiz for grade 7 learners was implemented jointly with the ArcelorMittal Science Centre and the South African Agency for Science and Technology Advancement (SAASTA). Unlike previous years when we implemented the quiz nationally, this was confined mainly to the town of Newcastle and was completely done online. Thanks to Dr Christian Hettlage for all the technical support provided. All the participants received certificates of participation and the winners received some prizes.

SOUTH AFRICA – ZAMBIAN STEM CAREER AND ROLE MODELLING PROJECT

A joint South Africa and Zambia collaboration focusing on careers in stem was held on the 28th of November, followed by a role modelling session for girls and included South African born scientists presenting to teachers and girl learners from South Africa and Zambia. This was preceded by a presentation from an SCBP staffer sharing her experiences with organizing and implementing career activities for girl learners at high schools.

ZOOM BASED OUTREACH FOR HOME SCHOOLERS

A zoom based program intended to reach home schoolers was organized and implemented. This involved Zoom based presentations for foundation phase learners based on the Moon and its relationship with the Earth and the Sun. These groups of home schoolers used to visit the Observatory pre- covid but transferred to an online platform during Covid.

THE CULTURAL ASTRONOMY PROJECT

A number of short video presentations by indigenous knowledge holders and professional indigenous researchers such as Professor Keith Snedegar, Professor Jarita Holbrook, Dr Motheo Koitsiwe, Mr Themba Matomela and others have been collected and will form part of the African Cultural Astronomy CD. Further animated stories shared as part of the Moments in the History programme will also be part of the African Cultural Astronomy CD.

In this vein competitions have been organized for the youth in Sutherland, teachers nationally and foundation phase learners nationally. The winners of the various competitions will be announced after the 31st of May.

2020 **200 DAYS FESTIVAL**

> As part of the bicentenary celebrations of the SAAO, a 200 Days festival was organized and this was implemented from the 27th of October to the 20th of December. The aim of the festival was primarily to share the beauty, relevance and power of astronomy and to highlight and celebrate the contributions and achievements of South African astronomy. Some of its objectives were to increase the participation of the broader public and to continue with the activities beyond the 20th of October 2020.

As part of community support and science education enhancement, Mr Thabo Ndaba has been employed to teach Mathematics and Science at the Roggeveld and Sutherland high school. This position is funded by the Southern African Large Telescope (SALT) and will be managed by the South African Astronomical Observatory (SAAO).

During this period a series of weekly seminars and panel discussions were organised. These were open to all members of the public and we were overjoyed to see international audiences participating in the various webinars sharing their experiences. The panellist and presenters were drawn from various astronomy and science institutions and included presenters from as far as Australia, Portugal, Germany, Poland, Uganda and many other countries.

The themes included the following: Indigenous Astronomy, Astronomy and Science Education, Careers in astronomy, Astro Tourism, Sutherland – Tourism and Development, Astronomy in science centres, Online learning and teaching.

As part of the festival, members of the general public were encouraged to observe the planets in our solar system, take pictures and share with the SAAO staff and public as well as encourage family members to observe. This was dubbed the planet chase and it was exciting to observe the Sutherland based staff and families taking up the challenge and sharing the various images of the various objects. Further professional astro photographers joined in and took beautiful pictures of Uranus and Neptune which were shared with the public.

Thanks to the SAAO Director and the SALT Board, we will also be able to offer undergraduate bursaries to Sutherland and Northern Cape students in science, engineering, tourism and Science Education. The closing date of the bursary is 15th of May and the 10 recipients will be announced after the 15th of May.

SUTHERLAND TOURS

With the relaxation in the lockdown conditions, Sutherland tours have re-opened. Initially tours were limited to drive through and visitors were allowed to take pictures at two pre-selected spots. With the changes to level 1, we were able to re-open the tours fully with limited numbers and covid prevention protocols such as social distancing and sanitization of hands. With the re-introduction of restrictions, we have had to suspend the tours in Sutherland. We will review and assess when the new regulations are confirmed by the President of the country.

SUTHERLAND COVID RELIEF PROGRAMME

We were able to distribute food parcels to indigent families of Sutherland through the financial support we received from the IAU OAD. With the support from the Director and the SALT board, we intend to utilize the services of the Gift of the Givers (an NGO) in further distributing food parcels to the poor and indigent families.

SAAO STUDENTS

SAAO **STUDENTS**

SAAO takes pride in the rich diversity and culture of our students who come from all over the world and, in particular, from other countries such as Rwanda, Uganda, Ethiopia, Mauritius, Sudan, Burkina Faso, Lebanon, Madagascar, and more.

During 2020, 12 SAAO staff members supervised or co-supervised 6 MSc and 12 PhD students registered at various South African universities (the majority at UCT).

Three MSc and one PhD student graduated during the year. SAAO also appoints a number of honours students and interns every year, particularly unemployed graduates, across all departments.

GRADUATED STUDENTS

PETRO JANSE VAN RENSBURG, MSC, UCT

Title:
Characterising small (<300m in diameter), close-approaching near-Earth asteroids
Supervisors:
Dr Nicolas Erasmus (SAAO), Prof Matthew Bershady (SAAO)

ABSTRACT

Near-Earth Asteroids (NEAs) are a population of asteroids in a steady state, constantly being replenished with asteroids from the main belt. NEAs have orbits that come close to or cross the Earth's orbit and therefore some could have impacting trajectories and pose a threat. Small NEAs (diameter < 300 m) pose a greater threat compared to large NEAs because they are more abundant and can cause significant damage on impact. The characteristics of small NEAs can give an indication of the most likely properties of potential future impactors. Even though in recent years the number of discovery and characterisation programmes of NEAs have increased, the characterisation of the small NEA population still lags behind because they can only be observed with 1-m class telescopes when they pass close to the Earth and become bright enough.

Presented here in this MSc thesis are 20 NEAs that were successfully observed and characterised with the South African Astronomical Observatory (SAAO) 40-inch telescope and the Sutherland High-Speed Optical Camera. Out of the 20 NEAs, 14 had diameters < 300 m (H>21). Characterisation involved assigning taxonomic probabilities to each NEA based on spectra from the Bus-DeMeo classification scheme and thereby inferring its most probable composition, as well as using a Lomb-Scargle periodogram to extract the rotation period from multi-band photometry. The taxonomic probabilities were determined with the colours g'-r' and r'-i', in combination with a machine learning (ML) algorithm trained on synthetic colours from observed spectra obtained from literature. The taxonomies considered were the S-, C-, and X-complexes, and the D-, Q-, and V-types.

In this thesis, the taxonomic probabilities are reported for all of the targets. A distinct taxonomic class was assigned to 15 NEAs that had a probability >50% in a specific taxonomy. New taxonomic classes are reported for 11 of the targets. A notable result of this study is the confirmation of the prediction that the most common meteorite, ordinary chondrites, are due to S-complex and Q-type asteroids. The fraction of meteorite falls due to ordinary chondrites are similar to the combined fraction of S-complex and Q-type asteroids in this study (~80%). This confirmation was only possible by including the Q-type asteroids in the classification and being able to differentiate between the C-complex and Q-type asteroids with two colours and a ML approach. A rotation period was extracted for nine NEAs that were observed for long enough to resolve a light curve period. The remaining targets had only partial or flat light curves and no period could be resolved from the periodogram. Reported here are also three small NEAs with H>22 magnitude which were found to have rotation periods smaller than the 2.2 hour spin barrier and could be rigid pieces of rock instead of rubble piles.

GEOFF MURPHY, MSC UCT

Title:
Modelling Formation in the L-Galaxies 2020 Semi-Analytic Model
Supervisors:
Dr Rob Yates (MPA-Garching), Dr Shazrene Mohammed (SAAO), Dr Daniel Cunnama (SAAO)

ABSTRACT

A study was carried out to determine how well the L-Galaxies 2020 semi-analytic model simulates the stellar halos of galaxies and the intracluster stellar (ICS) compo-nents of galaxy clusters. Two galaxy disruption models were tested, namely instan-taneous disruption and gradual disruption.

Furthermore, two stellar halo profiles were applied to the simulation results: a power-law profile with slopeγ=−3.5 and aNavarro-Frenk-White (NFW) profile. In the latter case, the stellar halo stars follow the distribution of the galaxy's dark matter. It was found that a combination ofan NFW profile and gradual disruption provided the best results across the widest range of literature data, namely measurements of stellar halo mass, total stellar mass, stellar mass fractions, and stellar halo iron abundances. Gradual disruption also produced more massive stellar halos than instantaneous disruption. Additional stellar halo formation mechanisms, such as in-situ star formation, were not needed,as the stellar halo masses seen in observations can be obtained in L-Galaxies by considering only tidal disruption of infalling satellite galaxies.

The number of high mass accretions into the halos of Milky Way-mass galaxies in the gradual disruption model agreed reasonably well with simulation literature. It was found that while galaxies can undergo many disruptions (over a thousand in some cases), the majority of the Milky Way-sized stellar halos in L-Galaxies are formed from only one to eight high-mass disruption events. Simulation literature showed a wider range of oneto fourteen disruptions, however. A population of galaxies with unexpectedly low stellar halo iron abundances was found. These were determined to be a result of disruptions of high mass, low metallicity satellite galaxies. Furthermore, rather than iron or oxygen, carbon was found to be the dominant element produced by stellar halo stars for the majority of redshifts in most high mass galaxies, due mainly to asymptotic giant branch stars. The relative contribution of stellar halo stars was found to be minor, however, with circumgalactic medium enrichment from halo stars in comparison to outflows from galactic stars being on average.1%. For clusters with virial masses exceeding 1.6×1014M, the brightest central galaxy and ICS(BCG+ICS) stars contained 42.44% of the total cluster stellar iron content, while thefractionMICSMBCG+MICSwas found to be 82.50%, both results being in good agreement with observation.

GRADUATED STUDENTS

KELEBOGILE GASEALAHWE, MSC

Title:
SALT and TESS MONITORING of CENTRAL STARS of PLANETARY NEBULAE
Supervisors:
Dr Brent Miszalski
Co-supervisors:
A/Prof Shazrene Mohamed (SAAO/UCT), Dr Itumeleng Monageng (SAAO/UCT), Dr Rajeev Manick (SAAO)

ABSTRACT

Planetary Nebulae (PNe) are the product of Asymptotic Giant Branch (AGB) evolution. Evolved from Solar-like intermediate mass stars (0.8 -- 8Msun), they have a hot, radiating core that ionizes the gas of the expelled envelope, producing a glowing nebula. The core eventually evolves into a white dwarf (WD), following the WD cooling track. Complex, aspherical morphologies are observed in PNe and binary central stars (CSs) have been the favoured explanation for deviations from spherical symmetry. Finding and characterizing the population of binary CSs is thus important to understand the physics behind their morphologies. The objects of this study are Hen3-1333, Hen2-113 and Hen2-47, all with Wolf- Rayet (WR) CSs that commonly exhibit fast, dense stellar winds. All exhibit multipolarity in their young nebulae, Hen3-1333 has a disk and dual-dust chemistry, while the other two have central stars offset from the geometric centre of their nebulae. The objects were chosen because most of these features, especially multipolar morphologies, are not well represented amongst PNe with known binary CSs. Here we develop a quantitative time-series analysis to determine whether these objects have binary CSs and develop constraints to permissible orbital parameters.

The High Resolution Spectrograph (HRS) of the Southern African Large Telescope (SALT) was used to collect 'echelle spectroscopic data over ~3 years and The Exoplanet Survey Satellite (TESS) was used to obtain photometric data for the objects. The medium resolution (MR) mode (R ≈ 40000) was chosen and 58, 60, and 35 spectra were collected for Hen3-1333, Hen2-113 and Hen2-47, respectively, with an average S/N of 40 at 4495 A. The TESS data had continuous sampling (30 min cadence) recorded for an orbit length of 27.4 days. Using cross-correlation and Gaussian line fitting, radial velocity (RV) time-series were compared to lightcurves determined from the TESS data. Lomb-Scargle periodograms were used to search for periodic variability in the RV and photometry time-series data. The results were discussed based on short (0 -- 10 days), intermediate (10 -- 10^3 days) and long (10^3 -- 10^4 days) orbital period ranges. Compatible scenarios for each range were estimated by combining observational constraints with different parameters expected for assumed companion star types. The quantitative variability analysis excludes short orbital period binary systems, suggesting that if their multiple features are due to binary interactions, the most likely case is the long orbital period range. If the variability observed is due to a companion, rather than pulsations from the CS, the companion masses, 0.10 -- 1.36 Msun for Hen3-1333, 0.043 -- 1.27 Msun for Hen2-113 and 0.077 -- 1.36 Msun for Hen2-47, correspond to main sequence stars and dwarfs.

JOHANNA (NAOMI) VAN JAARSVELD, PHD, UCT

Title:
Multi-wavelength study of neutron stars in the Magellanic Clouds
Supervisors:
A/Prof Vanessa McBride (SAAO/OAD/UCT), Dr David Buckley (SAAO)

ABSTRACT

Massive stars are essential drivers of galaxy evolution, as well as the synthesis of heavier elements, enriching the interstellar and intergalactic medium with metals through every cycle of star formation. Thus to understand the evolving universe, it is essential to quantify the formation and evolution of massive stars in different environments. Most massive stars are born in binaries, as such their evolution are significantly affected by episodes of mass transfer. In this thesis I explore neutron stars, one of the endpoints of massive stars' evolution, in a bid to further understand the effects of binarity on evolution. To start, I conduct an optical spectroscopic andtiming study of candidate X-ray binaries in the Large Magellanic Cloud (LMC), resulting in a50% increase in the confirmed population of accreting neutron stars in the LMC. Following this study, I carry out a targeted radio pulsar search in the Small Magellanic Cloud (SMC), leading to the discovery of new pulsars, corresponding to a population size increase of 40%. The new radio pulsars allow for further characterisation of the SMC pulsar population. To relate these observational incarnations of neutron stars (i.e. radio pulsars and accreting X-ray pulsars), Utilise a binary population synthesis code that enables the prediction of pulsars in the SMCunder the assumption that all pulsars are products of massive binary evolution. The simulations successfully reproduce the observed radio pulsar population of the SMC. Ultimately, pairing observational results with simulations can establish practical guidelines for future surveys, and provide a basis for using different observed populations of neutron stars to constrain binary interactions and evolution.

STUDENT PROFILES

PHD STUDENTS

Anja Genade | UCT

Title:
Observational studies of centaur characteristics
Supervisors:
Prof. Paul Groot (UCT/SAAO/Radboud University (NL), Dr. Amanda Bosh (MIT/ Lowell Observatory)

Antoine Mahoro | UCT

Title:
Outflows and feedback from star-forming galaxies and AGN
Supervisors:
Prof. Petri Väisänen (SAAO), Dr Mrijana Pović (ESSTI) , Dr. Kurt Van der Heyden (NRF) and Dr. Pheneas Nkundabakura. (University of Rwanda)

Bynish Paul | UJ

Title:
Analysis of the iron-rich spectra of a sample of Narrow-line Seyfert 1 galaxies.
Supervisors:
Prof. Hartmut Winkler (from UJ) and Prof. Stephen Potter (SAAO)

Christian Van Der Merwe| UCT

Title:
Explosive transients from stellar collisions
Supervisors:
Prof. Shazrene Mohamed (SAAO/UCT)

Daniel Egbo | SAAO

Title:
Multiwavelength studies of radio sources in the MeerKAT Galactic Plane and Magellanic Cloud Surveys
Supervisors:
Dr David Buckley (SAAO/UCT), Dr Itumeleng Monageng (SAAO/UCT), Prof Paul Groot (UCT/SAAO/Radboud), Prof Patrick Woudt (UCT)

Hannes Breytenbach | UCT

Title:
Magnetic cataclysmic variables
Supervisors:
Dr David Buckley (SAAO), Prof Patrick Woudt (UCT)

Jamie Bok | UCT

Title:
Probing the role of environment and HI content and galaxy evolution: a multi-wavelength study of isolated and paired galaxies
Supervisors:
Dr Rosalind Skelton (SAAO), Prof Tom Jarrett (UCT), Dr Michelle Cluver (Swinburne), Sarah Blyth (UCT)

Nazir Makda

Title:
Ultra-Diffuse Galaxies
Supervisors:
Dr Rosalind Skelton (SAAO), Dr Sarah Blyth (UCT).

Kelebogile Bonokwane | SAAO/UCT

Title:
SALT and TESS monitoring of central stars of planetary nebulae
Supervisors:
Dr Itumeleng Monageng (SAAO/UCT), Prof Patrick Woudt (UCT)

Zwidofhelangani Khangale | UCT

Title:
Accretion processes in magnetic cataclysmic variables: a detailed study of UZ Fornacis.
Supervisors:
Dr Stephen Potter (SAAO), Prof Patrick Woudt (UCT)

Michael Hlabathe | UCT

Title:
Reverberation Mapping of Active Galactic Nuclei
Supervisors:
Dr Encarni Romero-Colmenero (SAAO/ SALT), Dr Steve Crawford (STScI) and Prof Patricia Whitelock (UCT).

Petro Janse Van Rensburg | SAAO/UCT

Title:
Unravelling the gas and stellar kinematics of the SUNBIRD starbursts and LIRGS
Supervisors:
Dr Moses Mogotsi (SAAO), Prof Matthew Bershady (SAAO) and Prof Petri Väisänen (SAAO).

MSC STUDENTS

Brian Bichanga | UCT

Title:
Structure and Masses of Milky Way-like Galaxies in HI Deep Fields
Supervisors:
Prof. Matthew Bershady (SAAO)

Anke van Dyke | UCT

Title:
Capturing Transients: An application of Biostatistics to Astronomy
Supervisors:
Prof Paul Groot (UCT/SAAO) and Vanessa McBride (SAAO)

Munira Hoosain | UCT

Title:
Measuring galaxy environments in the LADUMA field
Supervisors:
Dr Rosalind Skelton (SAAO), Dr Sarah Blyth (UCT)

Jaco Brink | UCT

Title:
Spectroscopic Analysis of Transient Sources.
Supervisors:
Dr David Buckley (SAAO), Prof Paul Groot (UCT//SAAO/Radboud)

Katlego Ramalatswa | UCT

Title:
Simulations of Bow Shocks in Massive Stars
Supervisors:
A/Prof Shazrene Mohammed (SAAO/UCT)

Tamara Lancaster | UCT

Title:
The Broad Spectral Energy Distributions of Accreting White Dwarfs
Supervisors:
Prof Patrick Woudt(UCT), Dr Retha Pretorius (SAAO/UCT)

HONOURS STUDENTS

Tokelo Mashile (UCT)
Supervisor: Dr Retha Pretorius (SAAO)

SAAO PERFORMANCE

PUBLICATIONS

Refereed publications by SAAO staff:	125 (66 of which use SAAO & hosted facilities)
Refereed publications by non-SAAO staff based on SAAO & hosted facilities:	135
Total refereed publications:	**270**

BREAKDOWN OF REFEREED PUBLICATIONS USING SAAO & HOSTED FACILITIES BASED ON 162 PUBLICATIONS

SALT	64
IRSF	30
KMTNet	23
LCOGT	22
SuperWASP (de-commissioned)	17
MASTER	15
ATLAS	14
1.0-m	8
1.9-m	8
MONET	6
Robopol	2
BiSON	2
Meerlicht	1
0.75	1
0.5	1

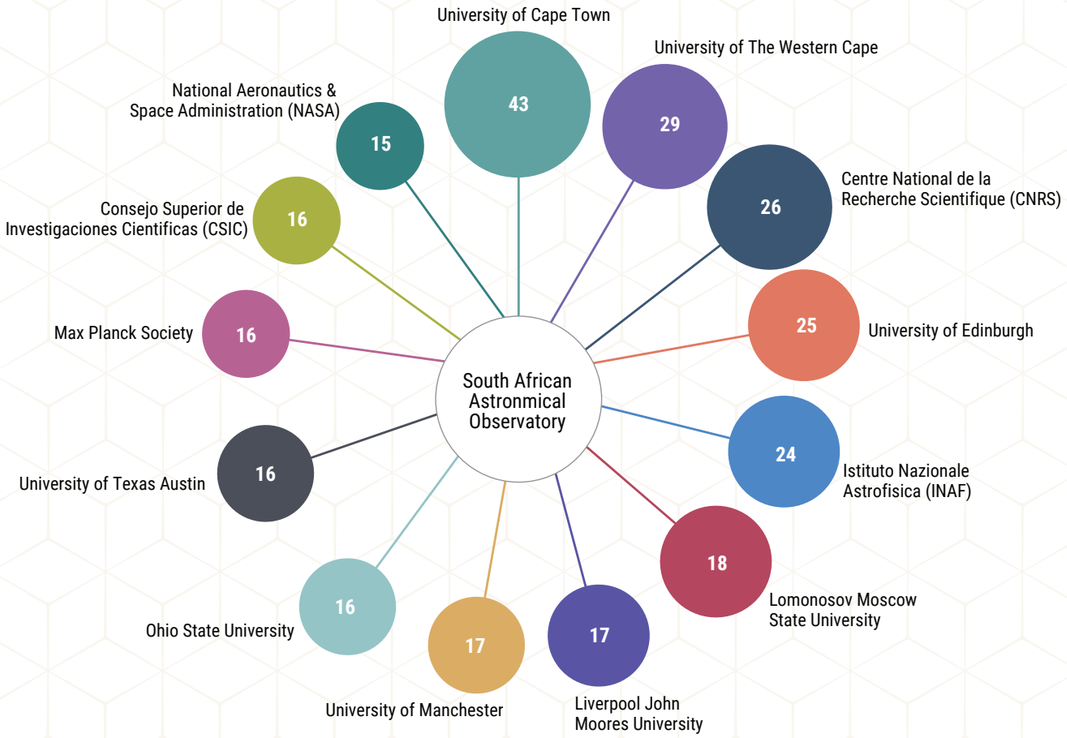
COLLABORATIONS

SAAO has a number of publications each year, many of which are collaborations of SAAO researchers with scientists from some of the most prestigious institutions across the globe. The impact of these publications stems not only from their contributions to the field of astronomy, but are highlighted in the number of citations and the headlines that these contributions sparked across the globe.

ORGANISATIONS SAAO HAS MOST FREQUENTLY COLLABORATED WITH, BASED ON 120 PUBLICATIONS

NAME	WEB OF SCIENCE DOCUMENTS
University of Cape Town	43
University of the Western Cape	29
Centre National de la Recherche Scientifique (CNRS)	26
University of Edinburgh	25
Istituto Nazionale Astrofisica (INAF)	24
Lomonosov Moscow State University	18
Liverpool John Moores University	17
University of Manchester	17
Ohio State University	16
University of Texas Austin	16
Max Planck Society	16
Consejo Superior de Investigaciones Cientificas (CSIC)	16
National Aeronautics & Space Administration (NASA)	15
California Institute of Technology	14
Space Telescope Science Institute	14
Universite de Paris	14
University of Oxford	14
European Southern Observatory	14
University of Arizona	13
University of Wisconsin Madison	13

ORGANISATIONS SAAO HAS MOST FREQUENTLY COLLABORATED WITH, BASED ON 120 PUBLICATIONS



STAFF

TOTAL NUMBER:	128				
BY DEPARTMENT:					
	Total	**Male**	**Female**	**CT Based**	**Sutherland Based**
Science	26	14	12	26	–
Technical/engineering	36	31	5	19	17
IT/Software support	15	15	0	11	4
Support (various)	35	14	21	20	15
Outreach	16	10	6	10	6
Students	18	11	7	18	–
Interns	8	2	6	8	0

OUTREACH

	Events	**Attendees**
Learners	152	25849
Educators	19	707
Public	58	15978

APPENDIX

PUBLICATION LISTS

Refereed Publications*

PUBLICATIONS WITH SAAO AFFILIATION

Ackley, K., Amati, L., Barbieri, C., et al.: "Observational constraints on the optical and near-infrared emission from the neutron star-black hole binary merger candidate S190814bv", 2020, Astronomy and Astrophysics, 643, A113.

Ahumada, R., Prieto, C. A., Almeida, A., et al.: "The 16th Data Release of the Sloan Digital Sky Surveys: First Release from the APOGEE-2 Southern Survey and Full Release of eBOSS Spectra", 2020, Astrophysical Journal Suppliment Series, 249, 3.

Andreoni, I., Goldstein, D. A., Kasliwal, M. M., et al.: "GROWTH on S190814bv: Deep Synoptic Limits on the Optical/Near-infrared Counterpart to a Neutron Star-Black Hole Merger", 2020, Astrophysical Journal, 890, 131.

Andrianomena, S., Rafieferantsoa, M., & Davé, R.: "Classifying galaxies according to their H I content", 2020, Monthly notices of the Royal Astronomical Society, 492, 5743.

Appleby, S., Davé, R., Kraljic, K., Anglés-Alcázar, D., & Narayanan, D.: "The impact of quenching on galaxy profiles in the SIMBA simulation", 2020, Monthly notices of the Royal Astronomical Society, 494, 6053.

Arnold, R. A., McSwain, M. V., Pepper, J., et al.: "Long-period High-amplitude Red Variables in the KELT Survey", 2020, Astrophysical Journal Suppliment Series, 247, 44.

Aydi, E., Chomiuk, L., Izzo, L., et al.: "Early Spectral Evolution of Classical Novae: Consistent Evidence for Multiple Distinct Outflows", 2020, Astronomical Journal, 905, 62.

Aydi, E., Sokolovsky, K. V., Chomiuk, L., et al.: "Direct evidence for shock-powered optical emission in a nova", 2020, Nature Astronomy, 4, 776.

Balona, L. A.: "The hot limit of solar-like oscillations from Kepler photometry", 2020, Frontiers in Astronomy and Space Sciences, 7, 85.

Balona, L. A., & Ozuyar, D.: "TESS observations of Be stars: a new interpretation", 2020, Monthly notices of the Royal Astronomical Society, 493, 2528.

Belkin, S. O., Pozanenko, A. S., Mazaeva, E. D., et al.: "Multi-wavelength Observations of GRB 181201A and Detection of Its Associated Supernova", 2020, Astronomy Letters, 46, 783.

Bonnet-Bidaud, J. M., Mouchet, M., Falize, E., et al.: "Fast quasi-periodic oscillations in the eclipsing polar VV Puppis from VLT and XMM-Newton observations", 2020, Astronomy and Astrophysics, 633, A145.

Borrow, J., Anglés-Alcázar, D., & Davé, R.: "Cosmological baryon transfer in the SIMBA simulations", 2020, Monthly notices of the Royal Astronomical Society, 491, 6102.

Bright, J. S., Fender, R. P., Motta, S. E., et al.: "An extremely powerful long-lived superluminal ejection from the black hole MAXI J1820+070", 2020, Nature Astronomy, 4, 697.

Buie, M. W., Porter, S. B., Tamblyn, P., et al.: "Size and Shape Constraints of (486958) Arrokoth from Stellar Occultations", 2020, Astronomical Journal, 159, 130.

Caleb, M., Stappers, B. W., Abbott, T. D., et al.: "Simultaneous multi-telescope observations of FRB 121102", 2020, Monthly notices of the Royal Astronomical Society, 496, 4565.

Chattopadhyay, S., Bershady, M. A., Wolf, M. J., Smith, M. P., & Hauser, A.: "Fiber positioning in microlens-fiber coupled integral field unit", 2020, Journal of Astronomical Telescopes, Instruments and Systems, 6, 025002.

Chen, P., Dong, S., Stritzinger, M. D., et al.: "The Most Rapidly Declining Type I Supernova 2019bkc/ATLAS19dqr", 2020, Astrophysical Journal Letters, 889, L6.

Coe, M. J., Monageng, I. M., Bartlett, E. S., Buckley, D. A. H., & Udalski, A.: "A major optical and X-ray outburst from the Magellanic Bridge source RX J0209.6-7427", 2020, Monthly notices of the Royal Astronomical Society, 494, 1424.

Colas, F., Zanda, B., Bouley, S., et al.: "FRIPON: a worldwide network to track incoming meteoroids", 2020, Astronomy and Astrophysics, 644, A53.

Cúneo, V. A., Muñoz-Darias, T., Sánchez-Sierras, J., et al.: "Discovery of optical outflows and inflows in the black hole candidate GRS 1716-249", 2020, Monthly notices of the Royal Astronomical Society, 498, 25.

Cunningham, J.-M. C., Feliz, D. L., Dixon, D. M., et al.: "A KELT-TESS Eclipsing Binary in a Young Triple System Associated with the Local "Stellar String" Theia 301", 2020, Astronomical Journal, 160, 187.

Davé, R., Crain, R. A., Stevens, A. R. H., et al.: "Galaxy cold gas contents in modern cosmological hydrodynamic simulations", 2020, Monthly notices of the Royal Astronomical Society, 497, 146.

de Blok, W. J. G., Athanassoula, E., Bosma, A., et al.: "MeerKAT HI commissioning observations of MHONGOOSE galaxy ESO 302-G014", 2020, Astronomy and Astrophysics, 643, A147.

Doan, L., Ramstedt, S., Vlemmings, W. H. T., et al.: "The extended molecular envelope of the asymptotic giant branch star π¹ Gruis as seen by ALMA. II. The spiral-outflow observed at high-angular resolution", 2020, Astronomy and Astrophysics, 633, A13.

Donevski, D., Lapi, A., Małek, K., et al.: "In pursuit of giants. I. The evolution of the dust-to-stellar mass ratio in distant dusty galaxies", 2020, Astronomy and Astrophysics, 644, A144.

Dorval, P., Talens, G. J. J., Otten, G. P. P. L., et al.: "MASCARA-4 b/bRing-1 b: A retrograde hot Jupiter around a bright A-type star", 2020, Astronomy and Astrophysics, 635, A60.

Driessen, L. N., McDonald, I., Buckley, D. A. H., et al.: "MKT J170456.2-482100: the first transient discovered by MeerKAT", 2020, Monthly notices of the Royal Astronomical Society, 491, 560.

Ďurech, J., Tonry, J., Erasmus, N., et al.: "Asteroid models reconstructed from ATLAS photometry", 2020, Astronomy and Astrophysics, 643, A59.

Erasmus, N., Navarro-Meza, S., McNeill, A., et al.: "Investigating Taxonomic Diversity within Asteroid Families through ATLAS Dual-band Photometry", 2020, Astrophysical Journal Supplement Series, 247, 13.

Ershova, O. A., Lipunov, V. M., Gorbovskoy, E. S., et al.: "Early Optical Observations of Gamma-Ray Bursts Compared with Their Gamma- and X-Ray Characteristics Using a MASTER
Gaibor, Y., Garnavich, P. M., Littlefield, C., Potter, S. B., & Buckley, D. A. H.: "An improved spin-down rate for the proposed white dwarf pulsar AR scorpii", 2020, Monthly notices of the Royal Astronomical Society, 496, 4849.

Global Network of Robotic Telescopes from Lomonosov Moscow State University", 2020, Astronomy Reports, 64, 126.

Glowacki, M., Elson, E., & Davé, R.: "The baryonic Tully-Fisher relation in the SIMBA simulation", 2020, Monthly notices of the Royal Astronomical Society, 498, 3687.
Gu, M., Conroy, C., Law, D., et al.: "Spectroscopic Co, Astrophysical Journal, arXiv e-prints, arXiv:1810.13242.

Gu, M., Conroy, C., Law, D., et al.: "Spectroscopic Constraints on the Buildup of Intracluster Light in the Coma Cluster", 2020, Astrophysical Journal, 894, 32.

Gvaramadze, V. V., Kniazev, A. Y., Gräfener, G., & Langer, N.: "WR 72: a born-again planetary nebula with hydrogen-poor knots", 2020, Monthly notices of the Royal Astronomical Society, 492, 3316.

Hassan, S., Finlator, K., Davé, R., Churchill, C. W., & Prochaska, J. X.: "Testing galaxy formation simulations with damped Lyman-α abundance and metallicity evolution", 2020, Monthly notices of the Royal Astronomical Society, 492, 2835.

Hlabathe, M. S., Starkey, D. A., Horne, K., et al.: "Robotic reverberation mapping of the broad-line radio galaxy 3C 120", 2020, Monthly notices of the Royal Astronomical Society, 497, 2910.

Hosenie, Z., Lyon, R., Stappers, B., Mootoovaloo, A., & McBride, V.: "Imbalance learning for variable star classification", 2020, Monthly notices of the Royal Astronomical Society, 493, 6050.

Huang, S., Katz, N., Scannapieco, E., et al.: "A new model for including galactic winds in simulations of galaxy formation - I. Introducing the Physically Evolved Winds (PhEW) model", 2020, Monthly notices of the Royal Astronomical Society, 497, 2586.

Jones, J. S.: "Living on an island", 2020, Astronomy and Geophysics, 61, 3.26.

Jordana-Mitjans, N., Mundell, C. G., Kobayashi, S., et al.: "Lowly Polarized Light from a Highly Magnetized Jet of GRB 190114C", 2020, Astrophysical Journal, 892, 97.

Kasliwal, M. M., Anand, S., Ahumada, T., et al.: "Kilonova Luminosity Function Constraints Based on Zwicky Transient Facility Searches for 13 Neutron Star Merger Triggers during O3", 2020, Astronomical Journal, 905, 145.

Kennea, J. A., Coe, M. J., Evans, P. A., et al.: "The newly discovered Be/X-ray binary Swift J004516.6-734703 in the SMC: witnessing the emergence of a circumstellar disc", 2020, Monthly notices of the Royal Astronomical Society, 499, L41.

Kennedy, M. R., Breton, R. P., Clark, C. J., et al.: "Optical, X-ray, and γ-ray observations of the candidate transitional millisecond pulsar 4FGL J0427.8-6704", 2020, Monthly notices of the Royal Astronomical Society, 494, 3912.

Khangale, Z. N., Potter, S. B., Woudt, P. A., et al.: "A spectroscopic, photometric, polarimetric, and radio study of the eclipsing polar UZ Fornacis: the first simultaneous SALT and MeerKAT observations", 2020, Monthly notices of the Royal Astronomical Society, 492, 4298.
Khangale, Z. N., Woudt, P. A., Potter, S. B., et al.: "A spectroscopic analysis of the eclipsing nova-like EC 21178-5417 - discovery of spiral density structures", 2020, Monthly notices of the Royal Astronomical Society, 495, 637.

Kniazev, A.: "Long-period eclipsing binaries: towards the true mass-luminosity relation. II. Absolute parameters of the NN Del system", 2020, Astrophysics and Space Science, 365, 169.

PUBLICATIONS **WITH SAAO AFFILIATION (CONT.)**

Kniazev, A. Y., Malkov, O. Y., Katkov, I. Y., & Berdnikov, L. N.: "Long-period eclipsing binaries: towards the true mass-luminosity relation. I. the test sample, observations and data analysis", 2020, Research in Astronomy and Astrophysics, 20, 119.

Kollatschny, W., Grupe, D., Parker, M. L., et al.: "Optical and X-ray discovery of the changing-look AGN IRAS 23226-3843 showing extremely broad and double-peaked Balmer profiles", 2020, Astronomy and Astrophysics, 638, A91.

Koribalski, B. S., Staveley-Smith, L., Westmeier, T., et al.: "WALLABY - an SKA Pathfinder HI survey", 2020, Astrophysics and Space Science, 365, 118.

Kraljic, K., Pichon, C., Codis, S., et al.: "The impact of the connectivity of the cosmic web on the physical properties of galaxies at its nodes", 2020, Monthly notices of the Royal Astronomical Society, 491, 4294.

Krishnarao, D., Tremonti, C., Fraser-McKelvie, A., et al.: "The Effect of Bars on the Ionized ISM: Optical Emission Lines from Milky Way Analogs", 2020, Astrophysical Journal, 898, 116.

Labadie-Bartz, J., Handler, G., Pepper, J., et al.: "New Beta Cephei Stars from the KELT Project", 2020, Astronomical Journal, 160, 32.

Lambert, T. S., Kraan-Korteweg, R. C., Jarrett, T. H., & Macri, L. M.: "The 2MASS redshift survey galaxy group catalogue derived from a graph-theory based friends-of-friends algorithm", 2020, Monthly notices of the Royal Astronomical Society, 497, 2954.

Lipunov, V. M., Kornilov, V. G., Zhirkov, K., et al.: "Optical Observations Reveal Strong Evidence for High-energy Neutrino Progenitor", 2020, Astrophysical Journal Letters, 896, L19.

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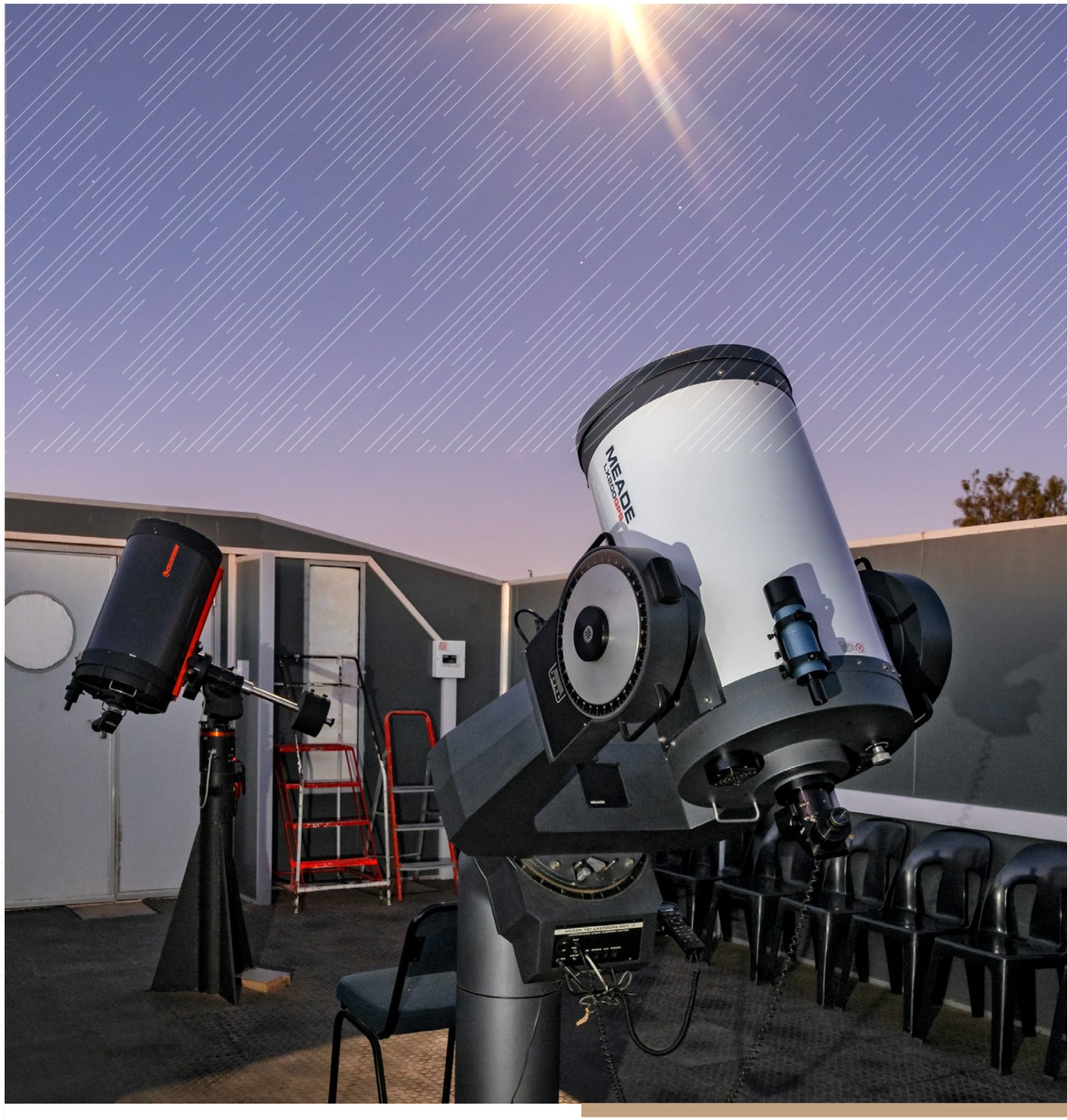
SAAO **STAFF**



SAAO **EXECUTIVE**

In the reporting period of April 2020 to March 2021, the **SAAO Executive** comprised the following:

PROF. PETRI VÄISÄNEN
Managing Director: SAAO

MR KEVINDRAN GOVENDER
Director: IAU OAD

MR EUGENE LAKEY
Manager: Finance and Operations

DR STEPHEN POTTER
Head: Astronomy

DR RAMOTHOLO SEFAKO
Head: Telescope Operations

DR ENCARNI ROMERO COLMENERO
Head: SALT Astronomy Operations

MR PAUL RABE
Head: SALT Technical Operations

MR HITESH GAJJAR
Head: Instrumentation

MR SIVUYILE MANXOYI
Manager: SALT Collateral Benefits Programme

MRS LINDA TOBIN
Manager: Human Resources

MR IRIWAAN SIMON
Manager: Information Technology

STAFF **LIST**

This list includes casual staff, honorary fellows and students working at SAAO between April 2020 and March 2021.

NAME	TITLE	GENDER	JOB TITLE	LOCATION
Anthony, Melissa	Mrs	F	Procurement Officer	CT
Appolis, Wade	Mr	M	Machinist	CT
April, Koos	Mr	M	Driver/Maintenance	S
Andrew, Firt	Mr	M	MSc student	CT
Anja, Genade	Ms	F	PhD Student	CT
Anke, Van Dyk	Ms	F	PhD student	CT
Arendse, Tamzyn	Ms	F	SAASTA Volunteer	CT
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ACRONYMS

LIST OF **ACRONYMS**

3D	Three Dimensional
ACT	Alan Cousins Telescope
AdvACT	Advanced Atacama Cosmology Telescope
AfAS	African Astronomical Society
AGB	Asymptotic giant branch
AGC	Asteroid Grand Challenge
AGN	Active galactic nucleus
AIMS	African Institute for Mathematical Sciences
AIO	African Intelligent Observatory
ALFA	Arecibo L-Band Feed Array
ALFALFA	Arecibo Legacy Fast ALFA
ALMA	Atacama Large Millimeter/sub-millimeter Array
ASSA	Astronomical Society of Southern Africa
ASSAf	Academy of Science of South Africa
ASAS-SN	All-Sky Automated Survey for SuperNovae
ASTMON	All-Sky Monitor
ATCA	Australia Telescope Compact Array
ATLAS	Asteroid Terrestrial-Impact Last Alert System
ATP	Acceptance Test Procedure
AUC	Area under curve
AURA	Association of Universities for Research in Astronomy
AVN	African Very long baseline interferometry Network
BCG	Brightest cluster galaxies
BiSON	Birmingham Solar Oscillations Network
CalTech	California Institute of Technology
CBNU	Chungbuk National University, Korea
CCD	Charge-coupled device
CDS	Astronomical Data Centre Strasbourg
CEO	Chief Executive Officer
CfA	Center for Astrophysics
CNN	Cable News Network
CNN	Convolutional Neural Network
CSIC	Spanish Research Council
CTA	Cherenkov Telescope Array
DLR	The German Aerospace Center
DNN	Deep Neural Networks
DPT	Discrete Pulse Transform
DSI	Department of Science and Innovation
DSSI	Differential Speckle Survey Instrument
DST	Department of Science and Technology
ESO	European Southern Observatories
FLI	Finger Lakes Instrumentation
FLOYDS	Folded Low Order whYte-pupil Double-dispersed Spectrograph
FOV	field-of-view
FRI	Fanaroff-Riley class I
GAN	Generative Adversarial Neural
GFZ	German Research Centre for Geosciences
H2	molecular hydrogen
HESS	High Energy Stereoscopic System
HIPPO	HIgh speed Photo-Polarimeter
HST	Hubble Space Telescope
IAU	International Astronomical Union
INAF	National Institute for Astrophysics, Italy
IO	Intelligent Observatory
IRSF	InfraRed Survey Facility
IRTF	NASA Infrared Telescope Facility
IT	information technology
IUCAA	Inter-University Centre for Astronomy and Astrophysics
JWST	James Webb Space Telescope
KASI	Korean Astronomy and Space Science Institute
KELT-South	Kilodegree Extremely Little Telescope
KMTNet	Korea Microlensing Telescope Network
kNB	k-Nearest Neighbours
LADUMA	Looking At the Distant Universe with the MeerKAT Array
LCO	Las Cumbres Observatory
LIGO	Laser Interferometer Gravitational-wave Observatory
LIRGs	Luminous Infra-Red Galaxies
LJMU	Liverpool John Moores University
LMC	Large Magellanic Clouds
LSST	Large Synoptic Survey Telescope
LTS	Long Term Support
MASTER	Mobile Astronomical System of the TElescope-Robots Network
MaxE	Maximum Efficiency spectrograph
MEARIM	Middle East and Africa Regional IAU Meetings
MIT	Massachusetts Institute of Technology
ML	machine learning
MLP	Multi Layer Perceptron
MNRAS	Monthly Notices of the Royal Astronomical Society
MONET	MOnitoring NEtwork of Telescopes
MORIS	MIT Optical Rapid Imaging System
MPG	Max Planck Society
MSc	Masters of Science
MWA	Multi-Wavelength Astronomy
NAOJ	National Astronomical Observatory of Japan
NASA	National Aeronautics and Space Administration
NASSP	National Astrophysics and Space Science Program
NB	Naive Bayes
NEO	near-Earth objects
NGC	National General Catalog
NHRA	National Heritage Resources Act
NIR	near-infrared
NOVA	Netherlands Research School for Astronomy
NRF	National Research Foundation
NSTF	National Science and Technology Forum
OAD	Office of Astronomy for Development
OGLE	Optical Gravitational Lensing Experiment
OSR	Optical Space Research
OSU	Ohio State University
PAC	postgraduate advisory committee
PRIME	PRime focus Infrared Microlensing Experiment
RESOLVE	REsolved Spectroscopy Of a Local VolumE
RF	Random Forest
RIRP	Research Innovation Reward Programme
RSS	Robert Stobie Spectrograph
SAAO	South African Astronomical Observatory
SAEON	South African Environmental Observation Network

LIST OF **ACRONYMS (CONT.)**

SAGOS	South African Geodynamic Observatory Sutherland
SAHRA	South African Heritage Resources Agency
SAIP	South African Institute of Physics
SALT	Southern African Large Telescope
SARAO	South African Radio Astronomy Observatory
SCBP	SALT Collateral Benefit Programme
SDG	Sustainable Development Goals
SDSS	Sloan Digital Sky Survey
SETI	search for extraterrestrial intelligence
SKA	Square Kilometre Array
SHOC	Sutherland High-speed Optical Camera
SIRIUS	Simultaneous 3-colour InfraRed Imager for Unbiased Survey
SMART	Small Aperture Robotic Telescope
SMARTnet	Small Aperture Robotic Telescope Network
SMARTS	Small & Moderate Aperture Research Telescope System
SMC	Small Magellanic Cloud
SNR	signal-to-noise ratio
SOAR	Southern Astrophysical Research telescope
SOFIA	Stratospheric Observatory for Infrared Astronomy
SPIRITS	SPitzer InfraRed Intensive Transients Survey
SpUpNIC	Spectrograph Upgrade Newly-Improved Cassegrain
sSFR	specific star formation rate
SSR	SAAO student representative
STScI	Space Telescope Science Institute
SUMSS	Sydney University Molonglo Sky Survey
SUNBIRD	SUperNovae and starBurst in the InfraReD
SuperWASP	Super Wide Angle Search for Planets
TNO	trans-Neptunian objects
UC	University of Canterbury, New Zealand
UCSB	University of California, Santa Barbara
UCT	University of Cape Town
UV	ultraviolet
UW	University of Warsaw
UWC	University of the Western Cape
VHE	Very High Energy
VLA	Very Large Array
WFTC II	Wide Field Cryogenic Telescope

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SAAO South African Astronomical Observatory 200 YEARS