



## PHYSICAL SCIENCES

# Towards an Intelligent Observatory

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**Abstract:** The Intelligent Observatory (IO) refers to the vision of the South African Astronomical Observatory (SAAO) to meet the scientific needs of both the South African and international astronomical communities by providing a better and more efficient service. The idea behind the IO is to harmonise the astronomical operations of all the hosted and local astronomical facilities on the Sutherland Plateau. The vision requires both upgrades to some of the telescopes and a re-design of the current Sutherland operations model. The primary science driver, for the IO, is time-domain and transient science.

**Key words:** Observatory, operations, telescopes, astronomy.

## INTRODUCTION

The South African Astronomical Observatory (SAAO) provides ground-based optical observational facilities for astronomers across South Africa, conducts world-class astronomical research, and communicates the excitement of astronomy to the people of South Africa. The headquarters are based in Cape Town whereas the telescopes are located on a barren plateau outside the Karoo town of Sutherland, approximately 350kms from Cape Town (Figure 1).

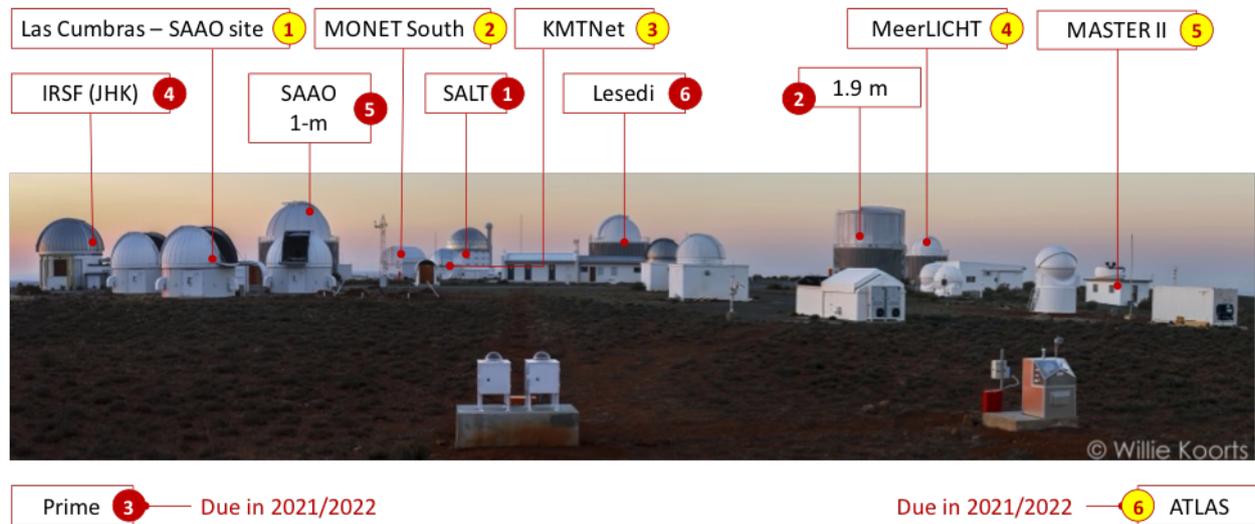
### The Telescopes

The SAAO is the premier facility for optical astronomy on the African continent, and owns and operates several optical and infrared telescopes which include the Southern African Large Telescope (SALT), Lesedi, the 1.0m and 1.9m telescopes.

## SALT

SALT (Väisänen & Buckley 2011) is funded by a consortium of international partners from South Africa, the United States, Germany, Poland, India and the United Kingdom. It is the largest optical telescope in the southern hemisphere with a hexagonal primary mirror array 11 metres across, comprising of 91 individual 1m hexagonal mirrors. SALT has an unconventional design, in that the telescope structure can only rotate in azimuth, while the elevation axis is fixed at an angle of 37° from the vertical. As the Earth rotates, astronomical targets move across the spherical primary mirror array. A tracker system carries the prime focus payload to follow the image over the spherical focal surface. Thus, there is an annulus of sky visible to SALT at any time and observations have to be scheduled to catch targets as they pass through that visibility window. About 70 percent of the Sutherland sky can be accessed in this way.

All of the SALT instruments are either housed at prime focus, or fibre-fed from there



**Figure 1.** The telescopes of the Sutherland plateau (from SAAO, Intelligent Observatory Operational Concept Description (OCD)).

to the spectrometer room situated beneath the telescope. The prime focus spectrograph (RSS) occupies the straight-through focus and is mounted on top of the payload. It provides normal long slit- and multi-object spectroscopy (MOS) and it is also capable of Fabry-Pérot imaging spectroscopy, narrow-band imaging, linear and circular polarimetry, and high-speed spectroscopy using a frame transfer detector mode.

Currently the High Resolution Spectrograph (HRS) is the only fibre fed instrument and it is housed in a thermal enclosure located in the spectrometer room beneath the telescope. HRS is a 2-channel white pupil high-resolution spectrograph covering the wavelength range from 370 nm to 890 nm. The FIF couples four pairs of 50 m long optical fibres from the telescope focal plane to the instrument and allows the selection of the appropriate fibre pair for a given instrument mode.

There is also an auxiliary port currently occupied by the Berkeley Visible Image Tube which is capable very high time-resolution photometric imaging observations. The

instrument is capable of recording photon events with a precision of 25 nanoseconds.

### **The 1.9m**

The 1.9m Radcliffe telescope was recently upgraded to be operated remotely. The telescope was originally commissioned for the Radcliffe Observatory in Pretoria where it was in use between 1948 and 1974. Following the closure of the Radcliffe Observatory it was moved to Sutherland where it became operational again in January 1976. Between 1951 and 2004 it was the largest telescope in South Africa. Three instruments are currently available for use namely:

- High-speed Photo-Polarimeter (HIPPO, Potter et al. 2008)
- Sutherland High-speed Optical Camera (SHOC, Gulbis et al. 2011)
- Spectrograph Upgrade: Newly Improved Cassegrain (SpUpNIC, Crause et al. 2019)

### **The 1.0m**

The 1.0m (40 inch) telescope was originally erected (1964) in Cape Town and later moved to Sutherland. Recent upgrades now permit remote observing. Two instruments are currently available for use namely:

- Sutherland High-speed Optical Camera (SHOC)
- Imaging STE camera

Currently under construction, at The Inter-University Centre for Astronomy and Astrophysics, Pune, India, is a wide angle imaging polarimeter which is expected to be installed in the 1.0m in 2020/21.

### **Lesedi**

Lesedi is the newest SAAO 1.0m telescope and was designed to be a robotic telescope. Currently undergoing commissioning and already offering remote operations. The Sutherland High-speed Optical Camera (SHOC) is in regular use and as of June 2020 a wide angle imaging camera (Sibonise) is undergoing commissioning. A low resolution spectrograph (Mokoodi) is being built at LJMU and expected to be delivered in 2021.

### **IRSF**

The Infrared Survey Facility (Glass & Nagata 2000) is a 1.4m (55-inch) reflector fitted with a 3 colour simultaneous infrared (JHK) imager which is also capable of imaging polarimetry.

### **Prime**

PRIME will be a 1.8 metre telescope similar to the MOA in New Zealand. The telescope will have a 1.3 x 1.3 degree field-of-view using four Hawaii 4RG detectors and will be fitted with zYJH filters. It is expected to be on-sky in 2022.

### **Hosted facilities**

Besides for the SAAO's flagship telescopes, the Sutherland facility houses a number of other telescopes and instruments. Some, like MeerLICHT (Paterson 2017) and IRSF are operated by SAAO, while others are operated by other research organisations such as the South African National Space Agency, or one of several international astronomy institutions, for example the All-Sky Automated Survey for Supernovae (ASAS-SN, Shappee et al. 2014), Las Cumbres Observatory (LCO), Mobile Astronomical System of the Telescope-Robots Network (MASTER-Net, Lipunov et al. 2012) and MONITORING NETWORK of Telescopes (MONET, Hessman 2001).

### **Astronomy Operations**

Each of the facilities have their own modes of operation primarily depending on the science driver and/or ownership. SALT issues 2 calls per year for applications from the partner institutes. The amount of time applied for and eventually awarded is tailored to meet the scientific goal of the application. The telescope uses a queue-based mechanism for executing the observing program, with dedicated SALT astronomers and operators performing the observations.

Applications to the SAAO 1.9m, 1.0m and the IRSF are made 3 times per year and the PI is expected to perform their own observations. Time is allocated in 1 week blocks as a result of the practicalities of travelling and accommodating in Sutherland. The recent development into remote observing is allowing some flexibility in the allocation of blocks of time. Applications are open to the entire national and international community and time is awarded primarily on scientific merit.

The hosted facilities are all generally operated for specific science goals and

**Table I. Sutherland hosted facilities and mode of operation.**

No	Telescope	Instruments	Current mode of operation
1	Las Cumbres Observatory (LCO) (1 metre) (x3)	Sinestro (Optical imager)	Queue-based robotic and not under SAAO control.
		SBIG (High Resolution Spectrograph)	
		NRES	
2	MONET (1.2 m)	Apogee (Optical imager)	Queue-based robotic Shared time on request
		Imager	
		MORISOT	
3	KMTNet	Wide field Imager	PI-based with operators onsite. Time allocated by SAAO TAC.
4	MeerLICHT	Wide-field Imager	Meerkat optical slave
5	MASTER (0.4 - m) (x2)	CCD Cameras (optical imager with polarimeter)	Queue-based robotic. Not under SAAO control.
6	ATLAS (0.6 m)	CCD Camera (wide-field optical imager)	Queue-based robotic and not under SAAO control.

consequently their mode of operation is mostly robotic and queue scheduled (see Table I).

## SCIENTIFIC RATIONALE

The main science driver for the IO is time-domain astronomy. The time over which astronomical objects can vary ranges from milliseconds to years depending of the characteristics of the objects. Synoptic monitoring of objects that are changing slowly are observed over time-scales of days and years, while the variability of close binary stars takes place on timescales of tens of minutes to hours, examples are cataclysmic variables and X-ray binaries. Then there are rapidly varying objects, such as pulsars and accretion instabilities in flows and discs that require high time resolution observations of sub-seconds.

A sub-set of time-domain astronomy is transients. A transient astronomical event is

an astronomical object or phenomenon whose duration can be measured in seconds, hours, days, weeks, or several years and are seen across a wide range of object classes including some of the most energetic events in the Universe. Many transients are found through e.g. all-sky surveys or high-energy events are discovered with X-ray, gamma-ray, and radio telescopes. More recently events are being discovered with gravitational wave and neutrino detectors. Examples might include:

- Asteroids
- Active galactic nuclei (AGN)
- Cataclysmic variables
- Eruptive variables
- Exoplanet transits
- Gamma Ray Bursts

- Gravitational Wave and Neutrino transients
- Novae and related objects
- Microlensing events
- Merging white dwarfs, neutron stars or black holes
- Tidal Disruption Events
- Transits and eclipses
- Solar system objects such as minor planets and comets
- Supernovae

Such a range of objects and their corresponding phenomena result in a variety of emissions across the entire electromagnetic and multi-messenger spectrum. It is through observing these timely events that we get the opportunity to improve our knowledge and understanding of these objects, their underlying physics and make new discoveries along the way. Ground and space based facilities will continue to provide a wealth of transient science opportunities. However, it is anticipated that new and upcoming facilities, especially LSST, will substantially increase the detection of transient phenomena. The magnitude of the increase will be such that the number of transient events is expected to be millions per night from LSST alone. Consequently some form of intelligent filtering or brokers will be required in order to identify the most interesting transients for focused detailed followup observations.

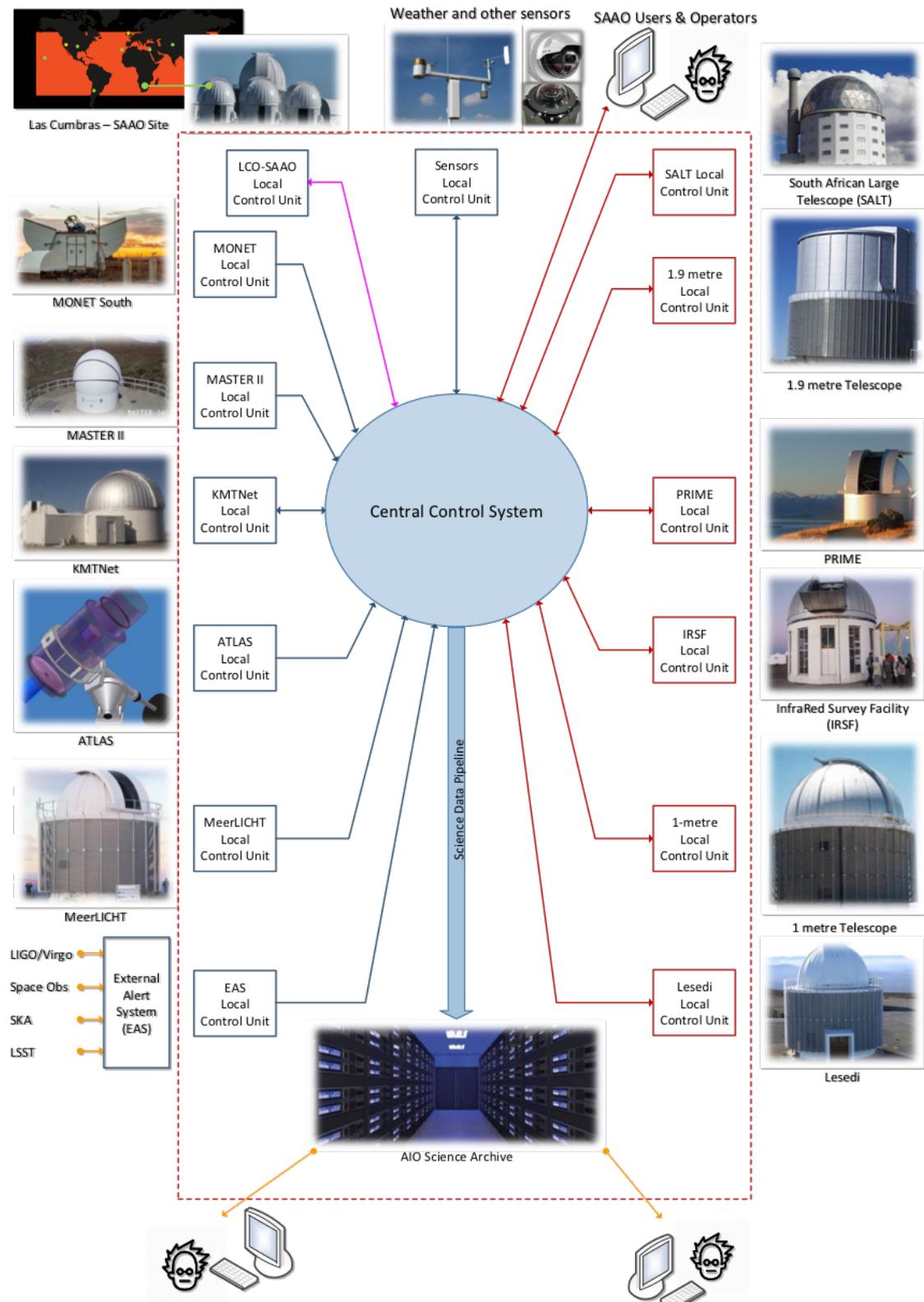
Each followup will have to be tailored to the type of object and the nature of the optical/IR emissions. With 25 different facilities operating on the Sutherland plateau with even more instruments ranging from wide-field imagers and spectrographs to specialised modes of high cadence observations or polarimetry, the SAAO is uniquely equipped to explore all transient

and time domain phenomena - provided that all the facilities can be intelligently managed and operated with this vision in mind.

## THE INTELLIGENT OBSERVATORY VISION

The vision for the SAAO is to have all the SAAO facilities (telescopes and instruments) integrated into the IO. The operational model for the IO will add additional functionality to the operations of the observatory. For example, in addition to the traditional call for proposals schedule, the IO will allow astronomers to submit observation proposals anytime. Observers will also be able to define whether they want their observation to be placed in a queue for automated observation, operated manually from the Cape Town control room, operated manually from a remote desktop anywhere in the world or by actually operating the facility manually on-site. In addition, the schedule of the observation programme, will be agile enough to run the most effective and efficient rolling observation programme queue system, where it is reactive to allow the queue to be updated continuously in real-time and even allow resources (telescopes or instruments) to be reallocated during a night's observing in the event of receiving an alert of a high priority target of opportunity (TOO).

The planned IO architecture is depicted in Figure 2. It will be an upgrade to the current architecture, of supporting ongoing projects, to additionally accommodate and be optimised for transient and time domain science. Furthermore the proposed architecture will permit observations to be carried out on different time scales adding to the current system of weekly allocations on some of the SAAO facilities. The IO will consist of all the SAAO owned and some of the hosted facilities, it will have a Central Control System (CCS), Local



**Figure 2. Intelligent Observatory Concept.**

Control Units (LCUs), an External Alert System, Weather Monitor System, and a Science Archive.

In order to achieve the IO vision, an initial program team has been formed consisting of a principle investigator (PI), a project manager (PM) and two software developers. The program will also pull on the resources across the observatory including the software developers, instrumentation development teams, astronomers and the operations division heads. Ultimately the objective of the intelligent observatory programme is to “intelligently” automate as much of the tasks that are currently performed by “the observatory” and astronomers. In that respect the deliverables can be grouped into 2 components associated with either the Central Control System (CCS) or the Local Control Units (LCUs).

### **Local Control Units (LCUs)**

As shown in the proposed system architecture (see Figure 2), each facility will require a LCU. The function of the LCU is to execute observations as commanded/requested by the CCS. The detailed design of each LCU will depend on the particular facility. For example, LCO and SALT already operate a queue based, fully automated and service based telescopes respectively. Therefore the LCO and SALT LCUs do not need to control the telescopes or instruments. Instead the LCU’s function will be to simply insert observation requests, specifically transient events or targets of opportunity, into the LCO and SALT scientific programmes.

On the other hand, the LCU for the Lesedi, 1.9m and the 1.0m telescopes will be required to be able to fully operate the telescopes and instruments, effectively performing all the tasks of an operator or astronomer at the telescope. In addition, each of these telescopes will require both hardware and software upgrades to enable operations via software. This will include,

for example, the design and construction of an instrument selector port for the 1.9m, or the development of software algorithms to e.g. accurately align targets on the slit of a spectrograph and to autofocus.

The function of the LCUs for the other hosted facilities will depend on the operation model in each specific case. For example, MeerLICHT’s scientific goal is to simultaneously optically monitor the radio sky as observed by MeerKAT. In the event of a radio transient, and its optical identification by MeerLICHT, MeerLICHT would make a request to the IO for followup observations. This may consist of, for example, using SALT to obtain a once off polarized spectrum of a radio flaring AGN, or request the 1.0m telescope to optically monitor the evolution of an un-identified target for the following week.

### **Central Control System (CCS)**

The CCS is the key component to intelligently manage the automated systems of the observatory. The CCS will manage the nightly queue of every facility taking into account that some facilities will be under manual control, service observing, remote control or fully automated. The queue(s) will consist of both PI approved observations and observatory routine calibrations. The queue(s) will be appropriately constructed taking into consideration target visibility details, proposal priorities and other parameters that will need to be defined. For the automated facilities, the CCS will intelligently manage the live observations of the facilities via constant communication with the relevant LCUs.

The CCS will employ some form of intelligent algorithm that will monitor the various alert streams (see e.g. those depicted in Figure 2 as the EAS) and provide a filtered priority alert service to the SAAO transient community. Furthermore, the intelligent algorithm may also automatically construct “Phase 2 proposals” to be injected into

the observing programme. Depending on the priority assigned to the alert this may override ongoing observations or simply add them to the queue. The intelligent algorithm will be aware of the current operation modes (manual, service or automated) and available telescopes and react accordingly. I.e. for manually operated facilities the observer (astronomer) will receive an alert notice/request, for service and automated facilities the alert will be inserted into the queue. Clear rules have to be applied regarding interrupting PI (manual) scheduled observations. As already mentioned above, the alert streams will very likely emanate from other Sutherland facilities such as the MeerLICHT telescope, MASTER network and the recently installed ASAS-SN.

The CCS will provide a centralized weather service. Currently weather services are provided in an ad hoc manner through multiple weather stations operated either by hosted facilities or by SAAO and SALT. The CCS would centralize the service providing an accessible interface for any facility to use. The CCS will also inform LCUs, currently under its control, when the weather becomes unfavorable and issue shutdown procedures. The LCUs will also do this independently. It is also expected that the weather service will employ some form of algorithm to derive more intelligent information from the weather stations, e.g. weather predictions or machine learned information from the live all-sky cameras data.

The CCS will also oversee and manage automated quick-look data services where appropriate. The automatic analysis of which may provide additional input to the alert stream. For each instrument, a set of pipeline data reduction tools will be required. These may also be used as part of the offline data analysis toolset for PIs.

## SUMMARY

The “Intelligent Observatory” refers to the upgrade of SAAO’s astronomy operations and facilities, in order to better meet the needs of the South African astronomers and SAAO’s international partners better (Väisänen et al. 2018). The vision for the SAAO is to have all the SAAO facilities (telescopes and instruments) integrated into the IO. The operational model for the IO will add additional functionality to the operations of the observatory. For example, in addition to the traditional call for proposals schedule, the IO will allow astronomers to submit observation proposals anytime. Observers will also be able to define whether they want their observation to be placed in a queue for automated observation, operated manually from the Cape Town control room, operated manually from a remote desktop anywhere in the world or by actually operating the facility manually on-site. In addition, the schedule of the observation programme, will be agile enough to run the most effective and efficient rolling observation programme queue system, where it is reactive to allow the queue to be updated continuously in real-time and even allow resources (telescopes or instruments) to be reallocated during a night’s observing in the event of receiving an alert of a high priority target of opportunity (TOO).

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