Smart Observatories:

The SAAO Intelligent Observatory
The African Integrated Observations System
The BRICS Intelligent Telescope and Data Network

David Buckley

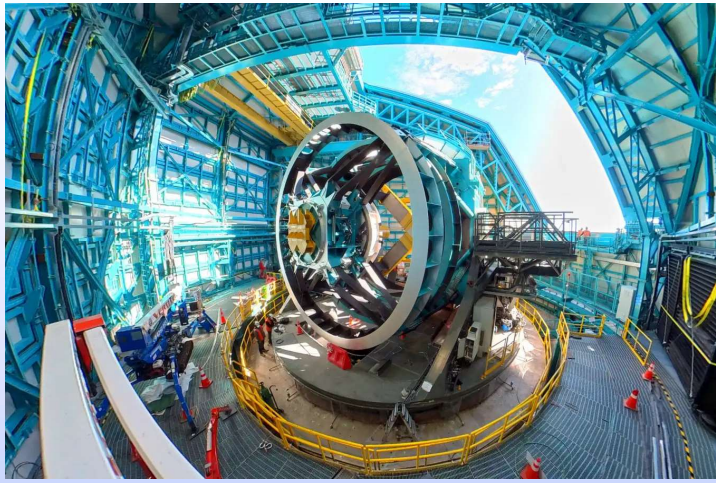
South African Astronomical Observatory
University of Cape Town
University of the Free State

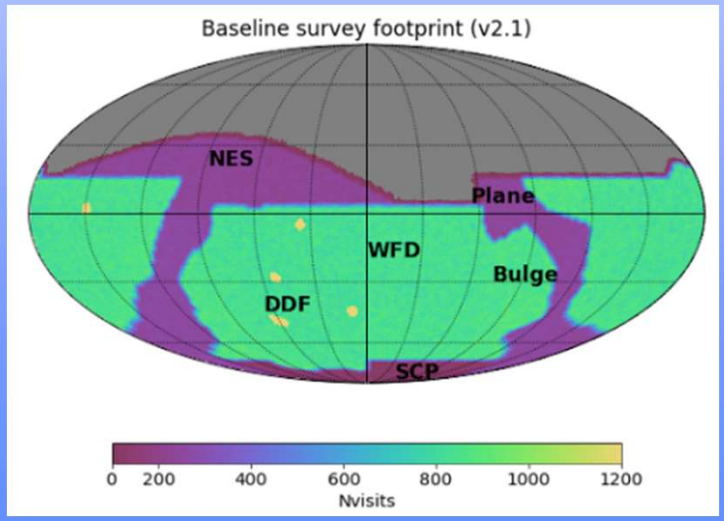
On behalf of the SAAO's Intelligent Observatory team (PI: Stephen Potter), The African Astronomical Society and the BRICS Astronomy Working Group and Flagship Programme (co-PI: Russ Taylor)

The Next Big Thing in Time Domain Surveys:

Rubin Observatory's *Legacy Survey of Space and Time (LSST)*

- International project to continuously survey the southern sky over 10 years (~18,000 square degrees) starting in 2025
- 8.4-m diameter telescope with wide field (~10 square degrees)
- Biggest camera ever built for astronomy (3.2 gigapixels)
- Deepest optical survey ever attempted (27th mag)
- Cadence of a few days for Wide Fast Deep (WFD) survey
- Average of ~825 observations in the WFD footprint
- Expecting ~10^7 alerts of transient or variable objects *per night!*
- Following up all alerts like drinking from a firehose of data so Machine Learning will help decide what's worth following up.
- *Networks of smart follow-up telescopes will be crucial!*





The Future of Transient & Variable Followup: Automated Intelligent Observatory Networks

Example: SAAO's Intelligent Observatory

- Network telescopes on the Sutherland site to allow automated follow-up from multi-wavelength alert brokers
- Science driver: follow-up on Rubin LSST transient & variable sources and transient alerts from other facilities (including space-based)
- Project started in 2020 with 3 telescopes and utilizing SW system developed at LCO
- Eventually extend to some of the other hosted facilities
- Telescopes now routinely remotely operated and one in fully autonomous mode
- ***Paving the way for automated global telescope networks including the BRICS Intelligent Telescope and Data Netwok plus the African Integrated Observation System (AIOS)***

South African Astronomical Observatory telescopes

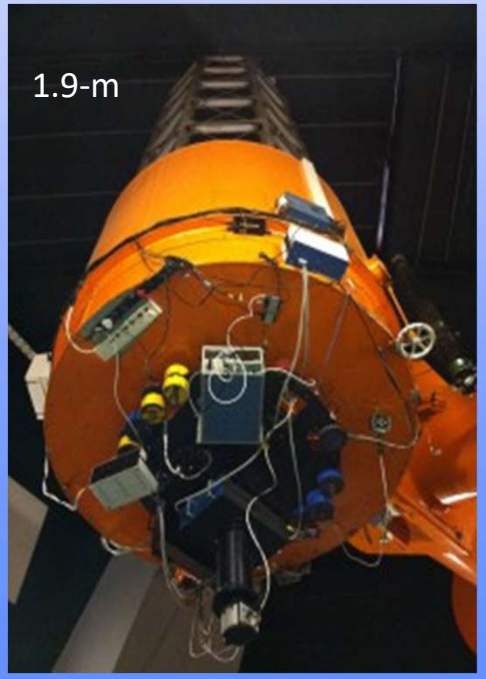
Key Numbers for SAAO & hosted Telescopes

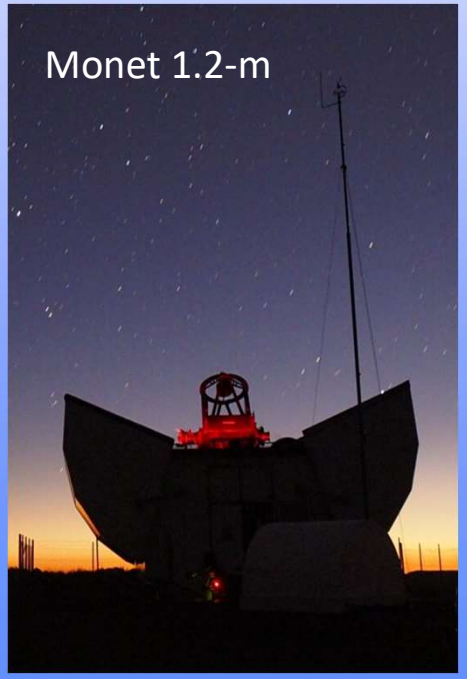
Apertures	1.9 m , 1.8 m PRIME (commissioning in 2023/24), 1.6 m KMTNet, 1.4 m IRSF, 1.2 m IRSF, 3 x 1.0 m LCO; 1.2-m MONET-South; 0.65 m MeerLICHT, 2 x 0.4 m MASTER
Wavelength range	320 – 900 nm (visible) for most NIR for two (zyJH PRIME and JHK_S IRSF)
Instrument suite	Wide field (1.5 – 4 deg^2) imaging: PRIME, MeerLICHT, KMTNet Low-medium resolution spectroscopy (Spupnic on 1.9-m, Mookodi on 1.0 m) High speed photometry (SHOC on 1.0 m's, Mookodi on 1.0m) High speed polarimetry (HIPPO on 1.9 m)
Other relevant facts	A suite of telescopes are being incrementally networked into the SAAO's *Intelligent Observatory*. Designed for automatic followup of transients, etc.

South African Astronomical Observatory telescopes

- Majority of facilities at the SAAO site in Sutherland
- ~20 telescopes with 0.40 – 1.9-m apertures, in optical and NIR

- Mostly supporting time series optical photometry, spectroscopy and photo-polarimetry





Diversity of facilities and instruments at the SAAO:

IRSF 1.4-m:
(SIRIUS, SIRPOL)

- Simultaneous JHK imaging
- Polarimetry

SAAO's 40-inch:
(SHOC)

- High speed photometry
- Imaging polarimetry

SALT 10-m :
(HRS, RSS, SALTICAM)

- Low-, Med- and High-resolution spectroscopy
- Spectro-polarimetry
- UV–Visible imaging

SAAO's 74-inch:
(SpUpNIC, SHOC, HiPPo)

- Medium resolution spectroscopy
- High speed photometry
- High speed photo-polarimetery

PRIME 1.8-m

- zYJH imager
- High res NIR spec

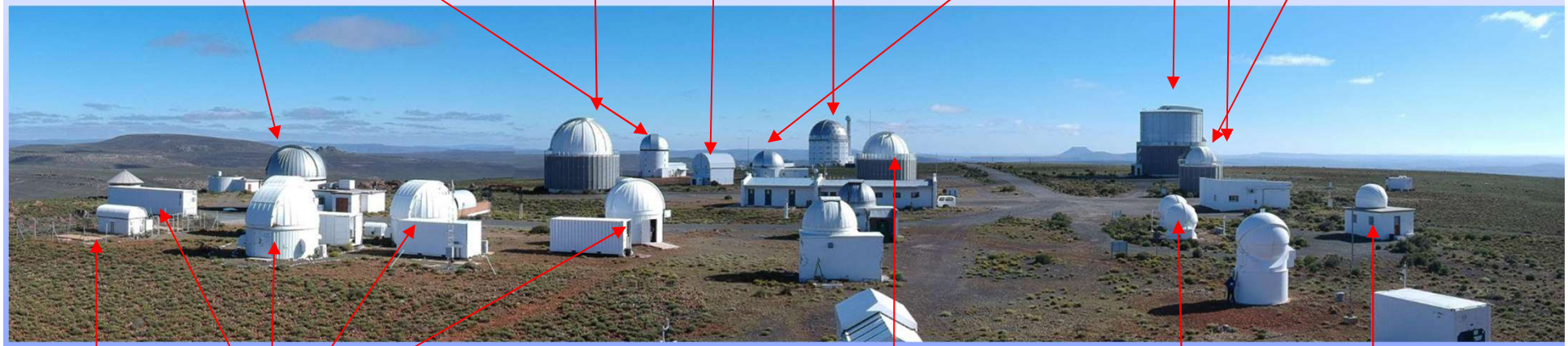
MONET 1.2-m

KMTNet 1.6-m

- UBVRI imaging

MeerLICHT 0.65-m

- ugrizq imaging



LCO 3 x 1-m:

- Imaging
- High resolution spectroscopy

LCO 40 cm

ASASSN

SAAO's 1-m Lesedi:
(Mookodi, Sibonise)

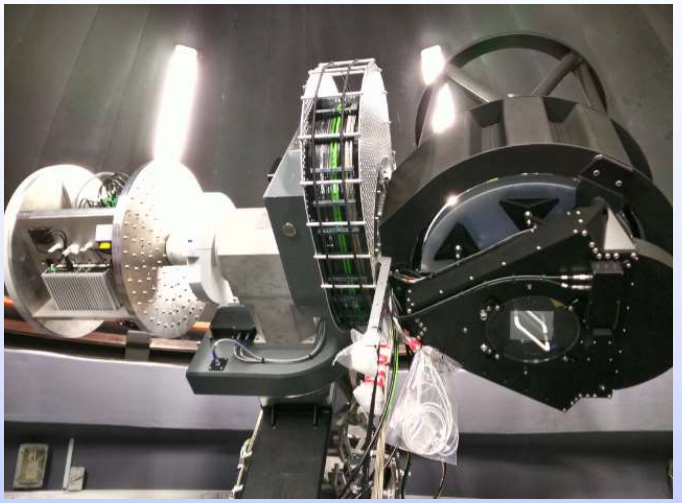
- Low-resolution spectroscopy
- High speed photometry
- Wide-field imaging

SOLARIS
2 x 0.4-m

MASTER
2 x 0.4-m

The Sutherland telescope farm

- **Own and joint facilities (SAAO telescopes, MeerLICHT, PRIME)**
- **Hosted facilities (e.g. LCO, Monet-South, Solaris, Master, ATLAS)**
- **Several dedicated to transient detections (MeerLICHT, MASTER, ATLAS)**



SAAO Hosted Telescopes: PRIME 1.8-m

Japan (Osaka/AstroBiology Centre)/US (NASA GSFC/UMD)/ South Africa collaboration)

***zyJH* imager (4 x Hawaii 4RG arrays; Roman Space Telescope)**

1.5 sq degree FoV

Main science exoplanet discoveries from gravitational microlensing detection in the Galactic bulge (spin-off for variable star studies)

ToO override for transients

Currently in commissioning (open calls in 2024)

Fibre-feb high resolution (R ~40,000) NIR spectrograph to be installed in 2025 (exoplanet followup)

SAAO Hosted Telescopes: MONET South 1.2-m

- Imaging CCD camera
- Fibre-fed low resolution spectrograph (being commissioned)
- Fully robotic
- Uses LCO portal as web frontend
- ToO functionality work-in-progress
- Can be on target within seconds, due to fully open roof

SAAO Intelligent Observatory (IO) Vision

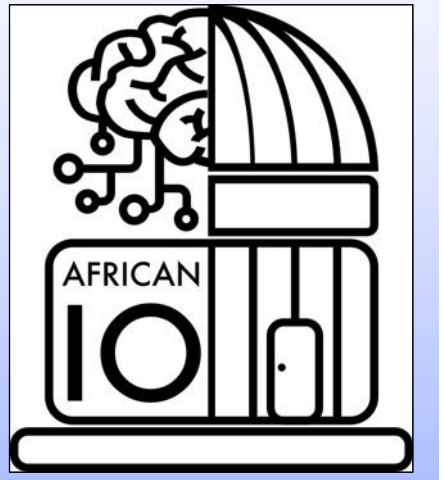
All telescopes integrated into the IO

- Coordinated science across telescopes in the era of multi-messenger and time domain astronomy
- Science on any time scale
- Submit observation requests at any time
- Observe from Sutherland, Cape Town or anywhere or automatically
- Respond to alerts, computer generated requests, automation, robotisation
- Advance SAAO into the 4IR
- Make Sutherland plateau an intelligent AI transient followup machine

What is the SAAO's Intelligent Observatory (IO) vision?

All telescopes integrated into an IO

- Coordinated science across telescopes in the era of multi-messenger astronomy
- Enhance our national and international partnerships
- Advance SAAO into the 4IR
- Turn the Sutherland plateau an intelligent AI transient followup machine



To better serve the community/users:

- Submit proposals at any time
- Science on any time scale (not restricted to 1 week blocks)
- Observe from Sutherland, Cape Town or anywhere
- Observe manually, queue or service
- Respond to alerts, computer generated requests
- Trigger automated requests for followup observations from alert triggers
- Will allow for the automated selection of telescopes, instruments & modes and appropriate observation setup and scheduling
- GCN socket, VOEvents, APIs for robotic & queue-scheduled telescopes
- Developing toolkits for automated scheduling, e.g. Target & Observation Manager (TOM) and Astronomical Event Observatory Network (AEON), used to coordinate observing requests across multiple participating facilities (LCO initiatives)

Steps to the Intelligent Observatory

1. Remotely operable telescopes
2. Service mode capabilities
3. Robotic capabilities
4. Networked autonomous operations

Status:

1.9m, 1.0m, Lesedi 1m telescopes have had hardware and software upgrades to allow for:

- Remote operations
- Scripted observations

Using Observatory Control System (OCS) from Las Cumbres Observatory (LCO)

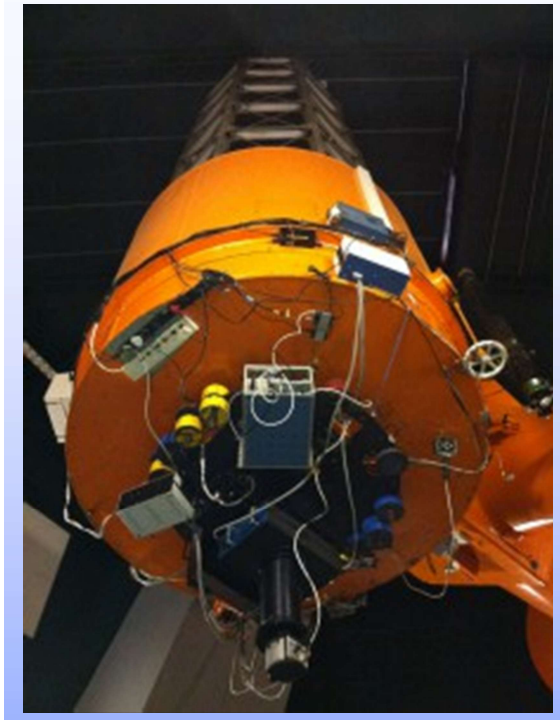
Locally installed and configured for Lesedi 1-m telescope

Programmatically submit observation requests which are undertaken robotically

Ongoing:
Adding other telescopes + instruments to the OCS

SAAO Telescopes currently in the IO:

- 1.9-m



Low-medium resolution spectrograph

Photopolarimeter

Andor emCCD high-speed camera

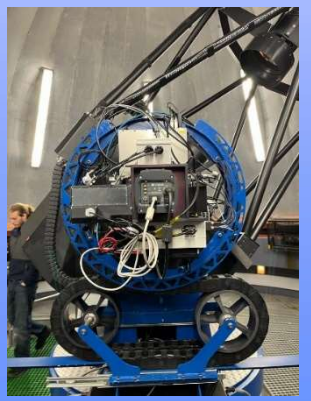
- 1.0-m

Andor emCCD high-speed camera

Wide-field imaging polarimeter (2024)

- 1.0-m *Lesedi*

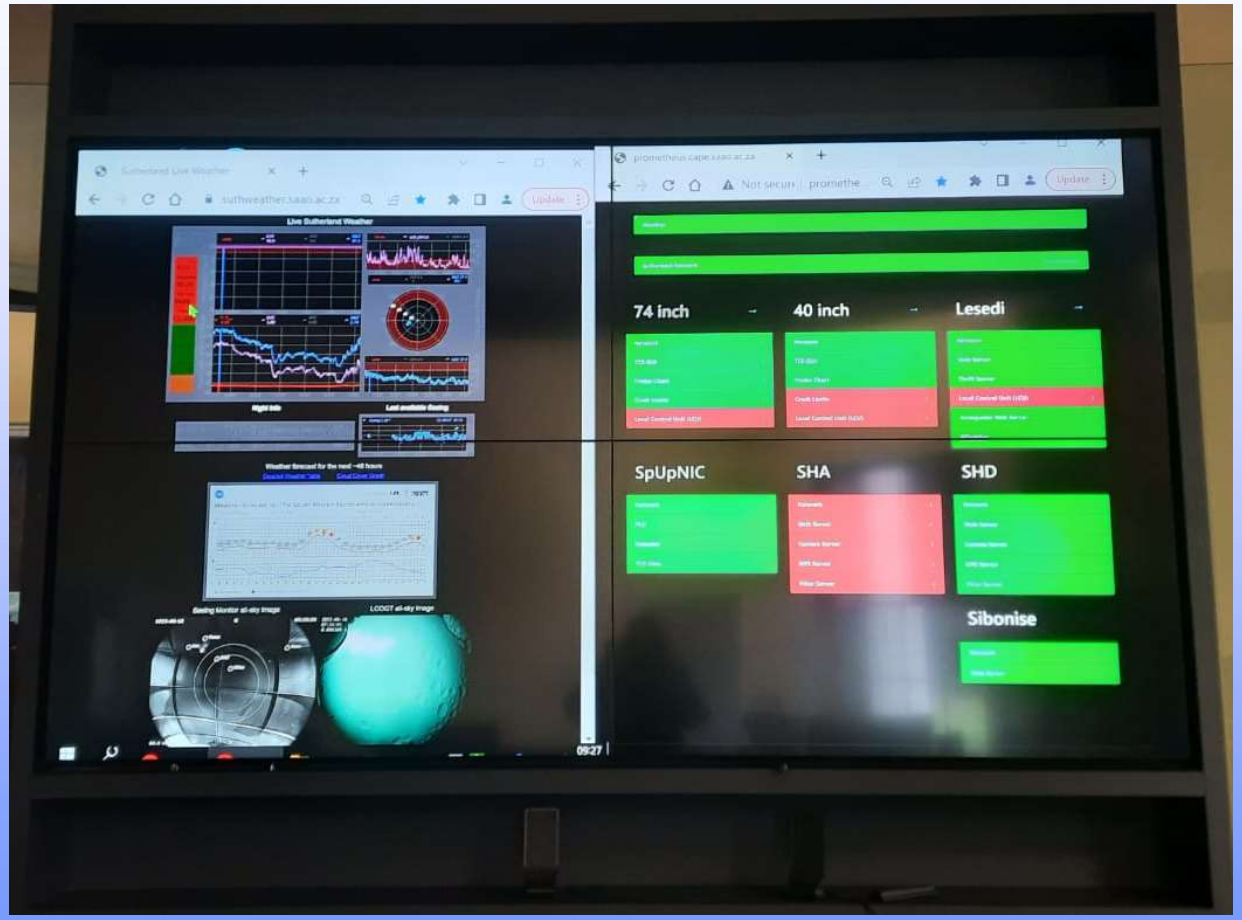
Nasmyth 1
Low res spectrograph & imager (fast)



Nasmyth 2
~20 arcmin FoV camera

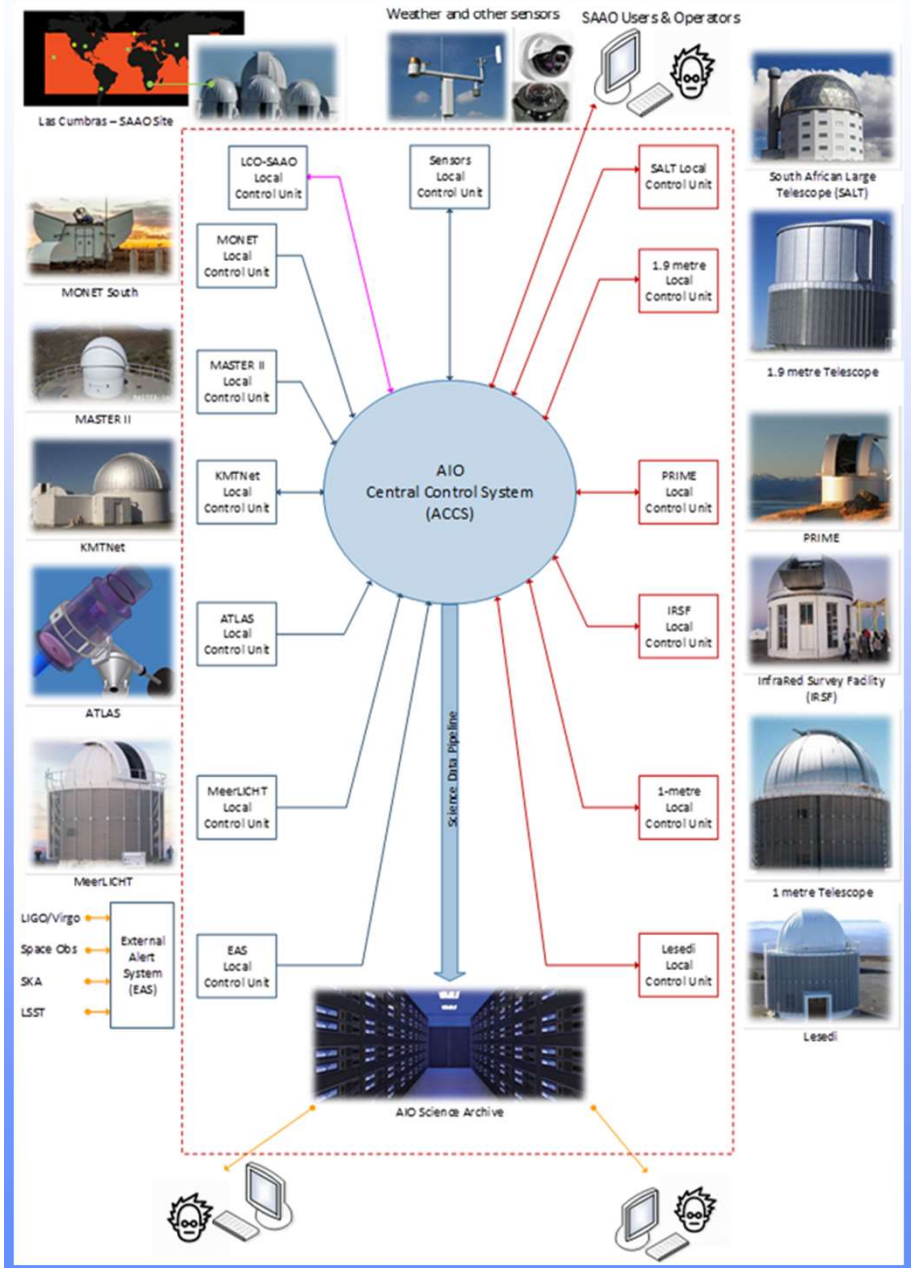
Remote Observing

From Cape Town HQ, from home and from overseas*



* With adequate bandwidth and communication

Automated Observing



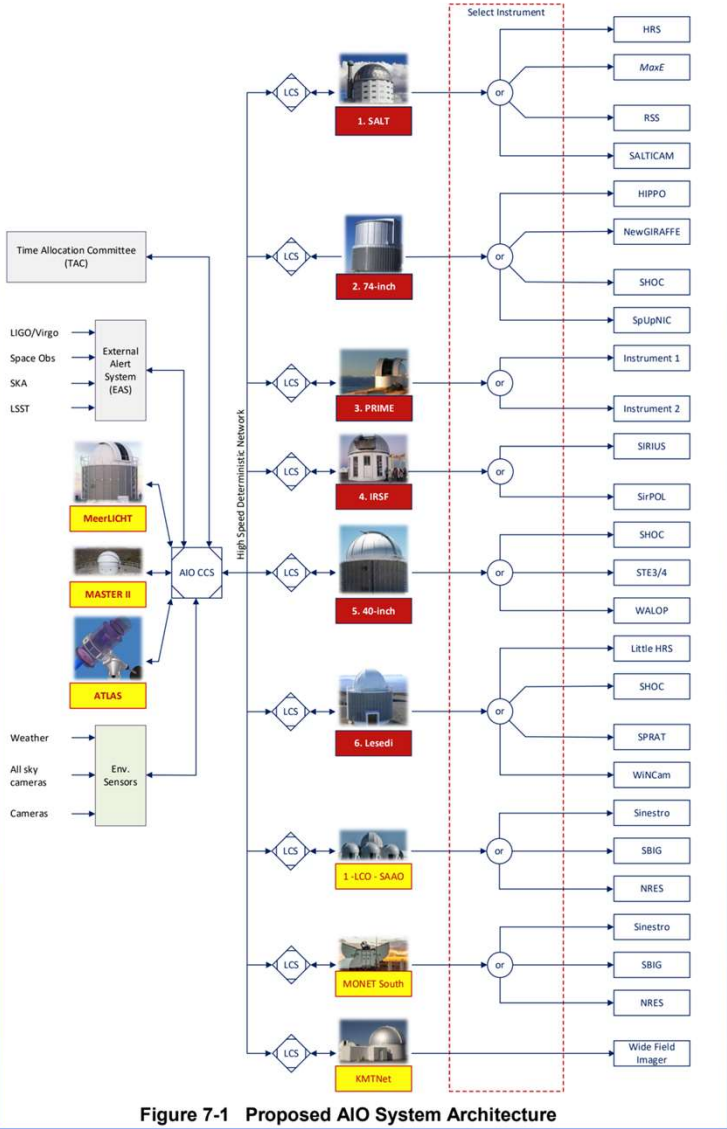
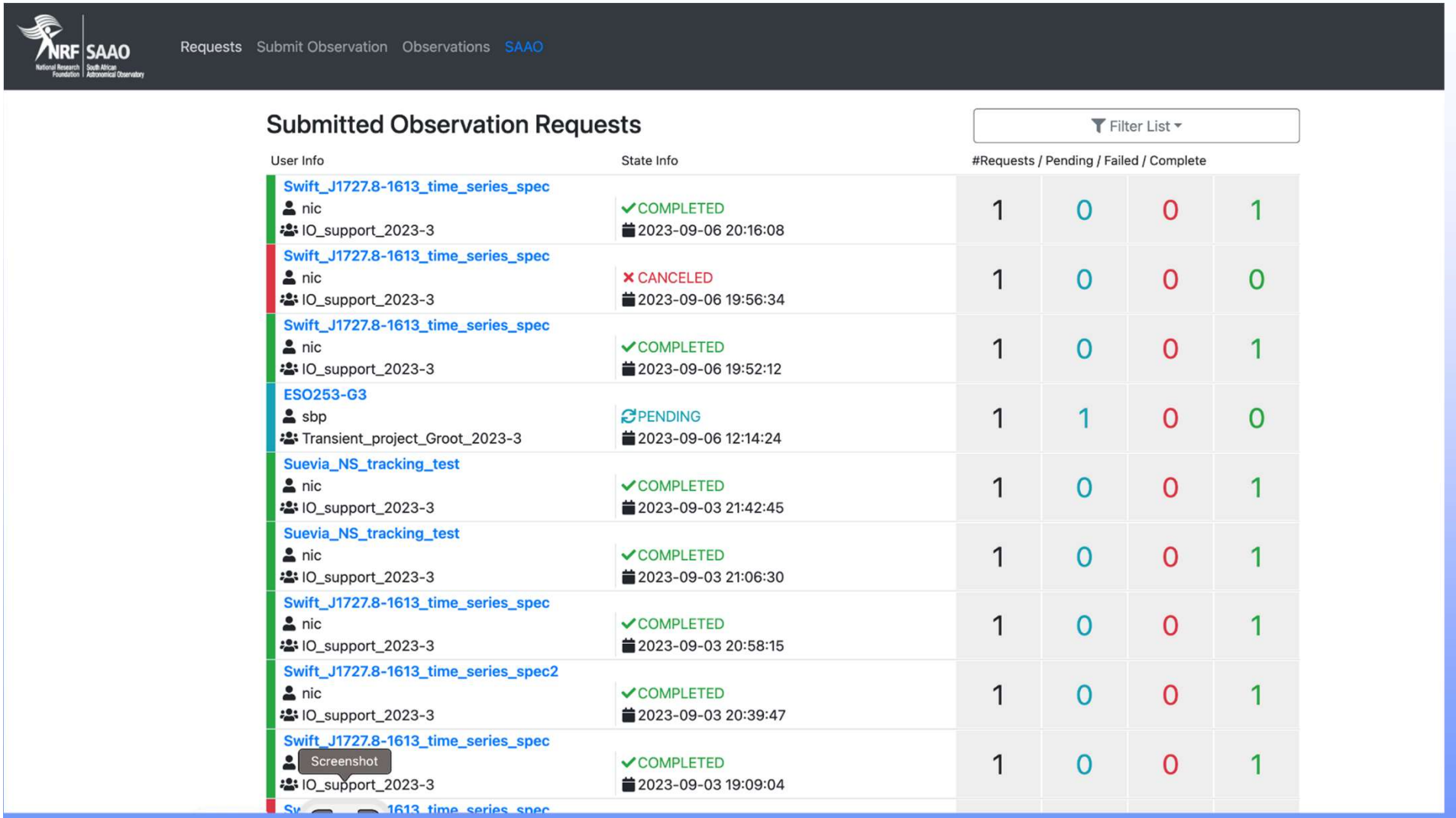


Figure 7-1 Proposed AIO System Architecture

Running Docker-based API services to automate the proposal submission, schedule generation/updates, and data disbursement

Example: Lesedi 1-m telescope



AfAS
African Astronomical Society

The Future:
Expand the IO concept into Africa

An African Astronomy Flagship Concept

African Integrated Observation System (AIOS)

(Leveraging the IO concept)

NRF National Research Foundation | SAAO South African Astronomical Observatory

IDIA Inter-University Institute for Data Intensive Astronomy

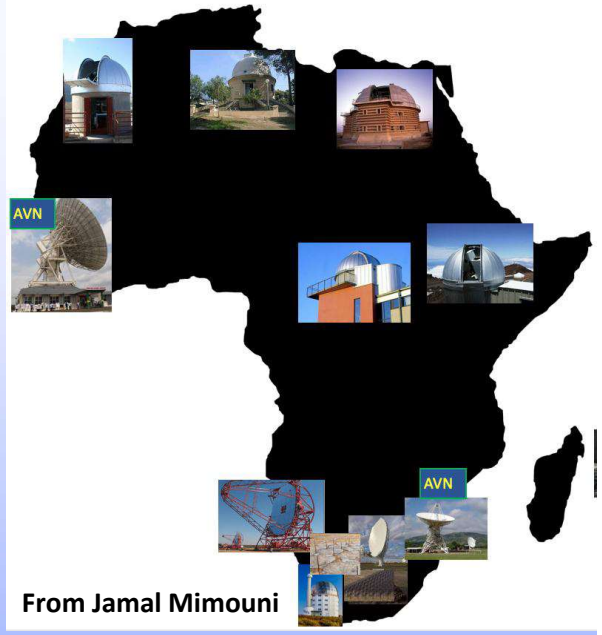
BRICS Astronomy Working Group

OAD
OFFICE OF ASTRONOMY FOR DEVELOPMENT

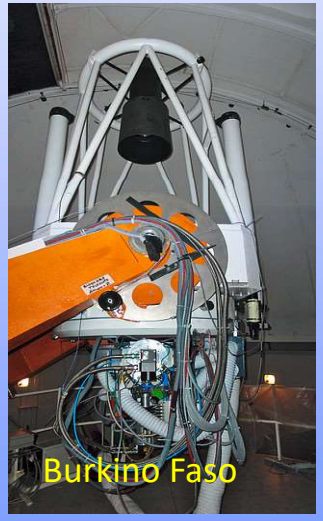
The Future: An African-wide Network

The African Integrated Observation Network (AIOS)

- **Expand the SAAO's *Intelligent Observatory* concept into Africa**
- **Use existing facilities networked together**
  - **Morocco**
  - **Algeria**
  - **Egypt**
  - **Ethiopia**
  - **Burkino Faso**



From Jamal Mimouni



- Develop international collaborations in transient/time domain astronomy
- Motivate for development of new facilities
- Train young scientists/engineers
- Need for maximize sky coverage (in position & time)

Potential Examples of other observatory integrations:

1. Kottamia Observatory, Egypt

- An old (1955) 74 inch (1.9-m) telescope, but well instrumented and capable (same model as the SAAO 1.9-m0

Potential Examples:

2. Entoto Observatory, Addis Ababa, Ethiopia

- Two well instrumented modern 1.0-m telescopes were installed in 2013. Could help drive compelling observational astronomy programmes, particularly within the AIOS.

Potential Examples:

3. Oukaimeden Observatory, Morocco

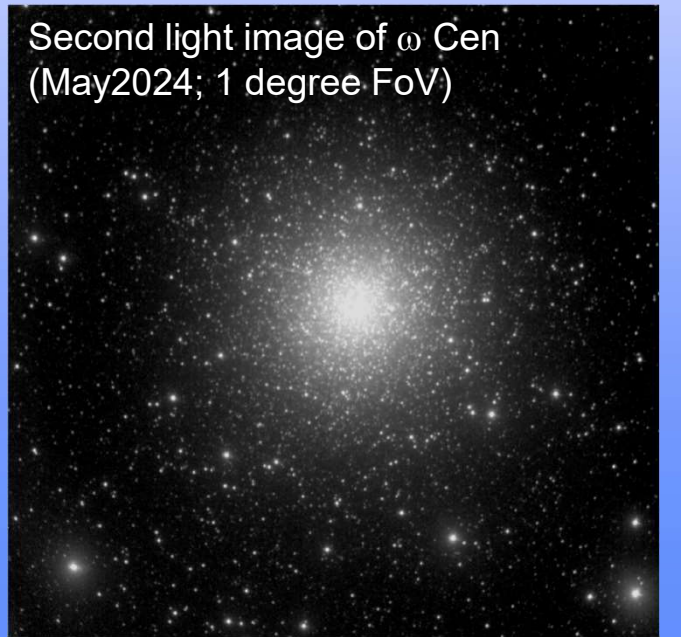
- Variety of well instrumented 40-60 cm telescopes (e.g. TRAPPIST, MOSS)
- Excellent site!
- *Most/all are either robotic or remotely operable*
- *Good internet & logistical support*

Potential Examples:

4. ROTSE (Robotic Optical Transient Search Experiment) HESS site, Namibia

- Fast (10's of sec response time) designed for robotic followup of GRBs (0.45 m aperture; ~2 deg FoV)
- De-commissioned in 2013 and now being revived under an AfAS-supported project the ROTSE telescope at the HESS site in Namibia for AfAS community
- Science goals: fast transient optical identifications/follow-up (e.g. GRBs, GW/multi-messenger, time domain, wide field, NEOs, asteroids, comets, exo-planets).
- *ROTSE to be made available for AfAS community as part of the AIOS*
- Site visits in Nov 2023 & May 2024, with "second light" achieved by new CMOS camera
- Plan to install new OCS and have full remote operation capability by end of next visit (~24 Oct 2024).


Site visit Nov 2023


Second light image of ω Cen (May2024; 1 degree FoV)

Benefits of the African Integrated Observation Network (AIOS)

- Expanding the IO to include facilities in the African continent
- Exploit geographical position for time-domain studies
- Where the whole could be greater than the sum of its parts
- Promote more collaboration within Africa and assist in research development and HCD on the continent
- Become engaged with international projects where AIOS could contribute

The Future: A global network

The BRICS Intelligent Telescope and Data Network Network (BITDN)

BITDN: a cast of many!

Lead Investigator

David A. H. Buckley
South African Astronomical Observatory, South Africa

Country Co-Principal Investigators

Ulisses Barres de Almeida	Centro Brasileiro de Pesquisas Físicas	Brazil
Fabio Porto	National Laboratory for Scientific Computing	Brazil
Boris Shustov	Institute of Astronomy, Russian Academy of Sciences	Russia
Oleg Malkov	Institute of Astronomy, Russian Academy of Sciences	Russia
Amitesh Omar	Aryabhatta Research Institute of observational sciences	India
Yogesh Wadadekar	National Centre for Radio Astrophysics	India
Liu Jifeng	National Astronomical Observatories, CAS	China
Chenzhou Cui	National Astronomical Observatories, CAS	China
Russ Taylor	Inter-University Institute for Data Intensive Astronomy	South Africa

+ 108 co-investigators from all 5 BRICS countries

- Investigating the transient and variable Universe
- Preparing for the Big Surveys to come

BRICS Astronomy Goals

- **Common aspirations for scientific and technological advancement through collaboration**
- **Enhancing human capital development and wider benefits to our societies**
- **Leveraging existing and future facilities within BRICS *or for which BRICS has access***
- **Develop an internationally competitive astronomy programme – a "flagship" – the *BRICS Intelligent Telescope and Data Network***
- **Focus on the enormous potential of the big astronomy survey programmes of the next 2 decades and the enourmous data and compute challenges they bring:**
  - **Optical: *The Rubin Observatory Legacy Survey of Space and Time (LSST)***
  - **Radio: *The Square Kilometre Array (SKA)***

Societal Benefits of the BITDN

- **Science goals are:**
  - **Transients & variables & time domain astronomy**
  - **Big Data, Big Compute for support of survey science**
- **Societal Benefits projects are a third *equally important* pillar of the program**
- **Large component of HCD through schools, workshops, hackathons**
- **Also tied to the UN Sustainable Development Goals (SDGs)**
  - **Synergies with projects of the IAU OAD**

First Phase:
Develop an Intelligent Observatory Network utilizing BRICS existing facilities

Leverage SAAO's initiative to network BRICS observatories into an intelligent machine for transient and survey follow-up

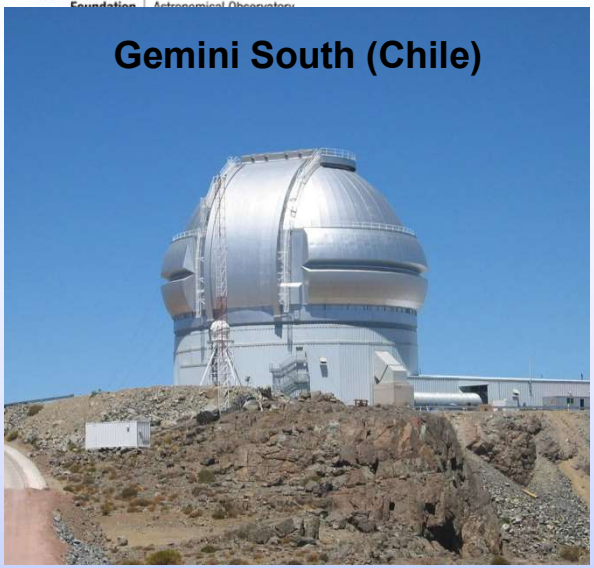
Requirements:

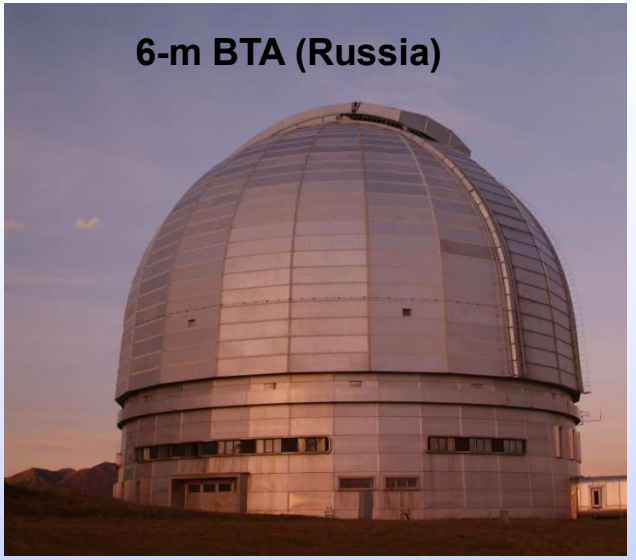
- agreement to dedicate telescope time for automated observations
- software tools to select targets from event brokers
- marshals to undertake automated observation scheduling
- dedicate resources to collaboratively develop these systems in collaboration with other groups (e.g. LCO)

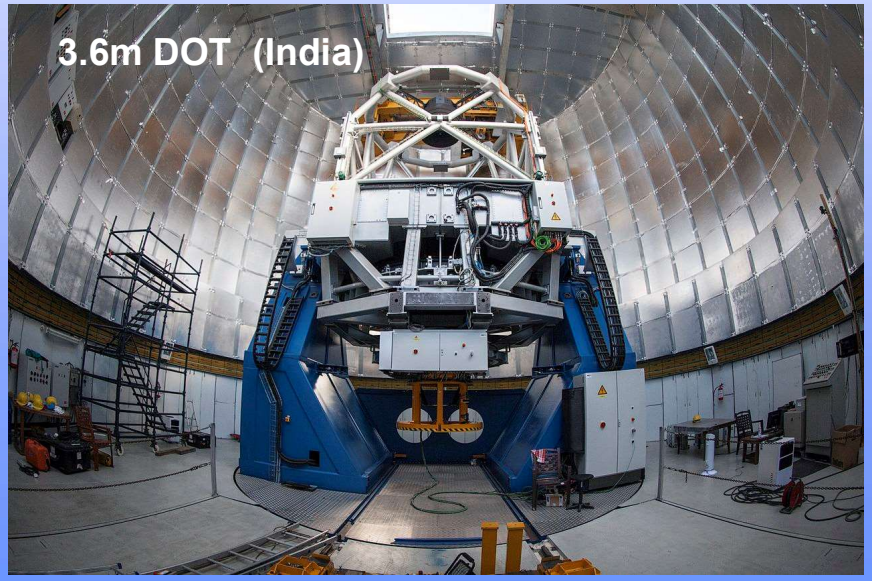
NRF National Research Foundation | SAAO South African Astronomical Observatory

Future Big Data Elephant's in the room:
Rubin Observatory LSST & SKA

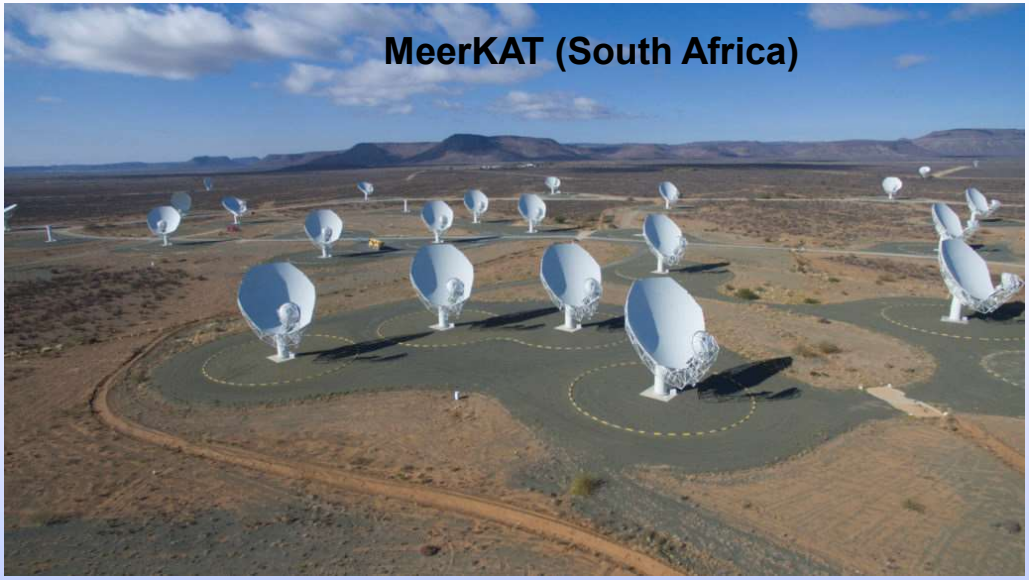
Exploit Existing BRICS Facility Access

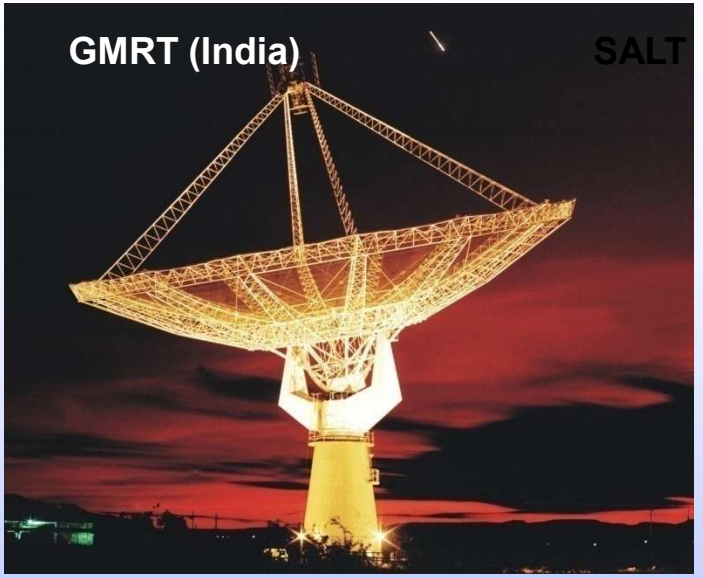


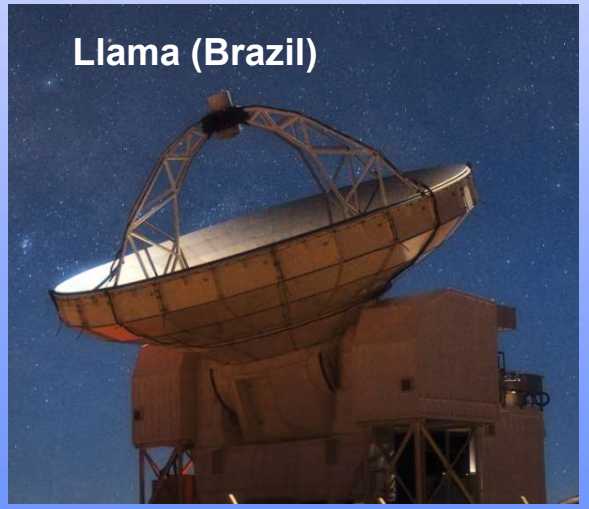


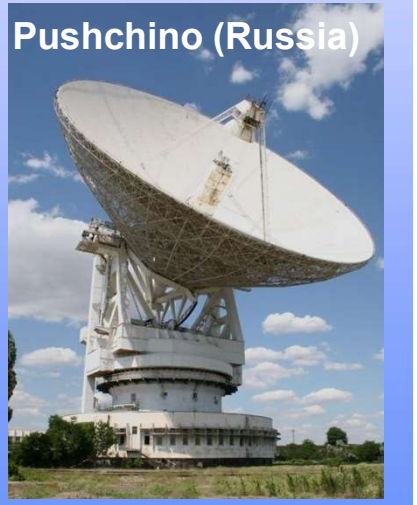


Exploit Existing BRICS Facility Access





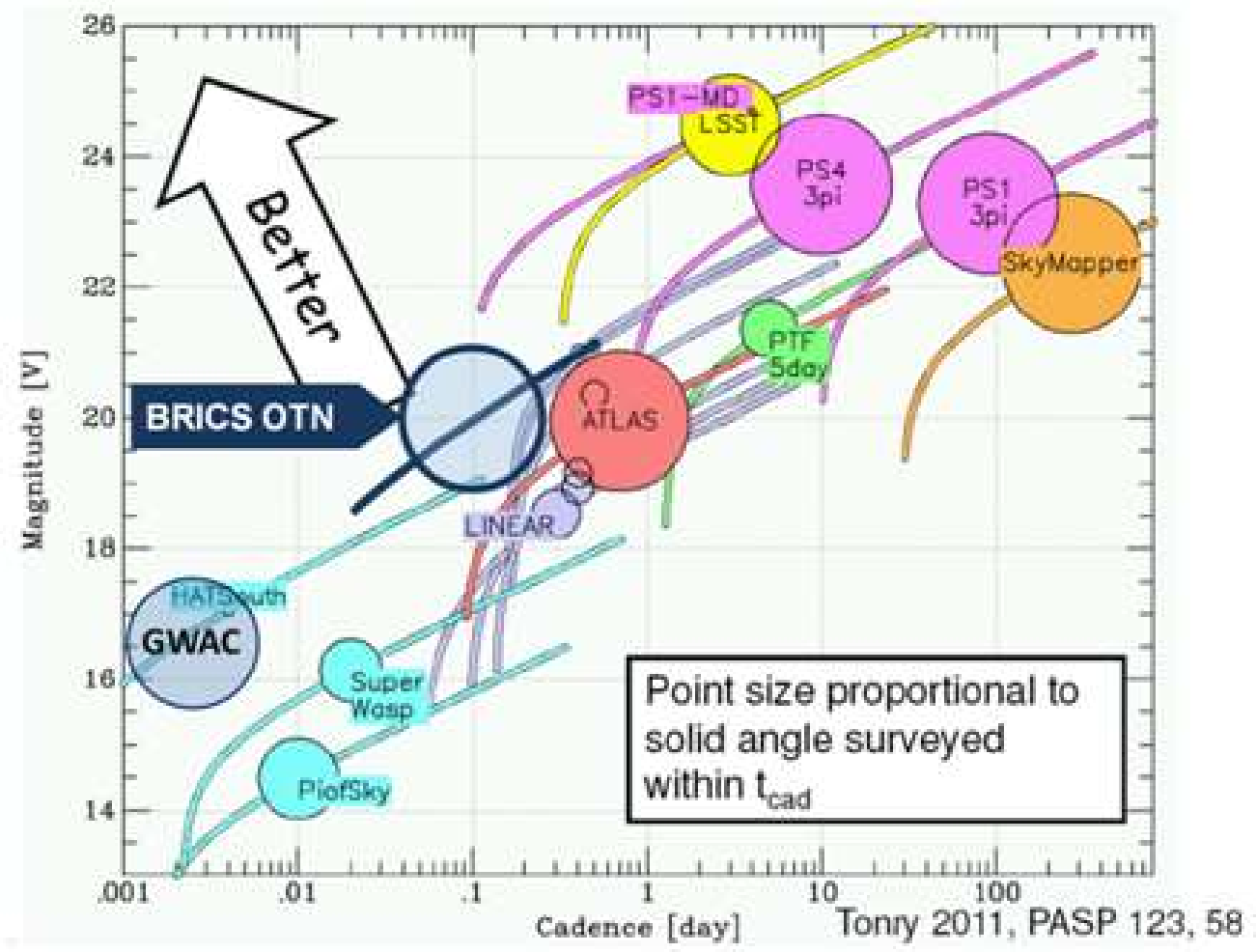




Future Developments of the BRICS Intelligent Telescope and Data Network

Second Phase: Development of a global network of *new* 1-m class wide field telescopes

New discovery space:



BRICS Intelligent Telescope and Data Network

Second Phase: Development of a network of *new* 1-m class telescopes

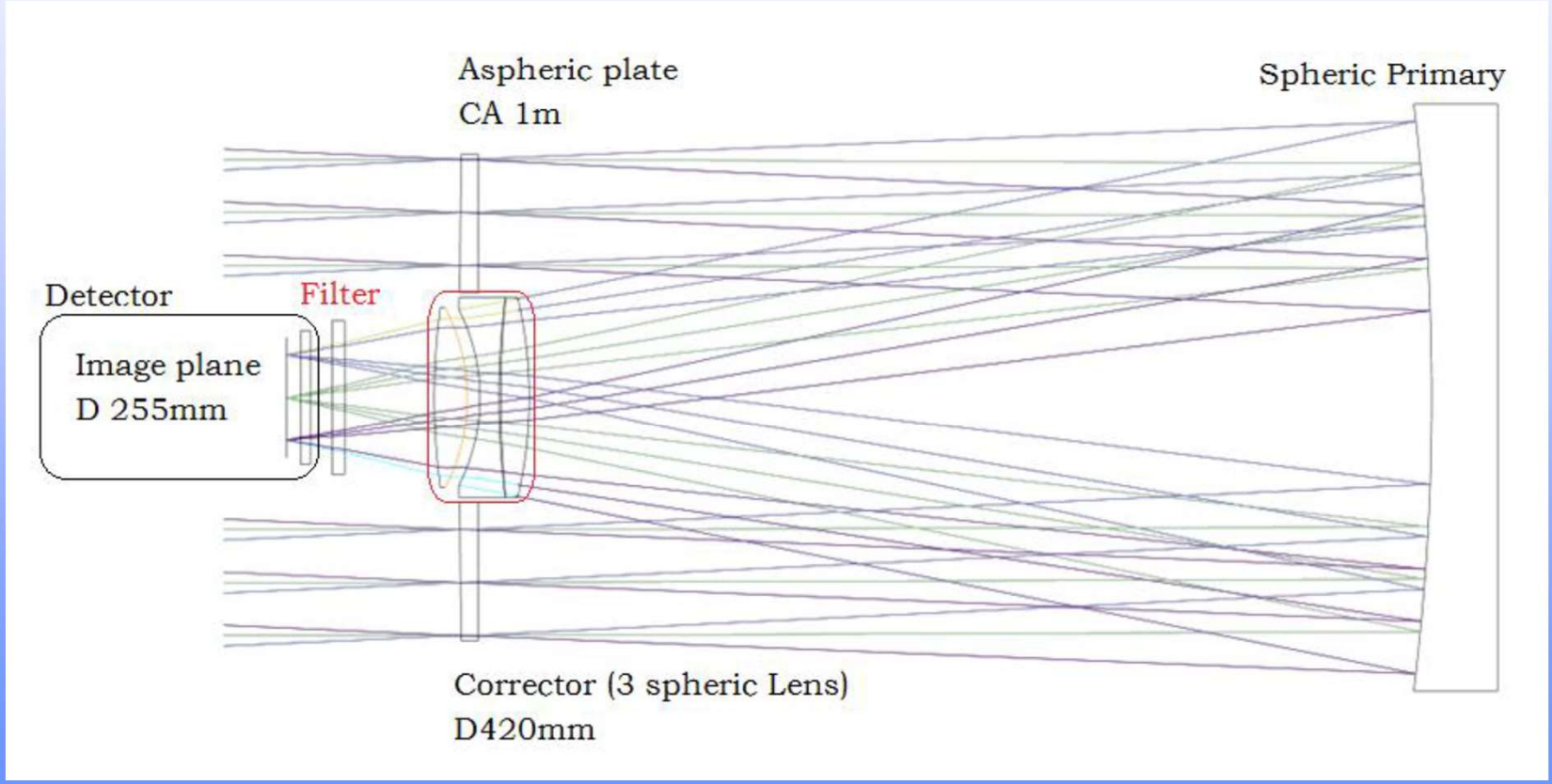
Top Level Requirements:

- A survey rate of >5000 deg^2/ hr to achieve an ultimate aim for ~1 h cadence *over the entire sky* (unique).
- Distributed in latitude & longitude, including (but not limited) within BRICS countries (e.g. Chile, Australia, La Palma as additional sites)
- 24h operation time. This requirement is important to ensure that the system will be able to respond to any alert and any given time on night sky.
- Limiting magnitude of at least AB ~ 21
- *g, r, i* filters (dedicated to specific telescopes)
- Fast readout cameras (also use for high time resolution photometry
- Angular resolution better that 2 arcsec is required (ideally match to seeing)
- *Will open new frontier on time domain astronomy potentially discovering fast and rare transients impossible to detect with more limited cadence surveys*

Builds upon the existing Sitian project in China

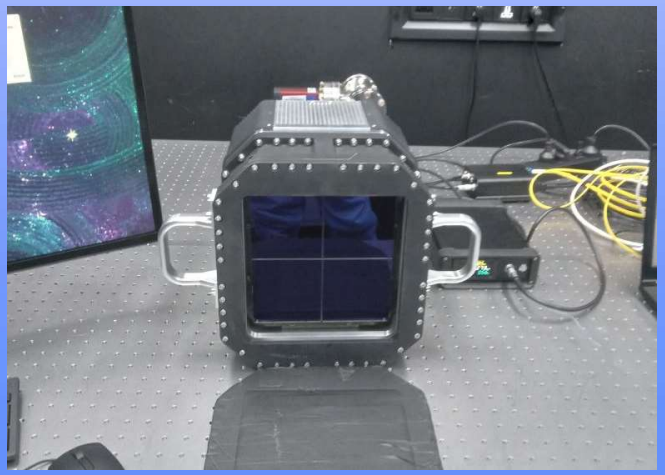
Build upon the Chinese Sitian project

- ***Sitian* concept**
  - **~70x 1-m wide field (25 sq degree) telescopes**
  - **2 -3x 4-m follow-up spectroscopic telescopes**



First Sitian Prototype

1-m Schmidt catadioptric at Xinglong station (Lamost)



Gpixel GENS 2 x 2 mosaic of 9k x 9k x 10μm CMOS chips

Possible Future Sitian & BITDN sites

- Plan to site first telescopes initially in China
- Expand to BRICS (& BRICS+) countries
- And also other good observing sites globally
  - Chile
  - Australia
  - Indian & Pacific Islands (Reunion & French Polyne

Article

Lenghu on the Tibetan Plateau as an astronomical observing site

https://doi.org/10.1038/s41586-021-03711-z
Received: 15 February 2021
Accepted: 9 June 2021
Published online: 18 August 2021
Open access
Check for updates

Licai Deng[1,2,3]✉, Fan Yang[1,2]✉, Xiaodian Chen[1,2,3]✉, Fei He[4,5]✉, Qili Liu[6], Bo Zhang[1], Chunguang Zhang[1,2,3], Kun Wang[2], Nian Liu[2], Anbing Ren[2], Zhiquan Luo[2], Zhengzhou Yan[2], Jianfeng Tian[1] & Jun Pan[1]

On Earth's surface, there are only a handful of high-quality astronomical sites that meet the requirements for very large next-generation facilities. In the context of scientific opportunities in time-domain astronomy, a good site on the Tibetan Plateau will bridge the longitudinal gap between the known best sites[1,2] (all in the Western Hemisphere). The Tibetan Plateau is the highest plateau on Earth, with an average elevation of over 4,000 metres, and thus potentially provides very good opportunities for astronomy and particle astrophysics[3–5]. Here we report the results of three years of monitoring of testing an area at a local summit on Saishiteng Mountain near Lenghu Town in Qinghai Province. The altitudes of the potential locations are between 4,200 and 4,500 metres. An area of over 100,000 square kilometres surrounding Lenghu Town has a lower altitude of below 3,000 metres, with an extremely arid climate and unusually clear local sky (day and night)[6]. Of the nights at the site, 70 per cent have clear, photometric conditions, with a median seeing of 0.75 arcseconds. The median night temperature variation is only 2.4 degrees Celsius, indicating very stable local surface air. The precipitable water vapour is lower than 2 millimetres for 55 per cent of the night.

Table 1 | Comparison of key site characteristics with other known best sites in the world

Site	Median seeing (arcsec)	Air stability, ΔT10–90% (°C)	Clear fraction (%)	Sky brightness (mag arcsec^{-2})	PWV <2 mm (%)
Lenghu	0.75	2.7	70	22.0	55
Mauna Kea	0.75	6.8	76	21.9	54
Cerro Paranal	0.80	3.6	71	21.6	36
La Palma	0.76	–	84	21.9	21

NRF National Research Foundation | SAAO South African Astronomical Observatory

Summary of BITDN Flagship benefits to BRICS

- Promotes collaboration and development amongst BRICS countries and their existing partners in science and engineering
- Large potential for human capacity development
- Focuses on the enormous scientific potential of multi-wavelength studies of astronomical transients and followup from surveys, for decades to come
- Will be ideal tool for supporting multi-messenger astronomy, e.g. E-M counterparts of GW Internationally competitive and unique – a true *flagship*
- Opportunity to collaborate globally
- Utilizes existing and future multi-wavelength facilities (optical, IR, radio, X-ray, γ-ray, UV)
- Impactful on a wide level
- Can start with relatively modest investment and grow as funding allows
- Ticks all the boxes for the criteria of a *flagship program*

Future Prospects at SAAO

- Urgent need for a modern, agile 4-m class telescope filling the 2-m to 10-m gap
- Spectroscopic follwup from survey like LSST
- Quick reaction to transients
- Filling the same needs as the NRS
- Needs to be innovative, cost effective and fast
  - Ideally a segmented mirror telescope
  - Not a copy of old technology
- Perfect solution the Semei 3.8-m (Okoyama), built for $8M (excl some FTE effort and instruments
- Uses petal mirror segmentaion (all built on modified CNC machines)

The End

The future is in our hands!