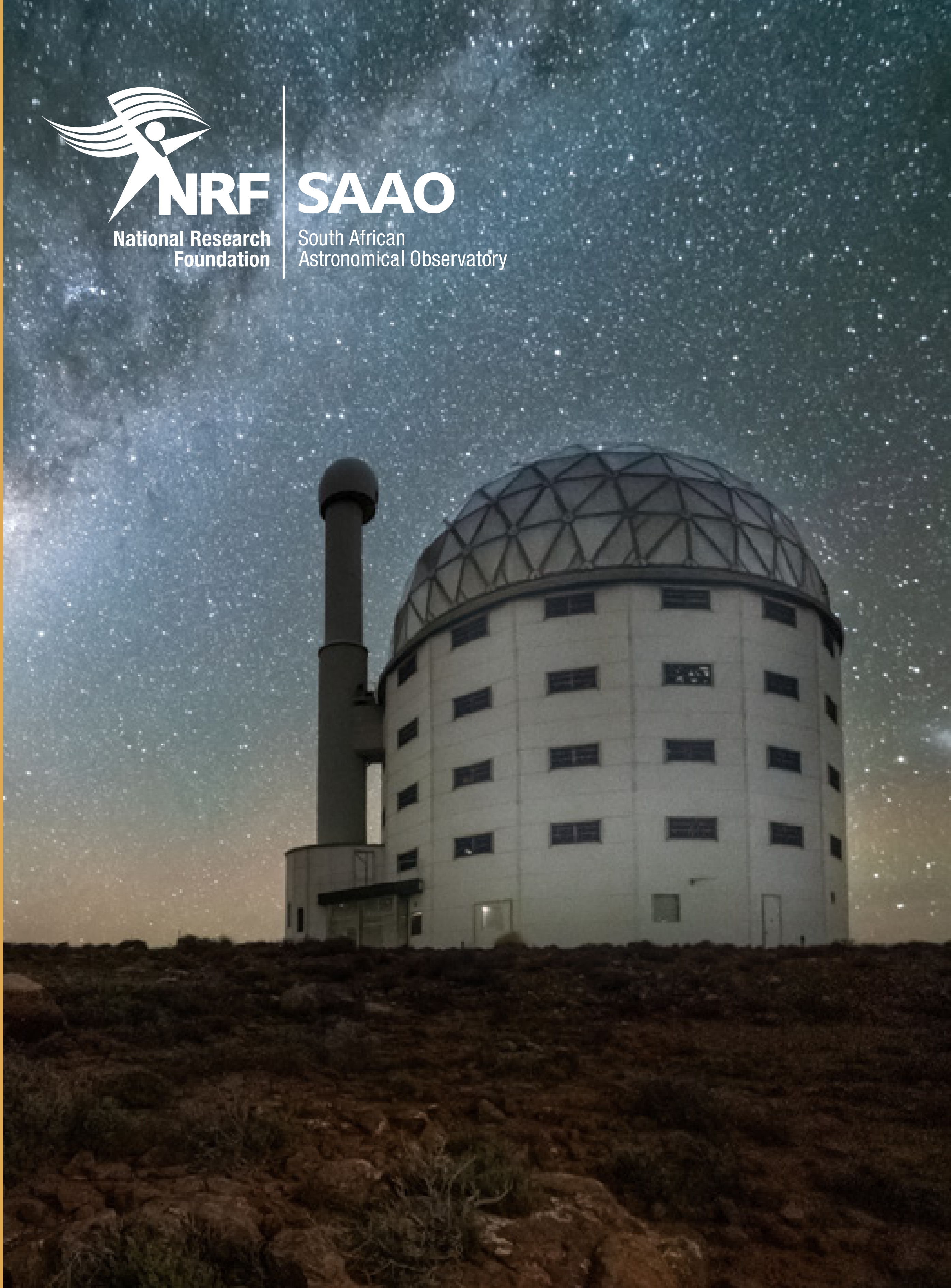
NRF
National Research Foundation

SAAO
South African Astronomical Observatory



# SAAO ANNUAL REVIEW
## 2021 | 2022

## SOUTH AFRICAN ASTRONOMICAL OBSERVATORY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# ACRONYMS/ABBREVIATIONS

3D - Three Dimensional

ADASS - Astronomical Data Analysis Software and Systems Conference

AERAP - African-European Radio Astronomy Platform

AfAS - African Astronomical Society

AGN - Active Galactic Nucleus

ALMA - Atacama Large Millimeter/sub-millimeter Array

APA - African Planetarium Association

ASSAP - African Science Stars Awareness Publication

ATLAS - Asteroid Terrestrial-Impact Last Alert System

BCG - Brightest Cluster Galaxies

BiSON - Birmingham Solar Oscillations Network

BITDN - BRICS Intelligent Telescope and Data Network

BRICS - Brazil-Russia-India-China-South Africa

CAD - Computer-Aided Design

CCD - Charge-Coupled Device

CEO - Chief Executive Officer

CERN - European Council for Nuclear Research

CMOS/sCMOS (scientific) - Complementary Metal Oxide Semiconductors

CNC - Computer Numerically Controlled

CSIR - Council for Scientific and Industrial Research

DSI - Department of Science and Innovation

EDM - Electrical Discharge Machining

ESO - European Southern Observatory

FRD - Foundation for Research Development, later NRF

GA - General Assembly

HESS - High Energy Stereoscopic System

HMI - Human Machine Interface

HRS - High-Resolution Spectrograph

HST - Hubble Space Telescope

HWU - Heriot-Watt University

IAU - International Astronomical Union

IDSAC - IUCAA Digital Sampler Array Controller

IFU - Integral-Field Units

INAF - National Institute for Astrophysics, Italy

IO/AIO - (African) Intelligent Observatory

IRSF - InfraRed Survey Facility

IT - Information Technology

IUCAA - Inter-University Centre for Astronomy and Astrophysics

JWST - James Webb Space Telescope

KELT-South - Kilodegree Extremely Little Telescope

KMTNet - Korea Microlensing Telescope Network

LADUMA - Looking At the Distant Universe with the MeerKAT Array

LCO - Las Cumbres Observatory

LFC - Laser Frequency Comb

LIRGs - Luminous Infra-Red Galaxies

LJMU - Liverpool John Moores University

LMC - Large Magellanic Cloud

LSST - Large Synoptic Survey Telescope

MASTER - Mobile Astronomical System of the TElescope-Robots Network

MaxE - Maximum Efficiency spectrograph

MeerKAT - Karoo Array Telescope

MIT - Massachusetts Institute of Technology

MNRAS - Monthly Notices of the Royal Astronomical Society

MONET - MOnitoring NEtwork of Telescopes

MPE - Max Planck Institute for Extraterrestrial Physics

MSc - Masters of Science

MSU - Michigan State University

NAOJ - National Astronomical Observatory of Japan

NASA - National Aeronautics and Space Administration

NASSP - National Astrophysics and Space Science Program

NEO - Near-Earth Objects

NGC - New General Catalog

NGTS - Next-Generation Transit Survey

NIR - Near-Infrared

NRF - National Research Foundation

NSTF - National Science and Technology Forum

OAD - Office of Astronomy for Development

OGLE - Optical Gravitational Lensing Experiment

PAC - Postgraduate Advisory Committee

PhD - Doctor of Philosophy

PI - Principal Investigator

PRIME - PRime focus Infrared Microlensing Experiment

QE - Quantum Efficiency

ROS - Remote Observing Station

RSS - Robert Stobie Spectrograph

SAAO - South African Astronomical Observatory

SAASTA - South Africa Agency for Science and Technology Advancement

SALT - Southern African Large Telescope

SANSA - South African National Space Agency

SARAO - South African Radio Astronomy Observatory

SCBP - SALT Collateral Benefits Programme

SDSS - Sloan Digital Sky Survey

SDSU - San Diego State University Astronomy Department

SKA - Square Kilometre Array

SHOC - Sutherland High-speed Optical Camera

SIRIUS- Simultaneous 3-colour InfraRed Imager for Unbiased Survey

SMC - Small Magellanic Cloud

SMI - Slitmask IFU

SNR - Signal-to-Noise Ratio

SOFIA - Stratospheric Observatory for Infrared Astronomy

SpUpNIC - Spectrograph Upgrade Newly-Improved Cassegrain

SUNBIRD - SUperNovae and starBurst in the InfraReD

SuperWASP - Super Wide Angle Search for Planets

TESS - Transiting Exoplanet Survey Satellite

TNS - Transient Name Server

UCT - University of Cape Town

UK - United Kingdom

UM - University of Miami

USA/US - United States of America

UV - Ultraviolet

VIS - Visible

WALOP - Wide Area Linear Optical Polarimeters

WISE - Wide-field Infrared Survey Explorer

ZTF - Zwicky Transient Facility

# CONTENTS

# MESSAGE FROM **THE DIRECTOR**

The year in review, April 2021 to March 2022, constituted the second full year of living and working under the COVID-19 pandemic. And I am sure many of us feel that the period was exhausting, with all the uncertainties, the ups and the downs, the losses. And against that backdrop in particular, I am amazed by the achievements at the SAAO during the year. These achievements are a testament to the attitude and dedication of the SAAO and SALT staff, for which I am immensely proud of.

The Observatory indeed continued to operate, without missing a beat in our mission to "explore the universe for the inspiration and benefit of all". Observations continued efficiently, in large part remotely, though in-person observing in Sutherland was available during the year as well. Remote observing included operating SALT from other countries for the first time, as well as using our brand-new modern Remote Observing Room in Cape Town. The service we provide for the astronomical community was reflected in a record number of papers published using data from all the telescopes in Sutherland in this period.

Our own research output, as measured in refereed papers by staff and students, remained high as well, albeit somewhat lower than the pre-pandemic levels, potentially starting to reflect the effects of the abnormal research environment. Nevertheless, as you will see later in this Review, many exciting results have been produced, ranging from distant gamma-ray bursts, gravitational wave follow-up, and supermassive black holes and their host galaxies, to black holes and other exotic phenomena in our own galaxy, to discoveries inside of our own solar system, featuring various kinds of asteroids in particular. All this work was done with a wide range of facilities, including our own SAAO telescopes and SALT of course, but with other international ground- and space-based facilities too, highlighting the crucial importance of international collaboration in our discipline. And finally, members of staff were active in using state-of-the-art computational facilities as well, as a feature article on novel 3D simulations of dying stars highlights.

While the pandemic situation has adversely affected students' opportunities in experiencing a "normal" active research community atmosphere, e.g. in-person conference attendance and networking, we are very happy with the level of student supervision, their research projects, and the graduated students from SAAO. This research is featured in both the Students and the Science Highlights sections in this Review, and some of our students also recently described their exciting projects in a new online SAAO Quarterly Newsletter.

On the astronomical technology front, this period saw two totally new telescopes come to Sutherland: ATLAS and PRIME. The former is hunting for potentially hazardous near-Earth asteroids in collaboration with NASA, and the latter will be bringing new infrared observation capabilities to South Africa together with a Japanese and U.S. collaboration. Two new astronomical instruments we completed at SAAO: Sibonise gave us our widest field-of-view camera, with capabilities for breath-taking wide-field images of the universe, while our newest instrument, an imaging-spectrograph Mookodi, has already been fitted with software to perform automated spectroscopic observations, a first for SAAO. This latter aspect is crucial for the Intelligent Observatory initiative, which is at the core of our vision for the decade, as featured in its own article in this Review. Please turn to the Instrumentation Highlights section – the SAAO workshops and the new Fibre Lab have been remarkably busy with a multitude of high-tech projects.



On the science engagement front, the year was challenging due to tours and other events having to constantly adapt to the changing circumstances. Nevertheless, there was a hive of activity as you will see from the relevant section below, and new tools for remote and online outreach and participation were also developed. And we are also very happy that after a long break we were able to return to in-person Open Nights right at the end of this reporting period. Furthermore, a new Cape Town Visitors' Centre is nearing completion.

We celebrated the Office of Astronomy for Development (OAD), which is hosted by the SAAO, passing its international review with flying colours, and having the hosting contract signed between the International Astronomical Union (IAU) and the NRF/DSI, extending OAD presence at SAAO. This arrangement has excellent synergies, and has helped the development of professional astronomy on the African continent also, even though it is not the primary goal of the OAD at all. Regarding African astronomy, we also gladly agreed to host the offices of the African Astronomical Society (AfAS) on our grounds, and have facilitated its first science conferences and workshops, and its General Assembly recently. The SAAO eagerly supports development of astronomy around Africa, and we see ourselves as key players in the global networking of the community, especially important for us as we head toward the IAU General Assembly in Cape Town, in 2024.

It is people that make SAAO the dynamic place that it is. But the hardships of the year mentioned in the beginning have also led to emotional fatigue, I think. Hence, as I have said to the staff previously, it has been more important than ever to find coping mechanisms and balance in life, to draw (and to give also) positive strength from friends, family, community, and from personal relaxation etc.

At the time of writing this, we are again hopeful that the overall pandemic situation would be heading to the better, though other national and global challenges remain.

I wish the readers of this SAAO Annual Review all the best for this new year, and that you find strength for it. I also hope you find some inspiration from the wide range of activities reported herein, as we study, and tell about, the magnificent universe we live in.

**Petri Väisänen**

# MESSAGE FROM THE **DCEO NATIONAL RESEARCH INFRASTRUCTURE PLATFORMS**

The National Research Foundation's strategic vision is that knowledge and research lie at the epicentre of national development and can enable a better society through research.

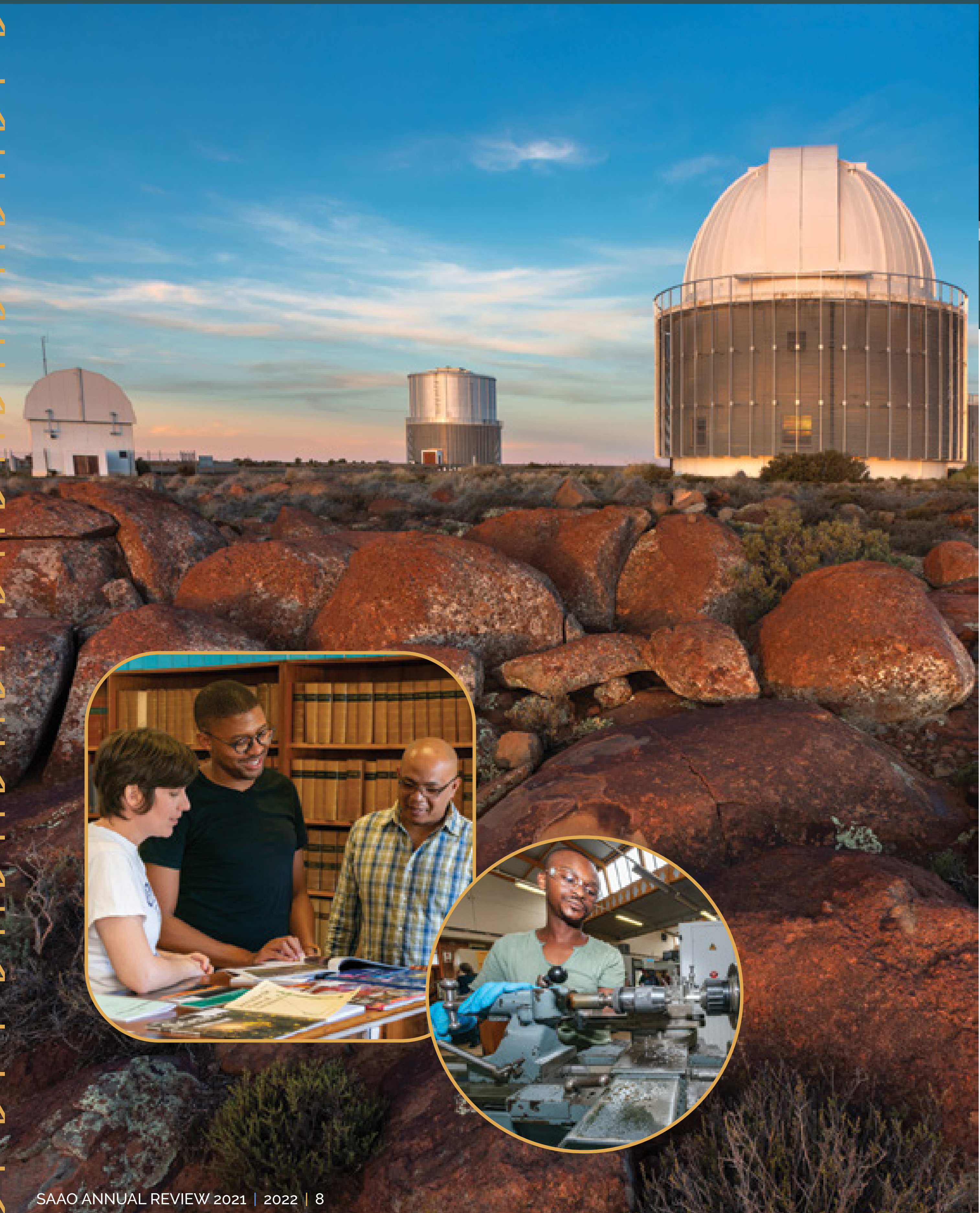
In spite of the myriad challenges faced over the past two years the National Research Foundation and the South African Astronomical Observatory continue to strive towards this vision. In addition to an array of achievements over the past year, the SAAO and SALT have implemented various Strategic Instrumentation Initiative (SII) projects aimed to make SAAO's flagship research platform, SALT, more attractive for new partners and provide an injection of funds and skills into instrumentation development.

These SII projects represent just a some of the exciting developments as the SAAO continues to be the premier optical and infrared astronomy facility in the country, and provide cutting edge research infrastructure for South African students and researchers.

**Clifford Nxomani**

NRF
National Research Foundation

# ABOUT THE **SAAO**





## Background

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).

It is the national centre for optical and infrared astronomy in South Africa. The SAAO is also the premier facility for optical astronomy on the African continent, and is the majority shareholder of (and responsible for) the operation of the Southern African Large Telescope (SALT), the largest optical telescope in the southern hemisphere.

The primary role of the SAAO is to provide modern, ground-based observational facilities for astronomers across the nation and the world, as well as to conduct world-class astronomical research through its own research staff.

The SAAO's headquarters are located in the 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 (then called the Royal Observatory Cape of Good Hope) was authorised. The Observatory is one of the oldest permanent structures in Cape Town and was declared a National Heritage Site in 2018. Some of the historical telescopes in Cape Town are still used for outreach and public events.

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.

Owing to light and air pollution in the city, research observations take place at the observing site 15 km from the small Karoo town of Sutherland in the Northern Cape, a four-hour drive from Cape Town. On a plateau, 1 800 metres above sea level and far from Cape Town's city lights, stand 24 telescopes of various sizes and forms, some owned by the SAAO and some hosted for international research institutes (see pages 19 - 22). The telescopes give astronomers in South Africa and all around 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.

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. The dissemination of research through publications and conference presentations spurs innovation across the nation and throughout the world.

The SAAO also supervises the education of numerous post-graduate students. Students trained at the SAAO are now leading researchers and educators throughout South Africa and across the African continent.

The SAAO also actively promotes astronomy and astrophysics in Southern Africa by sharing research findings and discoveries and participating in outreach activities to enthuse and engage citizens about physics and astronomy. It aims to sow the seeds of innovation in future generations of South Africans. The SAAO hosts the International Astronomical Union's (IAU) Office of Astronomy for Development (OAD), which coordinates projects across the globe to improve people's lives through astronomy.

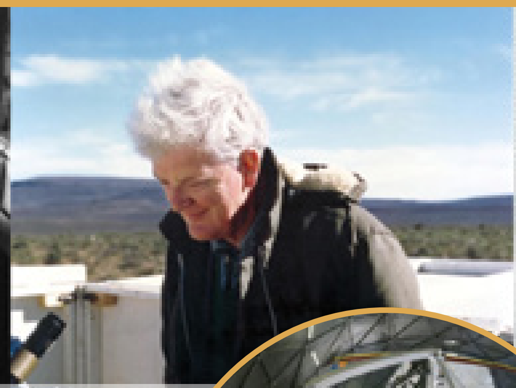
It also hosts the secretariat of the African Astronomical Society (AfAS).

AfAS

African Astronomical Society

***AfAS is a pan-African professional society of astronomers and is a not-for-profit company registered in South Africa. Its vision is to create and support a globally competitive and collaborative astronomy community in Africa. Its mission is to be the voice of astronomy in Africa and contribute to addressing the challenges faced by Africa through the promotion and advancement of astronomy. The key objective of AfAS is to develop astronomy and human capacity throughout the continent of Africa through a vibrant and active society. AfAS is currently funded mainly by the South African DSI.***





# 50 Years of the SAAO in Sutherland

## A Brief History of the SAAO

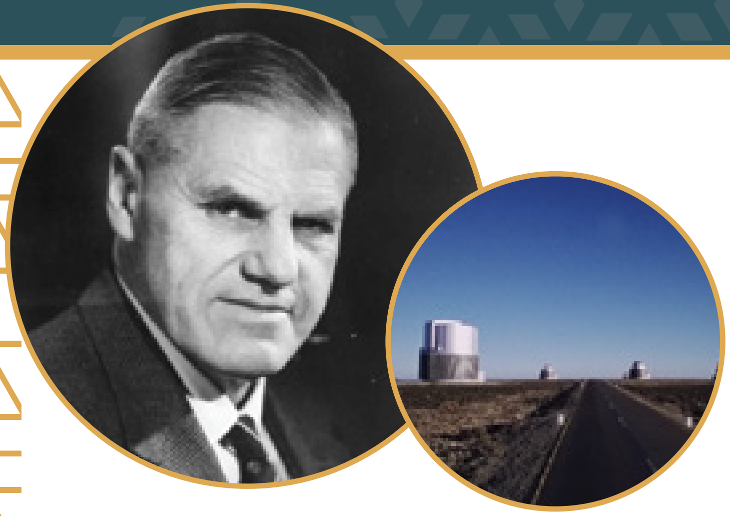
The SAAO was formed in 1972 by combining the Royal Observatory at the Cape, which was established over 150 years before, with the Republic Observatory in Johannesburg. This was a much needed new beginning for astronomy in South Africa. The main existing observatories were outdated. They had not kept pace with exciting developments in the field, such as new spectral regions, the arrival of more sensitive detectors, and the increased light grasp of telescopes. The skies above cities where the observatories were located were polluted and bright street lights prevented astronomers from observing faint objects in the night sky. Site testing had been carried out around the country to identify a more suitable location, but no project had come to fruition. In addition, the political situation in South Africa at the time discouraged foreign investment.

Nevertheless, it was accepted that conditions in South Africa were near ideal for viewing the sky and that the country had a natural advantage for astronomical science. Sir Richard Woolley, who had developed two major observatories, was appointed director of a new institution, supported by the South African Council for Scientific and Industrial Research (CSIR) and the United Kingdom (UK) Science Research Council. The existing British facilities in Cape Town and South African ones in Johannesburg were combined, and the more modern equipment was moved to a new site with clear skies near Sutherland, regarded as the logical place for a new observatory.

Even before the inauguration of the SAAO, the Sutherland Observatory was nearing completion, under the supervision of George Harding. He had been in charge of the Cape Observatory during its last few years. The new site was remote and had to be completely self-sufficient in terms of water and electricity. Roads, boreholes, a mini-generating station, workshops, and a library all had to be completed. Nine houses were constructed for staff. By mid-1972, the 0.5-m telescope was ready for use and the 1.0-m was completed by November. The Multiple Refractor Mount was installed a year later.

*George Harding, who initiated construction at Sutherland while "Officer in Charge" of the Royal Observatory Cape of Good Hope.*

Staff at the two original observatories were nearly all close to retirement and several new people were brought to the Cape. They carried on the traditional observations such as parallax photography, double stars, and fundamental positional observations. There were about 12 astronomers, plus administrative and technical staff.



## Sir Richard Woolley
### (Director 1972-1976)

Sir Richard's influence had begun to be felt even before he arrived in January 1972. He believed that an observatory should have a "scientific programme" under the control of the director. His interest at the time was in "classical" Galactic Structure, which led to an important long-term project for the SAAO, namely the study of Cepheid Variables. However, at the time, it was more common for individual scientists to conduct their own programmes. Those not in this category worked as assistants to the researchers. The era of large teams had not yet arrived and papers with just one or two authors were the norm.

Although Woolley was regarded as old-fashioned, he was surprisingly keen to adopt new techniques such as electronography and infrared in the new observatory. At the same time, Roy Edward Nather and Brian Warner joined a revived University of Cape Town (UCT) Astronomy Department and added another new technique, high-speed photometry, to the local instrumental complement. Though electronography did not turn out to be as useful as hoped, visible-region and infrared photometry soon became the main themes of work at SAAO and UCT. Anthony Patrick Fairall at UCT and Ian Glass began extra-galactic studies. Within a couple of years, research publications had increased greatly in number and a journal club was meeting weekly.

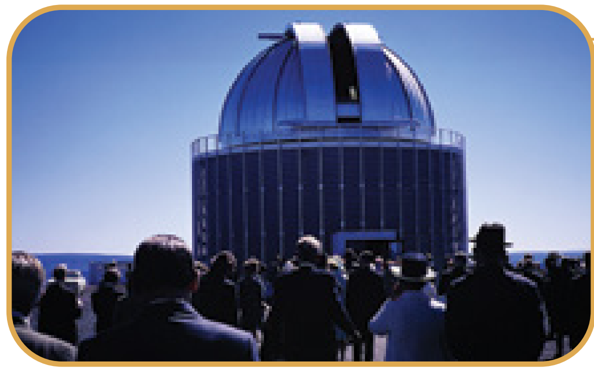
In 1973, the Sutherland Observatory was formally opened by the then Prime Minister, Balthazar Johannes "B. J." Vorster, and the British Secretary of State for Education and Science, Margaret Thatcher. This was followed by the first of several international conferences.

It was a very productive period as the southern sky was then virgin territory for the new techniques. The skies at Sutherland turned out to be of unusually high photometric quality, about 45 per cent of the time and were usable for spectroscopy somewhat more.

The planners of Sutherland were of the generation that had been brought up on photography, and as a result, the domes were well-equipped with dark rooms but lacked 'warm rooms' for electronics. This situation was soon remedied.

When the Radcliffe Observatory closed in 1974, the 1.9-m telescope was bought by the CSIR. With it came the image tube spectrograph that greatly extended the observing possibilities. They were ready to use in Sutherland by early 1976. Woolley had insisted on moving it "as is" to avoid delays, but an upgrade was clearly necessary. Its axes were encoded, new drives were installed, the dome rotation was automated, and an integrating television acquisition camera made locating faint objects much easier. These years saw the introduction of online instrument control with mini-computers and a gradual weaning away from punched cards and paper tape technology. There was, of course, no Internet and communication with the outside world was mainly by airmail, telex, and fax.

Observing was more hands-on than it is today and time was allocated for whole weeks. Astronomers left for Sutherland on a Monday morning and observed from Tuesday night until the following Monday morning. The addition of the 0.75-m telescope in 1974 and the 1.9-m telescope in 1976 led to the construction of the hostel.



*Pictures of Sutherland domes, taken on 15 March 1973.*

*Sutherland plateau in 1976 after the installation of the 1.9-m telescope.*

## Michael Feast
### (Director 1977-1991)

Michael Feast and several others joined the observatory towards the end of 1974 from the Radcliffe Observatory when it closed down. He was appointed director to succeed Woolley in 1977. He reorganised the Observatory to emphasise its research output and was strongly opposed to bureaucracy in all its forms. SAAO's international reputation was largely established during his directorship.

The first charge-coupled device (CCD) detector, one of several instruments contributed by UK institutes, appeared in 1982. This revolutionised imaging, with almost perfect quantum efficiency, far exceeding the earlier photoelectric devices and photography.

The UK, which had been contributing a third of the Observatory budget, withdrew in 1986, following which it became wholly South African owned and financed. However, outside observers continued to be welcomed, and the Observatory was able to maintain its international contacts.

In 1986, a new "technical building" with improved workshops and designing facilities was brought into use. Instruments had become more sophisticated and internal capacity for construction had to be improved. This freed up space for an auditorium and an instrument museum.

Infrared photometry of Mira variables was one of the main preoccupations of this period, following the discovery of a tight period-luminosity relationship by Ian Glass and Lloyd Evans. Extensive studies were made of Miras in the Milky Way and neighbouring galaxies.

The SAAO obtained some of the best observations of SN 1987A, the nearest supernova in several hundred years. This was a major programme of visual and infrared photometry and spectroscopy.

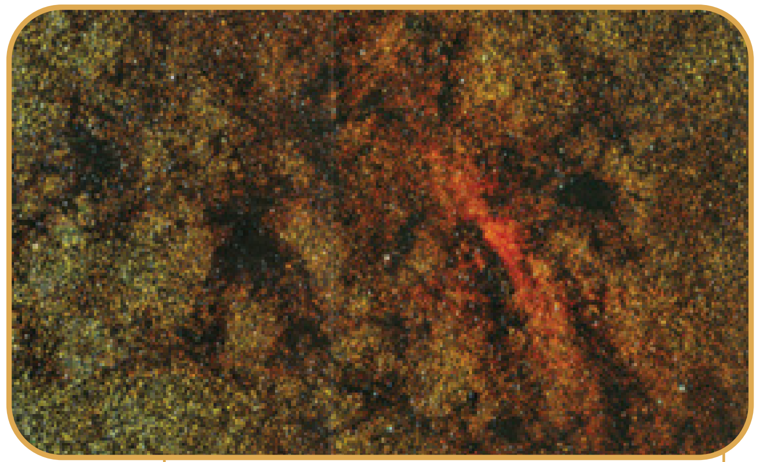
In 1988, the CSIR was reorganised and required to shed its pure science activities, the latter including the SAAO being hived off into the Foundation for Research Development (FRD), which later became the NRF.

It was becoming obvious by the late 1980s that the SAAO would have to obtain a larger telescope to remain competitive in research. However, progress had to await the arrival of a new director who was appointed specifically to address this issue.

*Sir Richard Woolley is director* · *Michael Feast is director* · *Robert S. Stobie is director* · *Philip A. Charles is director* · *Ted (TB) Williams is director* · *Petri Väisänen is director* · *Construction of SALT* · *Patricia A. Whitelock is director*

- 1820 – Royal Observatory established
- 1972 – The SAAO is formed
- 1973 – Sutherland Observatory opened
- 1974 – Radcliffe Observatory closes; 0.75-m added
- 1976 – 1.9-m added
- 1977
- 1982 – First CCD arrives in Sutherland
- 1986 – UK contribution to SAAO budget ends
- 1988 – The SAAO becomes part of the FRD, later the NRF
- 1991
- 1992
- 2000 – 1.4-m Infrared Survey Facility is completed
- 2002
- 2004
- 2005
- 2010 – SALT in full science operation
- 2011 – OAD is established
- 2013
- 2018 – Cape Town Observatory declared a National Heritage Site

*1.9-m telescope with infrared photometer and f/50 chopping secondary. Taken circa 1985. Photo by Robin Catchpole.*



*JHK false-colour image of the central 2 x 1 degrees of the Milky Way galaxy, taken with a specially designed scanning photometer in the 1980s. The dark cloud cores correlate with low-velocity 13-CO radio emission.*

## Robert S. Stobie (Director 1992-2002) and the SALT Project

Robert Stobie had previously worked in Edinburgh and, on appointment, was required by the SAAO Advisory Board to investigate building a clone of the ESO 3.5-m New Technology Telescope (NTT) telescope, as had been advocated in 1987 by Ian Glass. A full-scale engineering and cost study was carried out, but was not successful in getting the FRD and higher levels of government on board.

After the election of the democratic government in 1994, the Observatory began to receive proposals from other countries interested in establishing telescopes on the Sutherland site. Inside South Africa, it became much more involved in outreach activities and promoting public interest in scientific matters. It was no longer constrained by Apartheid laws in choice of personnel. Furthermore, more students from the black majority and formerly disadvantaged minorities began to study astronomy so that today, nearly 30 years later, the demographic distribution of the staff has become increasingly representative of the population as a whole.

A major addition to the telescopes at Sutherland was the 1.4-m Infrared Survey Facility, equipped with a three-colour JHK camera which was completed in 2000. This was a collaboration with Nagoya University and other institutes in Japan.

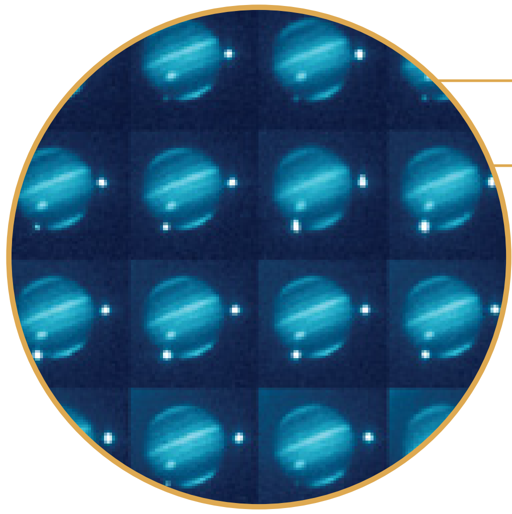
Around 1999, an offer was made to copy the Hobby-Eberly telescope of the University of Texas, a special-purpose spectroscopic instrument that offered a very large light collecting area at much less cost than a general purpose instrument. The consequent proposal was accepted by the Department of Arts, Science and Technology and financing of R50m was raised. A number of foreign countries agreed to contribute further to this project and a separate entity called SALT, managed by SAAO was set up. Construction took place between 2000-2005, with an official opening by President Thabo Mbeki. But problems, partly arising from an increase in design complexity, delayed full success until 2010.

The FRD was succeeded by the NRF in 1998.

Scientifically, Stobie's main contribution was the Edinburgh-Cape Blue Star survey which, inter alia, discovered a new class of variable stars, the sdB rapid pulsators.

Stobie died unexpectedly in 2002 and was succeeded temporarily by Patricia Ann Whitelock.





*Images of the Comet Shoemaker-Levy collision with Jupiter July 1994. 0.75-m telescope with PANIC infrared camera.*

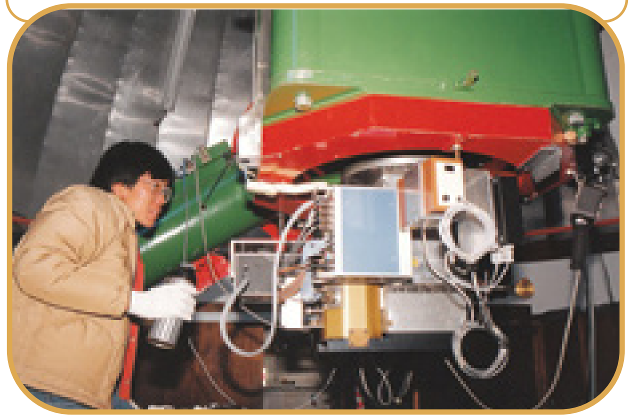
## Philip A. Charles (Director 2004-2011)

Charles came from a background in X-ray astronomy and his main task at first was to solve the problems associated with the SALT telescope. He was aided by Darragh O'Donoghue who had designed the upgrades to the original Texan design. The problems involved microscopic distortions of macroscopic optics near the prime focus and required some difficult engineering to diagnose and solve.

In 2011, the OAD of the IAU was established to implement its plan "Astronomy for the Developing World". The SAAO was selected as the headquarters of the organisation which funds astronomical projects in many countries.

Increasingly, small specialised automatic monitoring telescopes were being installed by various organisations at Sutherland.

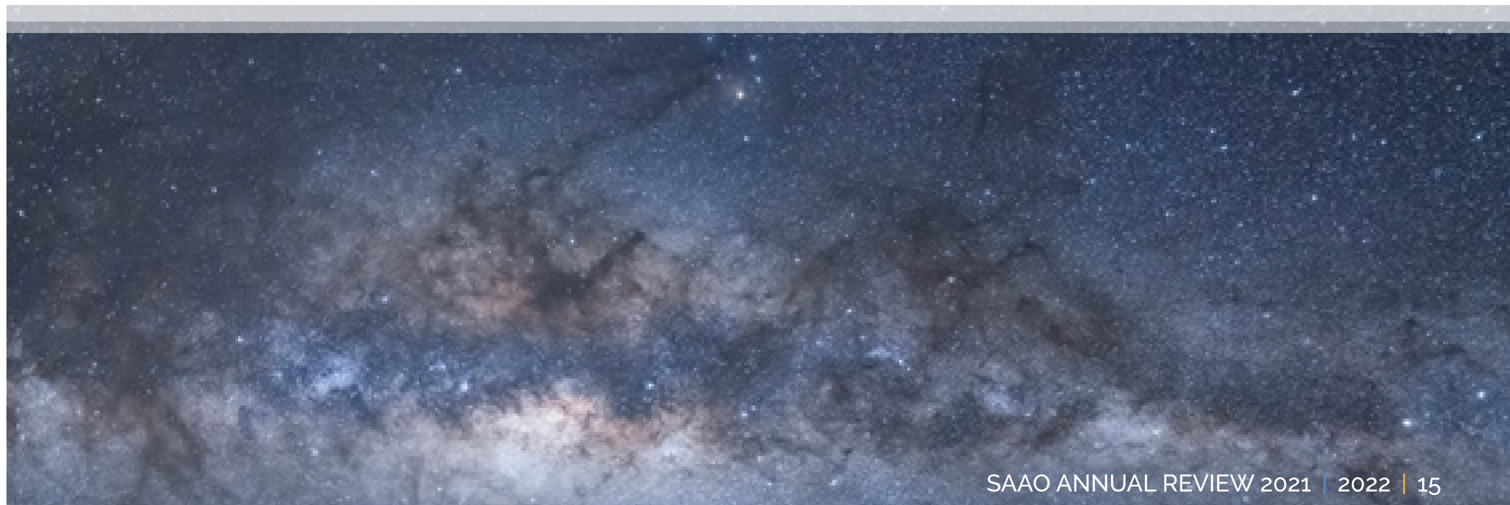
*Sekiguchi filling the "PANIC" infrared camera with liquid nitrogen. With the 0.75-m telescope at SAAO, 1994.*



## 2011 Onwards

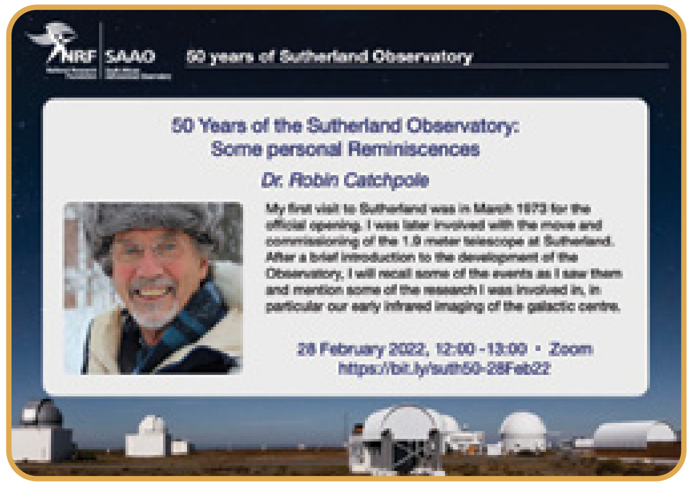
Charles was succeeded as Director by Patricia Ann Whitelock (2011-2013) and she in turn by Ted (TB) Williams (Director 2013-2017). Williams was a professor at Rutgers University in New Jersey before his appointment at SAAO. Among innovations during his period were the Lesedi 1.0-m automated Alt-Az telescope (2017) and the Meerlicht 60-cm wide-angle camera, designed to make CCD observations simultaneously with the MeerKAT radio telescope array. It was a collaboration with Radboud University (Netherlands) and certain other international observatories.

The current Director is Petri Väisänen (Director 2018+).



## 50 Years Celebrations

In celebration of 50 years of the observatory in Sutherland, the SAAO lined up a new history series of webinars with speakers from near and far, as well as current and former employees, talking about their time at the site. This included Robin Catchpole, who gave an account of his experiences, starting with his very first visit to Sutherland for the official opening in March 1973.





# Green SAAO

GREEN SAAO
South African Astronomical Observatory

Astronomy has always been about looking into the unknown and trying to understand humanity's place in the vast universe. Throughout the years, scientists have uncovered several facts that serve as constant reminders about the uniqueness of our planet. Astronomers truly recognise that there is no planet B and that climate change is an existential threat to all species on the planet. It is evident that human beings are accelerating global warming by emitting greenhouse gases, even to this day when alternatives exist.

Our fight for the planet can begin in our everyday lives by abolishing practices that worsen climate change. It starts with switching off lights when not required, recycling, composting, planting trees, and more.

Green SAAO was born out of the need to address the threat of climate change and the importance of astronomy's role in the fight for the planet. For this, the SAAO must first evaluate and adopt practices to curb our impact on the environment. As the SAAO continues to look out into the open skies, Green SAAO adds the promise of looking inward as a community, species, and planet. This is not a one-stop destination but an ongoing commitment in tandem with our scientific pursuits, and it requires dedication from all staff.

The organisation believes it is also its responsibility to effectively communicate the dangers of climate change and to push for global structural reforms, especially from the perspective of astronomy.



## What has Green SAAO been up to?

- Waste Management: Green SAAO will shortly put in place a complete waste management plan that will provide convenient recycling, composting, and even proper e-waste disposal solutions. After first introducing this in Cape Town, they will look for ways to implement the same in Sutherland.
- They are currently working to draft materials for climate change communication through astronomy outreach.
- They also plan to draft proposals for carbon footprint evaluation, fynbos restoration, and solar power generation in Cape Town.
- They have also introduced indoor recycling bins at several locations on site.

Green SAAO's Sriram Sankar thanks Petri Väisänen, Eugene Lakey, Glenda Snowball, Kevin Govender, Valencia Cloete, Daniel Cunnama, Sanchia Taylor, Ayanda Mgwatyu, and everyone else who has been extremely supportive of this movement.

*Community farm at the SAAO headquarters in Cape Town. It was set up as an experiment, and although it is not there anymore, it demonstrates what is possible for future Green SAAO projects.*

*Tree planting happening in various locations at the SAAO headquarters.*

*Recycling bins at the SAAO headquarters in Cape Town.*

*Recyclables drop-off.*

*Metal spoons have been placed in several kitchens to replace the plastic ones.*

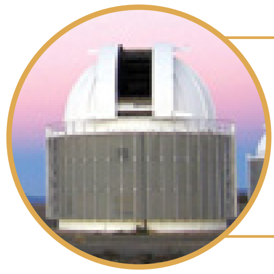
# TELESCOPE **OPERATIONS**

# Telescopes

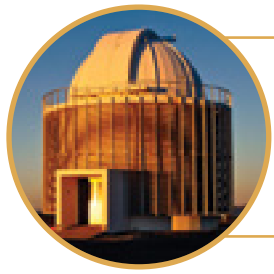
## SAAO Telescopes

Telescope: **SALT** (Southern African Large Telescope)
Size: 9 x 11 m
Instruments: Spectrographs (low and high resolution), CCD camera, Spectro-polarimeter
Start of science operations: 2011

Telescope: **1.9-metre**
Size: 1.9 m
Instruments: Spectrographs, CCD cameras, Polarimeter Spectrographs, CCD cameras, Polarimeter
Start of science operations: 1938-48



Telescope: **1.0-metre**
Size: 1.0 m
Instruments: CCD cameras
Start of science operations: 1964



Telescope: **Lesedi**
Size: 1.0 m
Instruments: Low-resolution imaging spectrograph; wide-field camera
Start of science operations: 2019

Telescope: **ACT** (Alan Cousins Telescope)
Size: 0.75 m
Instruments: Photometer
Start of science operations: 1999

Telescope: **DIMM**
Instruments: Sky monitor; part of SALT
Start of science operations: 1995

# Co-Owned Facilities

Telescope: **IRSF** (InfraRed Survey Facility)
Size: 1.4 m
Owner: Nagoya Univ, Kyoto Univ, NAOJ (Japan), and SAAO
Description: IRSF has been a fruitful collaboration between Japan and SAAO since 2000 and offers a near-infrared camera (SIRIUS) and polarimeter (SIRPOL).

Telescope: **MeerLICHT**
Size: 0.65 m
Owner: Six institutes in South Africa, the Netherlands and the United Kingdom
Description: MeerLICHT -- Dutch for 'MORE LIGHT' -- is fully robotic and aims to provide a simultaneous, optical view of the radio sky as observed by MeerKAT to help identify and classify transient events.

Telescope: **BiSON** (Birmingham Solar Oscillations Network)
Size: 0.5 m
Owner: Birmingham University (UK) and SAAO
Description: 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.

Telescope: **KELT-South** (Kilodegree Extremely Little Telescope)
Size: 4.2 cm / 7.1 cm telephoto lenses
Owner: Ohio State University, Vanderbilt University, Lehigh University, SAAO
Description: 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

Telescope: **KMTNet** (Korea Microlensing Telescope Network)
Size: 1.6 m
Owner: Korean Astronomy and Space Science Institute (KASI)
Description: 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.

Telescope: **MONET** (MOnitoring NEtwork of Telescopes)
Size: 1.2 m
Owner: University of Göttingen, Germany
Description: 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.



Telescope: **LCO** (Las Cumbres Observatory)
Size: 3 x 1.0 m and 1 x 0.4 m
Owner: Las Cumbres Observatory
Description: 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.

Telescope: **Solaris-1 and Solaris-2**
Size: 2 x 0.5 m
Owner: Poland
Description: 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.

Telescope: **OSR** (Optical Space Research)
Size: 0.5 m
Owner: SANSA (South African National Space Agency), DLR (the German Aerospace Centre)
Description: 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.

Telescope: **MASTER-SAAO** (Mobile Astronomical System of the TElescope-Robots Network)
Size: 2 x 0.4 m
Owner: MASTER-Net
Description: 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.

Telescope: **Xamidimura**
Size: 2 x 0.4 m
Owner: Keele University, UK
Description: Xamidimura (meaning "Eyes of the Lion") is a new installation in the enclosure formerly housing SuperWASP, dedicated to following up eclipsing binary discoveries.

Telescope: **ASAS-SN** (All-Sky Automated Survey for SuperNovae)
Size: 0.4 m
Owner: Las Cumbres Observatory, Ohio State University
Description: 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.

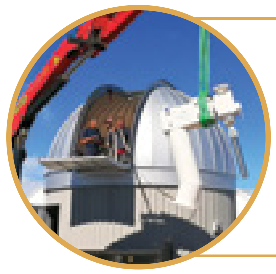
Telescope: **WFTC II**
Size: 2 x 0.5 m
Owner: Nagoya Univ, Kyoto Univ, NAOJ (National Astronomical Observatory of Japan)
Description: WFTC II is a special infrared telescope whose interior is under vacuum and cooled to cryogenic temperatures. It has not been used much in recent years. The roll-off roof building was named Sumi-hut for the Sumitomo Foundation that supplied funding.

Telescope: **bRing Project** (ß Pic b ring)
Size: 2 x 2.4 cm f/1.4 wide field lenses
Owner: University of Rochester, USA; NASA Jet Propulsion Laboratory; Leiden University, Netherlands
Description: 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.

Telescope: **ASTMON** (All-Sky Monitor)
Size: 2 fish-eye lenses
Owner:
Description: All-Sky Monitor; used to determine the sky brightness in magnitudes.

Telescope: **South African National Space Agency**
Owner: SANSA
Description: 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.

Telescope: **SAGOS** (South African Geodynamic Observatory Sutherland)
Owner: German Research Centre for Geosciences (GFZ)
Description: The SAGOS seismograph is a superconducting gravimeter providing continuous high-resolution monitoring of changes in the Earth's gravity field.



Telescope: **ATLAS-STH** (Asteroid Terrestrial-impact Last Alert System - Sutherland)
Size: 0.5 m
Owner: University of Hawaii Institute for Astronomy
Description: The Sutherland node of the four-telescope ATLAS system that surveys for hazardous near-Earth asteroids. The system also detects and reports many transient objects to the Transient Name Server (TNS).



# Telescope Operations Report

The SAAO telescopes continue to operate efficiently in a hybrid model of local and remote observing, with only 1.8% technical downtime on average per telescope over the year.

Operational protocols, software watchdogs and web interfaces have been developed to improve usability and safeguard the telescopes while in use remotely. The new Remote Observing Station (ROS, see page 50) on the Cape Town site, built to support the SAAO's Intelligent Observatory (IO) philosophy (see page 46), provides a well-equipped and convenient link to the telescopes and is now in frequent use by South African observers. International users are regularly observing remotely with Lesedi and the 1.0-m telescope from their institutes in the UK, with great success. Normality is beginning to return, with our first overseas observer since COVID-19 visiting to use the 1.9-m in December 2021, and a number of local users opting to observe from Sutherland.

There has been much activity on the plateau, with some fairly major developments – including the arrival of the Asteroid Terrestrial-impact Last Alert System (ATLAS) telescope (see page 24) and erection of the PRime focus Infrared Microlensing Experiment (PRIME) dome (see page 26) – in addition to the usual maintenance, support and repairs to the SAAO telescopes and hosted facilities.

The 1.0-m primary mirror was due for aluminising, but severe drought in Sutherland made the usual 24-hour running of water to cool the diffusion pump unconscionable. This led to the innovation of a closed-loop cooling system, repurposing old equipment and conserving the scarce water supply. The vacuum pressure achieved was better than in any previous instance, and the aluminising process was a resounding success. This system will be employed to conserve water during all future aluminising processes.

A number of upgrades have also been made to our telescope instruments (see section on Instrument Highlights, page 34).

Mookodi (meaning "rainbow" in Sesotho), a new low-resolution imaging spectrograph, was delivered by Liverpool John Moores University and mounted on Lesedi, our 1-m alt-az telescope (see page 43). Much of Lesedi's observing time in the latter part of the year was dedicated to testing and commissioning Mookodi, and developing software to incorporate it into the IO for robotic use. Mookodi replaces the Sutherland High-speed Optical Camera (SHOC), which was the first generation instrument on Lesedi. We received excellent feedback from users regarding the quality of photometric data produced by SHOC on Lesedi, and the ease of interacting with Lesedi's in-house, user-friendly, control interface. Six refereed papers using SHOC+Lesedi data obtained during the lockdown period were published in 2021, with several more submitted or in preparation. Mookodi is now permanently mounted on one of Lesedi's Nasmyth ports.

On the other port is Sibonise (meaning "show us" in isiXhosa), a wide-field camera developed at the SAAO. While work with the Inter-University Centre for Astronomy and Astrophysics (IUCAA) on the CCD controller is ongoing, some exquisite first-light images have been obtained with Sibonise on Lesedi.

# Telescope Highlights

## Asteroid Terrestrial-impact Last Alert System (ATLAS)

Led by locally appointed ATLAS-scientist and SAAO astronomer, Nicolas Erasmus, installation of a new ATLAS telescope in Sutherland, South Africa, took place in December 2021. The telescope is one of two new ATLAS telescopes, the other being at the El Sauce Observatory in Chile.

The system, operated by the group of Prof. John Tonry at the University of Hawaii Institute for Astronomy, already had two ATLAS telescopes in operation in Hawaii, but which only covered the northern hemisphere's night sky. These were developed under a 2013 grant from the National Aeronautics and Space Administration's (NASA) Near-Earth Objects Observations programme, now called the Planetary Defense Coordination Office. The two Hawaiin telescopes, on Haleakalā and Maunaloa, became fully operational in 2017.

The two new telescopes, built in Chile and in South Africa, will scan the southern hemisphere's night sky. The locations were selected for their access to the southern part of the sky, as well as their time zones which allow for night observation when it is daytime in Hawaii, and therefore 24-hour monitoring for potentially dangerous asteroids.

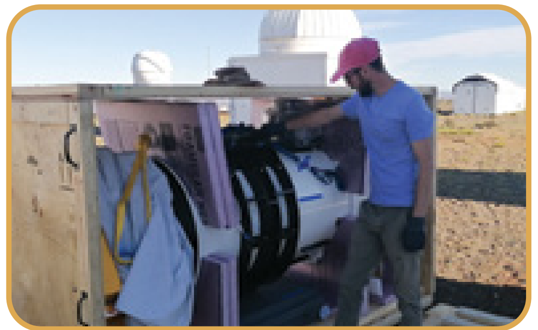
Initial installation of the telescope mount and tube assembly into the ATLAS dome in Sutherland took place in mid 2021. The final step, which included installing the primary mirror, Schmidt corrector lens, and CCD detector was planned for early December 2021. Despite a new COVID-19 variant at the time which hampered the Hawaiian ATLAS group to travel to South Africa, the installation went ahead, with the ATLAS team assisting SAAO staff remotely via Zoom from Hawaii. On 13 December, the telescope went on-sky for the first time and after testing that everything was functioning and doing a rough focus sweep, the team took the first-light image using ATLAS-Sutherland (ATLAS-STH). The telescope has since been operating fully robotically.

In January 2022, after the installation was completed by the SAAO's own instrumentation team, the Minister of Higher Education, Science and Innovation, Dr Blade Nzimande, said that he was delighted that ATLAS had expanded its reach to the southern hemisphere.

*Inspection and final balancing of the completed telescope by ATLAS Principal Investigator (PI), Prof. John Tonry.*

*Construction of the ATLAS telescope's dome building.*

*Installation of the primary mirror by SAAO staff Nicolas Erasmus and Willie Koorts.*



*Acceptance of telescope tube delivery by Nicolas Erasmus.*



The four-telescope ATLAS system is the first survey for hazardous asteroids capable of monitoring the entire dark sky every 24 hours. John Tonry, ATLAS PI and Professor at the University of Hawaii Institute for Astronomy, noted that an asteroid that hits the Earth can come at any time from any direction, so it is good to know that ATLAS is now surveying the whole sky, all the time. The modest-sized but state-of-the-art telescopes can capture an image of a section of the sky 100 times larger than the full moon in a single exposure.

The system is specially designed to detect objects that approach Earth closer than the distance to the Moon, which is about 240 000 km. It can provide one day's warning for a 10-m diameter asteroid, which would be capable of city-level destruction, and up to three weeks' warning for a 100-m diameter asteroid.

Despite some teething problems after its installation, by early February 2022 ATLAS-STH had already discovered two new near-Earth asteroids (2022 BK and 2022 BU4). It has also seen and reported many transient objects to the TNS, the first only two weeks after first-light (2021ahok). Two of those objects are "true southern discoveries", in other words not visible to the Hawaiian telescopes, at declinations of -72 and -58 (2022zj and 2022zi).

The additional spin-off of other astronomical transient discoveries that ATLAS-STH offers is also perfectly commensurate with the SAAO's flagship IO project that aims to modernise, fully robotise, and interconnect the diverse telescopes on our plateau in order to achieve rapid follow-up observations of all transients in the southern night sky.

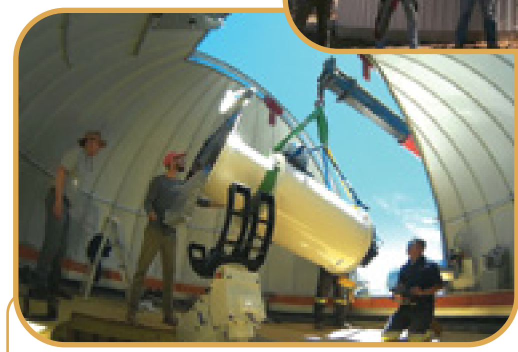
The southern discovery rate will improve once the reference sky-image has been refined with more observations. This image is required to see if anything in a specific new exposure has changed or moved, which could signify a potential asteroid or transient discovery.

Minister Nzimande said, "This is yet another achievement aligned to our vision of multiwavelength astronomy, which seeks to position Southern Africa as a preferred destination for scientific infrastructure and research. It also demonstrates once again that science and technology can facilitate foreign direct investment into the local economy. I am particularly pleased that the initial discussions on bringing this telescope to the country were directly initiated by our officials at the Department of Science and Innovation."

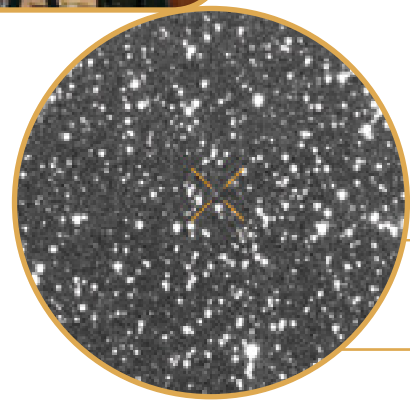
He added that these telescopes contribute to Africa's growing list of international instruments that are being hosted at South African astronomy research facilities.

*The Sutherland ATLAS station during construction in South Africa. Image credit: Willie Koorts/SAAO.*

*Left to right: Mr Takalani Nemaungani, Acting Chief Director: Astronomy, DSI. Dr Yonah Seleti, Acting Deputy Director-General: Research Development and Support, DSI. Dr Petri Vaisanen Director, SAAO.*



*SAAO staff installing ATLAS-STH. Left: Willie Koorts, Centre: Nicolas Erasmus, Right: crane operator. Image Credit: Willie Koorts/SAAO.*



*Images of the first ATLAS-STH near-Earth object (NEO) discovered: 2022 BK. Image Credit: ATLAS.*

# PRime focus Infrared Microlensing Experiment (PRIME)

PRIME, a 1.8-m telescope to be installed in Sutherland in 2022, will be used primarily to detect gravitational microlensing events at infrared wavelengths, in a bid to discover exoplanets, particularly Earth-mass systems.

The PRIME collaboration partners include the SAAO, the University of Osaka (where the PI, Professor Taka Sumi, is based), the Astro-Biology Centre of Tokyo, NASA's Goddard Space Flight Centre, and the University of Maryland.

The telescope was built by Nishimura Co. Ltd. in Japan, the same company that constructed SAAO's InfraRed Survey Facility (IRSF) telescope, as well as a similar size optical microlensing telescope, Microlensing Observations in Astrophysics (MOA), in New Zealand. Successful on-sky first light with PRIME was achieved at the factory on 21 September 2020.

PRIME's main instrument will be a wide field prime focus infrared (extending to the H-band) camera covering 1.25 degrees in diameter – a field of view six times the size of the Moon. It utilises flight spares of the infrared arrays used in the NASA Roman Space Telescope (formerly known as WFIRST) which is the same size as the Hubble Space Telescope but has a 100 times larger field of view and is due for launch by May 2027.

Apart from the camera, PRIME will also use a second instrument, a high-resolution fibre-fed infrared spectrograph based on a similar design for an instrument on the 8.2-m Subaru telescope in Hawaii, namely the Infrared Doppler instrument (IRD).

The telescope, spectrograph, dome, and plant equipment are being funded by the Japanese partners, while the United States (US) partners are contributing the camera.

The SAAO is responsible for the provision of the building and support services in return for an allocation of 14 per cent of the total telescope time for South African use and access to the survey data.

During the winter months, PRIME will be observing the central regions of our Milky Way – the bulge – in search of exoplanets, with the expectation of discovering about 12 per year.

For the rest of the year, it will be available for other programmes. The entire dataset obtained during the survey will be available for exploitation by the South African community, which is expected to provide many opportunities, particularly in the study of variable stars. In addition, there will be transient target-of-opportunity access as well.

The telescope building design work was completed in 2019. A site was selected on the western side of the Sutherland plateau, a position expected to be optimal in terms of minimising the effects of atmospheric "seeing", the image blurring caused by atmospheric turbulence. To mitigate seeing effects, the telescope is mounted on a pier five metres above ground level and also employs similar building design elements as those used in SALT, with a cylindrical steel ring wall consisting of insulation panels with ventilation louvres and an air conditioning system. Although the telescope was designed to have a control room, it will later be run remotely and eventually robotically, consistent with the SAAO's IO philosophy.

After various delays associated with the tendering process, some brought about by the COVID-19 pandemic, the construction company Eyethu Alpha Civils, based in Worcester, were awarded the construction contract. They have had previous successful contracts with the SAAO. On 26 October 2020, work began on the construction of the building to house the telescope.

Due to COVID-19, the suppliers were unable to travel to South Africa as planned to install the dome, so Willie Koorts of the SAAO led this effort, assisted by three people from Windmeul Engineering from Wellington.

The team travelled up to Sutherland on 24 May 2021. Every day during the erection and installation process, they conducted a Zoom meeting with the various PRIME stakeholders, including

David Buckley (SAAO PRIME Project Manager) and Nicolas Erasmus (SAAO), who together with Willie had experience with the ATLAS dome installation, Prof Taka Sumi, a representative from Nishimura, the local building contractor staff, and Riley Brannen from the supplier (Ash Dome).

Progress was hampered, however, when harsh winds during the night split the dome into three pieces. The next few days were spent doing damage control, leading to a setback in the schedule of about two days. When the team left Sutherland on day 12, they only had the electrical work left to do, before being ready for the dome lift.

On 17 June 2021, a 40-tonne crane was brought to Sutherland to do the dome lift. The dome was raised to fit some plates to the dome ring, and then progressively lowered, allowing the mounting bolts to be inserted.

Following this, various other elements needed to be mounted, connected, and tested, including the two dome drive motors, as well as the control box. The rubber seal was installed all around the dome, and the gear rack was greased. By November 2021, all internal renovations and installations were complete, and the building had been inspected.

The official handover to SAAO from Gert Labuschagne, the Contracts Manager of the building contractor, Eyethu, took place on 2 December. David Buckley, as well as SAAO Managing Director Petri Väisänen, and Piet Coetzee from the company Qunu (who did the building design and provided engineering oversight for the duration of the construction) were present.

The telescope installation, however, was postponed due to the discovery of the Omicron variant of COVID-19 in South Africa. The likely earliest date for the telescope installation is now July 2022. The telescope company, Nishimura, and Osaka University are expected to be visiting Sutherland. This will be followed by telescope commissioning.

The prime focus camera for PRIME is under construction at NASA Goddard Space Flight Centre and is expected to arrive later in 2022. The fibre-fed high-resolution spectrograph, to be situated in the instrument room, is under development at the Astro Biology Centre in Tokyo and is expected to be shipped towards the end of 2022 or early 2023.

PRIME represents a great advance in infrared capabilities at the SAAO, which is currently limited to the 1.4-m IRSF telescope, completed 20 years ago. The telescope, with its wide-field near-infrared camera, will open a whole new horizon for survey and time-domain studies in the infrared, and is a unique southern hemisphere facility, with the potential to work synergistically with IRSF and the new infrared spectrograph on SALT.

# INSTRUMENTATION

Nicolas Erasmus standing in front of the mounted QHY, with Lesedi open.



# The SAAO Instrument Workshop

An inescapable requirement for all astronomical and scientific instrument development is the evolution of an idea and concept into a design and then finally a material article that meets very exacting precision and tolerance demands.

A facility exists at the SAAO headquarters in Cape Town able to produce components and instruments to a precision not easily met with conventional manufacturing techniques.

The SAAO machine shop has unique facilities for electrical discharge machining (EDM), both with plunge and wire techniques. This is a process of using electrical sparks to erode material with very high precision. In addition, its unique value proposition includes computer numerically controlled (CNC) mills, lathes, etc., including a precision measurement arm able to verify the dimensional accuracy of components to two micrometres.

*Figure 1. Machine operator at one of the two 5-axis CNC milling machines.*

The SAAO workshop has also been manufacturing a range of incredible components in support of scientific and research endeavours, both within the NRF family of units, and globally. Our international collaborators include the IUCAA, the European Council for Nuclear Research (CERN), the Square Kilometre Array Observatory (SKAO), and iThemba Labs.

## Integral-Field Units (IFU) Components

Over the past year, the slit-mask IFUs for the SALT Robert-Stobie Spectrograph (RSS) have continued to move forward in the fibre-optics lab. The scientific motivation for these instruments are described on pages 41 - 42 in the Instruments Highlights. Here, we highlight the mechanical gems produced by the SAAO workshop that provide the opto-mechanical support for the SALT IFUs. We also illustrate the innovative 3D printing used in the fibre lab to develop and test a method to wrap and precisely position hundreds of fibres within the 100 x 100 x 8 mm cassettes that hold the IFUs. These cassettes will be housed in the RSS mask-exchanger and will be selectable by the telescope operator.

## Micro-optics for integral-field spectroscopy

Micro-optics are the forefront of advances in astronomical instrumentation, particularly in the field of imaging (integral-field) spectroscopy. Using EDM, both with plunge and wire techniques, the workshop team is able to produce high-precision micro-mechanics that are ideal for the mounting of fibre-optics, micro-lens arrays, as well as fixtures and mounts for compact, high-performance electronics used in remote sensing at low-light levels.

We give four examples of development over the past year in developing precision micro-optic apertures for one and two-dimensional arrays, mounts, and fabrication assemblies. These developments were guided by the design and construction of the slit-mask IFUs for SALT.

## 1. Precision fibre-optic 2D apertures

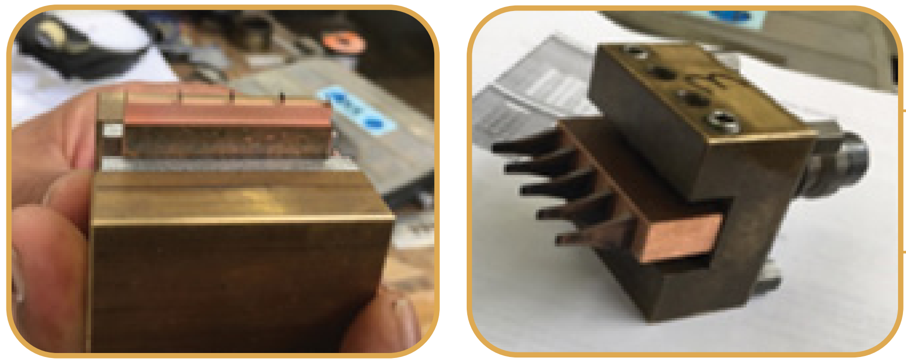
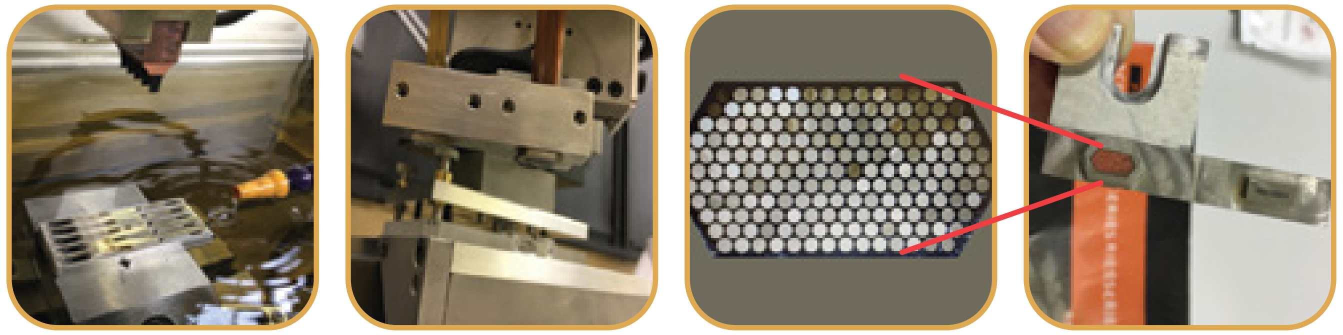


*Figure 2. Plunge-EDM electrodes for fabricating a test-piece (next figure) to determine aperture tolerances for holding fibre-optic arrays (IFUs).*

Arranging fibres into evenly-spaced arrays requires forming tapered apertures with hexagonal forms. Such apertures are not possible to fabricate with conventional milling machines. Instead, we use an EDM process. In figure 2, we show the copper 'positives' that have been precision-cut to form complex surfaces. With spark-erosion in the EDM process, these positives are used to create apertures (negatives) with the same tapered, hexagonal walls. These are first-of-their-kind in terms of overall scale, precision, and angular taper. They are also the first examples of elongated hexagonal shapes for IFUs in astronomical instruments. The left image shows a set of five 'small aperture' electrodes, while the right image shows different views of five 'large aperture' electrodes. Each of the electrodes in the group of five have slightly different dimensions, varying in width and length by 10-20 microns (about half to a fifth the thickness of a human hair). This range of sizes is used to determine, empirically, our fabrication tolerances for smooth fibre insertion and accurate fibre spacing.

Figure 3 illustrates the process of testing these apertures to accurately and precisely arrange our fibres, as described in the caption. The end product in this testing phase is a prototype fibre IFU. This completed the research and design (R&D) and proof of concept.

Figure 4 illustrates the final article with the IFU apertures that will be used on SALT. At the time of writing, these have been populated with fibres and are undergoing polishing.



PLUNGE EDM | FIBRE POLISHING | FIBRE IFU TEST ARTICLE ZOOM | FIBRE IFU TEST ARTICLE

*Figure 3. Testing the EDM process: Going clockwise from the top-left, a) the steel test-piece to determine aperture tolerances for holding fibre-optic arrays (IFUs) is shown in the plunge-EDM chamber. The copper 'teeth' illustrated in Figure 2 are shown here 'cutting' different sets of apertures of slightly different sizes. These are the positive (inverse) electrodes of the tapered hexagonal apertures being formed in the steel. This test-piece was used successfully to determine the aperture tolerances in this R&D process. The best aperture was cut out of the block, and then, b) in the fibre-optic lab, it was test-fit with short lengths of fibre and roughly polished (top-right) to verify c) and d) packing regularity (bottom right and left). The non-uniform fibre illumination is due to the unfinished back ends of the fibres (not seen in the images).*



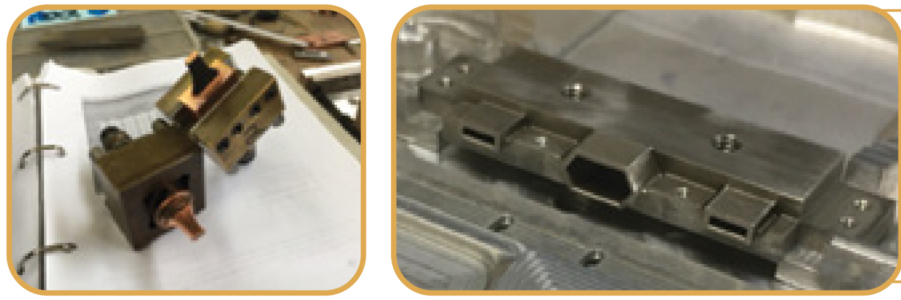


*Figure 4. At left are the final set of 'positive' electrodes for the 'large aperture' IFU mounts for the SALT slit-mask IFU. The final article, made in stainless steel is at the right, shown in a test-fit inside the cassette that will hold the IFU, before inserting fibre-optics.*

## 2. Precision fibre-optic linear arrays:

The light transmitted by the fibre optics in the IFU is fed into the RSS spectrograph after re-arranging the fibres into a line to form what is referred to as a fibre pseudo-slit. To accurately array the fibres evenly spaced in a line requires seating them in precision V-grooves that are machined with a wire-EDM process.

In addition to making V-groove blocks for the RSS-NIR (Near-Infrared) spectrograph slit for SALT, the SAAO shop has made super high-precision apertures for the slit-mask IFU fibres that guide them into a channel and pack them to within 2-3 microns of a perfect array. These are illustrated in Figure 5.

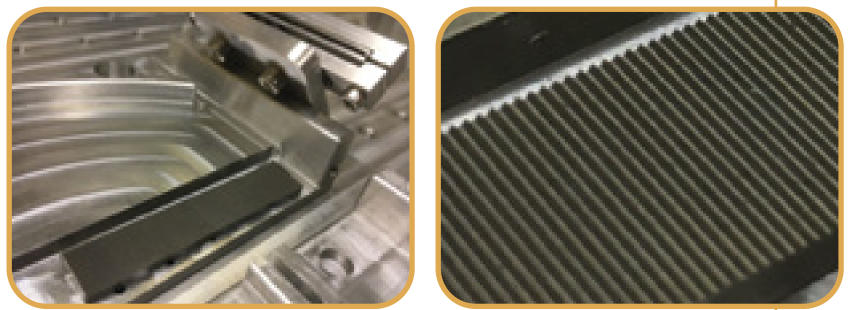


*Figure 5. A 50 mm V-groove array made in SAAO shop with a wire-EDM process (100um wire). A blow-up is on the right, showing the ultra-high precision V-grooves spaced at about ⅓ of a mm. A single fibre will lie (like a pipe) in each V-groove, with the full set of 120 fibres held in place with a lid and epoxy. The image at left shows the V-groove in the folding assembly cassette (see next section). In the upper right of the image is a second V-groove and lid placed in an assembly mount.*

## 3. Precision opto-mechanical mounts:

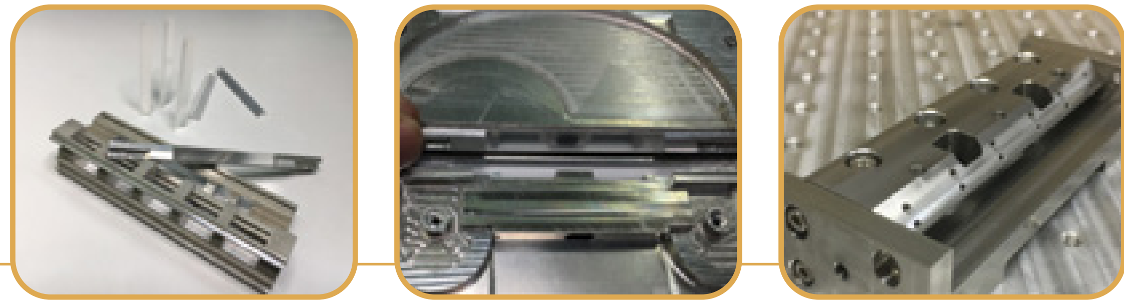


*Figure 6. (Left): Plexiglass replicas of fused-silica fold-prisms, aluminium prism mount test-article and prototype alignment jig. (Middle): Plexiglass fold-prism in a test-mount, held where it will be located in the IFU cassette. (Right): Final alignment jig to position fold-prisms during bonding. These are all custom parts designed in the fibre lab and fabricated in the SAAO shop.*

In Figure 6 are images of plexiglass replicas of custom-made fused-silica fold-prisms that will redirect images from SALT's focal plane onto the fibre IFUs for RSS. One of the replicas has been press-fit into a precision mount for testing assembly and gluing procedures. It is resting on two halves of a gluing and alignment fixture. These prototypes were designed in-house and exquisitely rendered out of aluminium in the SAAO shop. The final articles will be stainless steel.

## 4. Micro-optic assembly: from 3D plastic printing to cutting precision metal parts

This is a practical way to do research and design. The path forward in the development of state-of-the-art instrumentation in astronomy couples prototyping with 3D printers, and final fabrication of metal components with precision CNC and EDM machining.

Illustrated in Figure 7 (left) is a prototype assembly for routing fibre optics (brown strands in yellow tube) in a folding cassette (back plastic). This assembly is designed to hold the fibres while they are optically cemented into location, and then folded so their ends can be polished to sub-micron smoothness. The final assembly (right) inserts into a magazine that feeds light from SALT into the RSS in place of a long-slit assembly; it will deliver the first integral field spectroscopic capabilities to the Sutherland plateau, and in fact, all of Africa. The black plastic components were 3D printed in the fibre-optics lab, and once their design and performance were demonstrated, they were then fabricated at very high precision in the SAAO shop (middle) in aluminium, since the plastic is not rigid or strong enough for the required tolerances. Note the V-groove and V-groove mount, described in the previous section.

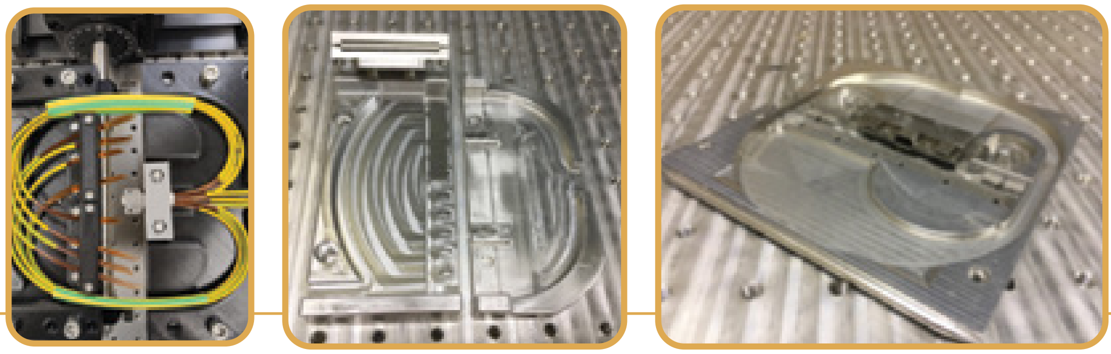


*Figure 7. The 3D printed prototype folding cassette is shown at the left. Once the design was proven, it was machined out of aluminium (middle). The final slit-mask IFU cassette (not yet populated) is at the right.*

## Cryostats for Imaging Detectors

A cryostat is a body which houses the CCD detector in an optimal environment to maximise the efficiency of the detector and therefore the light capturing ability. This environment is typically at cryogenic temperatures (approximately 160 Kelvin), which requires that the housing is kept under vacuum.

The workshop has manufactured a variety of cryostats for a number of detectors in operation on a multitude of telescopes at the SAAO and SALT.

The manufacture of these units is particularly specialised given the demanding mechanical dimensional constraints for optical alignment of the CCD chip, in addition to the vacuum considerations.

*Figure 8. Cryostat which has been installed on the Lesedi telescope.*



## Wide Area Linear Optical Polarimeters (WALOP)

The cameras on imaging systems like those required for the WALOP instrument need precision-machined mechanical mounts for the delicate optical elements. The precision and accuracy obtained is within five micrometres of ideal.

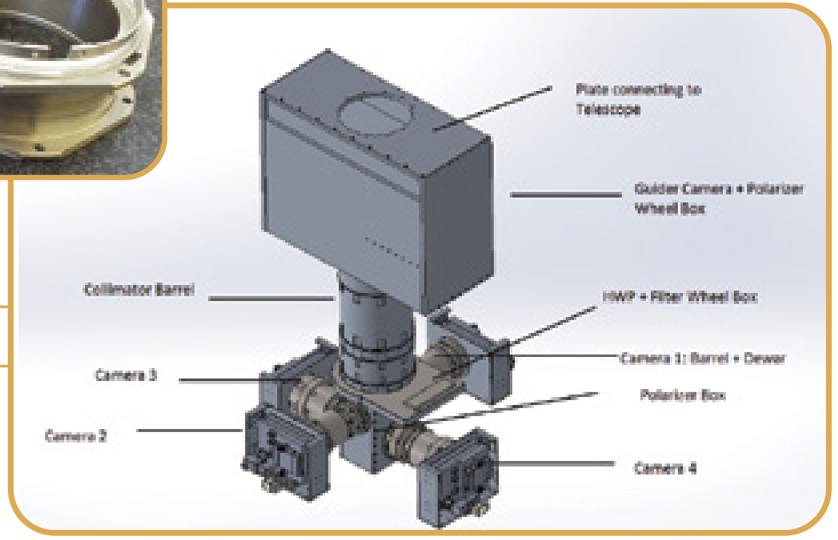



*Figure 9. This instrument will be installed on the 40-inch telescope in Sutherland.*

*Figure 10. Optical lens holders, WALOP.*

## Other Components

*Figure 11. Optical cell, SALT. This will hold lenses fitting on SALT's RSS.*

*Figure 12. Radiation shields, iThemba LABS. This shows the in-process manufacture of vial holders which are used to hold radioisotopes inside radiation shields. These isotopes will be used for treating cancer patients.*

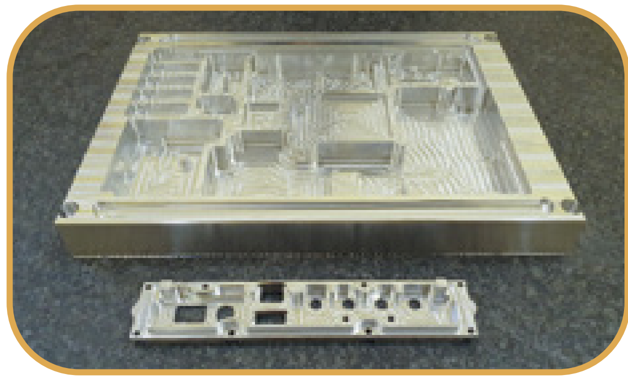


*Figure 13. Electronics enclosure, manufactured at the South African Radio Astronomy Observatory (SARAO). It is crucial that any radio frequency (RF) created by the electronics does not leak out.*

# Instruments Highlights

## A Laser Frequency Comb (LFC) for SALT's High-Resolution Spectrograph (HRS)

With a memorandum of understanding in place between SALT and Heriot-Watt University (HWU) by July 2021, the design work for the LFC began and certain items with long lead times were ordered. The full contract for the comb development was signed in January 2022 and the official kick-off meeting for this project took place on 1 March 2022. Since then, numerous local and international orders have been placed to acquire the multitude of components that will ultimately make up this new precision wavelength calibration device for SALT's HRS.

The Class IV Titanium-Sapphire femtosecond laser that will form the heart of the comb had a 16-week lead time and so it was ordered first. It arrived at SAAO at the end of 2021 and is awaiting testing in the laboratory in Cape Town. Unfortunately, the chiller unit for the laser cooling system has a leak and the team have not yet been able to use the 2000 mW, 800 nm laser. But they will do so once the spare parts for the chiller arrive from overseas. Some of the other major electronics modules have also already been delivered and their performance was verified in February.

The team is eager to recruit a local PhD student for the project, since this will be an excellent opportunity to participate in the development of a state-of-the-art instrument. The danger with instrumentation projects is often the relatively unpredictable timeframes involved. However, the schedule for the HRS LFC is very well defined at this stage (with assembly set to take place in early 2023) and so they feel confident that it will be a sound option for a suitable student. The candidate will get to spend time in the laser labs at HWU to learn about the comb technology, before participating in the integration, testing and commissioning of the LFC at SALT. After that, the focus will shift towards applying the LFC in support of exoplanet research, a field that SALT is keen to contribute to going forward.

*Figure 1. The 800 nm Ti:Sapphire femtosecond pulsed laser system that will drive the LFC.*

*Figure 2. Assorted LFC components that were delivered to SAAO in late December 2021.*



## The Era of Complementary Metal Oxide Semiconductors (CMOS) has Arrived

In 2021, the SAAO purchased its first scientific CMOS (or scientific CMOS, sCMOS) camera, a technology that is becoming increasingly popular in the world of astronomy.

CMOS sensors are an alternative to traditional CCD image sensors, which astronomers have been using for decades for imaging the night sky. While CMOS technology has been around since the 1980s, it has not been favoured by astronomers. This is partly because, up until recently, the quantum efficiency (QE) of CMOS sensors, which is how efficiently the sensor converts light into a detectable signal, has not been able to compete with CCDs. It was also less efficient in terms of the noise, which determines how well one can identify very weak signals from the background.

However, some of the strengths of CMOS cameras include that they are less expensive to manufacture and the capturing rate can be incredibly rapid because of the way the chips are "read out". This read-out can be fast even for large chips with many pixels, which is not the case for CCDs. Therefore, this is an attractive option for high time-resolution astronomy, which is one of the SAAO's specialities.

Very recent advances in the field of sCMOS technology mean that the QE can match that of current astronomical CCDs. The SAAO's new QHY600M sCMOS camera that was purchased from the company QHYCCD, has a QE almost identical to their Andor iXon "SHOC" cameras, which are the CCDs used by many astronomers doing time-resolved science. The noise specification is slightly worse but comparable to that of the SHOC cameras. The read-out rate of this sCMOS model is also similar to that of SHOC at 2.5FPS (full-frame), but more impressive considering that the physical chip size has an area ~5 times that of SHOC and 60 times the number of pixels.

However, one disadvantage that even the new improved sCMOS sensors have is that the binning of pixels occurs after read-out and not before, like in CCDs. The result is that there is only a linear gain in signal-to-noise ratio (SNR) when binning, compared to a CCD where the gain in SNR is the square of the binning factor. Therefore these sCMOS cameras with their many and physically tiny pixels are currently better suited where no binning is the norm, for example low f-ratio telescopes squeezing large field-of-views onto a detector.

Over the December 2021 period, the SAAO did some laboratory tests on the CMOS camera, and the results confirmed the advertised specifications. As a result, it was decided to test the QHY sCMOS on a Sutherland telescope as quickly as possible. After some minor modification of the computer-aided design (CAD) model of the SHOC cameras' mounting interface, a 3D printed version of the modified CAD meant that the SAAO could rapidly develop a mounting interface for the QHY on the same port that SHOC mounts onto the Lesedi telescope. The subsequent on-sky test was also very promising and the SAAO has subsequently procured several sCMOS camera models from various manufacturers. These cameras are undergoing further laboratory testing and control software development for possible future implementation on our telescopes.

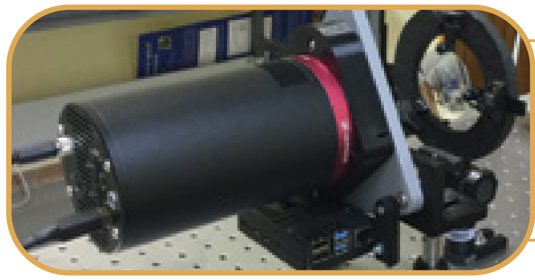


*Figure 1. QHY on a 3D printed mount-plate in the fibre lab.*

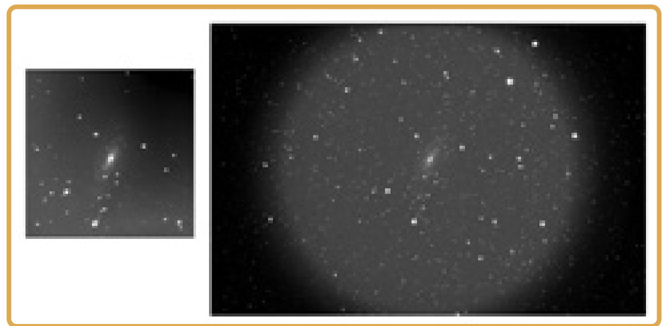


*Figure 2. Images taken of the spiral galaxy NGC2280 with SHOC (left) and the QHY (right). Both images are taken with the R-filter in the beam and 180 seconds of exposure. SHOC was binned at 1×1 (i.e., 0.335"/px). The image is 1024 pxs (5.72 arcmin). The QHY was binned at 4×4 (i.e., 0.388"/binned px) to match the on-sky plate-scale, and 1600 binned pxs (~10 arcmin). The QHY has much smaller pixels than SHOC). Vignetting is due to the 1-inch SHOC-exit port on Lesedi.*

# Robert Stobie Spectrograph (RSS) Dual Project
## - Maximum Efficiency spectrograph (MaxE)

The MaxE project aims to upgrade the current RSS instrument on SALT ("RSS VIS"). The upgrade involves adding an optical arm covering the red wavelengths (so-called "Red Arm"). Thus it forms an enhanced spectrograph, which simultaneously covers both visible (VIS) and red wavelengths, called "RSS Dual".

This will enhance the capability of the SALT telescope to perform transient identification spectroscopy and thus support the SAAO goals in transient science. The work involves the development of a fold mirror/dichroic mechanism which will enable dual and VIS mode selection, as well as a new red fold mirror, doublet, grating and camera, cryogenic detector, control electronics, and user interfacing software.

The MaxE team is currently working towards the preliminary design review, which is scheduled for later during 2022.

### Overview, Success, Challenges and Project Status

During the last year, the project made significant technical progress on the design, some of which will be described in more detail in this report.

A key achievement was the agreement with the science team on the system requirements. These are technical requirements derived from the stakeholder requirements (made up of the science, astronomy operations and technical operations requirements) which describe the RSS Dual in precise, technical language which engineers can use to design, build and verify the instrument.

On the science front, John Menzies assisted the project with a signal-to-noise simulator which simulates the integrated performance and also forms the basis of the observation planning tool which is to be developed later in the project. From May 2021, David Buckley assumed the role of PI on the project.

There was a delay of a few months in the project due to the resignation of Ockert Strydom in July 2021. Ockert was leading the designs for the opto-mechanical and overall structural design and progress in these areas had stalled when he left. From January to March, there have been a few key appointments to SALT and to the project, and the opto-mechanical design work is now well underway.

### Opto-Mechanics, Structure and Optics

An external review, with the aim of confirming readiness for optical blank procurement, was concluded favourably in November 2021. Following this review, there have been detailed discussions with suppliers as a final confirmation of manufacturability of the main optical elements by figuring vendors. This led to the orders for the blanks being placed during February. Figure 1 shows the optical layout of the Red doublet (left) and camera (right), and outlines the materials and dimensions of the optical elements to be figured from the blanks. The optical integration and alignment plan was matured, and it was confirmed that these lenses can be successfully mounted and aligned to within tolerances, given the opto-mechanical design shown in Figure 2.



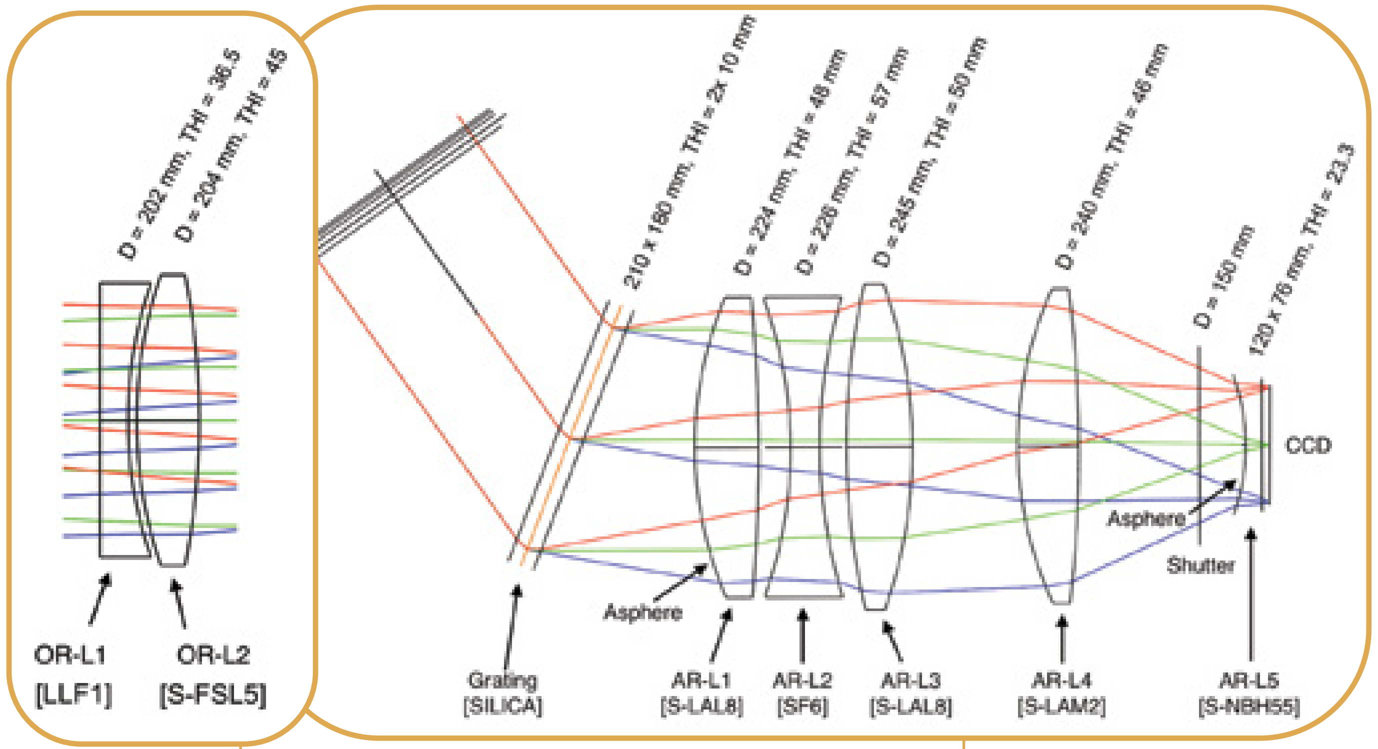



*Figure 1. Optical layout of the Red collimator doublet and camera.*

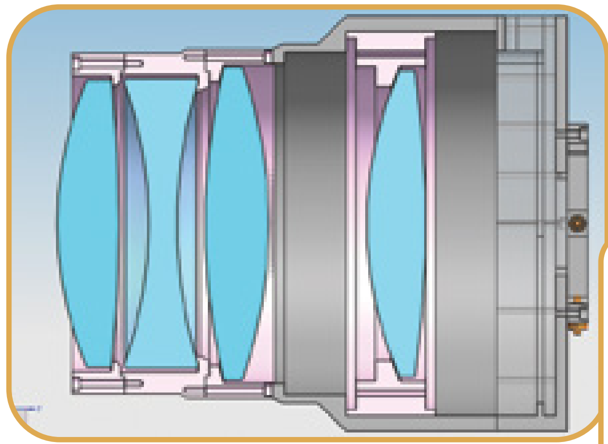


*Figure 2. Opto-mechanical layout of the camera.*

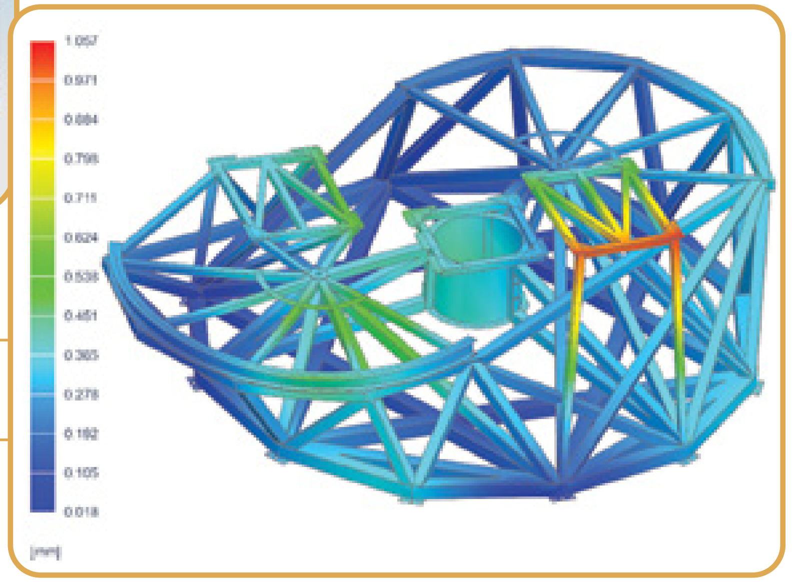


*Figure 3. Deformation plot of the RSS existing structure for rho = 0°*

Severin Azankpo from SARAO developed a finite-element model of the RSS structure and evaluated the expected deflection at various rho angles, in order to have a baseline against which to determine the effect of adding the Red Arm to the structure. With the delay in progressing the opto-mechanical and Red structure design, the finite element analysis was limited to the baseline "as-is" model until the Red structural design is further matured.

Figure 3 shows a deformation plot for rho = 0°. A plot like this lets one determine where the greatest deflection is experienced on the structure in this configuration. In the figure, note the platform which houses the VIS electronics cabinet on the right, reporting the maximum deflection of just over 1mm in this orientation. The analysis reports results at rho angles of 0°, 15°, 90°, 270°, and 345°. Results have been further processed to determine how the relative angle between various optical elements (e.g. the collimator barrel and the VIS camera barrel) changes through flexure as the rho angle changes. Once the Red Arm structure design is mature, the same results will be extracted to compare how the additional components influence this behaviour.

## Detector

The detectors for both the Red Arm as well as a new upgraded RSS VIS detector are being developed by the SAAO instrumentation team. The team has commissioned a test cryostat to house the large format 6k x 6k CCDs that are to be used in the RSS Red and upgraded VIS cryostats. This has enabled the test of various physical design concepts, as well as further development on the CCD controller integration on a representative electrical sample CCD at temperature, without having the final science cryostat design in place.

The detector cryostat design has been matured into close on final form, with practical commonalities between Red and VIS to reduce spares inventory and optimise on design effort. An assembly and alignment strategy has been determined to ensure the required tolerances are achieved on integration.

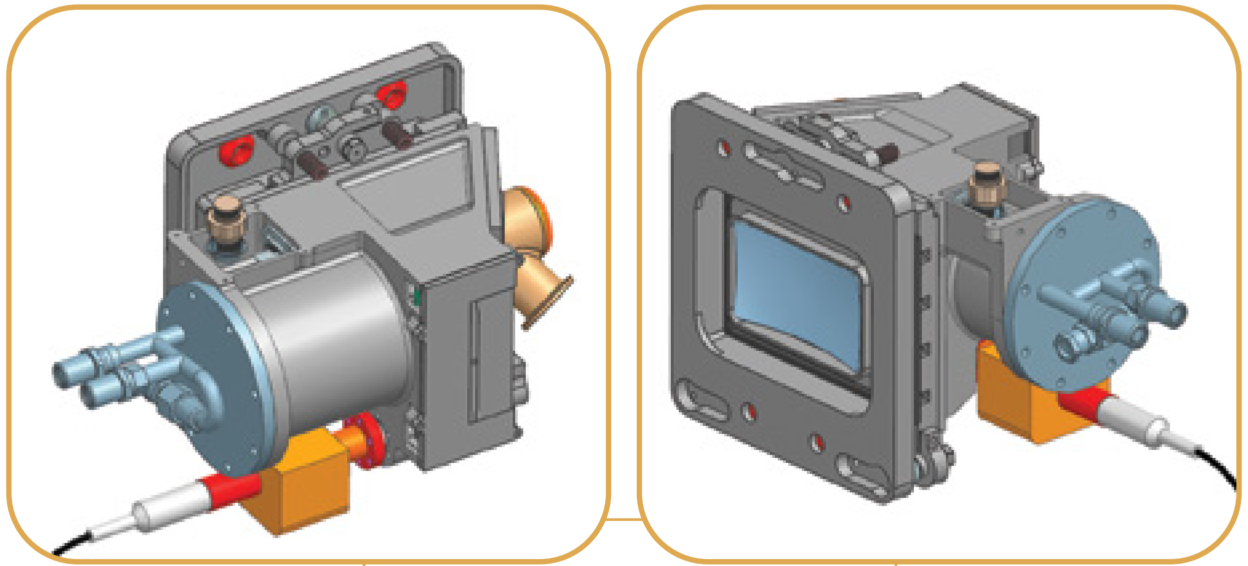


*Figure 4. Two views of the Red cryostat module.*

As the envisaged CCD controller (IDSAC - IUCAA Digital Sampler Array Controller, see https://arxiv.org/abs/1807.05528) functions are different to the San Diego State University Astronomy Department (SDSU) controllers that have been used on RSS to date, development of a new cryostat thermal control scheme using a programmable logic controller (PLC) was necessary. A number of options have been conceptualised and test versions have been developed to verify the suitability and performance of each.

Collaboration with the IDSAC developers is ongoing to determine the performance of the system with the intended large format CCDs. Field experience is being gained on the IDSAC performance during the commissioning of the Sibonise camera.



## Control System

The control subsystem design has made great strides since Dillon Klaasen joined the project team in March 2021. A key element of the control design is the RSS Human Machine Interface (HMI).

The RSS HMI (or operator interface) requires an upgrade to incorporate the RSS Dual functionality. For those familiar with the existing system, this upgrade will supersede the current PCON HMI being used. The MaxE team worked with the AstroOps team in designing the interface. The design is similar to the current PCON interface, but includes elements that will communicate with RedCON, the control system for the red portion of the MaxE instrument.

A summary of the different tabs of the HMI can be found at https://bit.ly/RSS_HMI, but shown in Figure 5 is a new summary that displays all the current settings for both VIS and Red. The "Get settings from TCS" button allows the user to populate the relevant fields with data from TCS instead of having to release control and the request control again.

In the case where there are differences between the current instrument settings and the fields displayed on the HMI, the HMI draws the user's attention by using a yellow background.

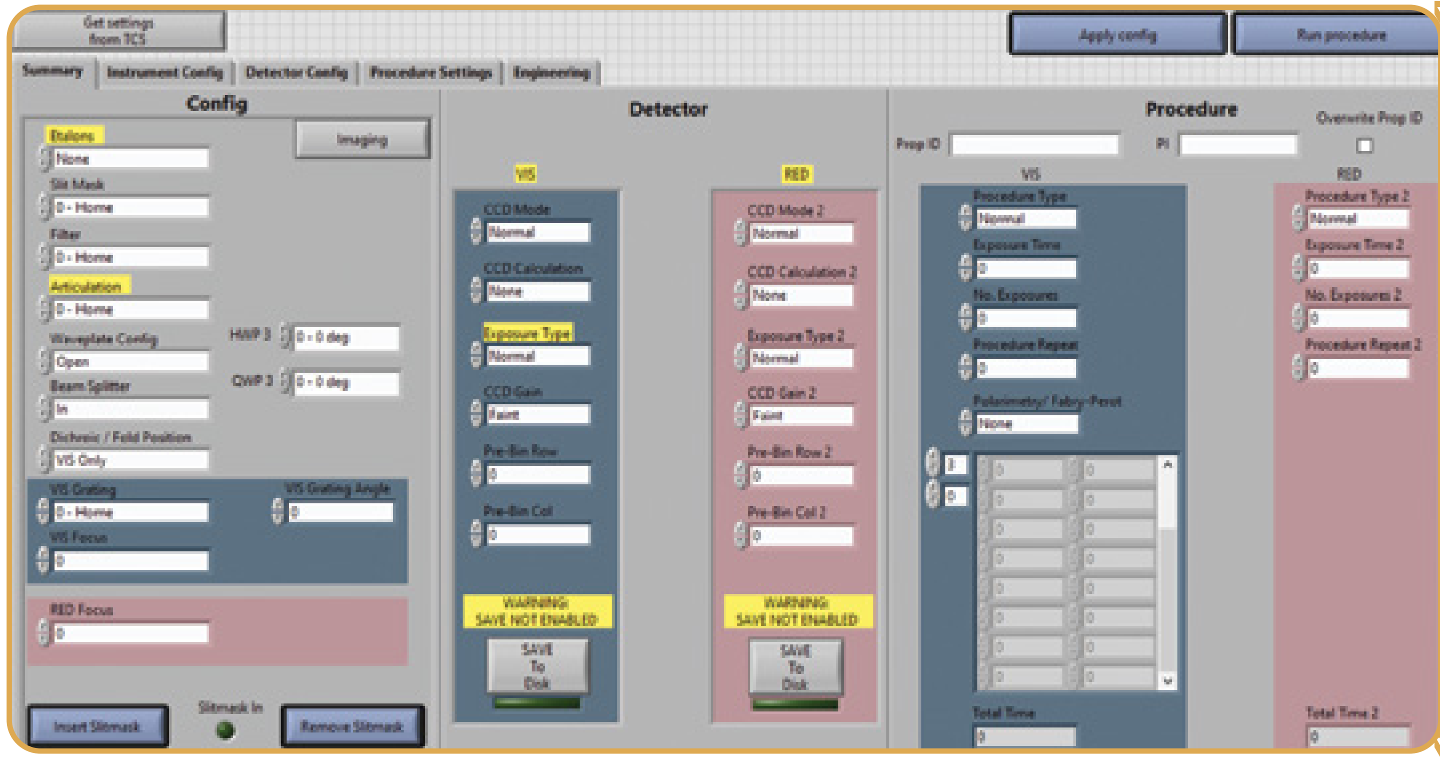



*Figure 5.*

# The RSS Detector Upgrade

The SAAO instrumentation division and SALT technical team are working on an upgrade of the detector on the RSS on SALT. The existing detector consists of a mosaic of three CCDs with an SDSU CCD controller. The controller hardware is increasingly unreliable and has become a risk to the instrument as spares are no longer available.

The new setup will feature a monolithic 6k x 6k CCD, which is being produced by Teledyne e2v, and updated controller hardware and software. The new CCD is expected to have better throughput and better fringe suppression in the red part of the spectrum. There will no longer be gaps between the CCDs, improving the efficiency of observations. The new RSS Red Arm, which together with the existing RSS operating in the bluer part of the visible range, forms “RSS Dual”, will use a very similar detector package, and work on the two detectors is progressing in tandem. See the RSS Dual Project Report on page 36 for technical updates on the detector projects in general.

The preliminary design review (PDR) for the new detector system was held in July 2021. Valuable feedback was received from the community and most of the issues raised have since been addressed or will be revisited during the PDR of the RSS Dual project later this year. The cryostat design work reached a mature level by the end of 2021, and work on the controller, mounting options, refrigeration system and software is ongoing. The SAAO is working closely with SALT partner IUCAA to implement upgrades to the IDSAC controller to meet the technical requirements for the new RSS detector. A prototype cryostat setup in the laboratory with an electrical sample CCD enables rapid testing and development of the thermal control and the IDSAC integration. In the second half of 2022, an advanced development model (i.e. a working prototype) will be produced in the lab in order to qualify assembly and integration methods, followed by the critical design review.

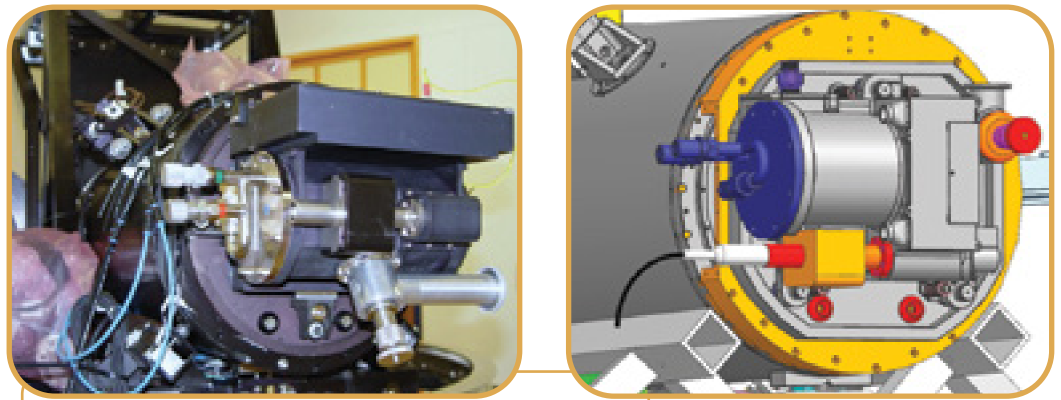


*Figure 1. The existing RSS detector (left) shown alongside the design for the new RSS VIS detector (right).*

*Figure 2. Final assembly of the test cryostat with a 6k x 6k engineering sample chip installed, allowing the development team to test various other aspects of the system on a representative CCD.*



# Slitmask IFUs for the RSS

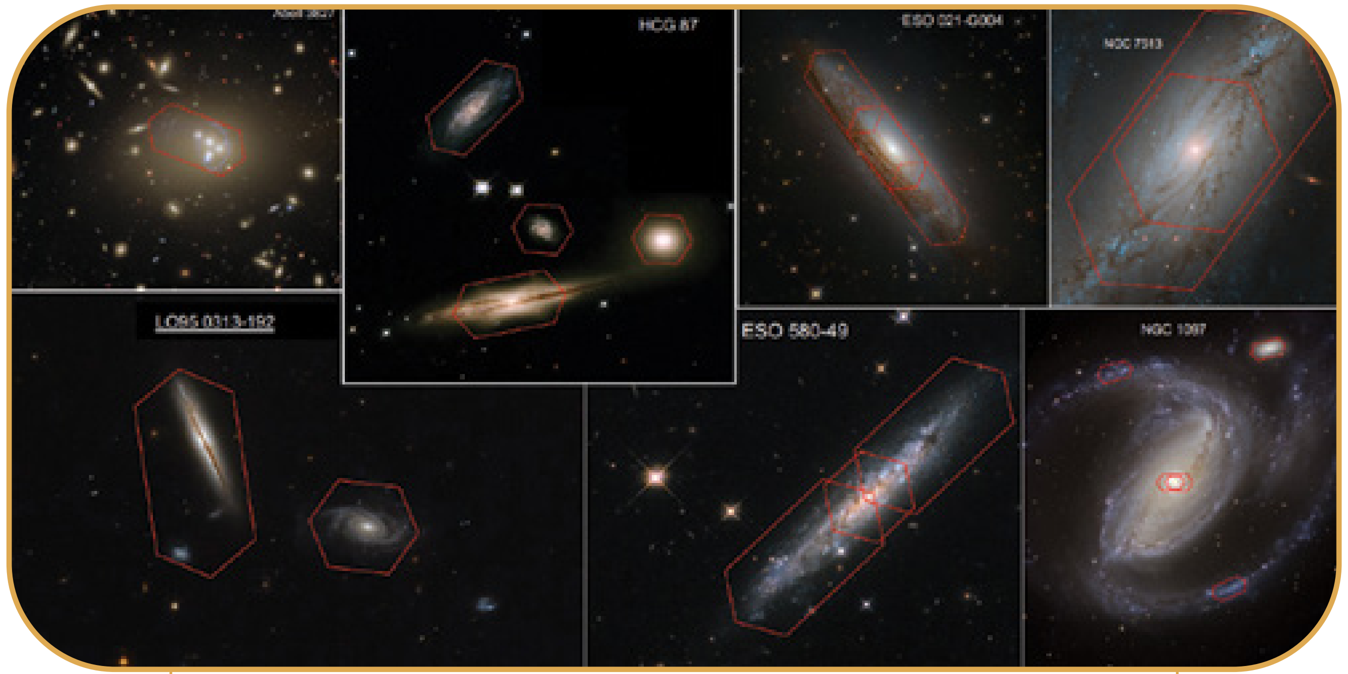



*Figure 1. Montage of Hubble Space Telescope (HST) images with the RSS IFUs overlaid (in red) to give an idea of coverage on galaxy cluster cores, groups, and individual galaxies.*

Two fibre IFUs are being built in the SAAO fibre-lab for the RSS’s VIS Arm and the future Red Arm (see Robert Stobie Spectrograph (RSS) Dual Project - MaxE, page 36).

An IFU unit is an optical device that samples a two-dimensional area on sky and reformats this area into a one-dimensional slit to feed a spectrograph. The two-dimensional area, for example, typically contains a portion or the entirety of an extended source, such as galaxies. Examples are given in Figure 1 for the IFUs being built for SALT. These IFUs are made out of a compact, hexagonal array of optical fibres. Once the spectra are recorded, the data are reassembled into a data cube (3D) so that images of the source can be analysed at each wavelength in the spectrum. This is similar to a Fabry-Perot imaging interferometer, except the IFU obtains many more spectral channels simultaneously. The broader wavelength coverage is ideal for (a) the analysis of the physical properties (density, temperature, metallicity), extinction, and ionisation mechanisms of the interstellar medium via nebular emission-line ratios, as well as (b) sampling the spectral continuum to characterise the ages, abundances and kinematics of stellar populations.

The IFUs for SALT will become available some time in 2022. They will complement the near-infrared IFU being delivered to SALT in May 2022 from the University of Wisconsin.

The SAAO team is building two IFUs to sample objects of different sizes. The smaller, 200 micron fibre IFU has 309 x 0.9 arcsec diameter spatial elements covering an elongated hexagonal footprint of 18 x 23 arcsec. The larger, 400 micron fibre IFU has 178 x 1.8 arcsec diameter spatial elements covering an on-sky area of 21 x 44 arcsec. In both cases there are two groups of 13 fibres offset by roughly 50 arcsec on either side of the primary array to sample sky. From the user/observer’s perspective, these

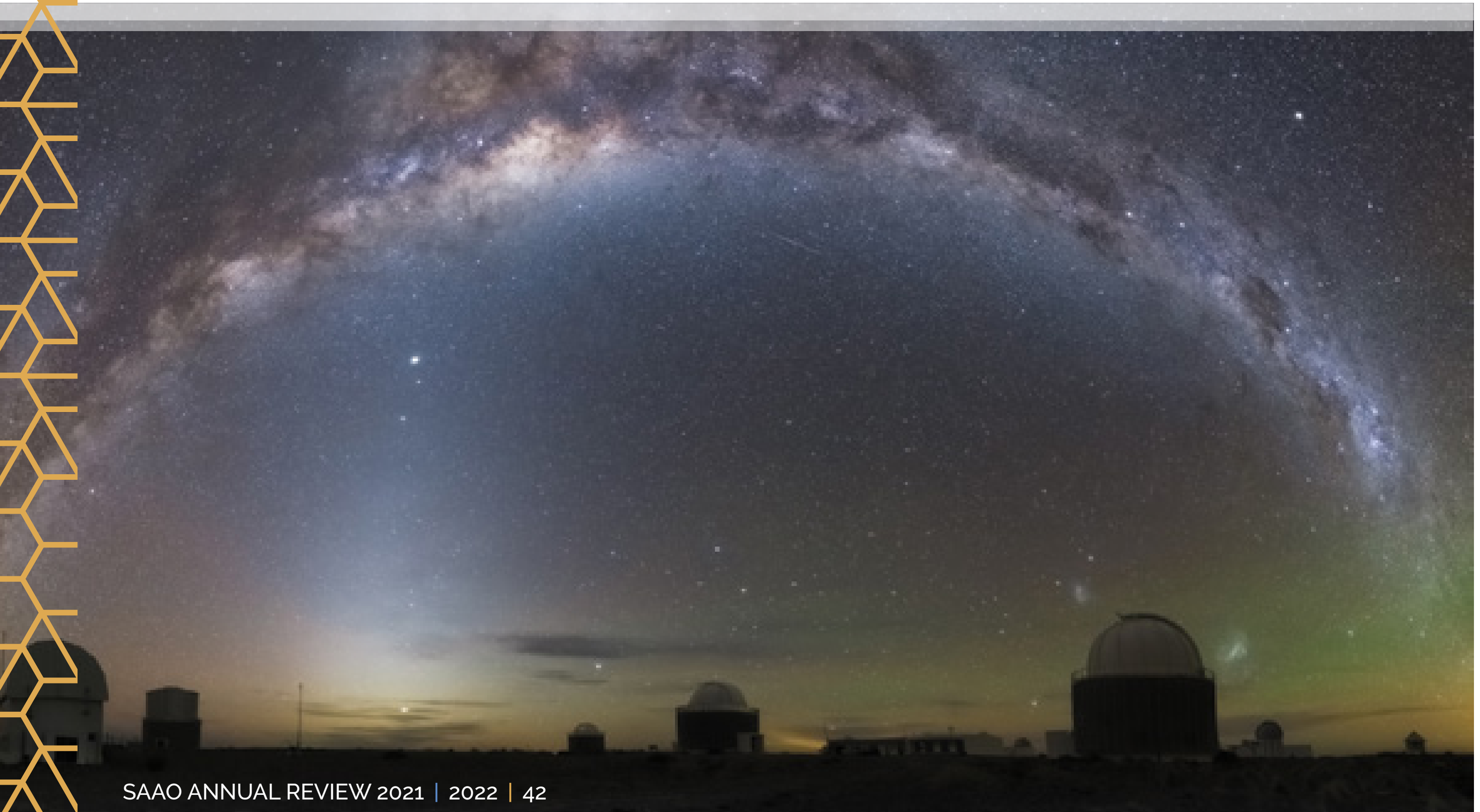
IFUs can be used with any grating and camera angle, yielding spectral resolutions comparable to 0.9 and 1.8 arcsec slit-widths. The IFUs have a fill-factor of roughly 60%. With a three-point dither pattern, the spatial coverage can be made truly integral.

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

In 2021, we designed and procured the fold prisms, procured fibre for the first two IFUs, and designed and fabricated the first mechanical cassette. During the 2021 SALT shutdown, the SMI exterior mechanical cassette was tested on the RSS cartridge-elevator-letterbox mechanism to ensure mechanical integrity and the longevity of the optical surfaces. The fibre polishing station was assembled and single-fibre cables of 200 and 400 microns were polished with satisfactory end finish. Using the SAAO fibre lab state-of-the-art optical metrology and characterisation system, we found that the polished fibres introduce marginal focal ratio degradation due to the additional bending inside the cassette. The scheme for interior fibre routing and polishing also has been tested through a prototype that was developed using a 3D printer.

Testing of the delicate bonding process of fold-prisms into their mechanical structures is currently being performed to confirm the choice of glue and its application method. 2D and 1D fibre array holder fabrication has advanced, with tolerance testing underway at the time of writing. Over the coming several months, we will obtain all the fabricated parts before polishing and characterising all the fibres, including the prism assembly for both SMIs, simultaneously.

A description of the exquisite opto-mechanical components built by the SAAO shop can be found in the section: The SAAO Instrument Workshop (page 29).





## Mookodi Instrument

### Mookodi at a glance:

**Camera:** Andor DU934P deep depletion camera, 1024 × 1024 CCD, 13 μm pixels

**Spectral range:** 400.5 – 799.5 nm

**Spectral resolution:**
**Dispersion:** 3.88 Å/px
**Resolution:** 80μm slit
R = 301.0 @4671.23 Å
R = 374.4 @5823.89 Å
R = 492.5 @7642.02 Å
160μm slit
R = 172 @4671.23 Å

**Plate scale:** 0.6 arcsec/px ± 0.06 arcsec/px

**Field of view:** 10′ × 10′

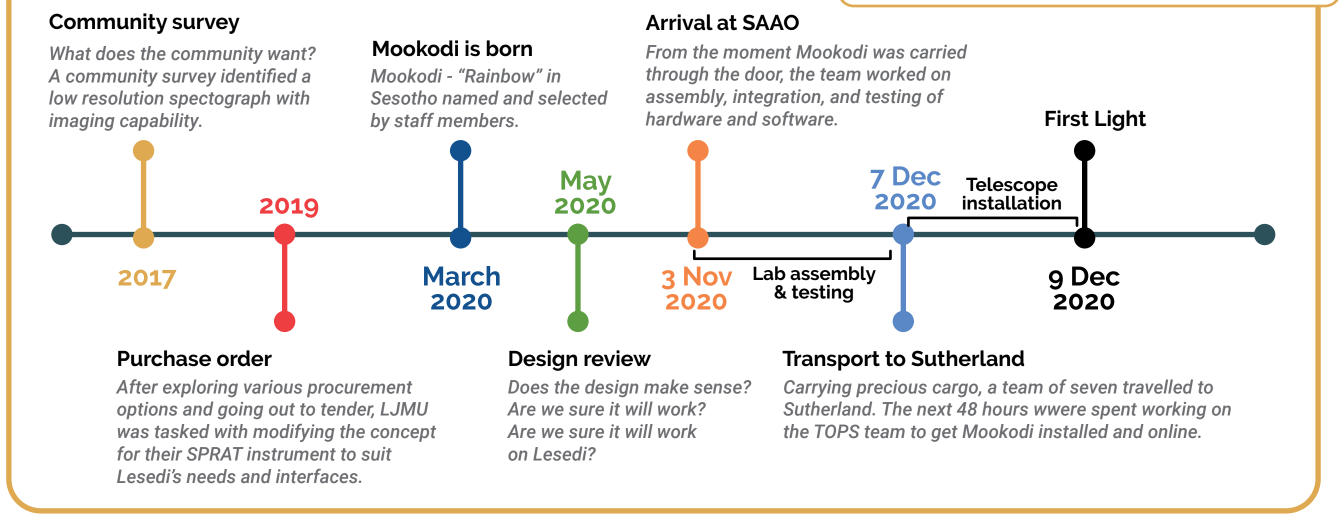
**Slit:** Long slit with narrow (80μm, 2″) and wide (160μm, 4″) sections.

**Filters:** Filter Slide A: Full set of SDSS filters (u′, g′, r′, i′, z′)
Filter Slide B: Longpass order blocking (OB) filter, and clear filter.
There are three empty slots in this slide available for future use.

At approximately 07:30 on the morning of 7 December 2021, the Mookodi instrument, SAAO's newest low-resolution spectrograph and imager, was loaded into a van in Cape Town. Two days and 13 hours later, the first-light image of Mookodi on the Lesedi telescope was timestamped.

The concept for Mookodi (which means "rainbow" in Sesotho) was first incarnated in 2017 in response to a survey by the astronomy community for a workhorse instrument on Lesedi, and is an evolution of the SPectrograph for the Rapid Acquisition of Transients (SPRAT) - the low-resolution spectrograph on the 2-m Liverpool Telescope on the island of La Palma in the Canary Islands. Designed and built by a team at the Astrophysics Research Institute at Liverpool John Moores University (LJMU) with design modification contributions from the SAAO engineering team, it is intended to be fully robotically operated with scripted observations. As such, Mookodi folds neatly within the mandate of the IO project at SAAO.

*Figure 1. Timeline of project implementation.*




## Development and Testing

The instrument design was finalised after a design review between LJMU and SAAO in May 2020. Mookodi finally arrived in the SAAO optical laboratory on 2 November 2021, after manufacturing and laboratory assembly had been severely hampered by COVID-19.

The project team carried out a carefully planned set of acceptance test activities that aimed to develop and cement their understanding of the build, operation, and performance of Mookodi. After five weeks of dismantling, assembling, filter installation, software integration, environmental testing, and operating in all major orientations, the instrument was ready to go to Sutherland.

## Installation

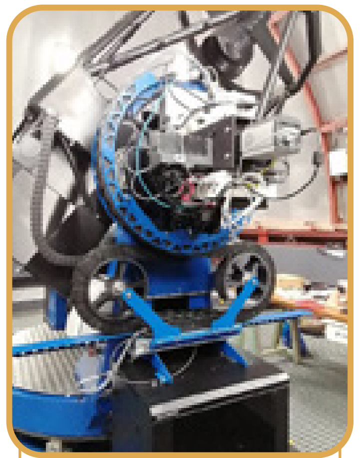


*Figure 2. Mookodi on Lesedi.*

After the team (which included technical staff, astronomers, students, and interns) arrived in Sutherland on 7 December, the rest of the day was spent unpacking boxes and setting up work areas, while the information technology (IT) team started getting the network configured for the new instrument. The following day, some final preparatory work on the Lesedi telescope was necessary to ensure that all the services (air, network, power) were delivered to the instrument port. In parallel, the instrument was re-assembled (after being dismantled and put back in its shipping crate for transport), and its cable chain was populated. By the afternoon of 9 December, Mookodi was mounted on the telescope, plugged in, and responding as commanded. At this point, it was a matter of waiting for darkness to fall. Two objects were identified for a first light demonstration of instrument capabilities: Messier 77 for the image, and Fairall 9 for the spectrum. With all hands on deck, the first of the data files was timestamped at 2021-12-09T18:47:51.168.

The following night, some more test objects and attempts at proper sky flats were made. At some point, it became clear that the focus of Lesedi's auto-guider and the instrument were quite far off from each other. Adjusting the focus of the autoguider involved removing the instrument from the telescope again and using on-sky objects to optimise the auto-guider focus. Fortunately, this exercise only needed to be performed once.

The remainder of the deployment trip was spent with astronomers moving through a series of test objects, with technical personnel standing by to monitor instrument stability and performance. The final tasks included day-time and night-time demonstration and induction sessions for the on-site technical personnel, who are responsible for monitoring and maintaining the instrument going forward.

The last of the Mookodi installation team arrived back in Cape Town on 15 December.

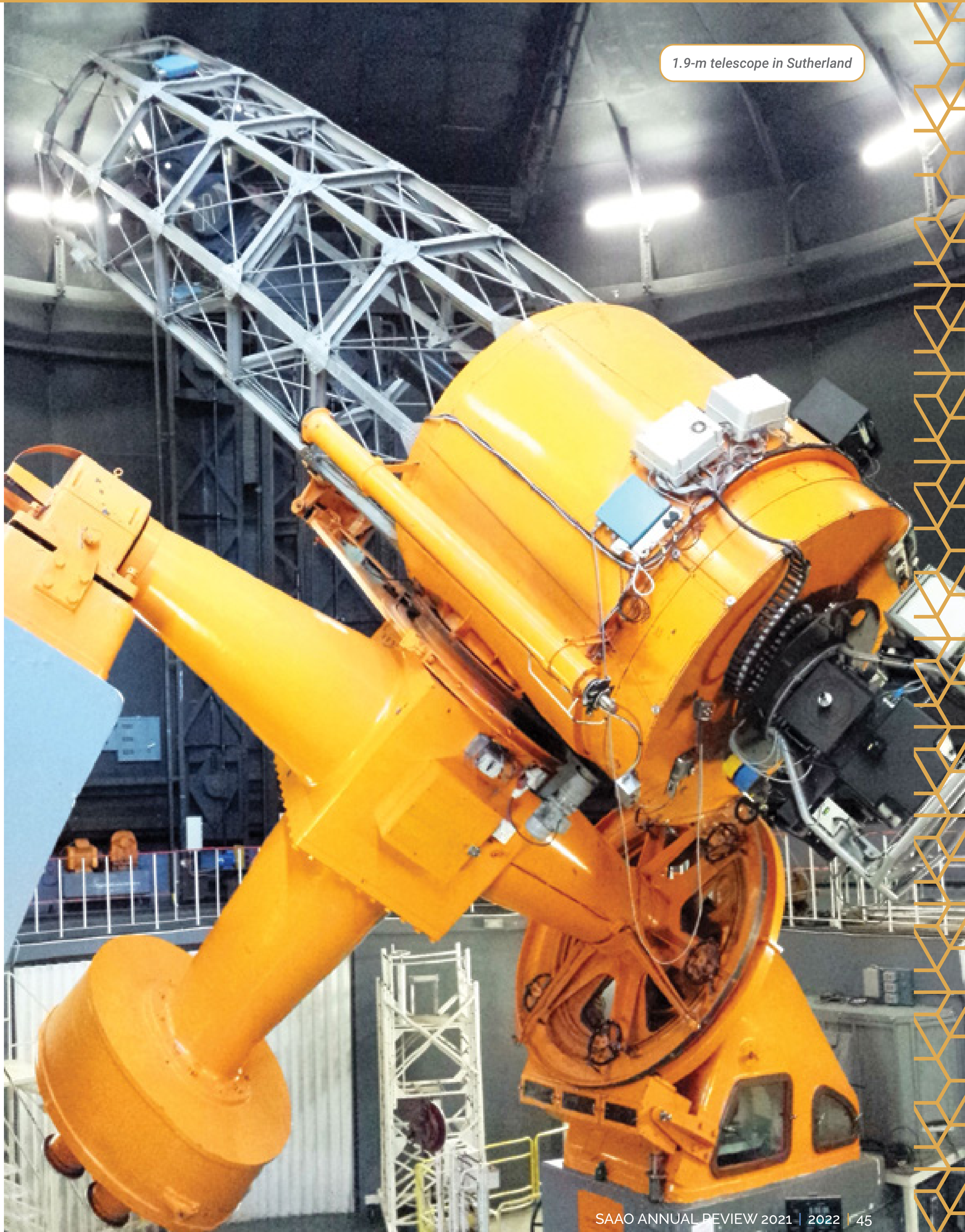
## Current Status (March 2022)

The first trimester of 2022 was dedicated to science commissioning of the various modes – spectroscopy and imaging – as well as development of software to enhance user experience and enable future robotic operation of the instrument. Mookodi's spectroscopy mode is now fully functional and commissioned for manual observing and many of the software building-blocks are now in place to eventually robotically collect spectra. Completed software development tasks required for robotic operation include scripting the startup procedure and pointing of the Lesedi telescope, auto-focusing the science camera analysing the point spread function (PSF) of sky-sources across the image, and performing World Coordinate System (WCS) calibration on the images to perform automatic target acquisition on the spectrograph's entrance slit. Additionally, Ulrich Geen (an MSc student supervised by Retha Pretorius) used this period to determine on-telescope performance values, and to get a sense of whether there are any features or anomalies that might need further investigation. The instrument was offered to observers on a high-risk basis during this time, which allowed for constructive feedback to prioritise further development requests.

## Acknowledgements

The number of people involved in getting Mookodi to South Africa and on Lesedi is momentous. This includes Glenda Snowball and the finance and Supply Chain Management (SCM) departments, as well as Martin Slabbert, Malcolm Hendricks, and Nkululeko Maerman in the workshop. Also, the instrumentation installation team: Nicolas Erasmus, Retha Pretorius, Ulrich Geen, Carel van Gend, Egan Loubser, Willie Koorts, Liam Higgo, Shalom Abiodun, Hitesh Gajjar, and Kathryn Rosie. Hannah Worters supported through nights on Lesedi whilst simultaneously observing on the 74". The site technicians included Paul Booysen, Jean Barnardo, and Avhapfani Malaudzi. Stephen Potter processed the Flexible Image Transport System (FITS) files to give us the astronomy images we see from Mookodi.





*1.9-m telescope in Sutherland*

# THE **INTELLIGENT OBSERVATORY (IO)**



## Remote Telescope Operations

The IO is an ambitious project to modernise and improve the efficiency of telescope operations at the SAAO.

Among the drivers for the IO is the need to be able to respond to the large number of follow-up targets expected from the Legacy Survey of Space and Time (LSST) telescope, the MeerKAT and SKA radio telescope arrays, and others. At the same time, regular research programs of long and short duration need to be accommodated.

Building the IO is a many-faceted process, but among the first tasks required have been the updating of the observatory's telescopes and instruments to allow these to be operated remotely and robotically, and the deployment of tools to permit the centralised control and scheduling of observations.

The team's initial emphasis has been on developing software and processes for the 1.0-m, 1.9-m and Lesedi telescopes and their associated instruments. In the first iteration, we concentrated on the newer Lesedi telescope and its instruments, Sibonise and Mookodi. Lesedi was acquired with the intention that it would serve as a pathfinder for robotic operations. The Sibonise instrument was developed to take advantage of Lesedi's wide field of view, and Mookodi was designed as a low-resolution spectrograph used for rapid follow-up of targets of interest. A feature of the Mookodi instrument is that it can be used in both imaging and spectroscopic modes.

Figure 1 shows an image taken in January 2022 using Mookodi of the galaxy NGC1566. The bright object at about the 10 o'clock position near the core is Supernova 2021AEFX. Figure 2 shows a spectrum taken with Mookodi of the supernova.

*Figure 1. Image taken using Mookodi of the SN2021AEFX in the galaxy NGC1566.*

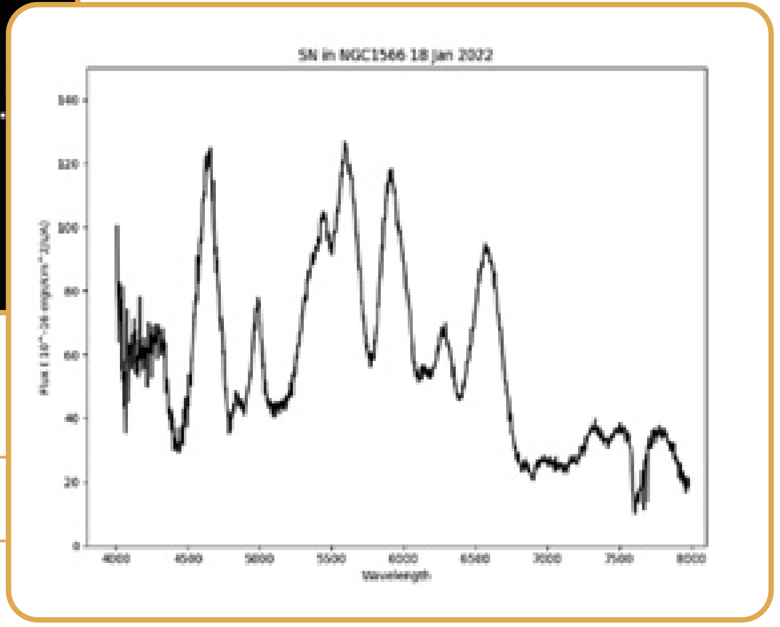



*Figure 2: Spectrum taken using Mookodi of SN2021AEFX.*

While focusing on Lesedi, we have not neglected the other telescopes. An instrument selector for the 1.9-m telescope is under development, and there have been improvements to the software on the SHOC instruments.

We have developed and deployed a software architecture which enables the programmatic control and querying of instrument and telescope hardware. This allows the development of complex applications able to communicate with several hardware components, as required.

A first application of this was the development of remote web interfaces to instruments, telescopes and associated autoguiders. This means that observers do not need to travel to Sutherland, but can do their observations remotely. A dedicated ROS (see page 50) has been set up in the main building of the SAAO in Cape Town for this purpose, but users can observe from anywhere with an internet connection. We regularly have observers working from Europe.

With the advent of remote observing has come the need for safeguards for the hardware. It may happen that a remote user loses connection or is unaware of changes in weather conditions that require the telescope to close. We have developed a Local Control Unit (LCU) for each telescope which monitors local weather conditions and the connection state of the user, and if necessary, issues a shutdown command to the telescope.

> The IO is an ambitious project to modernise and improve the efficiency of telescope operations at the SAAO.

As part of improving the efficiency of observations, we have developed software to undertake tasks which are otherwise tedious for observers.

An example of this is automatic focussing of the telescope on the instrument's detector plane. Changes in the ambient temperature through the night cause the focus position to change, requiring the best position to be determined again and the telescope set accordingly. The software autofocus function takes a number of observations over a range of focus positions, calculating a measure of the focus quality at each position. Software then fits a gaussian curve to the data, before automatically adjusting the telescope focus to the best calculated position.

Another example is precisely positioning the target on the detector. While indeed useful for some imaging observations, it is absolutely necessary for spectroscopy as the light from the target star needs to fall directly over the spectrograph's slit. We have developed software to image the area around the target, use this to calculate the offset required, and finally move the telescope so that the target is precisely where it needs to be.

A further example is automatically finding and selecting a guidestar. Guiding is essential when taking long exposures, and manually choosing and selecting a guidestar can be somewhat time consuming. Software developed in the IO is able to analyse an image, use this to move the guide camera into a suitable position, select a guide star and start guiding using this.

Each of the above tasks remove some of the manual effort required of observers, providing convenience and improving efficiency. When robotic, fully automated observations are to be done, these are essential.

With programmatic control available for telescopes and instruments, coupled with the automated tools described above, we are now able to construct (by hand) scripts which configure and handle individual observations, and schedules which describe sequences of such observations. Together, these can describe an observation programme from beginning to end, including starting up telescope and instruments, focusing the telescope, pointing at targets, fine-tuning the positioning, configuring instruments and taking exposures.

Figure 3 shows an image of the Tarantula nebula taken with this scripting system in December 2021 using the Sibonise instrument on Lesedi. The image is a composite of three overlapping images giving a total field of view one degree across. To take the images, a script was created instructing the telescope to point to each of the three locations required, and at each location to take images with a number of different filters. The only human intervention was then to start the script, and later to process the data to produce the image shown.

*Figure 3: A composite image of the Tarantula nebula, taken using Sibonise on Lesedi.*

Our future intention is not, however, to construct schedules of observations by hand. Instead, we aim to use automated tools to schedule these and update this schedule as targets of opportunity arise. Rather than develop such tools ourselves, we have adopted and are adapting to our specific purposes the Observatory Control System (OCS) made available by the Las Cumbres Observatory (LCO). In particular, this provides software for submitting and managing observation proposals and generating schedules from these. The scheduler takes a list of planned observations, examines their priority and observing parameters, then produces a schedule of observations for the telescope on a particular night. Our task (already underway) is to develop software which can interpret and implement such a schedule. When this is complete, we will have achieved a further important milestone for the IO project, that of being able to autonomously execute night-time observations.

# Towards an IO - Remote Operations Station (ROS)

To support the SAAO's IO philosophy, a state-of-the-art ROS was set up at the SAAO headquarters in Cape Town. The design concept is based on the user requirements developed by the project team, led by Stephen Potter.

Construction began in 2020, and by July 2021 it was complete. Since then, the installation of workstations began, and now two out of the four workstations are in operation. Regular night-time operations, including student training, are now ongoing.

The ROS room was divided into a relaxation area and a circular platform with desks, computers and a bank of monitors for the astronomers. In addition, a 6.2-m diameter overhead screen projects a live image of the Sutherland sky. The room uses a high-speed, high-data-rate link, to ensure smooth operations of either the SALT, 1.9-m, 1.0-m or the Lesedi telescopes and their instruments. This includes video and audio feeds from each of the telescope facilities and the ability to virtually share desktops and conference sessions with collaborators and other remote operators and astronomers.

There is also a backup internet link to Sutherland in case of fibre breakages. The room is also on uninterruptible power supply (UPS), and the entire Cape Town site has a backup generator, in cases of electricity outages.

In addition to being a remote control room for observers, it will also ultimately be the command centre from which all the autonomous functions of the IO will be managed and monitored.



# Towards an IO - Artificial Intelligence (AI) for Cloud Mapping

The African Intelligent Observatory (AIO) program from the SAAO is aimed at achieving multi-wavelength astronomy from existing instruments. This can be achieved by a carefully and intelligently coordinated synthesis of actions to ensure optimal use of resources, based on objects of interest and weather conditions. The prerequisites to having an IO are remote operability, service mode capabilities, robotic capabilities and autonomous operations.

## Data Analytics - Realising AI

In order to enable autonomous operations, the Observatory needs to know if the weather conditions are favourable for observing. This is where the inception of an AI-based detection and classification system stemmed from. The idea is to leverage the power of AI in the context of image-processing systems to determine the type of weather conditions on-sky in real-time. Since AI-based vision systems have enjoyed increasing success over the years, ranging from surveillance to security to obstacle detection in transport systems, this gave us some confidence in the prospect. Thus the SAAO and ATLAS teams decided to explore this prospect using data from the ATLAS team.

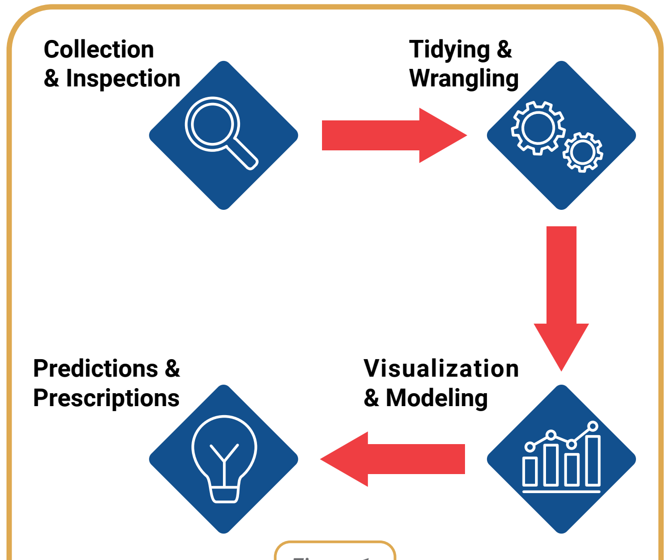



*Figure 1.*

To achieve this, the data analytics process in Figure 1 is followed.

## Data Ingestion

The system is fed with images from an ATLAS all-sky camera, which captures images of the entire southern sky, as in Figure 2.

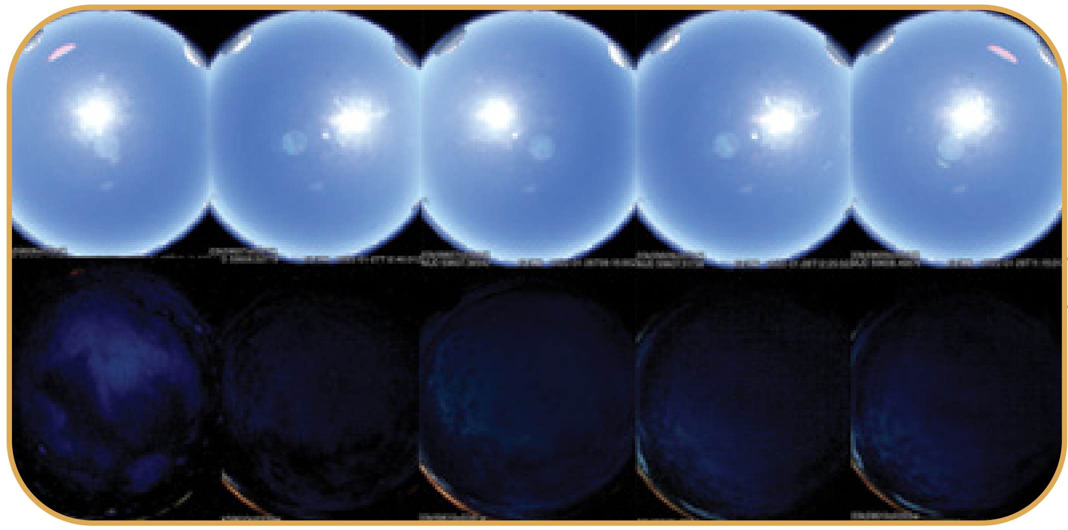


*Figure 2.*

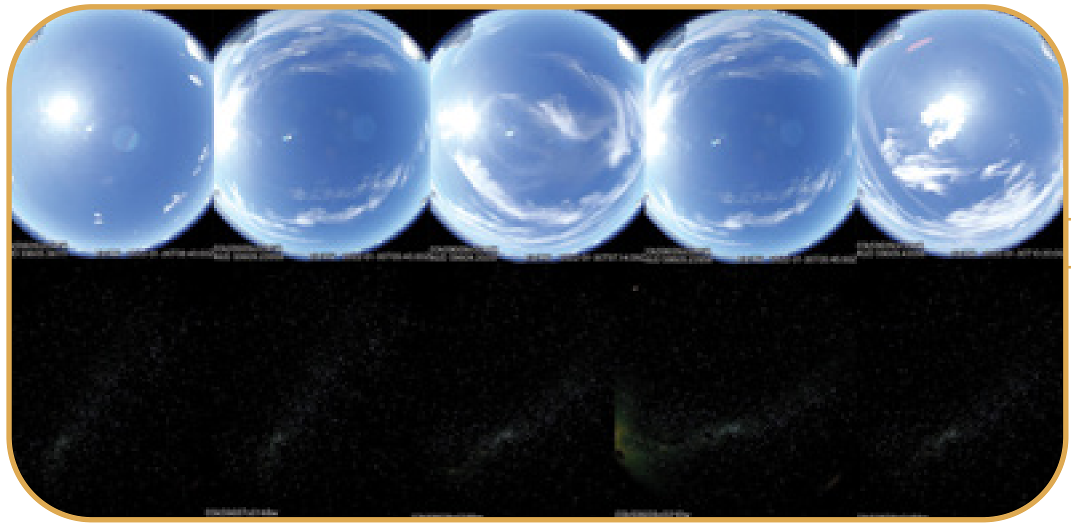
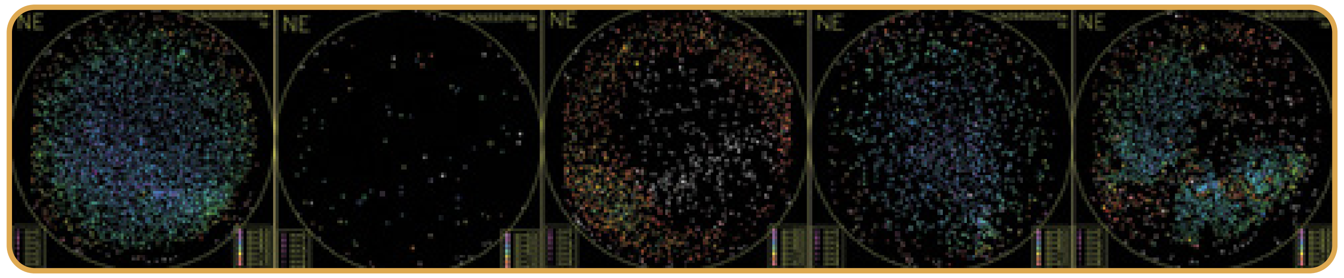


*Figure 2.*

## Feature Engineering

Since astronomy observations happen at night, only the night images are selected, like the ones on the second (cloudy) and last (clear) rows shown in Figure 2. As part of feature engineering, the images are converted to zero-point data for each source using astrometric and photometric data reduction processes performed by the ATLAS team. The zero-point data contain information about the atmospheric transparency at the sky-location of each stellar object detected in the all-sky image so ideal for cloud-detection or any other atmospheric condition that hampers astronomy.



The zero-point images are separable within five predefined categories including:

1. Clear. Favourable conditions for any kind of science.
2. Cloudy. Unfavourable conditions for any kind of science.
3. Hazy. Conditions could still be favourable for some science, but humidity conditions could be dangerous for exposed telescopes and instruments.
4. Dew forming. Unfavourable for operations as condensation could potentially damage optics and/or electronics.
5. Patchy. Partial observations are possible in clear parts of the sky, although caution should be taken as rain could be imminent.

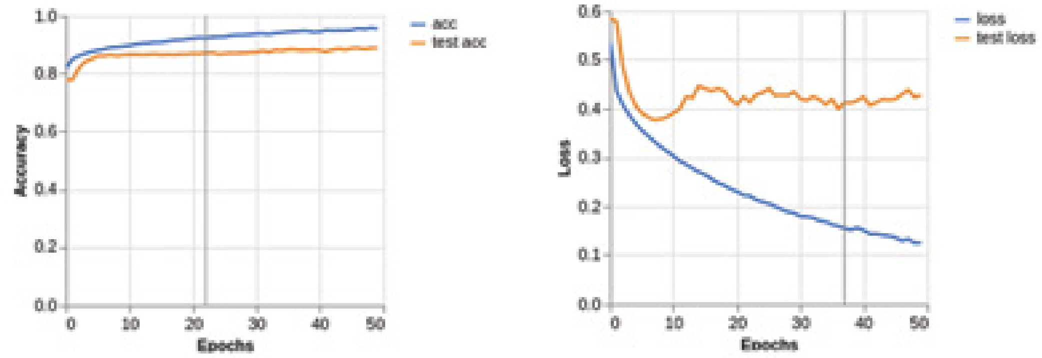
Once the images are sorted into these categories, they are ready for the model to be trained on, as part of supervised learning.

## Supervised Learning: Deep Neural Network

Deep Neural Networks (DNNs) are specialised forms of neural networks, machine learning models capable of extracting intricate features, shapes and other hidden properties from images. The training results are characterised by training accuracy and loss.

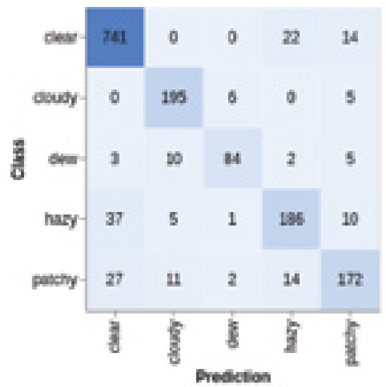


The training accuracy of the model is above 80%, including the validation (test) accuracy, which implies that the model is able to separate well between the different classes. The training loss, which is an indication of how well the model reinforces the training by introducing a penalty function, shows a convergence towards 0.1. During the training, it is too soon to tell whether the model needs optimization.



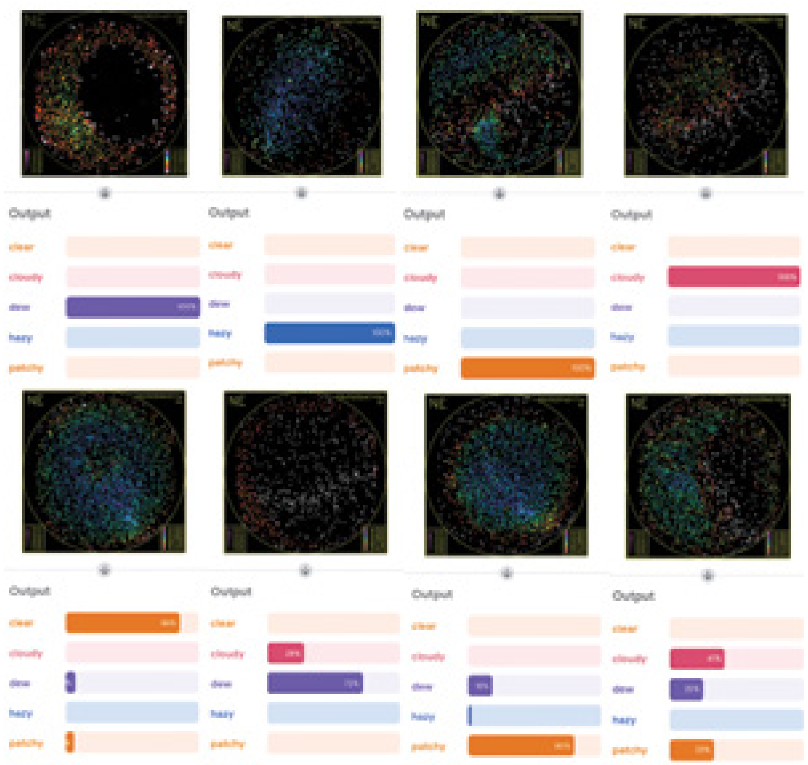

## Test Results

Once trained, the model can be tested on previously unseen data in order to evaluate performance. The performance of the model determines readiness for deployment, and is based on metrics including accuracy, precision, sensitivity and specificity. They are summarised in a confusion matrix (to the right).




The results indicate that the model is capable of predicting the different patterns as it achieved an overall accuracy of 89%. This is sufficient proof that the usage of a neural network model in the detection and classification of sky conditions for astronomy is a feasible prospect.

The next step is to deploy the neural network on a live host, where live streams of images from the all-sky camera are fed to the model, and real-time predictions are made. Based on the input, rules can be set to close the dome, double check the weather, switch to a different scientific observation, wipe the camera or continue operations.

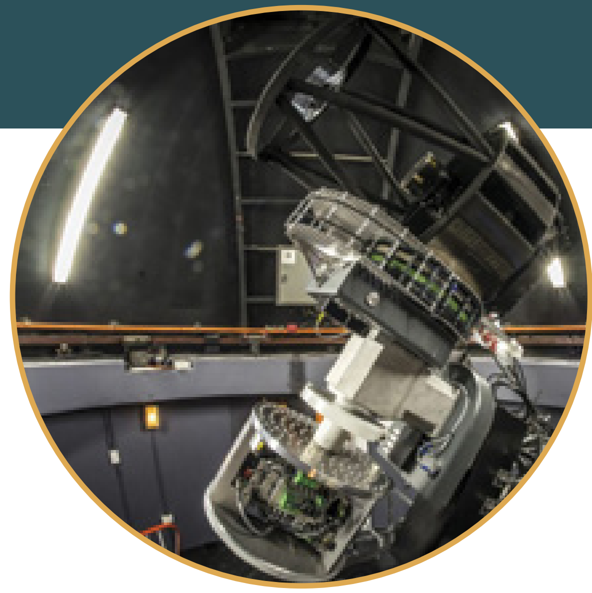


The SAAO extends its gratitude to the ATLAS team for their support and involvement in the realisation of this project. The dataset, test node and advanced image processing algorithms for feature engineering are provided by the ATLAS team, and the success of this project will be testament to the synergy produced through collaboration between the SAAO and ATLAS.

# ASTRONOMY **OPERATIONS**/ SCIENCE **HIGHLIGHTS**



## Research Groups



The 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.

### Stellar Astrophysics Group

The stellar astrophysics group meets for weekly discussions (virtual at present) organised by Kelebogile Gasealahwe on alternate Thursdays at 4pm and Fridays at 11am. Non-SAAO-based researchers are most welcome to join too. Regarding this or any other queries, contact bang@saao.ac.za.

Discussions cover a wide range of stellar and binary astrophysics and range from observational techniques to theoretical and computational astrophysics, all in a bid to understand the processes that drive star formation and evolution.

In the 2021/22 year, the SALT transient programme was awarded a significant fraction of observing time on SALT, and it continues to generate a variety of interesting results. One of the key results included SALT spectro-polarimetry of the afterglow of a gamma-ray burst (https://ui.adsabs.harvard.edu/abs/2021MNRAS.506.4621B/abstract). These observations, which were combined with photometry from the MASTER global robotic network, were used to constrain the models for the optical emission from long gamma-ray bursts. David Buckley, Danté Hewitt, Itumeleng Monageng, Danièl Groenewald and Jessymol Thomas from SAAO were involved in this work.

Another highlight from the stellar astrophysics group was the follow up of a gravitational wave source with MeerLICHT. The telescope is designed as the 'optical eye' to the MeerKAT radio telescope: its primary role being to observe the same patch of sky at the same time that MeerKAT is observing it.

During MeerLICHT's commissioning phase in 2019, its robotic operation mode and wide field of view were put to task to search for the optical flares from gravitational wave events. While these gravitational waves tell us a lot about the physics and evolution of these energetic events, it's incredibly difficult to pinpoint the exact site of such events in the sky.

Undaunted, astronomers have built a generation of wide field robotic telescopes, like MeerLICHT, along with state-of-the-art data pipelines and storage facilities, to narrow down the sites of these gravitational wave events. In this project (https://ui.adsabs.harvard.edu/abs/2021A%26A...649A..72D/abstract), led by Simon de Wet, a Master's student at UCT, and Paul Groot, from the SAAO, UCT and Radboud University, used MeerLICHT to search an area of sky equivalent to the angular size of approximately 60 full moons. Simon's work did not find an optical signature that could be identified as a counterpart to the gravitational wave event (labelled GW190814). This was expected, as the analysis of the gravitational waves showed that they were most likely caused by a merger of two black holes, which does not show a signal in the electromagnetic spectrum. Using the MeerLICHT observations, however, the authors could estimate the chances of detecting future neutron star merger events with MeerLICHT and similar size telescopes.

Shazrene Mohamed (SAAO) and Elias Aydi (who did his PhD at SAAO, and is now at the University of Michigan) created novel 3D simulations to investigate how dying stars interact with their environments (https://ui.adsabs.harvard.edu/abs/2022MNRAS.tmp..845A/abstract), including potential nearby planets. The insights come from methods of computational astrophysics, which involve the mechanics of fluid flows. The images generated through the simulations show a variety of spiral structures caused by a combination of pulsations in the dying star, and the orbital motion of a companion, potentially a planet. These images give us an idea of what our solar system may look like in the distant future. This work was published in Monthly Notices of the Royal Astronomical Society in March 2022.

In January 2022, Shazrene Mohamed took up an Associate Professorship in the Department of Physics at the University of Miami, Florida (she remains affiliated with SAAO and UCT). In March 2022, Sally Macfarlane joined the SAAO as a post-doctoral fellow and junior affiliate of the Rubin Observatory LSST transients programme.

Geoff Murphy successfully completed his MSc under the co-supervision of Rob Yates (primary supervisor, University of Surrey), Shazrene Mohamed (SAAO) and Daniel Cunnama (SAAO). His thesis work on the formation and chemical evolution of stellar haloes around Milky Way-type galaxies was published in the Monthly Notices of the Royal Astronomical Society (https://ui.adsabs.harvard.edu/abs/2022MNRAS.510.1945M/abstract). Geoff was awarded a Centre for Radio Cosmology (CRC) bursary to pursue his PhD studies at University of Western Cape.

Ms Anke van Dyk received her Master's degree from UCT in late 2021. Her dissertation was titled "Capturing transients: an application of biostatistics to astronomy" and involved translating methods for estimating population sizes in biology to estimates of various populations of astrophysical transients. Anke's MSc was supervised by Paul Groot and Vanessa McBride.

Katlego Ramalatswa, an MSc student (supervised by Shazrene Mohamed), was among about a dozen students selected from hundreds of applicants world-wide for the ASPIRE program (the Astrophysics Summer Program for International Research Experience) at the University of Amsterdam. On receiving his MSc results, Katlego will take up a PhD position working on models of supernovae at the MPA in Germany.

## 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, they focus on measuring rotational periods and colours of both near-Earth and main-belt asteroids, as well as activity in Centaurs through broadband photometry.

The group has primarily made use of the SHOC instrument, which is now available on the 40-inch and 74-inch telescopes. The high-speed SHOC cameras are ideal for our near-Earth asteroid programme as relatively short exposure times are essential because of the large sky motion of these objects.

In early 2021, there were observing contributions from the group to the global observing campaigns of the 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 results of that global observing campaign have recently been published in Reddy et al. (2022) with data contribution from both the 40-inch and Lesedi telescopes using the SHOC instrument.

The SHOC instrument on Lesedi has now been replaced by a low-resolution spectrograph, Mookodi, which this group will be using in future to perform spectral classifications of main-belt and near-Earth asteroids.

Through their collaboration with the ATLAS group at the University of Hawaii, the group has also made extensive use of the large and existing ATLAS photometry dataset for several main-belt asteroid studies. The data access has been possible through their partnership with ATLAS, linked to a third node of the ATLAS network which was successfully installed in Sutherland in December 2021.

## Galaxy Group

There is a wide range of extragalactic research being done at the SAAO. Current interests include star formation, super star clusters, active galactic nuclei (AGN), feedback processes in starbursts and AGN, ultra-diffuse galaxies, the evolution of brightest cluster galaxies (BCGs), dynamics of galaxy mergers and disc assembly, baryon cycle in galaxy groups and other environments, and galaxy transformation from active to quiescent.

The topics of interest are mostly explored from an observational perspective, using optical, near-infrared, and radio (continuum, HI, and molecular gas) data from telescopes around the world.

The new optical slitmask integral field unit (IFU) instrument for SALT is being developed at SAAO and preparations are being made for the installation of a new near-infrared IFU on SALT.

The SAAO welcomed Dr Zara Randriamanakoto to the staff. She will continue her work on multi-wavelength studies of massive star clusters in starbursts and LIRGs and on radio continuum studies of galaxies and AGN.

The extragalactic discussion group meets fortnightly on Fridays to discuss recent results in the literature, as well as technological and scientific developments related to galaxies, and they share interesting research updates.

There are a number of post-doctoral scholars and post-graduate students working with SAAO researchers on extragalactic astronomy. We are particularly proud of Munira Hoosain who received a distinction for her MSc thesis. We are also proud of Jamie Bok (PhD) and Omphemetse Mputle (MSc) who graduated.

Researchers at the SAAO are involved in a number of projects that utilise 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). 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

# eROSITA and SALT Witness the Awakening of Massive Black Holes - April 2021

Combined observations by eROSITA, the main instrument aboard the Spectrum-Röntgen-Gamma (SRG) satellite, and 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, and reach 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.

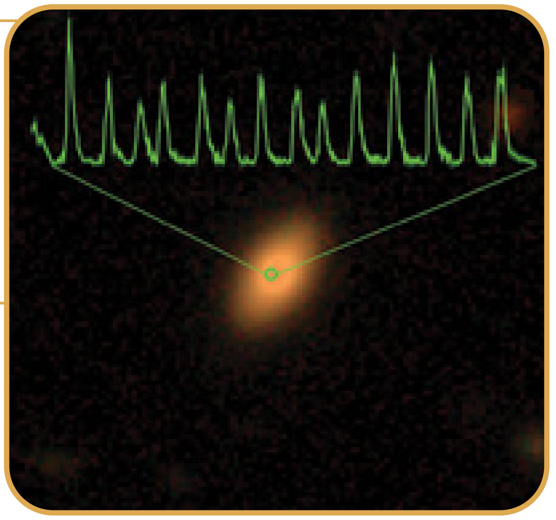


*Figure 1. Optical image of the first galaxy found with quasi-periodic eruptions in the eROSITA all-sky data, the Neutron Star Interior Composition ExploreR (NICER) X-ray light-curve is overlaid in green. The galaxy was identified as 2MASS 02314715-1020112 at a redshift of z~0.05, determined by SALT. The peak-to-peak separation of the X-ray outbursts is about 18.5 hours. Credit: Max Planck Institute for Extraterrestrial Physics (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. Arcodia added that, "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".

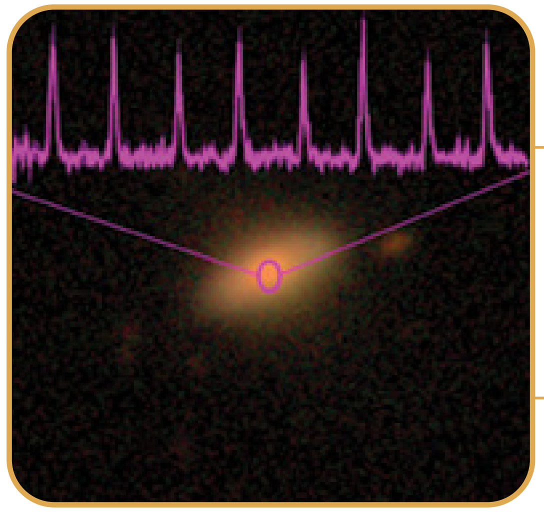


*Figure 2. Optical image of the second galaxy found with quasi-periodic eruptions in the eROSITA all-sky data, the XMM-Newton X-ray light-curve is overlaid in magenta. The galaxy was identified as 2MASX J02344872-4419325 at a redshift of z~0.02, determined by SALT. This source shows much narrower and 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 X-ray Multi-Mirror Mission (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, PI of eROSITA. "Without these sudden, repeating X-ray eruptions we would have ignored them," she added. 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 SAAO, PI 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*
*Arcodia, A. Merloni, K. Nandra, et al.*
*Nature, published 29 April 2021*
*Link/DOI: https://dx.doi.org/10.1038/s41586-021-03394-6*

# Discovery of a New Class of Super Slowly Rotating Asteroids - July 2021

SAAO researcher Nicolas Erasmus, together with NRF-funded student Petro Janse van Rensburg and other collaborators, reported the discovery of a new class of super-slowly rotating asteroids in July 2021. These asteroids have rotation periods of thousands of hours, and their discovery was made possible by the accumulation of lightcurves from telescopes specifically designed to monitor transients (the Zwicky Transient Facility, ZTF) and asteroids (ATLAS).

This treasure trove of very slow rotators in the asteroid belt begs the question of whether the asteroids are 'born' with such slow rotation rates, or whether they have been spun down over the past 4.5 billion years. Both of these interpretations are important for constraining the history of the asteroid belt in our solar system.

*This work was published in the Monthly Notices of the Royal Astronomical Society in July 2021: https://academic.oup.com/mnras/article/506/3/3872/6318876?searchresult=1*

# Active Main-belt Asteroid - July 2021

On 7 July 2021, Nicolas Erasmus of the SAAO was doing regular ATLAS-discovery vetting of the ATLAS Haleakala (Maui) observations, when an object appeared on the vetting page that appeared to have a slight comet tail (Figure 1).

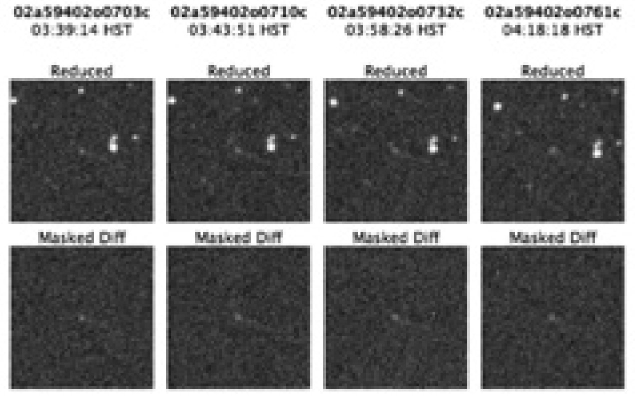



*Figure 1. The bottom row shows the "difference images", where the stars that are shown in the original top-row images have been removed. The asteroid is the object in the centre of each frame. ATLAS takes four images at different times and looks for moving objects to discover asteroids. Pointing towards the ~four o'clock position appears to be a faint tail.*

These types of objects regularly appear on the ATLAS discovery page and are often new comet discoveries. However, what was peculiar in this case was that this object was already a known main-belt asteroid and these normally do not show any cometary activity. Also, a known main-belt asteroid should not appear on the vetting pages, as ATLAS's software normally just submits the observations to the Minor Planet Centre automatically, along with the thousands of known asteroids it observes during the course of a night every night.

*Figure 2. Image taken by Audrey Thirouin (Lowell Observatory) and Henry Hsieh (Planetary Science Institute) on the 4.3-meter Lowell Discovery Telescope the night following initial observation. This confirms the extremely long tail that was only shown as a hint of a tail in the initial ATLAS "discovery" images.*

It was subsequently suspected that this object made it to the vetting pages because it was almost 1.5 magnitude (i.e. almost 5 times) brighter in the sky than what was predicted for this known asteroid, based on its known size estimate and distance from the Earth at the time of the ATLAS observation. So an asteroid had appeared where ATLAS, with only a 0.5-m primary mirror, would in theory not be able to see one, because it would be way too faint at a V-magnitude close to 21. Hence, the automated pipeline posted it to the vetting pages for a human eye to inspect, thinking it was a new discovery.

After Dr Erasmus notified the ATLAS team of the unsuspected tail, one of one of the people who co-vetted, Alan Fitzsimmons from Queen's University Belfast (QUB), confirmed that this was indeed a known asteroid: (248370) 2005 QN173 and undeniably a main-belt asteroid based on its orbit parameters. Because comet-like activity in main-belt asteroids is very rare, the ATLAS team then notified some of their collaborators that specialise in main-belt comets to do further investigation via follow-up observations on larger telescopes.

*This discovery and further analysis of the follow-up observations were presented by Henry Hsieh at the Division for Planetary Sciences of the ASS meeting in October 2021. There was also a subsequent paper by Dr Hsieh, which Dr Erasmus was a co-author on: https://iopscience.iop.org/art cle/10.3847/2041-8213/ac2c62*

# Researchers Discover Three Supermassive Black Holes Merging Together in our Nearby Universe - September 2021

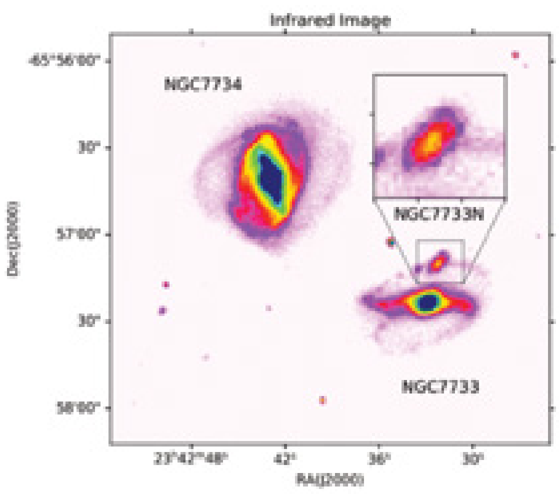



*Figure 1. Infrared images of NGC 7733–7734 group.*

Researchers, using the IRSF at the SAAO in Sutherland, have discovered three supermassive black holes from three galaxies merging together. The IRSF is a collaboration between Nagoya Univ-Kyoto Univ-NAOJ (Japan) and the SAAO (South Africa).

The merger has formed a triple active galactic nucleus, a compact region at the centre of a newly discovered galaxy that has a much higher-than-normal brightness. This rare occurrence in our nearby universe indicates that small merging groups are ideal laboratories to detect multiple accreting supermassive black holes and increases the possibility of detecting such rare occurrences.

Supermassive black holes are difficult to detect because they do not emit any light. But they can reveal their presence by interacting with their surroundings. When the dust and gas from the surroundings fall onto a supermassive black hole, some of the mass is swallowed by the black hole, but some of it is converted into energy and emitted as electromagnetic radiation that makes the black hole appear very luminous. They are called active galactic nuclei (AGN) and release huge amounts of ionised particles and energy into the galaxy and its environment. Both of these ultimately contribute to the growth of the medium around the galaxy and ultimately the evolution of the galaxy itself.

While studying a known interacting galaxy pair, NGC7733 and NGC7734, a team of researchers from the Indian Institute of Astrophysics (IIA) consisting of Jyoti Yadav, Mousumi Das, Sudhanshu Barway (formerly of the SAAO), and Francoise Combes of College de France (Chaire Galaxies et Cosmologie, Paris), detected unusual emissions from the centre of NGC7734 and a large, bright clump along the northern arm of NGC7733. Their investigations showed that the clump is moving with a different velocity compared to the galaxy NGC7733 itself. This means that it was not a part of NGC7733. Rather, it was a small separate galaxy behind the arm. They named it NGC7733N.

This study, published as a letter in the journal 'Astronomy and Astrophysics', used data from the Ultra-Violet Imaging Telescope (UVIT) onboard the first Indian space observatory ASTROSAT, the European integral field optical telescope called MUSE mounted on the Very Large Telescope (VLT) in Chile, as well as infrared images from the optical telescope IRSF in South Africa.

The ultraviolet (UV) and H-alpha images also supported the presence of the third galaxy by revealing star formation along with the tidal tails, which could have formed from the merger of NGC7733N with the larger galaxy. Each of the galaxies hosts an active supermassive black hole in their nucleus and hence form a very rare triple AGN system.

According to Dr Barway, a major factor impacting galaxy evolution is galaxy interactions, which happen when galaxies move close to each other and exert tremendous gravitational forces on each other. During such galaxy interactions, the respective supermassive black holes can get near each other. The dual black holes start consuming gas from their surroundings and become dual AGN.

The IIA team explains that if two galaxies collide, their black hole will also come closer by transferring the kinetic energy to the surrounding gas. The distance between the blackholes decreases with time until the separation is around a parsec (3.26 light-years). The two black holes are then unable to lose any further kinetic energy in order to get even closer and merge. This is known as the final parsec problem. The presence of a third black hole can solve this problem. The dual merging blackholes can transfer their energy to the third blackhole and merge with each other.

Many AGN pairs have been detected in the past, but triple AGN are extremely rare, and only a handful have been detected before using X-ray observations.

However, the IIA team expects such triple AGN systems to be more common in small merging groups of galaxies. Although this study focuses only on one system, the results suggest that small merging groups are ideal laboratories to detect multiple supermassive black holes.

*Journal reference: Astronomy & Astrophysics, Volume 651, id.L9, 6 pp. (https://www.aanda.org/articles/aa/full_html/2021/07/aa41210-21/aa41210-21.html)*



# Astronomers See White Dwarf "Switch On and Off" for First Time - October 2021

Astronomers have used a planet-hunting satellite to see a white dwarf abruptly switching on and off for the first time. The team observed the phenomenon in the white dwarf binary system, TW Pictoris, which is found about 1 400 light-years from Earth.

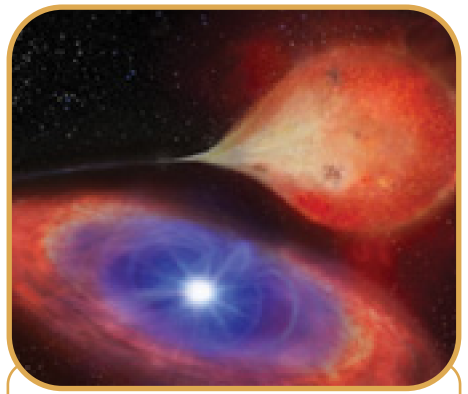


*Figure 1. An artist's impression of an example of a white dwarf . In this image, the white dwarf MV Lyrae is accreting as it draws in material from a companion star. Credit: Helena Uthas.*

It was discovered over 35 years ago by one of the co-authors, Prof David Buckley (SAAO), during his PhD, and was classified as a possible magnetic system. Its unusual nature went undetected until now. TW Pictoris consists of a white dwarf that feeds from a surrounding accretion disc fuelled by hydrogen and helium from its smaller companion star. As the white dwarf eats – or accretes – it becomes brighter.

The researchers led by Durham University, UK, used NASA's Transiting Exoplanet Survey Satellite (TESS) to observe the unique phenomenon.

White dwarfs are what most stars become after they have burned off the hydrogen that fuels them. They are approximately the size of the Earth but have a mass closer to that of the Sun. The white dwarf observed by the team is known to be accreting or feeding, from an orbiting companion star.

With the new observations, astronomers saw it lose brightness in 30 minutes, a process only previously seen to occur in accreting white dwarfs over a period of several days to months.

The brightness of an accreting white dwarf is affected by the amount of surrounding material it feeds on, so the researchers say something is interfering with its food supply.

They hope the discovery will help them learn more about the physics behind accretion – where objects like black holes, white dwarfs and neutron stars feed on surrounding material from neighbouring stars.

The findings are published in the journal 'Nature Astronomy'.

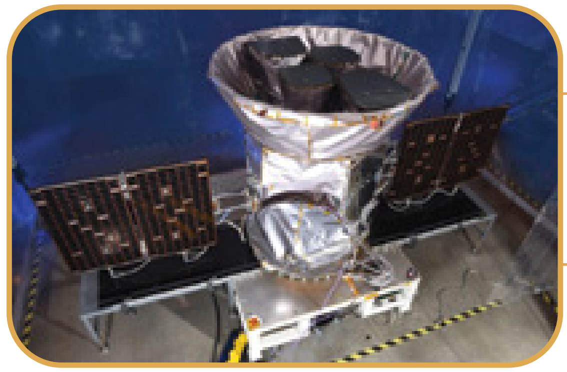


*Figure 2. The fully integrated TESS, which launched in 2018 to find thousands of new planets orbiting other stars. Researchers led by Durham University, UK, used TESS to observe the white dwarf binary system TW Pictoris. Credit: Orbital Alliant Techsystems Inc. (ATK) / NASA.*

Using the precise observational detail offered by TESS, normally used to look for planets outside our solar system, the Durham-led team saw abrupt falls and rises in brightness never before seen in an accreting white dwarf on such short timescales.

Because the flow of material onto the white dwarf's accretion disc from its companion star is relatively constant, it should not drastically affect its luminosity on such short timescales.

Instead, the researchers believe what they are witnessing could be reconfigurations of the white dwarf's surface magnetic field.

During the "on" mode, when the brightness is high, the white dwarf feeds off the accretion disc as it normally would. Suddenly and abruptly, the system turns "off" and its brightness plummets.

The researchers say that when this happens, the magnetic field is spinning so rapidly that a centrifugal barrier stops the fuel from the accretion disc from constantly falling onto the white dwarf.

During this phase, the amount of fuel the white dwarf is able to feed on is being regulated through a process called "magnetic gating".

In this case, the spinning magnetic field of the white dwarf regulates the fuel passing through a "gate" onto the accretion disc, leading to semi-regular small increases in brightness seen by the astronomers.

After some time, the system sporadically turns "on" again, and the brightness increases back to its original level.

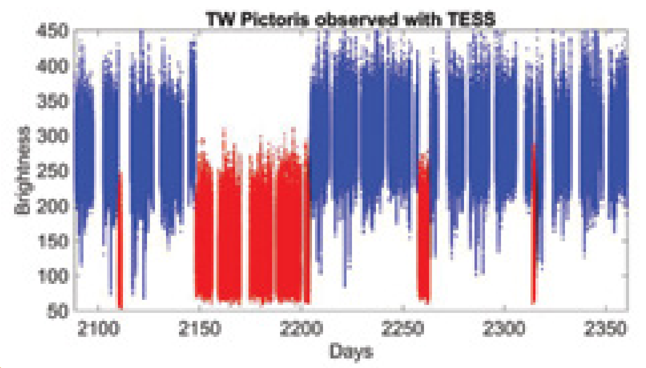



*Figure 3. TW Pictoris is a relatively bright binary system where a white dwarf accretes material from a companion star. Observations with the TESS have revealed how TW Pictoris suddenly and abruptly fades in less than 30 minutes.The figure shows how the TESS observations reveal this transition from a bright mode marked in blue, to a faint mode marked in red. Credit: Simone Scaringi.*

Lead author Dr Simone Scaringi, in the Centre for Extragalactic Astronomy at Durham University, UK, said, "The brightness variations seen in accreting white dwarfs are generally relatively slow, occurring on timescales of days to months. To see the brightness of TW Pictoris plummet in 30 minutes is in itself extraordinary as it has never been seen in other accreting white dwarfs and is totally unexpected from our understanding of how these systems are supposed to feed through the accretion disc. It appears to be switching on and off. This really is a previously unrecognised phenomenon and because we can draw comparisons with similar behaviour in the much smaller neutron stars, it could be an important step in helping us to better understand the process of how other accreting objects feed on the material that surrounds them and the important role of magnetic fields in this process."

As white dwarfs are more common in the universe than neutron stars, the astronomers hope to look for other examples of this behaviour in future research projects to learn more about accretion.

The research was funded in the UK by Durham University. The research team also included the Italian National Institute for Astrophysics, the SAAO, UCT, the University of the Free State (South Africa), Radboud University (The Netherlands), the University of Southampton (UK), and the University of Notre Dame (USA).

*Source Information:*
*An accreting white dwarf displaying fast transitional mode switching, Scaringi, S, et al, is published in Nature Astronomy, DOI 10.1038/s41550-021-01494-x.*



# Observations from Amateur Astronomers Lead to the Discovery of a Warped Disc around a Black Hole in our Milky Way - October 2021

An international team of astrophysicists from South Africa, the UK, France and the US have found large variations in the brightness of light seen from around one of the closest black holes in our Galaxy, 9 600 light-years from Earth, which they interpret as being due to a huge warp in its accretion disc.

*Figure 1. An artist's impression of the black hole system MAXI J1820+070, based upon observed characteristics. The black hole is seen to feed off the companion star, drawing the material out into a vast disc of spiralling matter. As it falls closer to the black hole itself, some of that material is shot out into energetic pencil-beam 'jets' above and below the disc. The light here is intense enough to outshine the Sun a thousand times over. ©John Paice*

This object, MAXI J1820+070, erupted as a new X-ray transient in March 2018 and was discovered by a Japanese X-ray telescope onboard the International Space Station. These transients, systems that exhibit violent outbursts, are binary stars, consisting of a low-mass star, similar to our Sun and a much more compact object, which can be a white dwarf, neutron star or black hole. In this case, MAXI J1820+070 contains a black hole that is at least eight times the mass of our Sun.

The first findings have now been accepted for publication in the international highly ranked journal, Monthly Notices of the Royal Astronomical Society, whose lead author is Dr Jessymol Thomas, a Postdoctoral Research Fellow at the SAAO. Dr Thomas worked closely with fellow SAAO colleagues Professors David Buckley and Stephen Potter, and University of Southampton (UK) researcher and former SAAO Director, Professor Phil Charles, who played a leading role in this project.

The discovery presented in the paper was made from an extensive and detailed light-curve obtained over almost a year by dedicated amateurs around the globe who are part of the AAVSO (American Association of Variable Star Observers).  MAXI J1820+070 is one of the three brightest X-ray transients ever observed, a consequence of both its proximity to Earth and being outside of the obscuring plane of our Milky Way Galaxy. Because it remained bright for many months, this made it possible to be followed by so many amateurs.

Professor Charles explained, "Material from the normal star is pulled by the compact object into its surrounding accretion disc of spiralling gas. Massive outbursts occur when the material in the disc becomes hot and unstable, accretes onto the black hole and releases copious amounts of energy before traversing the event horizon. This process is chaotic and highly variable, varying on timescales from milliseconds to months."

The research team have produced a visualisation of the system, showing how a huge X-ray output emanates from very close to the black hole, and then irradiates the surrounding matter, especially the accretion disc, heating it up to a temperature of around 10 000K, which is seen as the visual light emitted. That is why, as the X-ray outburst declines, so does the optical light.

But something unexpected happened almost three months after the outburst began when the optical light curve started a huge modulation – a bit like turning a dimmer switch up and down and almost doubling in brightness at its peak – with a period of about 17 hours. Yet there was no change whatsoever in the X-ray output, which remained steady. While small, quasi-periodic visible modulations had been seen in the past during other X-ray transient outbursts, nothing on this scale had ever been seen before.

What was causing this extraordinary behaviour?

"With the angle of view of the system as shown in the pictorial, we could quite quickly rule out the usual explanation that the X-rays were illuminating the inner face of the donor star because the brightening was occurring at the wrong time," said Professor Charles. Nor could it be due to varying light from where the mass transfer stream hits the disc as the modulation gradually moved relative to the orbit.

This left only one possible explanation, the huge X-ray flux was irradiating the disc and causing it to warp, as shown in Figure 1. The warp provides a huge increase in the area of the disc that could be illuminated, thereby making the visual light output increase dramatically when viewed at the right time. Such behaviour had been seen in X-ray binaries with more massive donors, but never in a black-hole transient with a low mass donor like this. It opens a completely new avenue for studying the structure and properties of warped accretion discs.

Professor Charles continued, "This object has remarkable properties amongst an already interesting group of objects that have much to teach us about the end-points of stellar evolution and the formation of compact objects. We already know of a couple of dozen black hole binary systems in our Galaxy, which all have masses in the 5-15 solar mass range. They all grow by the accretion of matter that we have witnessed so spectacularly here."

Starting some five years ago, a major science programme on SALT to study transient objects has made a number of important observations of compact binaries, including black hole systems like MAXI J1820+070. As the PI for this programme, Professor Buckley, states, "SALT is a perfect tool to study the changing behaviour of these X-ray binaries during their outbursts, which it can monitor regularly over periods of weeks to months and can be coordinated with observations from other telescopes, including space-based ones.

*ArXiv Link: https://arxiv.org/pdf/2108.05447.pdf*

*Original article: https://academic.oup.com/mnras/advance-article-abstract/doi/10.1093/mnras/stab3033/6410674*

*This study was published in Monthly Notices of the Royal Astronomical Society, authored by Jessymol Thomas, David A.H. Buckley, Marissa Kotze and Stephen Potter (all at the SAAO), Phil Charles and John Paice (University of Southampton), Jean-Pierre Lasota (University of Paris), and Jack Steiner (Massachusetts Institute of Technology - MIT). This work formed part of Jessymol's postdoctoral studies of transients under the guidance of David Buckley and Stephen Potter and was supported by the South African NRF, tSTFC, and a UGC-UKIERI (University Grants Commission & UK-India Education and Research Initiative) Thematic Partnership.*

*Figure 1 was produced by Dr John Paice who recently graduated from the University of Southampton and the Inter-University Centre for Astronomy & Astrophysics in Pune, India, with support from a UKIERI (UK-India) grant.*

# In the Wake of the Dying Sun - March 2022

A team of scientists from the SAAO, Michigan State University (MSU), and the University of Miami (UM) have created novel 3D simulations to investigate how dying stars interact with their environment and nearby planets.

The team created simulations of the interaction of red giant stars which eject dense outflows of gas and dust into their surroundings, on nearby companions such as planets and brown dwarfs. In this way, the team is able to study the effect of such close companions on the stellar outflow properties, for example its shape, mass and momentum.

"Our simulations show that the interaction of the nearby companion with the stellar winds or outflows creates complex structures, such as spirals, arcs and bars," said Dr Elias Aydi, a research associate at MSU and a former PhD student at SAAO, who led the study along with Prof. Shazrene Mohamed (UM and SAAO). "These simulations give us a peek into what the Solar System might look like when our Sun turns into a giant star, in a few billion years from now," he added.

At the end of their lifetime, stars like our Sun become unstable and expand in size, turning into red giant stars. During this phase, the extended outer layers are only loosely bound to the star by gravity, so the star loses a considerable amount of its mass through stellar winds. Our Sun is expected to turn into a giant star in a few billion years from now, likely expanding beyond Earth's orbit, and swallowing the inner planets like Mercury, Venus, and Earth.

At a certain point of the giant phase, a star with a mass close to that of the Sun experiences regular pulsations with periods longer than 100 days. These pulsations are actual expansion and contraction of the unstable atmosphere of the giant star, in an attempt for the star to regain its equilibrium. The brightness of the star oscillates due to the pulsations, showing an increase by a factor of 10 up to more than 100. The pulsations produce radial shock waves that travel through the circumstellar environment, similar to ripples propagating on the surface of a pond when we throw a rock in it.

"These shock waves interact with the wake of the nearby companion, producing even stronger, enhanced shocks — regions of abrupt change in velocity, temperature, and density," said Prof. Mohamed. "The process is similar to what happens when ocean waves meet the wake of a speedboat, just more extreme," she added.

While the companion orbits the giant star, it periodically meets a new cycle of stellar pulsations. "If there is a certain resonance between the orbital period of the companion and the stellar pulsations, in other words the companion meets the stellar pulsations every time around the same place, the strong shocks between the pulsations and the companion wakes cluster into multiple spiral structures, extending for billions of kilometres around the system," Prof. Mohamed explains.

The results of the simulations also show that if the companion travels around the star at a more extended orbit, it forms a single spiral structure created by its wake, but punctuated by undulations due to the pulsations.

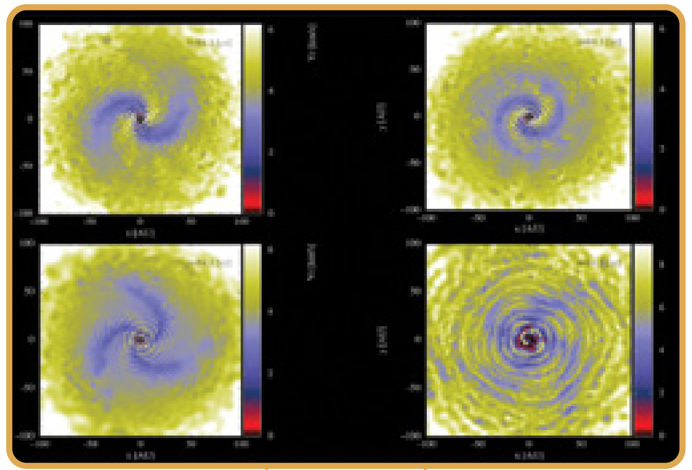


*Figure 1.*

*Figure 1. These images show four different possible patterns that could emerge around a giant star, orbited by a nearby giant planet. Each image shows a broad expanse of space, billions of miles across, with the star as a black orb at the centre. The companion is too small to see clearly at this scale, but it creates a visible wake behind it as it travels through the gas and dust that fill the circumstellar environment. The gas is coloured shades of green and blue, with green gas moving faster than blue. It's in the green gas that we see different possible patterns: two-armed, three-armed, and four-armed spirals. Credit: Elias Aydi / MSU.*

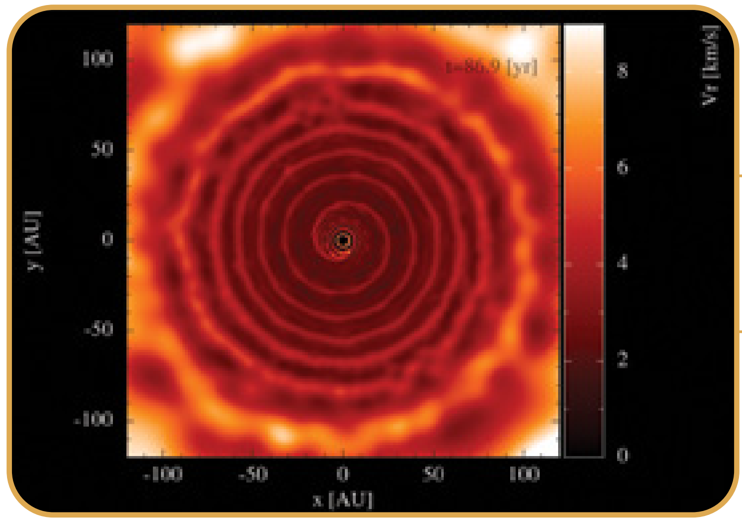



*Figure 2. If the companion ends up far enough from the star, a spiral with a single arm would be seen. Credit: Elias Aydi / MSU.*

The team used the smoothed particles hydrodynamic method, a computational method used to simulate the mechanics of fluid flows, to produce the simulations and simulate the interaction between the stellar pulsations with the nearby companion.

"This is the first time such simulations are done in 3D and it took weeks up to months of computational time to run each one of these simulations on a super-computer," Dr Aydi said.

A super-computer or a computer cluster is the equivalent of ~hundreds of computers working together, performing calculations to solve the fluid equations." If we ran these simulations on a normal, commercial laptop or desktop instead, we would have to wait thousands of years for an answer," he added.

When our Sun runs out of fuel in its core and turns into a giant, pulsating star, the stellar pulsation might interact with the giant, gaseous planets in our solar system, such as Jupiter. The team suggests that if Jupiter ends up in a nearby orbit around the future giant Sun and if there is a resonance between Jupiter's orbital period and the solar pulsations, multiple spiral structures might form around the Sun. If Jupiter ends up in an extended orbit around the Sun, a single spiral arm might form.

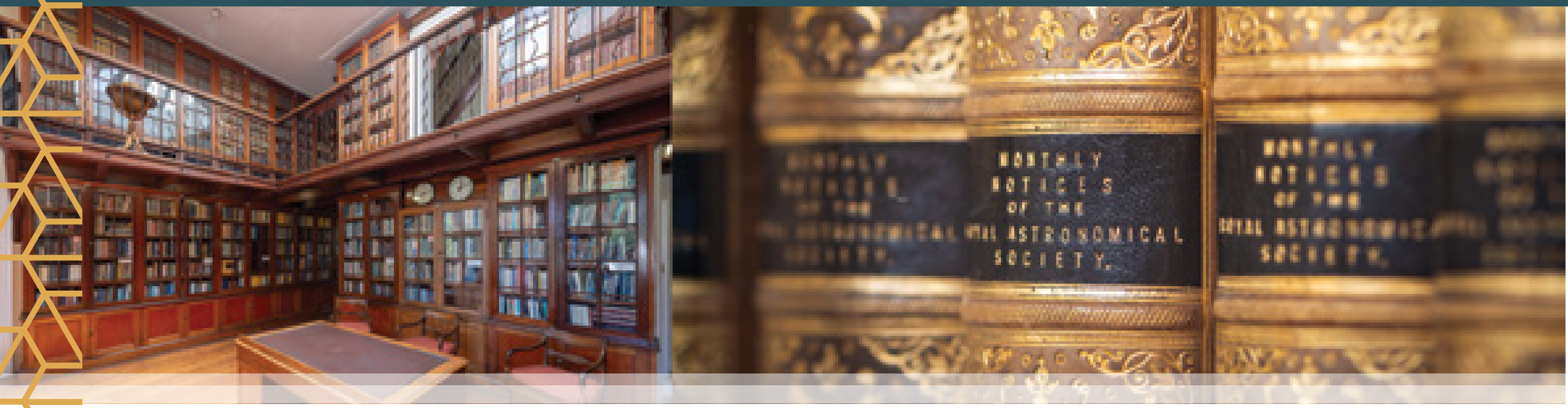
While such multiple spiral structures have not yet been observed, single spiral structures have been observed frequently around red giant stars, but these are due to the interaction of the star with a more massive, binary star companion in a very wide orbit dozens of times the distance Sun-Earth. However, the team hopes that with current and future high-resolution and high-sensitivity facilities such as the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile or the recently launched NASA's James Webb Space Telescope (JWST), we might start observing such multiple spiral structures around giant, evolved stars.

*Link: https://arxiv.org/abs/2203.08318*
*Video Download: https://www.dropbox.com/s/s4qi1p19c68zxw7/SAAO_edited.mp4?dl=0*



# **SUPPORTING** DEPARTMENTS

# LIBRARY/INFORMATION SERVICES



2021 was a busy year with the library "Shape-Up" project and the subsequent launch of the new GeniePlus library management system.

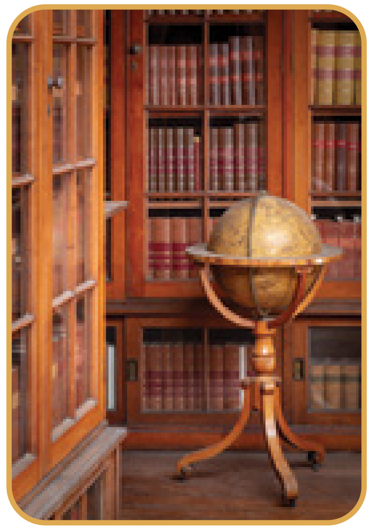
This system allows the sharing of resources between facilities within the NRF, including the SAAO, iThemba Labs, and SARAO. As such, in 2022, two contract workers were employed over a five-month period to help improve the library system. The library material had become an issue to locate, as a result of years of shifting the books to various locations around the Observatory to accommodate the increase in staff and students.

The physical locations of over 10 000 library items were identified, checked and changed where necessary, and items not yet in the system were catalogued. This was done to ensure that material can be searched and found by users of the library, whether they are physically visiting the library or accessing it electronically. The online publications database was updated and a telescope bibliography was added to the new GeniePlus SAAO library portal.

In addition, in 2022, for the first time, the library celebrated South African Library Week by marketing the library amongst the SAAO staff, who were informed about the services offered, and the new library system. SAAO librarians also collected suggestions as to what other services the staff would like to see coming from the library.

They also attended and participated in three library-related virtual conferences during 2021, where they delivered papers and shared ideas for possible ways to improve on the library services that were already being offered.

The library continued to provide critical access to hundreds of e-journals, e-books and physical books to support the research being done at the SAAO. It also provided statistical data on the key performance indicators (KPIs) of the SAAO for reporting purposes.





# INFORMATION/TECHNOLOGY (IT) SERVICES

The IT team was fortunate to have two new members join them in 2021. They were a welcome addition and have helped to lighten the load on the other members of the team. In addition, they have also brought new skills and have improved the reach of the IT department.

## Servers:

The IT department has upgraded memory in all the servers in the Cape Town data centre, since they were getting close to their limits, due to hosting more services. We are also ordering a new server to replace machines that are out of warranty.

## Storage:

The original tender for storage replacement units was published, but there were only three respondents. All of them came back with much higher prices than expected, higher than what the department's budget allowed. Subsequently, we decided to change some of our specifications and will be going out for tender in the new year. Since the old storage is still under pressure, we decided to purchase a Network Attached Storage (NAS) device to archive some of the old data and remove it from primary storage.

## Network:

IT has managed to identify the causes for slow and unreliable Wi-Fi, and has dealt with the issue. The cabinet in the fibre laboratory has been moved to the foyer to reduce contamination and the need to enter the laboratory. New switches have been purchased to replace the old hardware.

## E-mail:

E-mail related issues, due to the change from the saao.ac.za to the saao.nrf.ac.za domain, have caused more bouncing from our list servers. Gmail upgraded their security requirements and we had to add additional security to the SAAO mail servers for Gmail to accept messages from us.

## Fibre:

As in previous years, the IT department has faced issues due to the fibre being out. The fibre problems in 2021 were not isolated to Sutherland. The Cape Town site had a few days of downtime as well due the link at the UCT campus going down. The second link to the Pinelands hop has since been reinstated and is now providing redundancy. The mitigation for Sutherland fibre outages are the new fibres that have now been approved, and the supplier has been given the go-ahead to start work on the installation. The connectivity of a few buildings at the Cape Town site was affected by rats that ate the fibre near the McClean telescope. The affected buildings were Riverside, the Director's house, Jakaranda and House 4. The IT department sent a network team to replace the affected piece.

## Power:

Loadshedding has again been a source of difficulty, but less so than in the previous years. The power for the SAEON (South African Environmental Observation Network) building was installed.

## New Projects:

Since IT is an ever-changing landscape, there are always new challenges to tend to. The department is planning on upgrading the mail servers, as well as the identity-management systems.

# SCIENCE ENGAGEMENT AND OUTREACH





## Visitors' Centre

The construction of the new Visitors' Centre in Cape Town began in March 2021. Although the weather, especially the rain, caused some delays, the project finished mostly on schedule by November 2021.

The Visitors' Centre will house various exciting and engaging exhibits showcasing the science and technology at the SAAO. It will also incorporate artworks, and animations based on traditional Khoi and San starlore.

The exhibits will include an interactive astronomical data presentation, where visitors can explore astronomical data through the ages. We will also have a technical exhibit highlighting the incredible SALT instruments. The Centre will also house various cultural exhibits. The highlight will be a spectacular backlit ceiling of the night sky, incorporating indegineous Kora(!Ora) constellations, which project manager Dr Daniel Cunnama conducted research on, based on works by Bleek and Lloyd in 1874.

The installations will be accompanied by a conceptual write up of each piece provided initially in four languages: Khoekhoegowab, isiXhosa, Afrikaans and English. This multilingual approach to communication and education is at the forefront of inclusivity at the Visitors' Centre, and in the future we hope to add additional national minority languages.

The solar and spectroscopy display includes a heliostat. This is an instrument which tracks the Sun throughout the day, and projects a large live image of the Sun and a solar spectrum into the room below. The heliostat was initially due to be housed in Sutherland, but due to difficulties in securing the cost needed to build the required infrastructure, this was unable to happen. The project manager, Dr Daniel Cunnama, identified the original coal storeroom of the old Pump House as an ideal location for the heliostat and incorporated this into the Visitors' Centre building design. Slight adaptations needed to be made to the instrument to account for the 1.55 degrees difference in latitude from Sutherland.

The exhibits are currently under construction, with a target date of mid-2022, after which the Centre will be opened to the public.

*Figure 1. The Visitors' Centre, SAAO headquarters, Cape Town.*

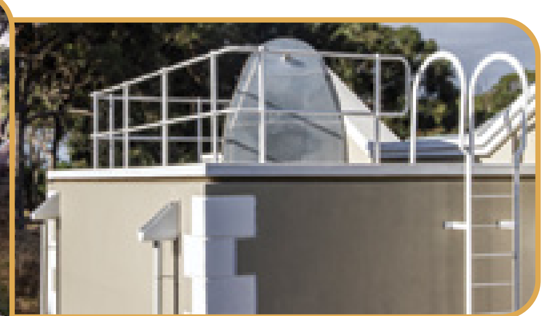


*Figure 2. The heliostat.*

## Cape Town Open Nights

The SAAO Cape Town Open Nights resumed in March 2022, after stopping due to COVID-19 concerns and regulations two years earlier.

These take place at the SAAO headquarters in Observatory, at 20h00, on the second and fourth Saturday of every month.

The Open Nights include a talk about a topical subject related to astronomy or physics, and a visit to the historic McClean telescope, the observatory museum, and the library. The talks so far have included one about asteroids (by Nicolas Erasmus), the fate of the Universe (by Bruce Bassett) and black holes (by Vanessa McBride).

If the weather is clear, visitors also get the chance to do some stargazing using the McClean and other telescopes set up for the night.

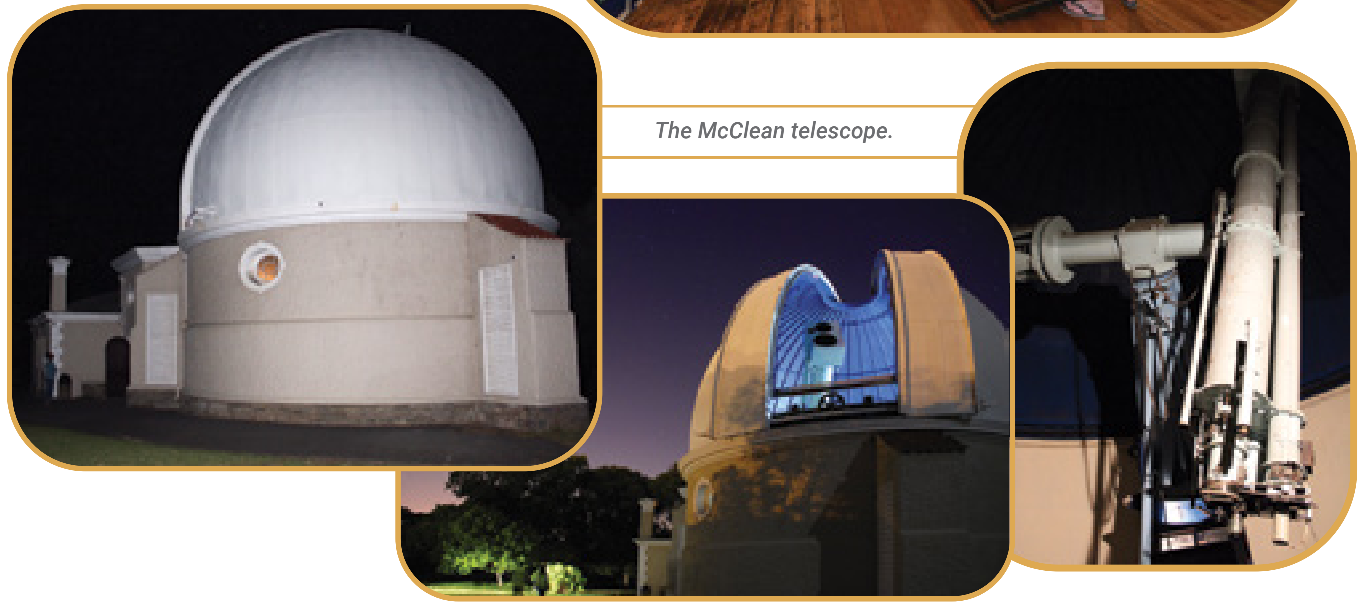
Due to COVID-19 regulations, the number of visitors is currently limited to 40 people and booking is required. Nevertheless, the Open Nights have been a huge success and are always booked up very fast.

*Vanessa McBride giving a talk on black holes in April 2022.*

*Christian Hettlage giving a tour of the library and a short talk on the history of the Observatory.*

*Visitors looking through the telescopes set up for the night.*

*Visitors in the SAAO museum.*



*The McClean telescope.*

## SALT Virtual Tour

In April 2021, the SAAO and SALT launched an all-new virtual tour of the Sutherland site. The tour, which is available on the SAAO and SALT websites, provides an interactive 360-degree experience where visitors can tour the Sutherland plateau, as well as enter various telescopes to explore inside.

The tour also includes night-time vistas of the Sutherland sky, and a full tour of the inside of SALT.


*Website: https://storage.net-fs.com/hosting/7138936/1/*

## Connect South Africa

In 2021, Connect South Africa announced they would be granting a funded residency to one artist from Switzerland and another from Southern, East or West Africa. They invited submissions from artists with a distinct interest in an interdisciplinary approach, and a keen engagement with scientific thinking and fundamental science.

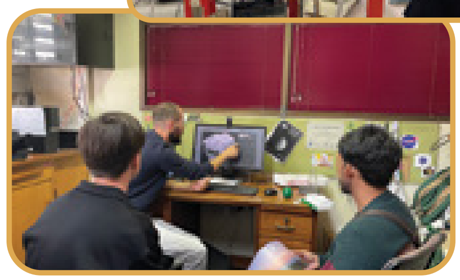
Connect South Africa is part of the Connect collaboration, which serves as a global platform for interactions and dialogue between artistic and scientific communities across Switzerland, Chile, South Africa and India, which will be realised during the course of 2021-2024.

Connect South Africa supports artistic residencies in Switzerland and in South Africa that germinate new projects, which in turn feed into and animate an ongoing programme of professional exchange between artists and scientists across this international network. Each country is host to some of the most singular scientific facilities and minds in the world, dedicated to advancing our understanding of the origins and the evolution of the universe. Each context provides different and unique opportunities for artists to be confronted with the scale, reach and implications of cutting-edge experimentation in the scientific field.

The two selected artists were Kamil Hassim and Ian Purnell.

They were invited to research and explore new expressions in connection with fundamental research and the physics of the cosmos. The artists participated in a dual residency split between CERN, the European Laboratory for Particle Physics in Geneva (home of the world's largest particle accelerator), the Large Hadron Collider (LHC), and the array of optical and radio astronomy observatories across rural and urban South Africa, particularly in the vast semi-desert expanses of the Northern Cape. These include SARAO's MeerKAT radio telescope, the precursor to the South African component of the SKA telescope, as well as SALT, and a large number of telescopes operated by the SAAO. They spent three weeks at CERN, Geneva, and five weeks in South Africa.

This research-led residency programme successfully led to the development of new work, resulting from collaborations between the scientists, engineers and staff of the laboratories and observatories, and with the support of the combined curatorial team of arts at CERN in Geneva and "–defunct context" in South Africa.



*Artists Kamil Hassim and Ian Purnell visiting the SAAO headquarters in Observatory, Cape Town. SAAO staff are showing them around and explaining the work they do.*

*Artists Kamil Hassim (right) and Ian Purnell (left) visiting the SAAO telescope site in Sutherland (SALT is in the background).*



# Salt Collateral Benefits Programme (SCBP) Report

The SCBP was established during the construction of SALT and is aligned to the South Africa Agency for Science and Technology Advancement (SAASTA), IAU's OAD, and the Department of Science and Technology's decadal strategy for astronomy development in South Africa.

Its mandate is to utilise the knowledge, technology and other available resources within the SAAO and similar institutions in order to facilitate education enhancement, science communication, socio-economic development and public engagement, and thereby contribute to the improvement of the quality of life of all people within reach.

Over the period 2021/2022, the SAAO education and outreach teams continued persistently to communicate the beauty, relevance and power of astronomy, despite the disruptive and restrictive nature of the COVID-19 pandemic and associated preventative protocols.

3 534 people were reached over this period, and they engaged through a number of programmes including: girl-focussed programmes, school outreach, the astronomy debate, astronomy quiz, astronomy competitions for teachers, projects aimed at Sutherland learners and youth, teacher-based workshops, Sutherland site tours, indigenous astronomy programmes, the production and dissemination of a gravitational documentary, as well as the production of a new SAAO career brochure.

## School Outreach

### *Port Nolloth & Namaqua High*

In a bid to further extend the SCBP footprint in the Northern Cape Province, a massive outreach programme was implemented in November 2021. This included presentations, as well as hands-on activities such as telescope building, solar system scaling, and evening star gazing using our Dobsonian telescopes. The students also learnt about the phases of the moon. 944 learners from Namaqua High, Port Nolloth Primary and High School participated in the outreach programme.

*Port Nolloth school learners.*



*Jeremy Stuurman of the SAAO at Namaqua High School.*

### *Cape Town School Visits*

Outreach programmes were implemented at Rhenish Primary, Learning Kat School, Bergvliet High, and Cannons Creek Independent School, reaching 120 learners.

These activities included presentations, Stellarium demonstrations and hands-on activities, such as telescoping building and learning about the phases of the moon.

The Cannons Creek Independent School visit was conducted by Cedric Jacobs on 20 August 2021, under very strict rules and COVID-19 protocol enforced by the school's principal and educators. Cedric presented 29 Grade 3 learners with a lesson on the solar system, as well as a telescope and binocular workshop.

*Cedric Jacobs teaching Cannons Creek children how to make a telescope out of everyday materials.*

*Learning Kat school teachers and pupils*

On 3 December 2021, Cedric Jacobs visited Rhenish Primary School in Stellenbosch, where he held Stellarium and telescope workshops for 60 Grade 6 learners.

Collaborating with other NRF facilities and DSI entities, the SCBP also participated in a "Youth in Science and Robotics" programme, which was held in Phillipi on 22 February 2022. 100 learners participated.

Cedric Jacobs hosted 11 learners in grades 8, 9 and 10 from Learning Kat School at the SAAO in Cape Town on 2 March 2022. He provided a tour, and hosted telescope and binocular workshops. A talk was also held by science engagement astronomer Daniel Cunnama.

On 29 March 2022, Thembela Mantungwa presented a site tour to 20 Astronomy Club learners (grades 11 and 12) from Bergvliet High School. This included visits to various departments at the SAAO in Cape Town as well as a look at the ROS and the McClean telescope. A highlight of the tour was the visit to the technical building where engineers from both the mechanical and electronics divisions spoke to the group of eager learners about instrumentation and the role that it plays in advancing astronomy.

*Bergvliet High School learners visiting the SAAO headquarters in Observatory.*

### *Sutherland School Visits*

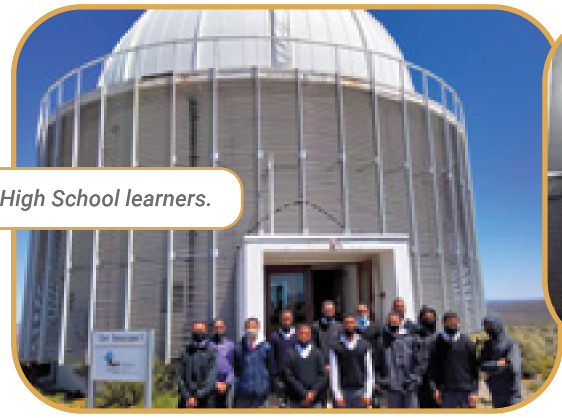
On 3 November 2021, the SCBP hosted their first Sutherland site tour, conducted by Jeremy Stuurman and Anthony Mietas, with 24 Grade 9 learners from Sutherland High School.

Since then, 49 other learners (from Cedar House in Cape Town and Sutherland High) have visited Sutherland.

Patrick Van Wyk took 15 Sutherland High School learners in grades 9, 10 and 11 on a day tour of the telescopes in Sutherland on 7 December 2021, and Jeremy Stuurman took eight Grade 8 learners from Sutherland High on 8 December.



Cedar House visited the Sutherland site on 5 and 12 March 2022, where Jeremy Stuurman gave them a tour of SALT.



*Sutherland High School learners.*

*Cedar House school learners in SALT.*

### *Girl-focused Events*

Thanks to SAASTA who provided funding, three girl-focused learner events were organised at De Kruine Secondary School, Spine Road High School and Elsies River High School, and are discussed in the next few paragraphs. A total of 205 learners participated in these programmes, in grades 10 and 11.

On 24 June 2021, Cedric Jacobs and Buzani Khumalo of the SAAO travelled to De Kruine Secondary School in Touws River where they held a Careers Science Talk event, aimed at girls in science. They invited three guest speakers who delivered their talks via Zoom. A scientist, Prof. Carolina Ödman-Govender, who is a professor of astrophysics at the University of the Western Cape, spoke about data science. Prof. Anna Franckowiak from the Ruhr University in Bochum, Germany, gave a talk on high-energy neutrinos, and Cape Peninsula University of Technology (CPUT) lecturer, Lusani Vhangani, spoke about food science as a career. The event drew the interest of a few boys who requested to be part of the event, as they wanted to find out more about these careers. The learners engaged virtually with the scientists by asking questions. 20 learners took part.

On 2 November 2021, Buzani Khumalo and Cedric Jacobs visited Elsies River High, where they held presentations for 75 learners.

Buzani Khumalo and Cedric Jacobs visited Spine Road High School on 4 November, where they held presentations for 110 learners.

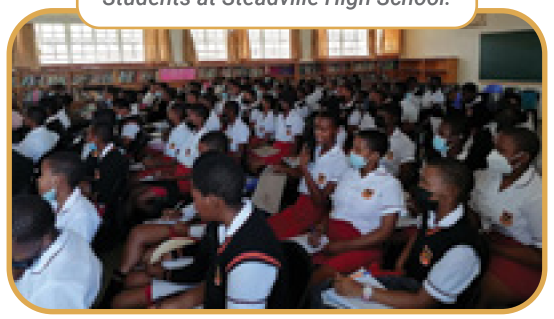
The audiences at these programmes were addressed and had an opportunity to engage with female scientists from fields including astronomy, data science, etymology, chemistry, and food technology. The presentations and follow-up deliberations were based on career information and the sharing of relevant resources and aimed to inspire youth to continue with science and technology education.

These were in a hybrid format, which consisted of a combination of in-person and Zoom-based participation. The events were also shared live on social media, which allowed anyone interested to participate.

Joining the international community in celebrating the International Day of Girls and Women in Astronomy, a series of five whole-day hybrid events (in-person in Ladysmith and online) were held in February and March 2022. 434 girls from five schools in the area (namely Silindokuhle, Steadville, Bhevu, Qophindlela and Sakhelwe) were addressed.

The head of SALT astronomy, Dr Encarni, also presented to girl learners at Wynberg Girls' School.

*Students at Steadville High School.*



## The Maths and Science Teacher in Sutherland Schools

We thank the SALT Board for the support and funding. The SCBP has been able to employ Mr Thabo Banda to teach mathematics at both Roggeveld and Sutherland High Schools. He is also helping with the co-curricular and extracurricular mathematics and science programmes. This will go a long way in retaining and improving the performance of Sutherland learners. He has adapted his teaching and is committed to contributing towards improving maths and science in the area. In October 2021, 148 learners were involved in these classes.

## Laboratory Programme with the Association for Educational Transformation (ASSET)

Working with ASSET, the SCBP has initiated a laboratory assistance programme. The aim is to support the completion of the prescribed curriculum science experiments. Since many schools in South Africa still lack some of the necessary laboratory apparatus, the SCBP decided to provide alternatives, mostly kitchen-based products, that can be utilised to complete the experiments. This also encourages the learners to repeat the experiments at home. In June 2021, 64 learners participated in this programme at Sinenjongo High School, in grades 10 and 11.

## Online Teacher Training Workshop

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

## Astronomy Debate

A new astronomy debate competition was successfully designed and implemented. The aim of the programme is to empower high school science learners by teaching them the art of debating and logical argumentation. It also seeks to encourage critical reading, research and writing in science. It intends to encourage collaborative working among learners, and create opportunities for postgraduate students to act as coaches, while scientists act as judges. The Academy of Mathematics, Science and Technology and Elsies River High School participated in the augural debate.

In September 2021, the Cape Town Science Centre hosted the final, which involved 12 learners debating the pros and cons of the intended human invasion and settlement on Mars. The judges selected Elsies River as the winner. Scientists from NASA, SARAO and SANSA acted as judges.

With the success of the pilot, the intention is to extend to more high schools in Cape Town and the Karoo Hoogland.

## Special Edition Career Brochure

The SAAO Online Careers Brochure went live in May 2021 and the feedback from teachers, learners, parents, and guidance counsellors has been very positive.

When the COVID-19 pandemic hit South Africa, we faced several periods of strict restrictions, which meant that we were not able to run activities such as our Job Shadow Programme. Since we could no longer have learners on site, we needed to find ways of taking the programme to them. Our Communications and Resources Officer, Natalie Jones, then developed the idea of the SAAO Online Careers Brochure. Spearheading this project from beginning to end, Mrs Jones aimed to give learners the necessary information online so that they could make informed decisions regarding their future studies and subsequent career paths.

The brochure showcases 11 careers, with astronomy featuring twice - from a male and female perspective - as well as electrical, mechanical, and software engineering, and librarianship, to name just a few. SAAO staff members were interviewed and highlighted hard facts about their tertiary education and experiences, as well as specific details around their career. The brochure also includes current salary ranges for each career.


Although it does not replace our Job Shadow Programme, the perk of having the Careers Brochure online is that we can now reach many more learners, as the face-to-face programme is currently only able to cater for about 30 learners per year.

The SAAO Careers Brochure will also be printed and made available at various venues, including the SAAO Visitors' Centres in both Cape Town and Sutherland. In addition to encouraging learners into various fields of mathematics and physics, the intention is also to use it as a marketing tool for future school visits, festivals, and career events.

## The Astro Quiz

Thanks to the work done by the SALT software developer, Dr Christian Hettlage, the SCBP put together an astronomy quiz. It was implemented online nationally and learners from all the provinces were able to participate, even during the fourth wave of COVID-19 pandemic in South Africa.

The SAAO, in collaboration with SAASTA, also successfully implemented the first mobile version of the AstroQuiz. A small team led by Pran Govender (SAAO), Mohammed Omar and Vuyolewethu Mpetsha (DSI SAASTA NYS Volunteers), Moloko Matlala and Erna Taljaard (SAASTA), together with Hawk Mobile (an app development company), decided to use the current SAAO App and added the SAASTA AstroQuiz to it.

The mobile version of the quiz had a strong sustainability focus, given that it promoted the need to reduce paper use. The team had to brainstorm ways to ensure that all learners had an opportunity to take part in the quiz, as most learners and educators in many rural areas in South Africa may not have access to laptops/computers or stable internet connectivity. Developing the quiz on an app meant that it could be easily accessible using phones that have access to Google Play Store, using little data. Furthermore, the intermittent internet connection will not severely affect the quiz once the learners have started.

Through these efforts, 371 schools around the country participated in the AstroQuiz in 2021, and 753 teams.

## Competitions

In 2021, we celebrated 200 years since the founding of the Royal Observatory at the Cape of Good Hope, which later became the SAAO. To commemorate this, the SAAO organised a number of events and competitions.

### *April 2021: Teaching Earth and Beyond Competition*

Early in 2021, the SAAO invited all teachers to enter our Teaching Earth and Beyond Competition. The aim was to showcase teachers who have implemented innovative ways of bringing this important field across to their learners. To enter the competition, teachers had to send us a 5-10 minute long video of themselves teaching Earth and Beyond in an engaging manner. Five teachers won laptops.


### *April 2021: SAAO 200 Bursaries*

The SAAO also gave away ten R20 000 bursaries to first or second year university students from the Northern Cape who have a household income of R 600 000 or less per annum, and are pursuing studies in tourism, mathematics, science education, science or engineering at a South African university. These bursaries were intended to assist with needs like textbooks, travelling, food, computers, and educational equipment.



### *June 2021: SAAO 200 Astrophotography Competition Winners Announced:*

The SAAO and SciFest Africa launched the SAAO 200 Astrophotography Competition. We had six categories: deep sky, shallow sky, planets, moon, Milky Way, and constellation. The winners will have their pictures on display as part of the new SAAO Cape Town Visitors' Centre.

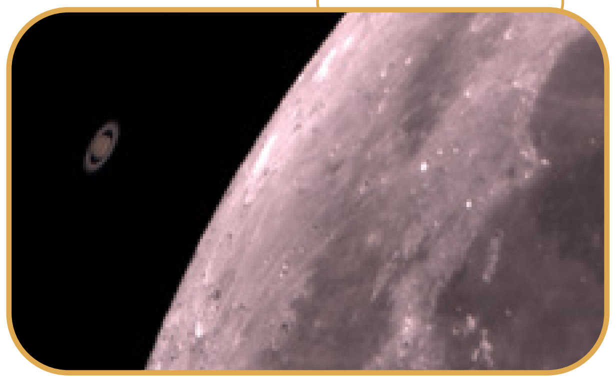
The winners are:

Deep Sky
Janco Moolman

Moon
Carol Botha

Constellation
Keshav Bechoo

Planets
Jaco Brink



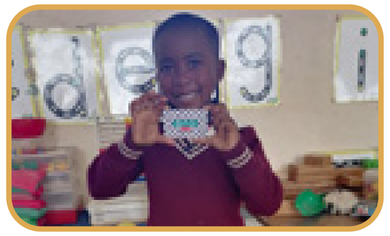
Shallow Sky
Gary Deacon

Milky Way
Damien Peterson

### *June 2021: AstroArt Competition*

Last year, the SCBP organised an AstroArt Competition for foundation phase learners. Prize money of R35 000 was up for grabs, with a R15 000 gift card going to the school with the most entries. There were also gift cards up for grabs: R2 500 for first prize, R1 500 for second prize, and R1 000 for third prize. The competition ended at the end of May 2021. 2 556 entries were received. After a couple of days of judging, we announced the winners of the competition and they received their prizes. Kosie de Wet Primary of Grabouw walked away with the prize for the most entries.

Winners



### *Sutherland Tourism Competition:*

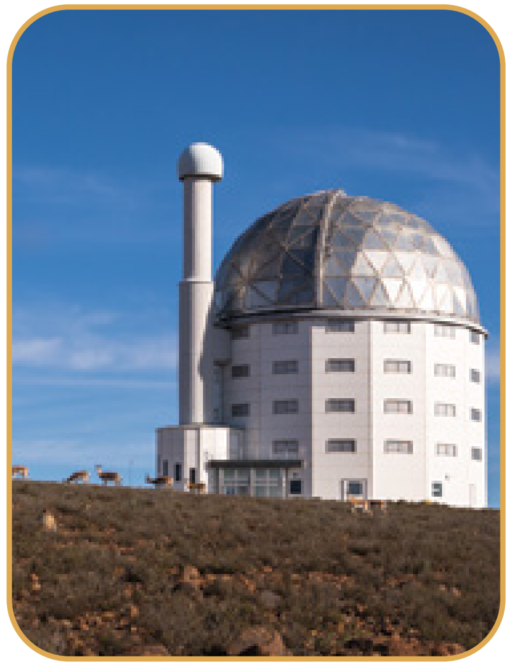
The Sutherland Tourism Competition took place from 23 February 2021 to 31 May 2021. The winner received R10 000 and two runner-ups won R5 000. The SCBP aims to assist the winners in establishing their own tour guiding companies by working with the South African Tourism Board and the Northern Cape Department of Tourism.

## Gravitational Waves Documentary

We thank SAASTA for funding a 45-minute-long documentary celebrating the detection of the gravitational waves by SALT. This was created as part of the National Science Week, using a combination of interviews and graphics. Professor Petri Väisänen, Dr David Buckley, Professor Bruce Basset, Dr Ramotholo Sefako, Dr Itumeleng Monageng, Dr Naomi Titus and Dr Nicolas Erasmus took part in the production. The documentary will be available on SAAO and SALT websites for watching, downloading and distribution.

## Tours in Sutherland

The Sutherland-based tours remain popular. 2 331 people visited the Observatory in 2021. We had to suspend all tours due to the fourth wave of the COVID-19 pandemic and had no tours from late December 2021 until the end of February 2022. Even when we opened, we had to reduce the group sizes of both the day and night tours to 17 and 15 per tour respectively. This was done in order to comply with COVID-19 protocols.



Due to the number of restrictions being removed and the fact that a critical percentage of the population has been vaccinated, we are slowly seeing everything returning to normal. There has been a rise in in-person activities and a sharp increase in visits to Sutherland. 1 439 people participated in our day and night tours in Sutherland in the last quarter of this financial year.

## Indigenous Astronomy

Three cultural astronomy events focused on stimulating interest in astronomy using storytelling, poetry, dance and music were held in Hammersdale and Durban. These were hosted jointly with South Africa's national literacy laureate and world-acclaimed storyteller Dr Gcina Mhlope. Dr Mhlophe utilised her storytelling ability, combined with music and dance, to narrate some stories based on the stars, drawn from indigenous cultures of South Africa.

Another event focussed on astronomy and space careers and involved members of the DSI, SARAO and SAAO sharing information on astronomy and career-related information. Dr Mhlophe performed between the various presentations.

This is an ongoing project, which has included the collection and documentation of indigenous astronomy knowledge and heritage, the production of an indigenous astronomy video, and the creation of indigenous star lore posters.

The last programme of this financial year, dubbed "The Magic of Indigenous Astronomy and Storytelling", was held from 14 to 17 March 2022 in Sutherland. This involved a team of seven indigenous storytellers and the New Environment World Foundation (NEWF). The programme included visits to the telescopes including SALT, a stargazing session, and also to the People's Dome, which is a symbolic dome in Sutherland that recognizes the knowledge of the indigenous people of the Northern Cape and South Africa in general.

The second segment of the programme involved recorded interviews with elderly members of the Sutherland Community and also with selected SAAO staff members.

For the third segment, the storytellers presented indigenous astronomy stories and legends to the learners from Sutherland schools.

The last aspect was the visit to the Sutherland Planetarium and the Cape Town Planetarium to watch the new indigenous planetarium show and "Cosmic Africa". The storytellers travelled to Cape Town and then flew back to their home provinces.

### *Communicating Science Using Indigenous Languages*

A webinar on communicating astronomy using indigenous languages was held. Mr Sibusio Biyela, a world-acclaimed science journalist and employee of Science Link, presented to our post-graduates and scientists. The title of his presentation was "Decolonising the language of astronomy: communicating science through indigenous translation".

Dr Itumeleng Monageng was interviewed by Lesedi FM and communicated astronomy in Setswana.

Dr Zolile Mguda (working with SCBP staff, mainly Ms Thembela Mantungwa and Ms Buzani Khumalo) was involved in the design and translation of posters into isiZulu and isiXhosa, which shared information on the Jupiter-Saturn conjunction and eclipse.

Ms Buzani Khumalo translated and edited Lucy Hawking's book on astronomy and space science from English to isiZulu.

## The Multi-Wavelength and Stargazing Programme at the Karoo Botanical Gardens

Thanks to SAASTA priority grant funding, the SAAO was able to organise and jointly implement a multi-wavelength presentation, learner workshop, and a public stargazing programme with the Karoo Botanical Gardens in Worcester on 19 February 2022.

The programme sought to use astronomy to inspire and stimulate interest in science and technology, and share career-related information on science and engineering. It aimed to develop an appreciation of the night sky and its objects.

Mr Jeremy Stuurman, the SAAO outreach officer based in Sutherland, presented and led the programme. The first session focused on learners and was based on the theory and use of telescopes and binoculars. The learners were presented with the basic theory of optics, including the structure and functioning of various lenses and mirrors. This was related to the physical sciences content on waves, light and diffraction in Grade 10 and 11 curriculum. Information on astronomy as a career was shared with the learners, as well as the relevant SAAO and SKA links for bursary information and job shadowing opportunities.

The second session of the programme was a presentation on multi-wavelength astronomy. It aimed to share the advantages of utilising telescopes operating at different wavelengths in studying celestial objects, in this case optical, radio and high energy wavelengths. It also shared the advancements in South African astronomy by highlighting the major telescopes based in Southern Africa, namely SALT, MeerKAT, MeerLicht, and the High Energy Stereoscopic System (HESS) in Namibia. This was well received by the audience and a number of questions were asked, including whether SALT and MeerKAT were an expense or an investment. There were also questions about the birth and death of stars, primarily focussed on the age and death of our Sun. The presentation and discussion assisted in displaying the beauty, relevance and power of astronomy in Africa and the world at large.

The stargazing was the last session held and, as usual, served as a platform for more intense questions and debates. Using Dobsonian telescopes, the participants were given an opportunity to view Sirius (the brightest star), Canopus (the second brightest star), and Betelgeuse (the red supergiant and a dying star). Exotic and objects deeper in the sky, such the Orion Nebula, Tarantula Nebula, Pleaides open cluster, and 47 Tucana (a closed cluster) were observed. Questions about the different colours of stars, ages and distances were raised during the session and the relevant information was provided for the participants.

Due to the success of this programme, a follow-up is planned for June 2022. This will provide an opportunity for participants to view different objects, especially the planets. It will also give the SAAO the chance to collaborate with the Karoo Botanical Gardens on the indigenous plants hosted there and to discuss how these link with the indigenous knowledge on stars, as so many of them feature in stories about the stars. This is also a step towards presenting science in a more holistic way to the public, in this case exploring links between environmental diversity and astronomy.

> 2021/2022 has been a challenging year for science engagement and outreach programmes, due to all the COVID-19 restrictions, but we have nevertheless successfully implemented a number of programmes.



# NOTABLE **WORKSHOPS**

# Astronomical Data Analysis Software and Systems Conference (ADASS)

## 24-28 October 2021


ADASS is a conference series dedicated to the intersection of astronomical data and software.

Even though its history goes back to the year 1991, it took until 2021 before ADASS was first hosted on African soil. ADASS-2020 ended up being fully virtual, but the organisers for 2021 decided to have an in-person component. Almost 50 participants signed up to attend in person, and another 300 or so people attended online. An advantage of having the conference online was that many more people could attend and, crucially, the carbon footprint was significantly lower.

The local organising committee entrusted an external service provider, "Social Natives", with running the audio and visuals for the event. Some of the presentations were held live at the venue, some were done live via the web, and some were pre-recorded. Questions were asked via the Discord app. There were some posters at the conference venue, and many more online, accessible via the "Gather. Town" website.

The presentations at ADASS covered a broad range of topics, ranging from software development methodology over software tools to machine learning aspects. These were complemented by birds-of-a-feather sessions and hands-on tutorials.

The SAAO was represented in the presentations as well. SAAO Director, Prof. Petri Väisänen, gave one of the welcome addresses, and Dr Stephen Potter talked about the IO.



# African Astronomical Society (AfAS) Workshop

## 8 November 2021

Astronomers and some other key individuals from optical observatories across the African continent came together on 8 November 2021 for a one-day virtual workshop, under the auspices of the AfAS.

The aim was to discuss a new concept to network their existing and future facilities. This initiative has been coined the 'African Integrated Observation System' (AIOS) and will leverage two other initiatives, namely the recently launched BRICS Intelligent Telescope and Data Network (BITDN) flagship project, as well as the SAAO's IO.

Participants shared information on the status of the observatories, telescopes, instruments, and scientific capabilities, and discussed potential future collaboration possibilities and synergies with these other projects. The rationale is to network African telescopes to allow for coordinated observations across the continent, leading to enhanced collaboration possibilities and capacity development for astronomy research.

One major science driver is transient and time-domain astronomy, where the AIOS would receive, interrogate and react to discovery alerts from facilities around the world, including the future Vera C. Rubin Observatory, and automatically conduct follow-up observations of targets of interest.

In the context of the African continent, the development of a network of optical telescopes is envisaged, building on the SAAO IO and incorporating facilities like the Entoto Observatory in Ethiopia, the Bouzareah Observatory in Algeria, the refurbished Kottamia Astronomical Observatory in Egypt, Oukaimeden Observatory in Morocco, plus future optical telescopes in Burkina Faso, and Kenya (Kenya Optical Telescope Initiative - KOTI). In addition, university observatories (e.g. University of the Free State's Boyden Observatory and the observatory at North-West University) will be involved.

The workshop also received a presentation on cloud technologies, data challenge aspects, and solutions the AIOS network could require. Further efforts towards the network is a need to organise more African-driven scientific meetings and technical focus workshops.

Following the workshop, the observatories that will join the network are to discuss further details on both software and logistical protocols and how telescope time could be dedicated to AIOS programmes. Investigations also need to be made on detailed technical requirements for a fully automated network. The AIOS will be developed and rolled out, while keeping in mind and incorporating cloud technologies and big data aspects.

The workshop endorsed the concept of the AIOS, and AfAS, through its Science Committee, has the responsibility to drive the discussions and expand on the concept by, among other efforts, forming a working group and planning follow-up workshops.

*The Kottamia Astronomical Observatory in Egypt.*

# BRICS Intelligent Telescope and Data Network (BITDN) Project Planning Workshop

## 17-18 February 2022

The BITDN project held a virtual two-day planning workshop on 17-18 February 2022. The aim was to focus on ideas for concrete projects to begin this year.

The first session was dedicated to status updates from all BRICS partners. Information was collected from presentations given by participants. Informal discussions were presented, namely on country-specific projects for collaboration in areas relevant to the BITDN.

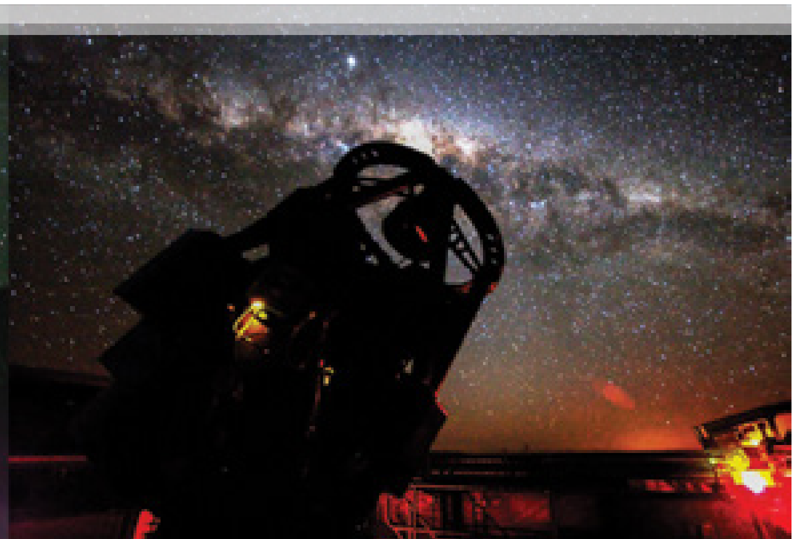
Day two involved more discussion about ideas for specific projects and activities to be implemented, and clear action points.

The presentations and discussions were centred around the core themes of the project which are transients and variable objects, big data and survey science, and societal benefits activities. The forthcoming BRICS STI proposal, a new three-year programme, was also one of the focal points of discussion at the workshop. All the BITDN project partners in the respective countries are currently working on submitting the full proposal following their success at the pre-proposal.

Various speakers from across the BRICS countries (Brazil-Russia-India-China-South Africa) shared their presentations. Mr Takalani Nemaungani, the Director for Multiwavelength Astronomy from the DSI, as well as the BRICS Astronomy Secretariat, gave the opening remarks.

Progressive ideas were shared, and concrete decisions were made regarding short-term projects. These include plans for a workshop on wide-field telescope/detector design for transient science to be held in China at the next BRICS Astronomy Working Group meeting, later in 2022. A second virtual workshop, focusing on big data and survey science will also be held later in 2022, with an emphasis on developing a BRICS-wide federated cloud computing. In terms of societal benefits, one initiative which will be explored is a Global Worldwide Telescope Tour Contest, which is a data-driven citizen science project developed as part of the collaboration between the IAU OAD and International Virtual Observatory Alliance (IVOA).

We hope that amidst all the current challenges that the BITDN project will continue to progress during 2022.





# AfAS-2022 & General Assembly (GA)

## 14-18 March 2022

The second annual conference of AfAS (AfAS-2022) took place as a hybrid event from 14 to 18 March 2022. Over 350 astronomers and representatives of African countries registered to attend. Over 40 local and international delegates participated in the meeting in person at the SAAO in Cape Town, and the remainder attended virtually.

AfAS organised the conference in partnership with the DSI, OAD, SAAO, the African Science Stars Awareness Publication (ASSAP), the African Planetarium Association (APA), and the African-European Radio Astronomy Platform (AERAP).

AfAS-2022 focused on the science, outreach, communication, and education activities emanating from astronomy in Africa, and sought to enhance further collaborations among countries in Africa and the rest of the world. It also looked at the status of astronomy infrastructure, AfAS-led flagship projects, astronomy for development, and initiatives to attract and retain youth and women in astronomy and to strengthen existing activities in the field.

A total of 68 abstracts were accepted for talks - 46 science talks, and 22 education/development/outreach. An additional 37 abstracts were accepted for posters and "lightning talks". There were also seven special sessions organised by AfAS sub-committees and partner projects dedicated to:

- Advancing global collaborations
- The APA and building a planetaria community across Africa
- Gearing up for the IAU GA in Cape Town in 2024
- Current status of the African Network of Women in Astronomy (AfNWA) after one year since its official launching
- New Approaches to Economic Challenges (NAEC) Africa Discussion: Opportunities for pan-African collaboration in astronomy education
- Virtual observatory tools
- Stellarium and other tools

The conference's final day was dedicated to the GA, held every three years. They acknowledged the excellent progress made by AfAS since the relaunch of the society at the Astronomy in Africa meeting in 2019. They also allowed the AfAS Executive Committee and its sub-committees, together with its partners (ASSAP & AERAP), to report on activities over the last three years, and the planned activities for the coming three years. Amendments to the constitution, as approved by the Executive Committee, were presented to the members. Their amendments and comments were noted by the AfAS Secretariat and incorporated in the updated Constitution as appropriate. (https://www.africanastronomicalsociety.org/constitution-of-the-african-astronomical-society/).

The GA also elected a new Executive Committee for the period 1 April 2022 to 31 March 2025. The elected members are:

- Thebe Rodney Medupe (President)
- Naomi Asabre Frimpong (Vice-President)
- Elizabeth Naluminsa
- Alemiye Mamo Yacob
- Mirjana Pović
- Sinenhlanhla Precious Sikhosana
- Sthabile Kolwa

The South African DSI was acknowledged for its continued support. The GA thanked all partners of AfAS from Africa and abroad, the African astronomy community, and participants of the conference for their valuable support.

Petri Väisänen.


Kevin Govender.



# SAAO STAFF

# SAAO Executive

In the reporting period of April 2021 to March 2022, 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**

**Prof. 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**

**Assoc/Prof. Vanessa McBride**
**Head: Research**

# Staff Highlights

## Daniel Cunnama in the Media

### Expresso, Rising Star, Sida Tsoatsoas, TEDx and The Cosmic Savannah

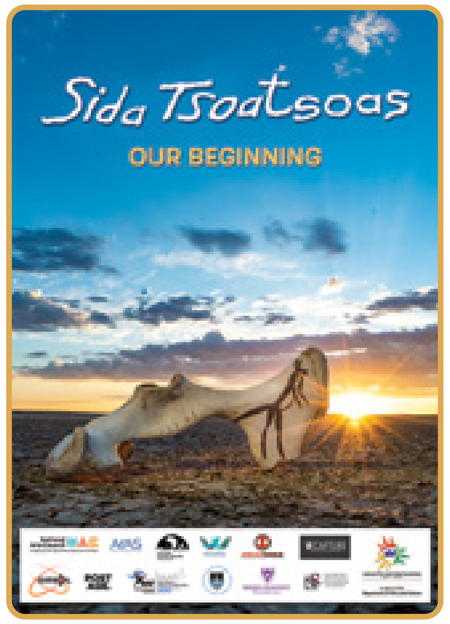
SAAO science engagement astronomer Dr Daniel Cunnama continues to feature regularly in the media, with the purpose of raising the profile of the SAAO and astronomy in general among stakeholders, learners, educators and the general public. He was selected as a finalist for the 2021 South African NSTF-South32 Communication Award.

*Left to right: Lucy Cunnama, Daniel Cunnama, Petri Väisänen*


The Expresso Show on SABC3 features a weekly update with Daniel, “The Final Frontier with Dr Daniel Cunnama”. The segment focuses on the latest in astronomy and space news from South Africa and around the world and presents it in a fun and engaging manner. The viewership reaches a peak of ~500 000 unique viewers daily and is targeted at all ages and backgrounds.

The Cosmic Savannah Podcast created, produced and hosted by Daniel and Dr Jacinta Delhaize has received over 140 000 unique downloads. The podcast highlights the amazing astronomy and astrophysics coming out of the African continent. Released once a fortnight, the episodes introduce the public to the telescopes, instrumentation, researchers, discoveries, and public engagement efforts coming out of the African continent. In particular, they regularly feature a diverse range of young African astronomers who can serve as role models for the next generation. The Cosmic Savannah was also selected as a finalist in the 2021 South African NSTF-South32 Communication Award.

In October 2021, Daniel also presented a TEDx talk at TEDxRiversdale on the topic: "Inspiration and Engagement with Astronomy Through Khoi and San Starlore". He touched on content which will be on display in our Cape Town Visitor Centre, as well as the Iziko Planetarium.




In 2020, Daniel and Sally Macfarlane (UCT), in collaboration with the company VR Capture, locally produced a planetarium film on South African Astronomy, called Rising Star. The following year, the film was featured in “The Dome Under Festival” in Melbourne, which shows a selection of the best full-dome films from around the world.

Daniel also produced a second planetarium film, called Sida Tsoatsoas, which is accessible to all ages and presented in Afrikaans and Nama, with English subtitles. It was produced in collaboration with the ǂKhomani San community of the Northern Cape and created 29 jobs, the majority of which were within this community. It was featured in a fixed slot at the Iziko Planetarium over the 2021-2022 holiday season. Sida Tsoatsoas was selected as one of the winners of the International Tourism Film Festival Africa 2022 and was selected for the Jena FullDome Festival 2022 as one of the best international full-dome films of 2022.

## Zara Randriamanokoto: Mail & Guardian 200 Young South Africans Award Recipient

Dr Zara Randriamanakoto was selected as one of the 2021 winners for the annual Mail & Guardian 200 Young South Africans award. Zara is currently working as a staff astronomer at the SAAO, after having successfully conducted a SAAO PDP post-doctoral fellowship and another three-year post-doctoral research fellowship at the Astronomy Department of UCT.

She is not only involved in mentoring programmes at the Observatory, but has also co-founded a global movement known as Ikala STEM, which is a non-profit organisation that rallies about 500 women scientists across four continents to inspire mainly girls and women to consider careers in science, technology, engineering and mathematics.

On 15 and 20 October 2021, Zara was also interviewed on the SAAO grounds by film crews from France Télévisions and Brut Africa, respectively. The French media were looking for female scientists to be portrayed in short video interviews, with the aim of promoting the research work and science engagement done by African women in science. Given that Zara is a 2020 laureate of the prestigious L'Oréal-UNESCO Young Talents Programme, and is actively engaged with the promotion of women in science on the continent, it was no surprise that she came to their attention.

## David Buckley: 30 Years of Service for the SAAO

2021 saw the commemoration of 30 years of service for the SAAO by Prof. David Buckley. David is originally from New Zealand and studied towards his doctorate in astronomy at the Australian National University. Following that, he took up his first post-doctoral fellowship position at UCT in 1988. Then in 1991, he took a job at the SAAO as a research astronomer, with some instrumentation responsibility.

David served as the SALT Project Scientist during the design and construction phase of the telescope (1998-2005). He then became the first SALT Astronomy Operations manager and SALT Science Director (2005-2015). In 2017, he was appointed as the first SAAO Darragh O'Donoghue Astronomer and is currently also serving as the SALT Global Ambassador.

His research has mostly focused on compact accreting binary stars, including X-ray binaries and cataclysmic variables, particularly magnetic systems, which he studies with both optical ground-based telescopes (e.g. with SALT and other SAAO telescopes) and UV/X-ray space-based telescopes.

In 2013, he was the recipient of a CV Raman Senior Fellowship when he visited the Tata Institute for Fundamental Research to formulate SALT/AstroSat collaborations.

His more recent research (since 2016) has focused on astrophysical transients, where he is the PI of the SALT transient programme and a South African Affiliate PI on the Vera C. Rubin Observatory's LSST.

He is also an investigator on a number of international projects, including leading a BRICS astronomy initiative to establish a flagship programme on astrophysical transients and big data.

David is also an expert on optical telescopes, instrumentation and site testing and characterization. In recent years, he has also assisted in astronomy capacity development in other African countries, including Ethiopia and Kenya, where he has been involved in projects to establish optical telescopes for research.

He has a total of over 285 refereed authored/co-authored papers to his name, with over 10 200 citations. He also has a B1 NRF rating. In 2021, he was appointed as an Honorary Research Affiliate at UCT and an Affiliate Professor at the University of the Free State.

# Staff List

This list includes casual staff, honorary fellows and students working at SAAO between April 2021 and March 2022. Staff are listed in alphabetical order, according to surname.

| Surname, Name | Title | Gender | Position | Municipality |
|---|---|---|---|---|
| Adams, Shamiel | Mr | Male | Software Engineer | Cape Town |
| Anthony, Melissa | Mrs | Female | Procurement Officer | Cape Town |
| Appolis, Wade | Mr | Male | CNC Machinist | Cape Town |
| April, Koos | Mr | Male | Driver Maintenance | Sutherland |
| Arendse, Tamzyn | Ms | Female | SAASTA Volunteer | Cape Town |
| Baadjies, Dawid | Mr | Male | Driver Maintenance | Sutherland |
| Baadjies, Elizabeth | Mrs | Female | Receptionist | Sutherland |
| Banda, Richard | Mr | Male | Mechatronics Engineer | Sutherland |
| Banda, Thabo | Mr | Male | Maths and Science Educator | Sutherland |
| Bernardo, Jean | Mr | Male | IT Support Technician | Sutherland |
| Bershady, Matthew | Dr | Male | SARChi Chair | Cape Town |
| Bichanga, Brian | Mr | Male | MSc Student | Cape Town |
| Booysen, Paul | Mr | Male | IT Systems Administrator | Sutherland |
| Botha, Lucian | Mr | Male | Senior Systems Engineer | Cape Town |
| Breytenbach, Hannes | Mr | Male | PhD Student | Cape Town |
| Brink, Jaco | Mr | Male | MSc Student | Cape Town |
| Brink, Janus | Mr | Male | Software Engineer | Cape Town |

| Surname, Name | Title | Gender | Position | Municipality |
|---|---|---|---|---|
| Browne, Keith | Mr | Male | SALT Electronics Engineer | Sutherland |
| Buckley, David | Dr | Male | Astronomer | Cape Town |
| Bynish, Paul | Mr | Male | PhD Student | Cape Town |
| Chandra, Sunil | Dr | Male | Post-Doctoral Fellow | Cape Town |
| Chipembe, Bryne | Mr | Male | SALT Software Engineer | Sutherland |
| Christian, Brendt | Mr | Male | Mechanical Technician | Sutherland |
| Christians, Alrin | Mr | Male | Mechanical Design Draughtsman | Sutherland |
| Claassen, Siphosethu | Mrs | Female | Human Resources Officer | Cape Town |
| Cloete, Valencia | Mrs | Female | Office and Grant Manager | Cape Town |
| Crause, Lisa | Dr | Female | Scientist | Cape Town |
| Crook-Mansour, Justine | Ms | Female | Science Engagement Intern | Cape Town |
| Cunnama, Daniel | Dr | Male | Science Engagement Astronomer | Cape Town |
| De Water, Katriena | Ms | Female | Housekeeper and Mirror Cleaner | Sutherland |
| De Young, Theresa | Ms | Female | Librarian | Cape Town |
| Dirkse, Andrew | Mr | Male | Lead Maintenance Assistant | Cape Town |
| Dyantyi, Akhona | Mr | Male | Casual Worker | Cape Town |
| Dyantyi, Goodwell | Mr | Male | Casual Worker | Cape Town |
| Egbo, Daniel | Mr | Male | PhD Student | Cape Town |
| Erasmus, Nicolas | Dr | Male | Instrumentation Scientist | Cape Town |
| Firth, Andrew | Mr | Male | MSc Student | Cape Town |
| Fischer, Dalene | Mrs | Female | Financial Controller | Cape Town |
| Fortune, Jason | Mr | Male | Casual Worker | Cape Town |
| Fransman, Timothy | Mr | Male | Mechanical Technician | Sutherland |
| Gajjar, Hitesh | Mr | Male | Head of Instrumentation | Cape Town |
| Gasealahwe, Kelebogile | Ms | Female | PhD Student | Cape Town |
| Geen, Ulrich | Mr | Male | MSc Student | Cape Town |
| Genade, Anja | Ms | Female | PhD Student | Cape Town |
| Gibbons, Denville | Mr | Male | Mechanical Assistant | Sutherland |



| Surname, Name | Title | Gender | Position | Municipality |
|---|---|---|---|---|
| Govender, Kevindran | Mr | Male | Director: IAU OAD | Cape Town |
| Govender, Pranesthan | Mr | Male | Public Outreach Officer | Cape Town |
| Groenewald, Danièl | Dr | Female | SALT Astronomer | Cape Town |
| Haupt, Jamie-Lee | Ms | Female | Intern | Cape Town |
| Hendricks, Johan | Mr | Male | Driver Maintenance | Sutherland |
| Hendricks, Malcolm | Mr | Male | CNC Operator | Cape Town |
| Hercules, Nazli | Mrs | Female | Personal Assistant | Cape Town |
| Hettlage, Christian | Dr | Male | SALT Software Engineer | Cape Town |
| Higgo, Liam | Mr | Male | MSc Student | Cape Town |
| Hlabathe, Michael | Mr | Male | PhD Student | Cape Town |
| Hoosain, Munira | Ms | Female | PhD Student | Cape Town |
| Hulme, Stephen | Mr | Male | Software Engineer | Cape Town |
| Ilonze, Chijioke | Ms | Female | Casual Worker | Cape Town |
| Jacobs, Amelde | Ms | Female | Casual Worker | Cape Town |
| Jacobs, Cedric | Mr | Male | Education Officer Assistant | Cape Town |
| Jacobs, Nicolaas | Mr | Male | Mechanical Trainee Assistant | Sutherland |
| Jones, Natalie | Mrs | Female | Communication and Resource Officer | Cape Town |
| Kabini, Sunnyboy | Mr | Male | SALT Software Engineer | Cape Town |
| Kamfer, Hilton | Mr | Male | Mechanical Technician | Sutherland |
| Kayyunnaparayil Thomas, Jessymol | Ms | Female | Post-Doctoral Researcher | Cape Town |
| Khangale, Zwidofhelangani | Mr | Male | PhD Student | Cape Town |
| Kgengwe, Mpho | Mr | Male | Purchasing Officer | Cape Town |
| Khumalo, Buzani | Miss | Female | Education Officer | Cape Town |
| Klaasen, Dillon | Mr | Male | SALT Software Engineer | Cape Town |
| Klaaste, Petrus | Mr | Male | Driver/ Maintenance | Sutherland |
| Klein, Francois | Mr | Male | Tour Guide | Sutherland |

| Surname, Name | Title | Gender | Position | Municipality |
|---|---|---|---|---|
| Klein, Reginald | Mr | Male | Electronics Assistant | Sutherland |
| Klein, Sina | Mrs | Female | Hostel Assistant | Sutherland |
| Knaizev, Alexei | Dr | Male | Astronomer | Cape Town |
| Koen, Thea | Miss | Female | Telescope Operator | Sutherland |
| Koeslag, Anthony | Mr | Male | Software Engineer | Cape Town |
| Koorts, Willem | Mr | Male | Electronics Technician | Cape Town |
| Kortje, Sofia | Mrs | Female | Housekeeper | Sutherland |
| Kotze, Enrico | Dr | Male | Astronomer | Cape Town |
| Kubheka, Duduzile | Ms | Female | Project Coordinator | Cape Town |
| Kuhn, Rudolf | Dr | Male | SALT Astronomer | Cape Town |
| Lakey, Eugene | Mr | Male | Manager: Finance and Operations | Cape Town |
| Lancaster, Tamara | Ms | Female | MSc Student | Cape Town |
| Lande, Cornelius | Mr | Male | Casual Worker | Cape Town |
| Lethetsa, Katleho | Mr | Male | Intern | Cape Town |
| Lewis, Sanchia | Ms | Female | Safety and Site Officer | Cape Town |
| Loubser, Egan | Mr | Male | Mechanical Technician | Cape Town |
| Love, Jonathan | Mr | Male | Mechanical Technician | Sutherland |
| Maartens, Deneys | Mr | Male | Software Engineer | Cape Town |
| Mabadi, Vusumzi | Mr | Male | Honours Student | Cape Town |
| Makda, Nazir | Mr | Male | PhD Student | Cape Town |
| Macebele, Nhlavutelo | Mr | Male | SALT Software Developer | Cape Town |
| Macfarlane, Sally Ann | Dr | Female | Post-Doctoral Research Fellow | Cape Town |
| Madhanpall, Nikhita | Ms | Female | OAD Big Data Fellow | Cape Town |
| Maerman, Nkululeko | Mr | Male | Machine Operator | Cape Town |
| Mahoro, Antoine | Mr | Male | PhD Student | Cape Town |
| Makananise, Thabelo | Mr | Male | Instrumentation Technician | Sutherland |
| Makoloane, Lehlohonolo | Mr | Male | IT Systems administrator | Cape Town |
| Malan, Adelaide | Ms | Female | SALT Supply Chain and Administration Officer | Sutherland |



| Surname, Name | Title | Gender | Position | Municipality |
|---|---|---|---|---|
| Mantungwa, Thembela | Ms | Female | Communications Officer | Cape Town |
| Manxoyi, Sivuyile | Mr | Male | Head of Salt Collateral | Cape Town |
| Maqam, Malibongwe | Mr | Male | Systems Administrator | Cape Town |
| Marang, Freddie | Mr | Male | Intern | Cape Town |
| Mashile, Tokelo | Mr | Male | Honours Student | Cape Town |
| Matlala, Kgothatso | Mr | Male | Electronics Engineer | Cape Town |
| Matthys, Jan | Mr | Male | Casual Worker | Cape Town |
| Mcbride, Vanessa | Dr | Female | Astronomer | Cape Town |
| Meswatu, Julie | Mr | Male | Manager: Sutherland Site | Sutherland |
| Mgwatyu, Ayanda | Mr | Male | Site Supervisor | Cape Town |
| Mgwatyu, Sithembele | Mr | Male | Groundsman | Cape Town |
| Mietas, Anthony | Mr | Male | Manager: Collateral Benefits Sutherland | Sutherland |
| Mkhize, Dumazile | Ms | Female | Intern | Cape Town |
| Mnisi, Mandle | Mr | Male | Honours Student | Cape Town |
| Mofokeng, Chaka | Mr | Male | SALT Astronomy Software Developer | Cape Town |
| Mogotsi, Moses | Dr | Male | Astronomer | Cape Town |
| Mohamed, Shazrene | Dr | Female | Researcher | Cape Town |
| Moosa, Surayda | Mrs | Female | Accounts Clerk | Cape Town |
| Mpetshwa Vuyolwethu | Ms | Female | SAAST Volunteer | Cape Town |
| Mulaudzi, Avhapfani | Mr | Male | Electronics Technician | Sutherland |
| Mvakade, Zuthobeke | Miss | Female | Librarian Assistant | Cape Town |
| Naicker, Tasheen | Mr | Male | Senior Mechanical Engineering | Cape Town |
| Naluminsa, Elizabeth | Dr | Female | Post-Doctoral Fellow | Cape Town |
| Ndaliso, Xola | Mr | Male | SALT Operator | Cape Town |
| Nel, Sherelene | Ms | Female | Housekeeper | Sutherland |
| Ntame, Masixole | Mr | Male | Electronics Assistant | Sutherland |

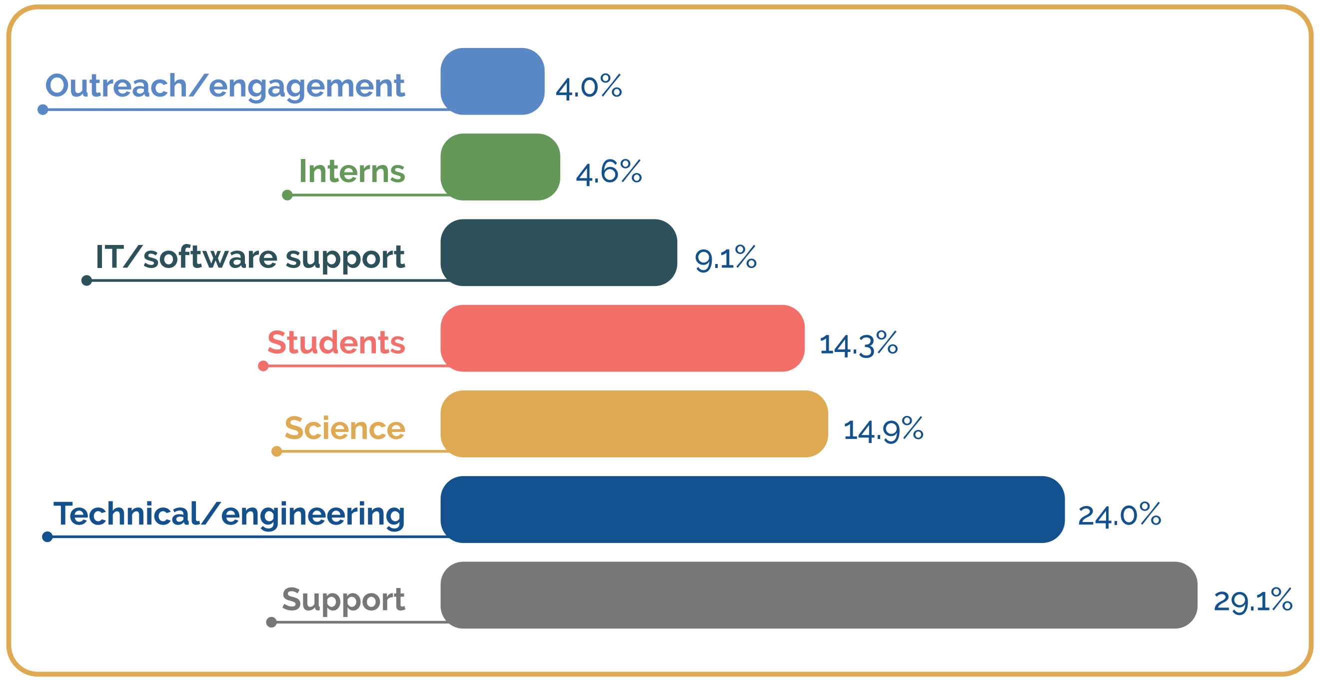
| Surname, Name | Title | Gender | Position | Municipality |
|---|---|---|---|---|
| Ntozakhe, Mduduzi | Mr | Male | Machine Operator | Cape Town |
| Omar Mohamed Riaz | Mr | Male | SAASTA volunteer | Cape Town |
| Pieterse, Jonathan | Mr | Male | SALT Supply Chain and Administration Officer | Sutherland |
| Potter, Stephen | Dr | Male | Head of Astronomy | Cape Town |
| Pretorius, Magaretha | Dr | Female | Instrumentation Scientist | Cape Town |
| Prins, Willem | Mr | Male | Lead Maintenance Assistant | Sutherland |
| Rabe, Paul | Mr | Male | SALT Technical Operations Manager | Sutherland |
| Ramalatswa, Katlego | Mr | Male | MSc Student | Cape Town |
| Randriamampandry, Solohery | Dr | Male | SALT Astronomer | Cape Town |
| Randriamanakoto, Zara | Dr | Female | Astronomer | Cape Town |
| Romero Colmenero, Encarnacion | Dr | Female | Head of SALT Astronomy Operations | Cape Town |
| Roode, Susan | Ms | Female | Hostel Assistant | Sutherland |
| Rosie, Kathryn | Ms | Female | Mechanical Engineer | Cape Town |
| Rust, Michael | Mr | Male | Electronics Technician | Cape Town |
| Saayman, Melanie | Miss | Female | Optical Engineer | Cape Town |
| Sanker, Sriram | Mr | Male | MSc Student | Cape Town |
| Sass, Craig | Mr | Male | Head of Mechanical Workshop | Cape Town |
| Saulse, Elias | Mr | Male | Casual Worker | Cape Town |
| Scheepers, Garthvine | Mr | Male | Casual Worker | Cape Town |
| Sefako, Ramotholo | Dr | Male | Head of Small Telescope Operations | Cape Town |
| September, Juliana | Miss | Female | Receptionist | Sutherland |
| Simon, Etienne | Mr | Male | Electronics Technician | Sutherland |
| Simon, Iriwaan | Mr | Male | Head of IT | Cape Town |
| Skelton, Rosalind | Dr | Female | SALT Astronomer | Cape Town |
| Snowball, Glenda | Mrs | Female | Financial Officer | Cape Town |
| Solomon, Nuhaah | Mrs | Female | Office Manager : IAU OAD | Cape Town |

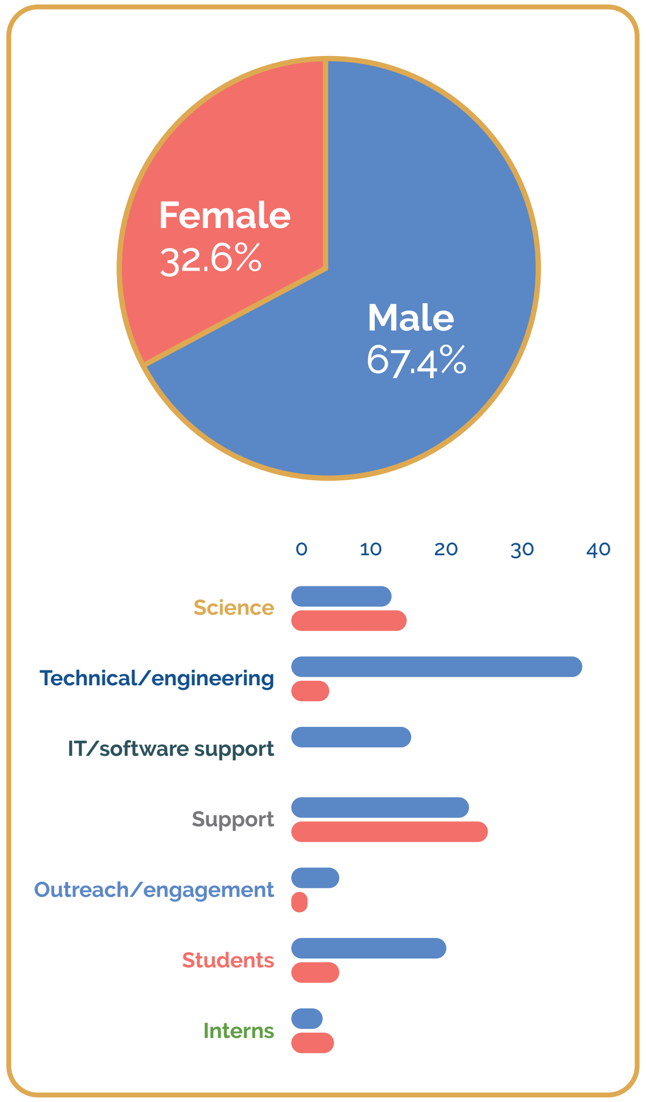


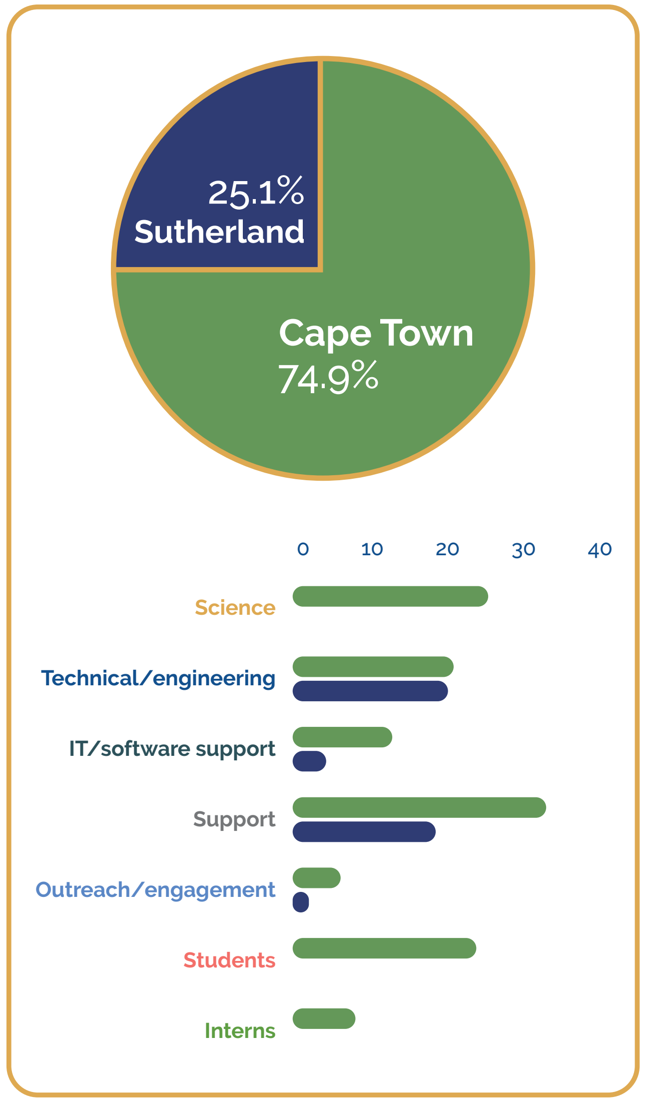
| Surname, Name | Title | Gender | Position | Municipality |
|---|---|---|---|---|
| Southey, Grant | Mr | Male | Supply Chain Manager | Cape Town |
| Strydom, Ockert | Mr | Male | Senior Mechanical Engineering | Cape Town |
| Stuurman, Jeremy | Mr | Male | Tour Guide | Sutherland |
| Swanevelder, Pieter | Mr | Male | Electronics Engineer | Cape Town |
| Taaibos, Sinethemba | Mr | Male | All Sky Monitor Operator | Sutherland |
| Thomas, Chad | Mr | Male | Honours Student | Cape Town |
| Titus, Keegan | Mr | Male | Electronics Technician | Cape Town |
| Tobin, Linda | Mrs | Female | Manager: Human Resources | Cape Town |
| Townsend, Lee | Dr | Male | SALT Astronomer | Cape Town |
| Tromp, Frikkie | Mr | Male | Casual Worker | Cape Town |
| Väisänen, Petri | Dr | Male | Director: SAAO | Cape Town |
| Van de Merwe, Christian | Mr | Male | PhD Student | Cape Town |
| Van Der Merwe, Nicolaas | Mr | Male | SALT Mechanical Engineer | Cape Town |
| Van Dyk, Anke | Ms | Female | PhD Student | Cape Town |
| Van Gend, Carel | Dr | Male | Software Developer | Cape Town |
| Van Rensburg, Petro Janse | Ms | Female | PhD Student | Cape Town |
| Van Wyk, Magdalena | Mrs | Female | Hostel Supervisor | Sutherland |
| Van Wyk, Patrick | Mr | Male | Tour Guide | Sutherland |
| Van Wyk, Veronica | Miss | Female | Telescope Operator | Sutherland |
| Vernooi, Claudine | Ms | Female | Tour Guide | Sutherland |
| Visser, Martin | Mr | Male | CNC Operator | Cape Town |
| Whitelock, Patricia | Prof | Female | Scientist | Cape Town |
| Wiid, Eben | Mr | Male | Mechanical Technician | Sutherland |
| Worters, Hannah | Dr | Female | Astronomer | Cape Town |

Total: 175

## SAAO Staff






# SAAO STUDENTS

# Summary Of Students

The SAAO takes pride in the rich diversity and culture of our students who come from all over the world and, in particular, from other African countries.

During the reporting period, 25 students were supervised by SAAO staff. 11 staff members acted as their SAAO supervisors, with others as UCT supervisors or mentors. 1 PhD, 1 MSc, and 1 Honours student graduated at the start of 2022. The MSc student has now proceeded to their PhD, and is again being supervised by SAAO staff. 12 students are currently busy with their PhD (7 are male and 5 are female). 8 students are doing their MSc (7 are male and 1 is female). 3 students enrolled with us for their Honours, all of which are male.

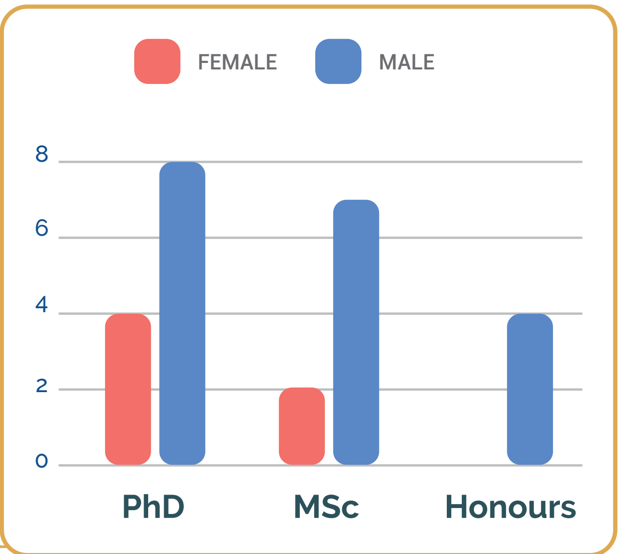



*Figure 1. 25 students were supervised by SAAO staff in the period April 2021 to March 2022 (these students are shown in the Student Profiles section, starting page 107). If a student is both recently graduated (at the start of 2022) and currently enrolled for their next degree, they are only counted once for the degree they just graduated from.*

# Student Support

With a view of providing higher levels of support to both student and supervisor and trying to get more students to completion on the prescribed timescale, the following measures were 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. Because of the COVID-19 pandemic, it was necessary to hold all PAC meetings via Zoom, but this worked surprisingly well and allowed the easy participation of international PAC members.

A student coordinator (astronomer) and a student administrator were 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, prior to the COVID-19 pandemic, the students worked 40 hours per year (i.e. approximately one hour per week) for the 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. Payment of the students was continued during the National State of Disaster, but they were not expected to perform any duties.

Two large offices, suitably furnished, have been set aside for use by the students and we hope another one will be available soon.



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. This has proved quite popular, and continued via Zoom during lock-down.

Students are encouraged to attend colloquia and journal clubs to broaden their general scientific knowledge.

A system of mentors comprising young staff astronomers or post-docs, 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. All meetings were virtual during lock-down.

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. From early 2022, one of the young staff members also took on the responsibility of helping the students organise skills-training events. These include learning about Python and Astro-Py. We hope that most of the students based at SAAO will also learn the practicalities of observing in the near future.

# Student Profiles

## Graduated Students

**Bynish Paul** (University of Johannesburg and SAAO)
PhD Thesis (Submitted, October 2021)

Research Title: **Analysis of Optical Fe II Emission in a Selected Sample of Active Galactic Nuclei of Narrow-Line Seyfert 1 Galaxies**

**Abstract:** This study presents the analysis of medium resolution optical spectra of Narrow-Line Seyfert 1 galaxies. The sample includes fourteen bright AGNs from the Southern hemisphere, which shows moderate to strong iron emission in their spectra. Parameters were determined from spectra of high signal-to-noise ratio, which were obtained by averaging four up to ten spectra for each target. The parameters obtained from the fits of Fe II, Hβ and [O III] 5007 Å lines include width, asymmetry, and relative strength. This study tests the applicability of different standard profiles to Hβ. The Hβ profile is decomposed into broad and narrow components, as seen in all Seyfert 1 galaxies, and also an intermediate component. A satisfactory fit is achieved when Hβ is fitted with three Gaussian functions, while the fit improves when the intermediate component is fitted with a Lorentzian profile instead of a Gaussian for most of the sample. The Hβ intermediate component accounted for the largest fraction of the Hβ flux when a Lorentzian is used. The width of the Hβ Lorentzian was found to be consistent with that of the Fe II lines, also a strong and significant correlation exists between the Fe II shift and asymmetry of Hβ intermediate component. Unlike many other types of AGNs, no drastic optical spectral variations were detected over a period of two years for the NLS1 sample, which includes even objects that are highly variable in X-ray. In particular, the variability of the Fe II lines relative to the Hβ intermediate component seems to be minimal. The [O III] line asymmetries are identified in almost all the targets that could be accounted for a primary central and a second blue-shifted component. A strong correlation between [O III] 5007Å asymmetry and the FWHM [O III] core component was also found and are all in agreement with the previous results. The asymmetry possibly suggests versatile gas dynamics driven by nuclear outflow.

*Supervisors: Prof. Hartmut Winkler (UJ) & Prof. Stephen Potter (SAAO & UJ)*

**Anke van Dyk** (UCT/SAAO)
MSc (graduated end of 2021)

Research title: **Capturing Transients: An application of Biostatistics to Astronomy**

**Abstract:** Capture-recapture has been identified as a possible use case for estimating the underlying size of astrophysical transient populations. In this work, we present a series of exploratory analyses using capture-recapture methods from biostatistics.

In the first of three separate analyses, we reproduce results of Laycock (2017). Strategically sampled X-ray lightcurves of simulated populations of high mass X-ray binaries (HMXBs) are used to probe estimator behaviour and efficiency. Overall, these statistically closed population estimators converge to the input population with increasing number of observations, yet estimator efficiency is shown to be significantly be affected by sampling strategy. I then employ non- standard estimator models to account for variations in capture probability of individuals within the population, categorised into 'behavioural', 'temporal', and 'heterogeneous' effects.

In the second analysis, we present a methodology for closed population capture-recapture analysis using real data from the OGLE-IV XROM survey. The data samples consisted of observations that were grouped into epochs. The large variation in quiescent magnitude of the population creates heterogeneity in the capture probability of sources which requires non-standard modelling. Estimation of population size is therefore limited by the choice of observational magnitude threshold. Bias corrected estimation proves to be potentially useful in this context.

In the third and final investigation, we present a 'robust design' approach with a population of Dwarf Nova located towards and in the Galactic Bulge identified from the OGLE-II, -III, and -IV phases. This approach combines closed and open population practices that allows new individuals identified between the survey phases to be added to the study sample for dynamical estimation.

These investigations provide a future course for population size estimation of transients and variable stellar population alongside population synthesis simulations. The generation of capture histories remain non-trivial through the choice of observation grouping, brightness scale, and imposed flux threshold. Further, there remain several unexplored avenues of inquiry and refinement for this methodology pertaining to astronomy using explanatory variables in the modelling. Recommendations are made for further exploration of the topic.

*Supervisors: Prof Paul Groot (UCT/SAAO/Radboud University (NL)) & Vanessa McBride (SAAO/UCT)*

**Tokelo Mashile** (UCT-NASSP/SAAO)
Honours

**Research Title: Defining an interesting Sample of New MeerKAT Radio Sources**

**Abstract:** The MeerKAT radio interferometer is an SKA precursor consisting of 64, 13.4m diameter antennas. In every field that MeerKAT observes, it detects thousands of previously unknown radio sources. In this work, I have explored methods to select interesting Galactic objects from a set of MeerKAT observations, for further investigation. I used various selection cuts and online tools to find, out of several thousand radio sources, a handful that are also bright X-ray and optical sources. I have also retrieved optical light curves for this set of objects, and looked for variability. In this way of data analysis, I have identified 4 bright variable stars, one of which is a periodic variable. These stars were not previously known to be radio sources. The observations included detected radio emission from Cataclysmic Variables and Novae and I have used ASAS-SN to plot the light curves of these bright sources over several epochs.

*Supervisor: Dr Margeritha Pretorius (SAAO)*

## Current Students

### PhD students

**Petro Janse van Rensburg**
(UCT/SAAO)

Research Title: **Studying gas flows in the SUNBIRD starburst galaxies and LIRGs**

*Supervisors: Dr Moses Mogotsi (SAAO/SALT), Prof. Petri Väisänen (SAAO/SALT) & Prof. Matthew Bershady (SAAO/UCT/UW-Madison)*

**Nazir Makda**
(UCT/SAAO)

Research Title: **Ultra-diffuse Galaxies: A Multiwavelength study**

*Supervisors: Dr Rosalind Skelton (SAAO), Assoc Prof Sarah Blyth (UCT)*

**Christian van der Merwe**
(UCT/SAAO)

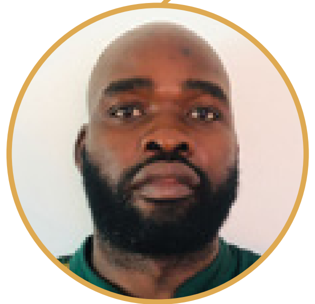
**Research Title: Explosive transients from stellar collisions**

*Supervisors: A/Prof. Shazrene Mohamed (UCT/SAAO/University of Miami (UM))*

**Kelebogile Gasealahwe**
(UCT/SAAO)

**Research Title: The study of Stellar Mass Black Hole and Neutron Star X-ray Binaries**

*Supervisors: Dr Itumeleng Monageng (UCT & SAAO), Prof. Rob Fender (University of Oxford & UCT), Prof. Patrick Woudt (UCT)*



## Zwidofhelangani Khangale
(UCT/SAAO)

Research Title: **Accretion processes in magnetic Cataclysmic Variables**

*Supervisors: Prof. Patrick Woudt (UCT/ UNIVEN), Dr Stephen Potter (SAAO/UJ)*

## Okwudili Danie Egbo
(UCT/SAAO)

Research Title: **Multi-wavelength study of MeerKAT Galactic Plane Point Sources**

*Supervisors: David Buckley (SAAO/UCT)*

## Anja Genade
(UCT/SAAO)

**Research Title: Observational studies of centaur characteristics**

*Supervisors: Prof. Paul Groot (UCT/SAAO/Radboud University (NL)), Dr Amanda Bosh (MIT/Lowell Observatory)*

## Antoine Mahoro
(UCT/SAAO)

**Research Title: Outflows and feedback from star-forming galaxies and AGN**

*Supervisors: Prof. Petri Väisänen, Dr. Mirjana Pović, Dr. Kurt van der Heyden and Ass. Prof. Pheneas Nkundabakura. (SAAO, Ethiopian Space Science and Technology Institute, UCT and University of Rwanda)*

## Hannes Breytenbach
(UCT/SAAO)

Research Title: **A Study of Quasi-Periodic Oscillations in magnetic Cataclysmic Variable Stars**

*Supervisors: Dr. David Buckley (SAAO), Prof. Patrick Woudt (UCT)*



## Anke van Dyk
(UCT/SAAO)

Research Title: **Transient follow-up and characterisation in the LSST era**

*Supervisors: Emeritus Prof David Buckley (SAAO), Vanessa McBride (SAAO/UCT)*

## Munira Hoosain
(UCT/SAAO)

Research Title: **Measuring the Cosmic Neutral Hydrogen Density in LADUMA**

*Supervisors: Associate Professor Sarah Blyth (UCT) & Dr Rosalind Skelton (SAAO)*

# MSc students

## Liam Higgo
(UCT/SAAO)

**Research Title: Conceptual design of a distributed spectro-scopic telescope array**

*Supervisors: Prof Paul Groot (UCT/SAAO), Dr Retha Pretorius (SAAO)*

## Tamara Jayne Lancaster
(UCT/SAAO)

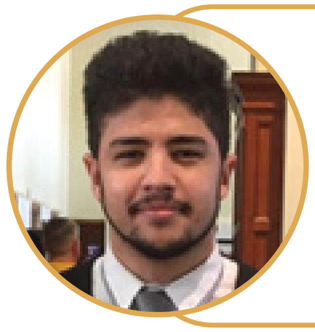
Research Title: **Broad Spectral Energy Distributions of Accreting White Dwarfs**

*Supervisors: Supervisors: Patrick Woudt (UCT, SAAO), Retha Pretorius (SAAO)*

## Jaco Brink
(UCT/SAAO)

**Research Title: Spectroscopic Analysis of Transient Sources**

*Supervisors: Prof David Buckley (SAAO/UCT/UFS), Prof. Paul Groot (SAAO/UCT/Radboud)*



### Andrew Leon Firth
(UCT/SAAO)

Research Title: **Resolving Atomic Hydrogen in Galaxies in Next-Generation Radio Surveys Using High-Resolution Optical-Near-infrared Imaging**

*Supervisors: Prof Matthew A. Bershady (SAAO / UCT / UW Madison)*

### Brian Ongeri Momanyi Bichang'a
(UCT/SAAO)

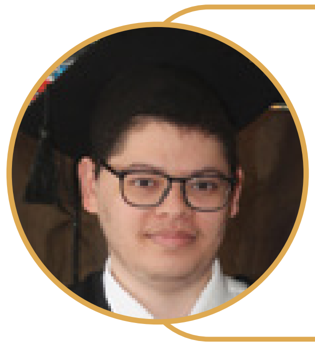
Research Title: **Structure and Masses of Milky Way-like Galaxies in HI Deep Fields**

*Supervisors: Prof. Matthew A. Bershady (UCT/SAAO/UW Madison)*

### Sriram Sankar
(UCT/SAAO)

**Research Title: Linking the evolution of galaxies, groups, and the baryon cycle using MeerKAT and SALT**

*Supervisors: Moses Mogotsi (SAAO, SALT), Matthew A. Bershady (SAAO, UCT, UW-Madison)*



### Ulrich Geen
(UCT/SAAO)

**Research Title: A new spectrograph: Characterization and early transient science**

*Supervisors: Dr Retha Pretorius (SAAO), Dr Nicolas Erasmus (SAAO), Prof. Paul Groot (UCT/SAAO)*

### Katlego Ramalatswa
(UCT/SAAO)

Research Title: **Multi-dimensional simulations of bow shocks of massive, high-velocity runaway stars**

*Supervisors: Assoc. Prof. Shazrene S. Mohamed (UCT/SAAO)*



## Honours students

**Chad Thomas**

**Vusumzi Mabadi**

**Mandle Mnisi**

# SAAO PUBLICATIONS

2021

# REFEREED PUBLICATIONS

**Refereed publications by SAAO staff:** 94

**Refereed publications by non-SAAO staff based on SAAO & hosted facilities:** 182

**Total refereed publications:** 278

## Breakdown of Refereed Publications using SAAO & Hosted Facilities

| Telescope/Network | Number of publications |
|---|---|
| 0.5m | 1 |
| 1.9m | 8 |
| 1.0m | 12 |
| Lesedi | 6 |
| SuperWasp | 26 |
| 0.75m | 2 |
| African Intelligent Observatory | 1 |
| ASAS-SN | 6 |
| ATLAS | 16 |
| LCO | 34 |

| Telescope/Network | Number of publications |
|---|---|
| BISON | 1 |
| bRing | 1 |
| KELT | 5 |
| KMTNet | 25 |
| MASTER | 7 |
| MeerLICHT | 6 |
| MONET | 1 |
| PRIME | 1 |
| SALT | 51 |

## Collaborations

The 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 also by the number of citations and headlines that these sparked across the globe.

### Organisations the SAAO has Most Frequently Collaborated with, based on the Refereed SAAO Staff Papers:

| Affiliation | Record count |
|---|---|
| LEAGUE OF EUROPEAN RESEARCH UNIVERSITIES LERU | 50 |
| UNIVERSITY OF CAPE TOWN | 46 |
| ISTITUTO NAZIONALE ASTROFISICA INAF | 26 |
| UNIVERSITY OF THE WESTERN CAPE | 21 |
| UNIVERSITY OF CALIFORNIA SYSTEM | 17 |
| UNIVERSITY OF EDINBURGH | 17 |
| CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS | 16 |
| UNIVERSITY OF OXFORD | 16 |
| UDICE FRENCH RESEARCH UNIVERSITIES | 15 |
| MAX PLANCK SOCIETY | 14 |
| NATIONAL AERONAUTICS SPACE ADMINISTRATION NASA | 14 |
| CHINESE ACADEMY OF SCIENCES | 13 |
| UNIVERSITE DE PARIS | 12 |
| UNIVERSITY OF TEXAS SYSTEM | 12 |

| Affiliation | Record count |
|---|---|
| CALIFORNIA INSTITUTE OF TECHNOLOGY | 11 |
| PENNSYLVANIA COMMONWEALTH SYSTEM OF HIGHER EDUCATION PCSHE | 11 |
| UNIVERSITY OF LEICESTER | 11 |
| UNIVERSITY OF TEXAS AUSTIN | 11 |
| LEIDEN UNIVERSITY | 10 |
| LEIDEN UNIVERSITY EXCL LUMC | 10 |
| MASSACHUSETTS INSTITUTE OF TECHNOLOGY MIT | 10 |
| PENNSYLVANIA STATE UNIVERSITY | 10 |
| PENNSYLVANIA STATE UNIVERSITY UNIVERSITY PARK | 10 |
| RHODES UNIVERSITY | 10 |
| RUSSIAN ACADEMY OF SCIENCES | 10 |
| UNIVERSITY OF LONDON | 10 |
| UNIVERSITY OF WISCONSIN MADISON | 10 |
| UNIVERSITY OF WISCONSIN SYSTEM | 10 |



## Publications with SAAO Affiliation

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# IMPRESSUM

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