African Optical Telescopes

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Overview

- Telescopes in South Africa
  - SAAO
  - Boyden Observatory
- SALT
- Other telescopes in Africa
- Future Plans

The South African Astronomical Observatory (SAAO)

- SAAO Headquarters in Cape Town, observing facilities in Sutherland Established in 1972 with HQ at the original Royal Observatory at the Cape of Good Hope, established in 1820
- Until early 1980s jointly funded by the UK
- A national research facility of the South African NRF (National Research Foundation), funded by South African Department of Science & Innovation (staff complement of ~130, with ~20 PhD astronomers)
- Sutherland site established by relocating telescopes from other observatories
- From 1974 – 2005 only 4 SAAO owned telescopes + several hosted facilities

Where is SAAO ?

HQ in Cape Town

Sutherland:

Good dark site used by SAAO for 50 years

Aseasonal with ~70% nights useable (spectroscopic +); 50% photometric (cloud free)

Median seeing of ~1.3 arcsec

~1800 m altitude

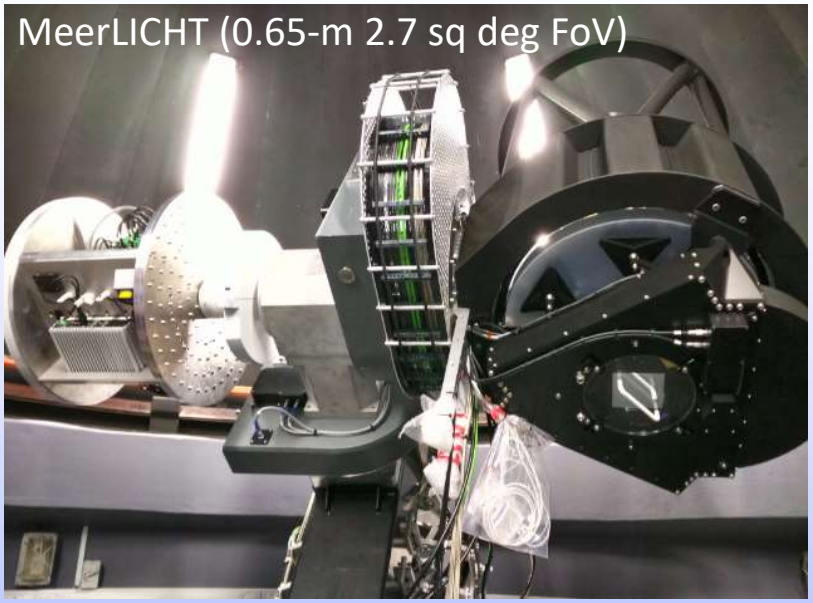
Dry: IR observations

The SAAO Sutherland site

- until 2005 (SALT), largest telescope was 1.9-m
- since 2002 have added 7 telescopes of 1.0-1.8m aperture & many smaller ones
- Some of these and others are either robotic or remotely operable
  - Las Cumbres Observatory
  - MONET-South
  - SuperWASP
  - KELT
  - ASASSN
  - MASTER
  - MeerLICHT
  - ATLAS
  - PRIME

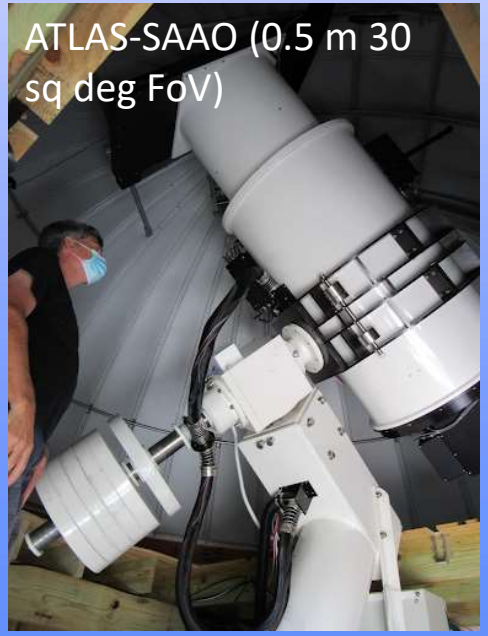
The Sutherland telescope farm

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


MeerLICHT (0.65-m 2.7 sq deg FoV)


MASTER-SAAO

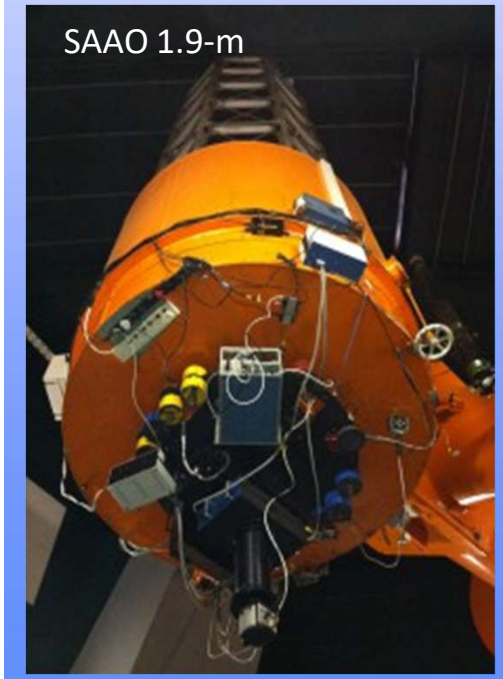
MASTER-SAAO (2 x 0.4 m x 4 sq degrees)

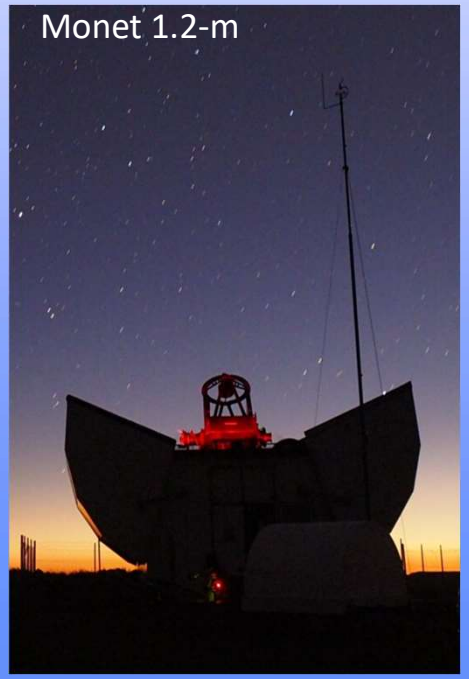

ATLAS-SAAO (0.5 m 30 sq deg FoV)

South African Astronomical Observatory telescopes

- ~20 telescopes with 0.40 – 1.9-m apertures, in optical and NIR

- Mostly supporting time series optical photometry, spectroscopy and photo-polarimetry
- Covering visible (3400 – 9000Å) and near IR (1 – 2.5 μm) wavelengths





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

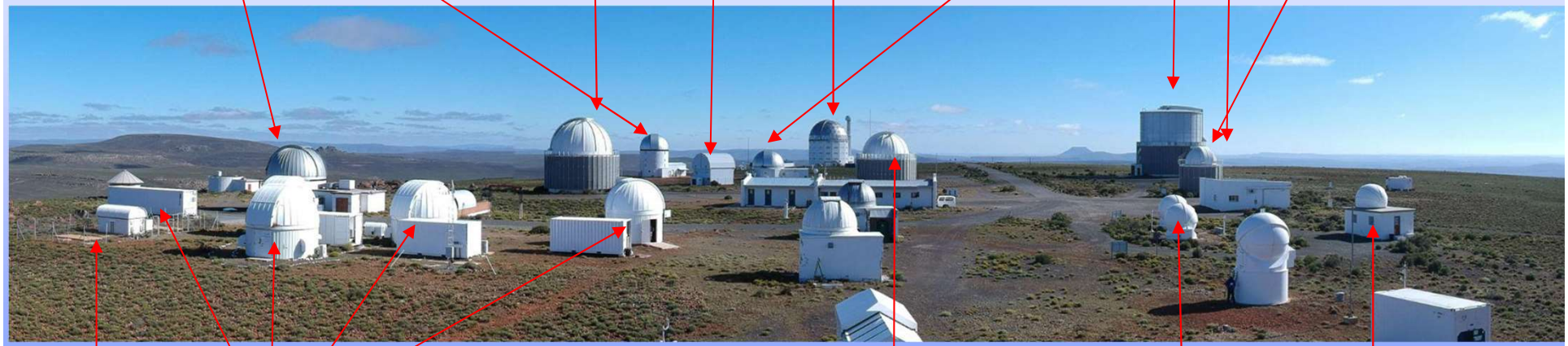
MONET 1.2-m

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

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 spares)

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

The Challenge of Transient & Variable Follow-up: Global Automated Telescope Networks

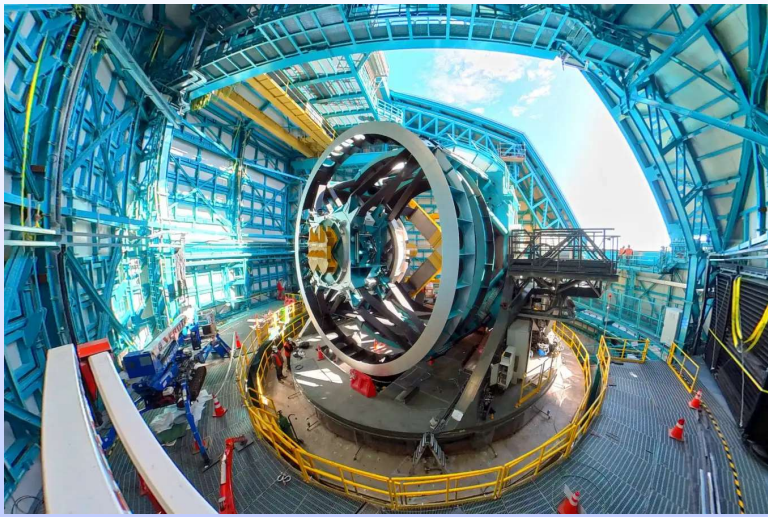
Example: SAAO's Intelligent Observatory (IO)

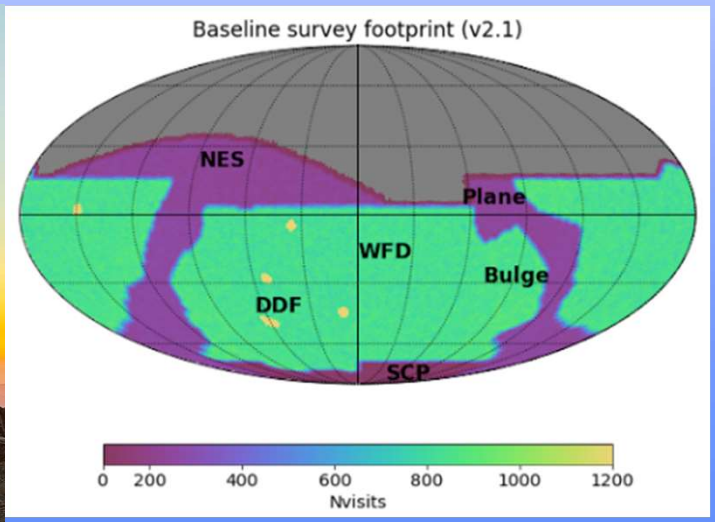
- Network telescopes on the Sutherland site to allow automated follow-up from multi-wavelength alert brokers
- Science driver: follow-up on Rubin LSST transient & variable sources and transient alerts from other facilities (including space-based)
- Project started in 2020 with 3 telescopes and utilizing 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 Optical Transient Network & the African Integrated Observation System (AIOS)***

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 these alerts will be like drinking from a firehose of data! Machine Learning will help decide.





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 (e.g. LSST)

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)

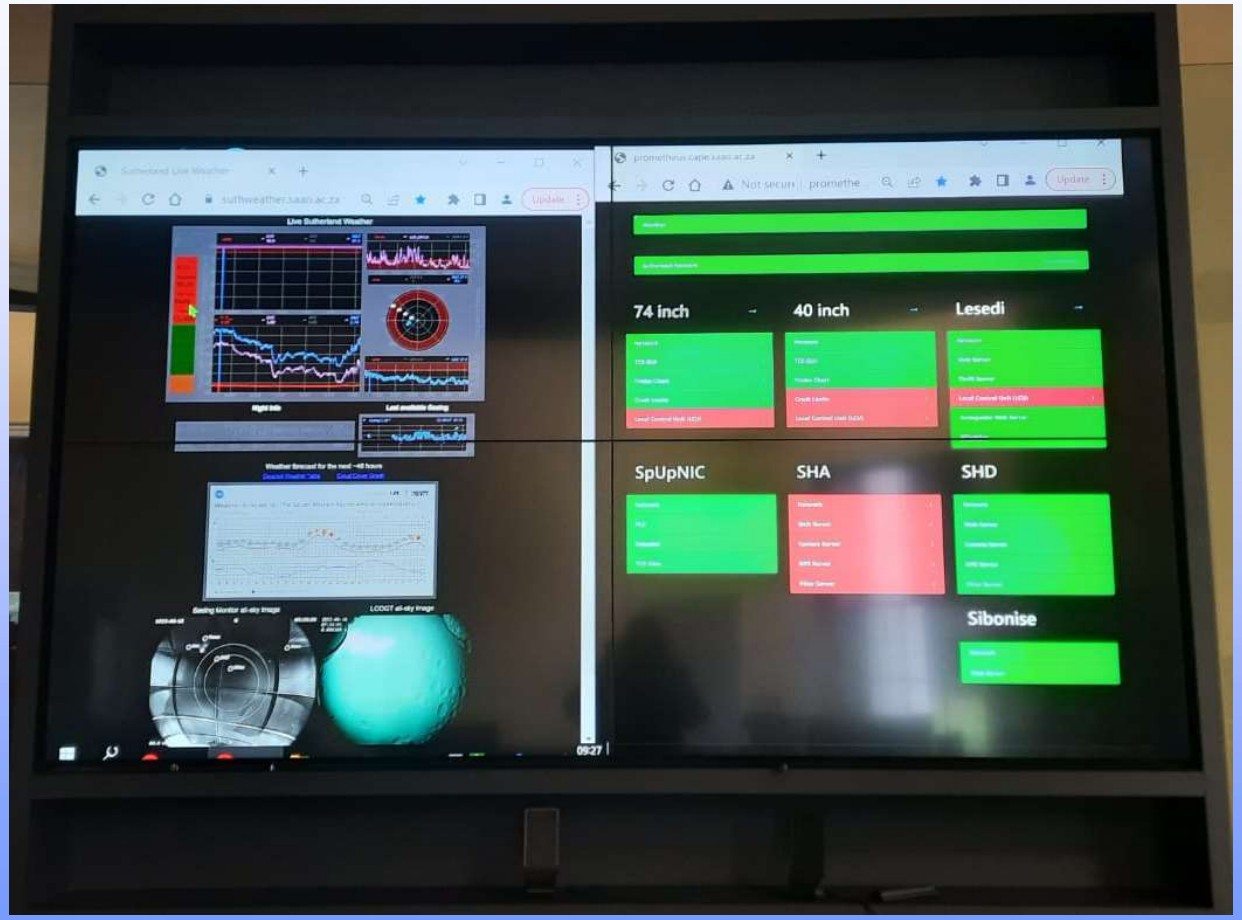
Locally installed and configured for Lesedi 1-m telescope

Programmatically submit observation requests which are undertaken robotically

Ongoing:
Adding other telescopes + instruments to the OCS

Remote Observing

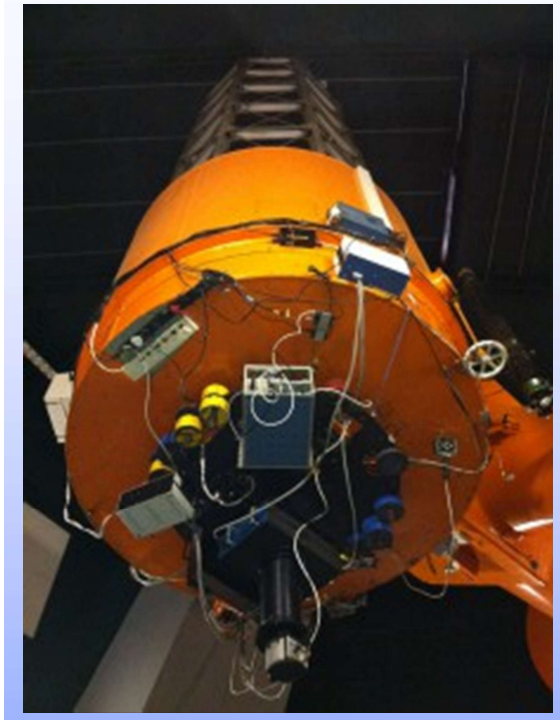
From Cape Town HQ, from home and from overseas*



* With adequate bandwidth and communication

SAAO Telescopes currently in the IO

- **1.9-m**



Low-medium resolution spectrograph

Photopolarimeter

Andor emCCD high-speed camera

- **1.0-m**

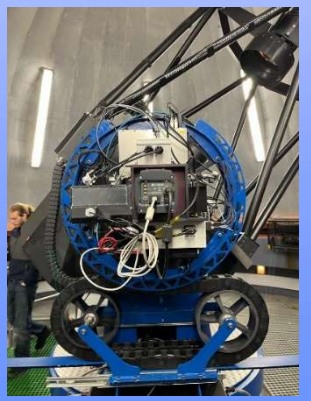
Andor emCCD high-speed camera

Wide-field imaging polarimeter (2025)

- **1.0-m *Lesedi***

Nasmyth 1

Low res spectrograph & imager (fast)



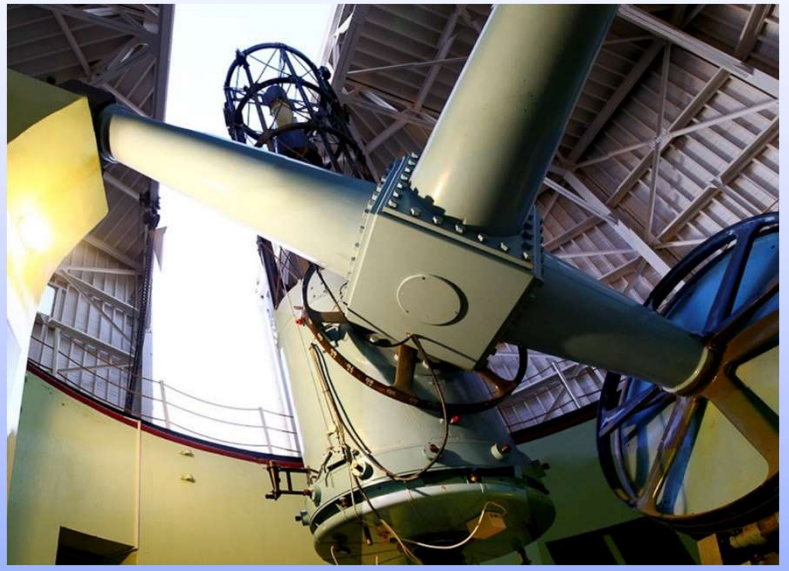
Nasmyth 2

~20 arcmin FoV camera

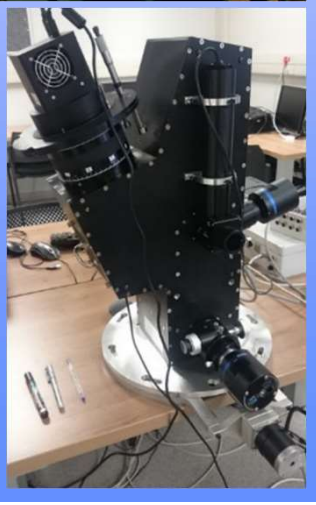
Other South African Observatories

Boyden Observatory (University of the Free State) ~20 km from Bloemfontein

- Rapid followup telescopes (Watcher, Boötes)
- Refurbishment of Boyden 1.25-m telescope with new spectrograph/spectropolarimeter (~2023)



- Potential for new facilities in future at various South African Universities



New spectrograph & spectropolarimeter

The Southern African Large Telescope (SALT)

One of the "Big Five": 10-m Segmented Mirror Telescopes

- **Keck I (1993) & Keck II (1996): Hawaii, USA**
- **HET (1999): Texas, USA**
- **SALT (2005): South Africa**
- **GRANTECAN (2009): Canary Islands, Spain**
- SALT the only one in the southern hemisphere (until E-ELT is built)

Background Socio-Political climate in RSA

From the ANC's White Paper on S&T 1996:

"Scientists engaging in basic research contribute to the intellectual vibrancy of society as part of a strong R&D base needed …. For participating in and sometimes leading, a global scientific community."

"Scientific endeavour is not purely utilitarian in its objectives and has important associated cultural and social values … Not to offer 'flagship' sciences (such as physics and astronomy) would be to take a negative view of our future - the view that we are a second class nation, chained forever to the treadmill of feeding and clothing ourselves."

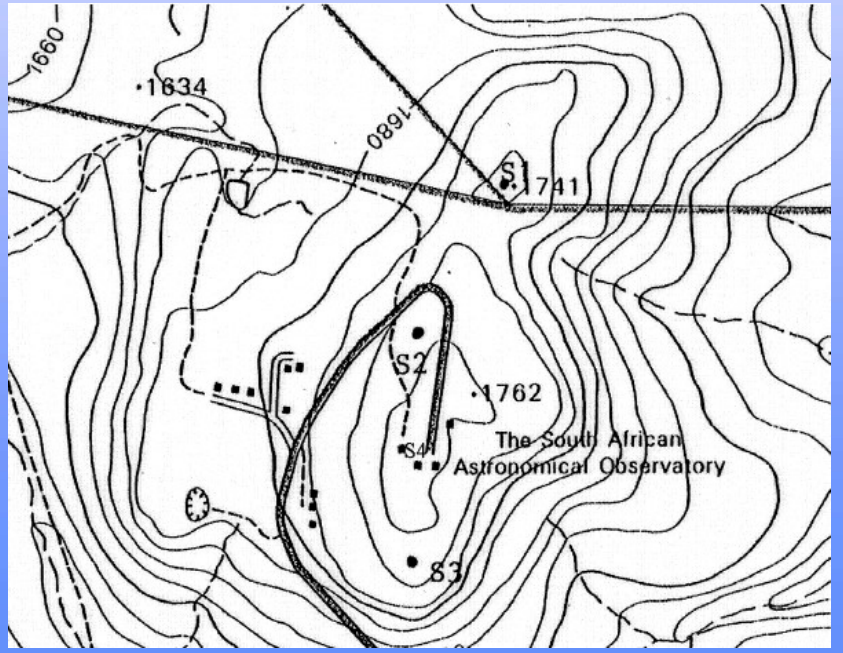
So the SALT proposal (in 1998, 3 year after the ANC came to power) was the right project at the right time for Government support:

- "blue sky" science
- international collaborators
- perceived spin-offs
- cost-effective & innovative
- concentrate on sciences with already established credentials

Equally important was the international interest in the new democratic South Africa helping to raise interest in joining SALT

SALT's first steps

- Following the workshop an interim SALT Board was set up with representation from potential partners
- Interim project team appointed to take the project forward
  - Stobie, Sebring, Buckley, Palmer
  - Determine cost estimate
  - Investigate local industry capability
- Development of the concept of *SALT Collateral Benefits* (Sebring & Mokhele)
- Site selection at Sutherland
  - Testing where on the plateau to build
  - Mobile DIMMs
  - Microthermal sensors
  - Meteorological testing
  - Measurements from 1998 – 2000
  - Culminated in Erasmus report
  - Site S2 selected



Original (2000) SALT Partners

Total Cost ~$48M*:

- $20M: telescope construction
- $8M: three first-generation instruments
- $20M: 10 years operations

(in US $ @ Mar 99)*

• National Research Foundation	34.4%
• University of Wisconsin	15.5%
• CAMK (Poland)	11.0%
• Rutgers University	10.8%
• Dartmouth College	9.4%
• Göttingen University	4.9%
• University of Canterbury (NZ)	4.1%
• UK SALT Consortium	3.9%
• University of North Carolina	3.1%
• Carnegie - Mellon University	3.1%

(HET garners fixed 10% allocation for 10 years)

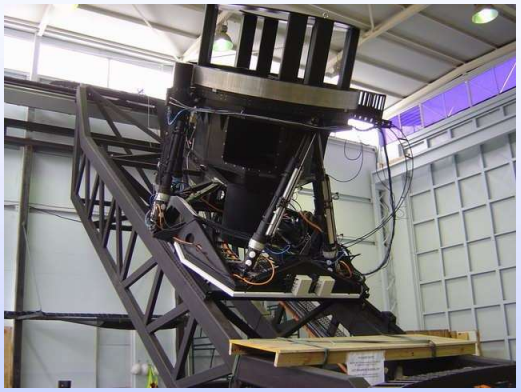
SALT Begins

- Government's intention to support SALT given in 1998/99 budget vote, contingent on raising of matching funds from partners
- Project unilaterally supported by all parties in Parliament
- SALT Project Scientist (David Buckley) appointed Nov 1998
- SALT Project Manager (Kobus Meiring) appointed July-1999
- Government gives the "green light" in Nov 1999
- SALT Project Team recruited from late 1999 to mid 2000

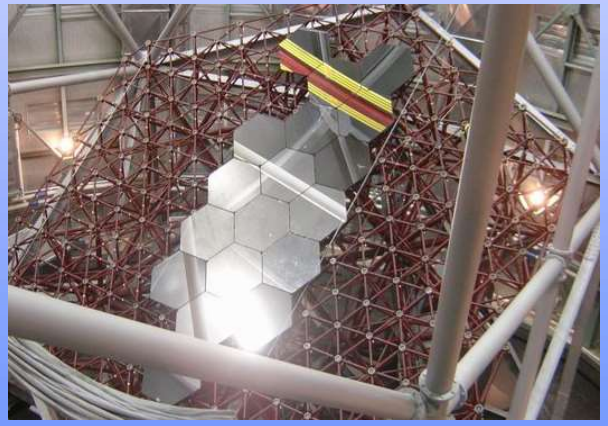
The Telescope Subsystems:

Structure & Dome

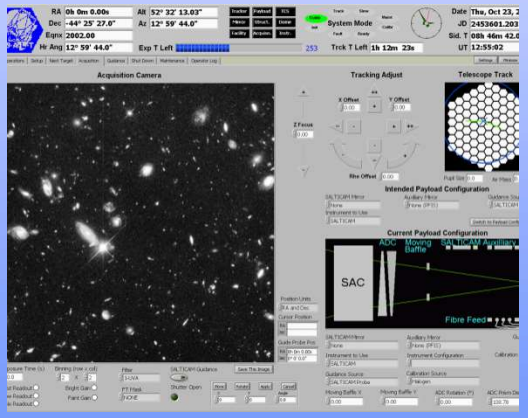
Facility Building & Services



Tracker



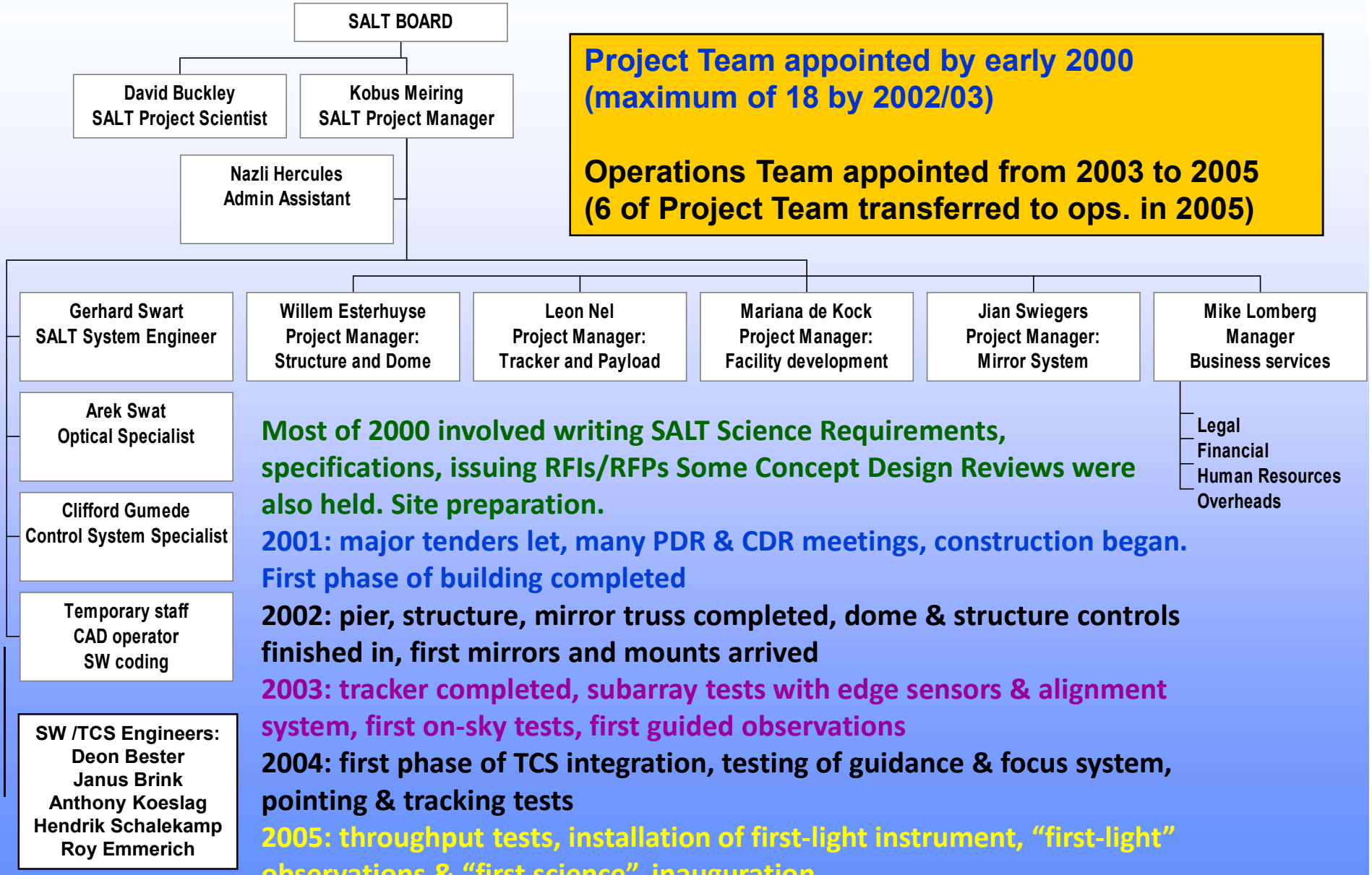
Primary Mirror System



Software

Payload

The SALT Project Team



Project Team appointed by early 2000 (maximum of 18 by 2002/03)

Operations Team appointed from 2003 to 2005 (6 of Project Team transferred to ops. in 2005)

Most of 2000 involved writing SALT Science Requirements, specifications, issuing RFIs/RFPs Some Concept Design Reviews were also held. Site preparation.

2001: major tenders let, many PDR & CDR meetings, construction began. First phase of building completed

2002: pier, structure, mirror truss completed, dome & structure controls finished in, first mirrors and mounts arrived

2003: tracker completed, subarray tests with edge sensors & alignment system, first on-sky tests, first guided observations

2004: first phase of TCS integration, testing of guidance & focus system, pointing & tracking tests

2005: throughput tests, installation of first-light instrument, "first-light" observations & "first science", inauguration

Design Improvements

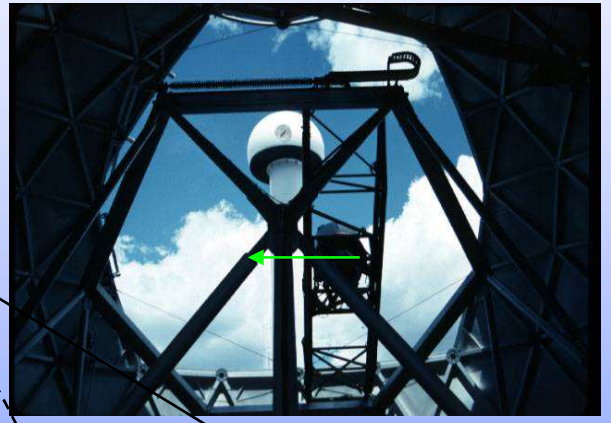
- Telescope elevation changed from 55° to 53° to access SMC
- Improved optical design (the Spherical Aberration Corrector) by Darragh O'Donoghue (SAAO)
- More efficient multi-layer coatings (LLNL) for mirrors
- Holistic integrated payload design, increased mass budget (~1000 kg) and use of carbon composites.
- Use of mirror edge sensors on the mirror segments will give
- Use of natural ventilation (e.g. louvres) and aggressive attitude to heat sources

The Arecibo Tracking Concept: extended to optical telescopes

Fixed elevation spherical mirror telescope with tracking on focal surface

Star moves E to W on sky

Centre of curvature at radius of primary mirror



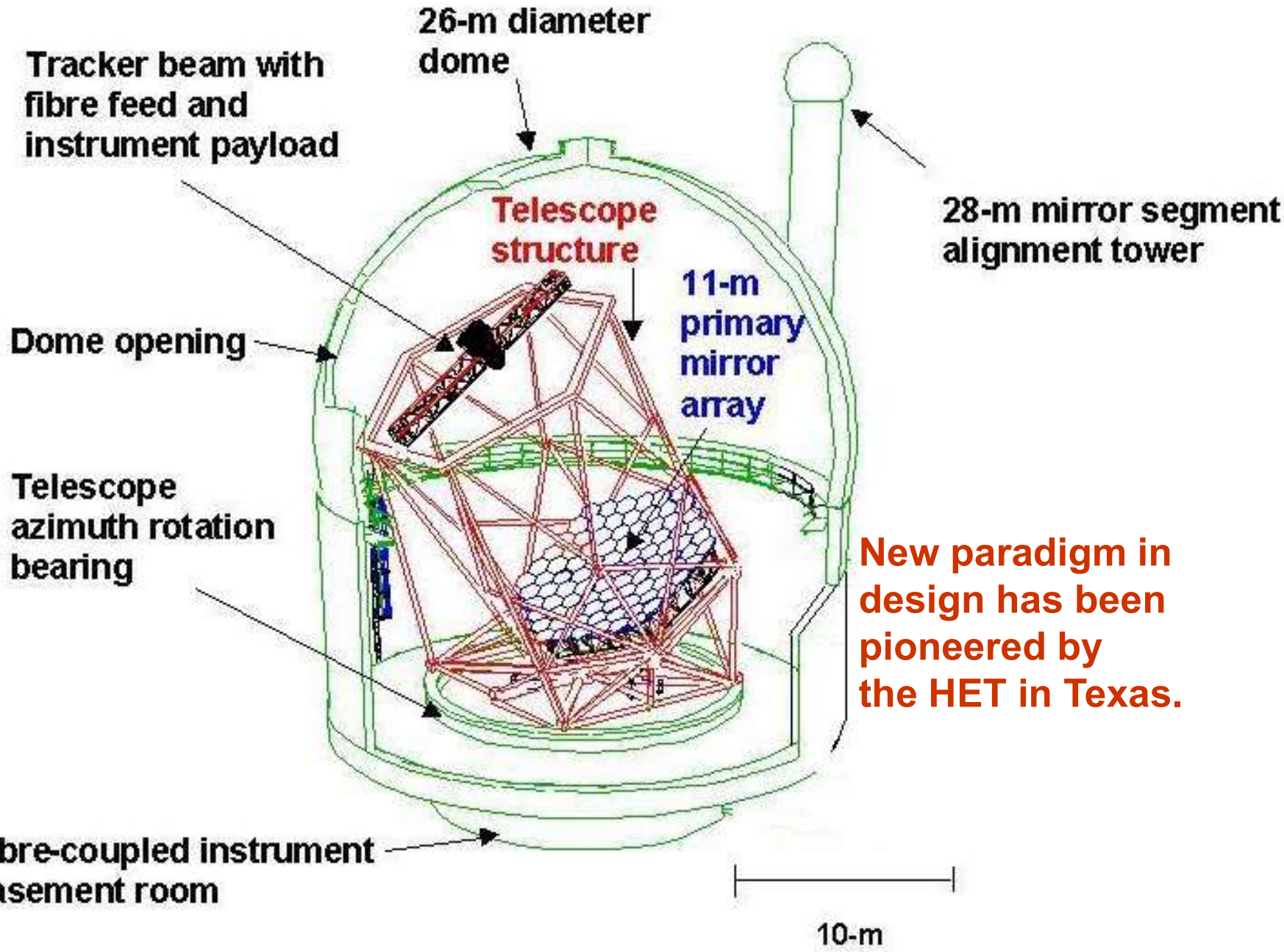
Spherical focal surface: 1/2 of primary mirror radius

Image moves W to E on the focal surface

Tracker (with instruments) follows focus of star.

Spherical Primary Mirror

Southern African Large Telescope

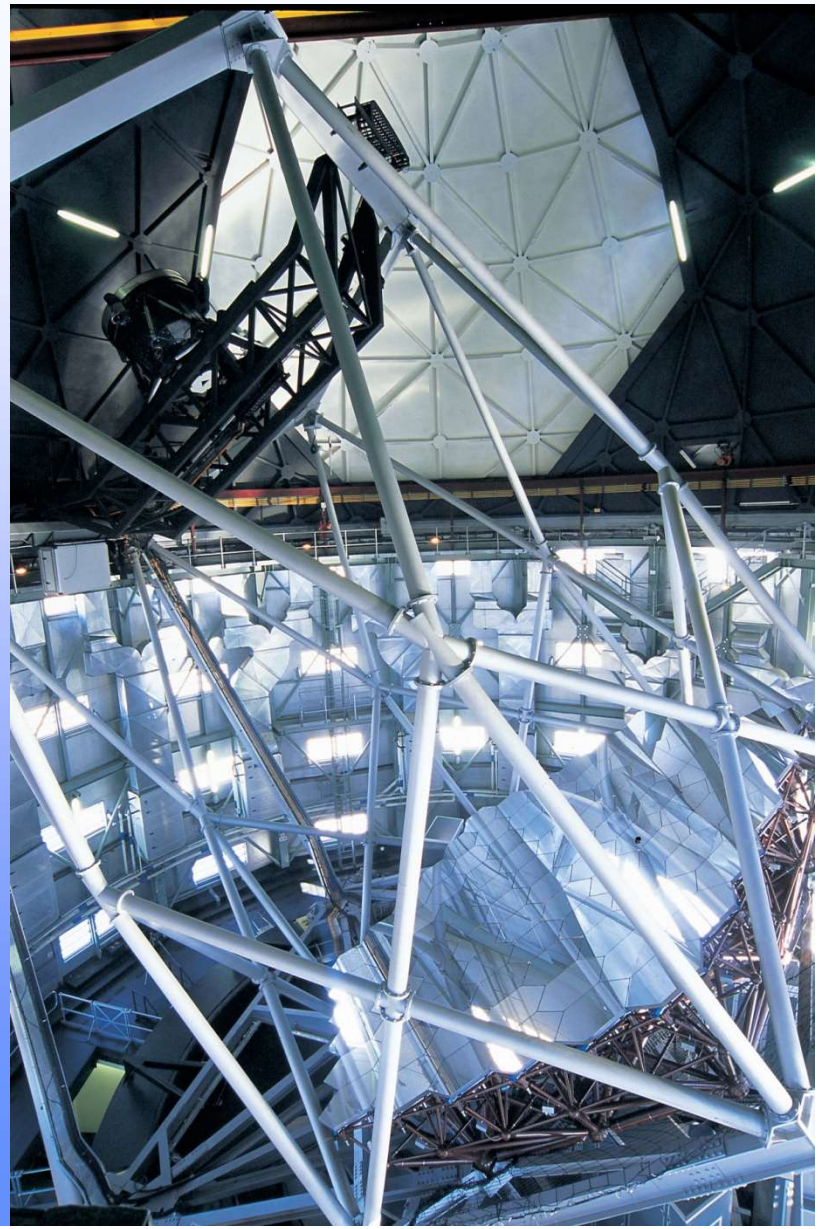


New paradigm in design has been pioneered by the HET in Texas.

SALT: *A Tilted Arecibo-like Optical-IR Telescope modelled on the Hobby-Eberly Telescope (HET)*

BASIC ATTRIBUTES

- **PRIMARY MIRROR ARRAY (10 X 11 m)**
  - Spherical Figure (need to correct aberrations)
  - 91 identical hexagonal segments
  - Unphased (i.e. not diffraction limited 10-m, just 1-m)
  - Mirrors (*Sitall:* low expansion ceramic) supported on a steel structure
- **TELESCOPE TILTED AT 37°**
  - Declination Coverage $+10^\circ < \delta < -75^\circ$
  - Azimuth rotation for pointing only
- **OBJECTS TRACKED OVER 12° FOCAL SURFACE**
  - Tracker executes all precision motions (6 d.o.f.)
  - Tracker contains Spherical Aberration Corrector (SAC) with 8 arcminute FoV (*Prime Focus*)
- **IMAGE QUALITY**
  - Telescope error budget of ~0.7 arc-second FWHM
  - Designed to be seeing limited (median = 0.9 arcsec)



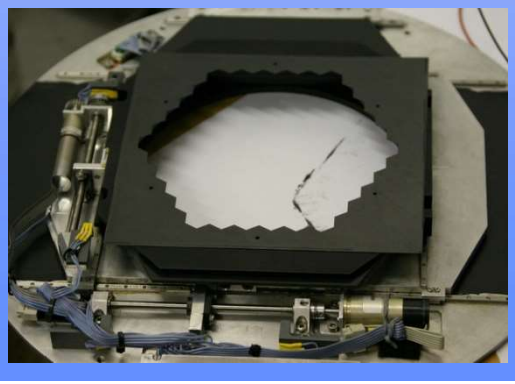
Peculiarities of SALT

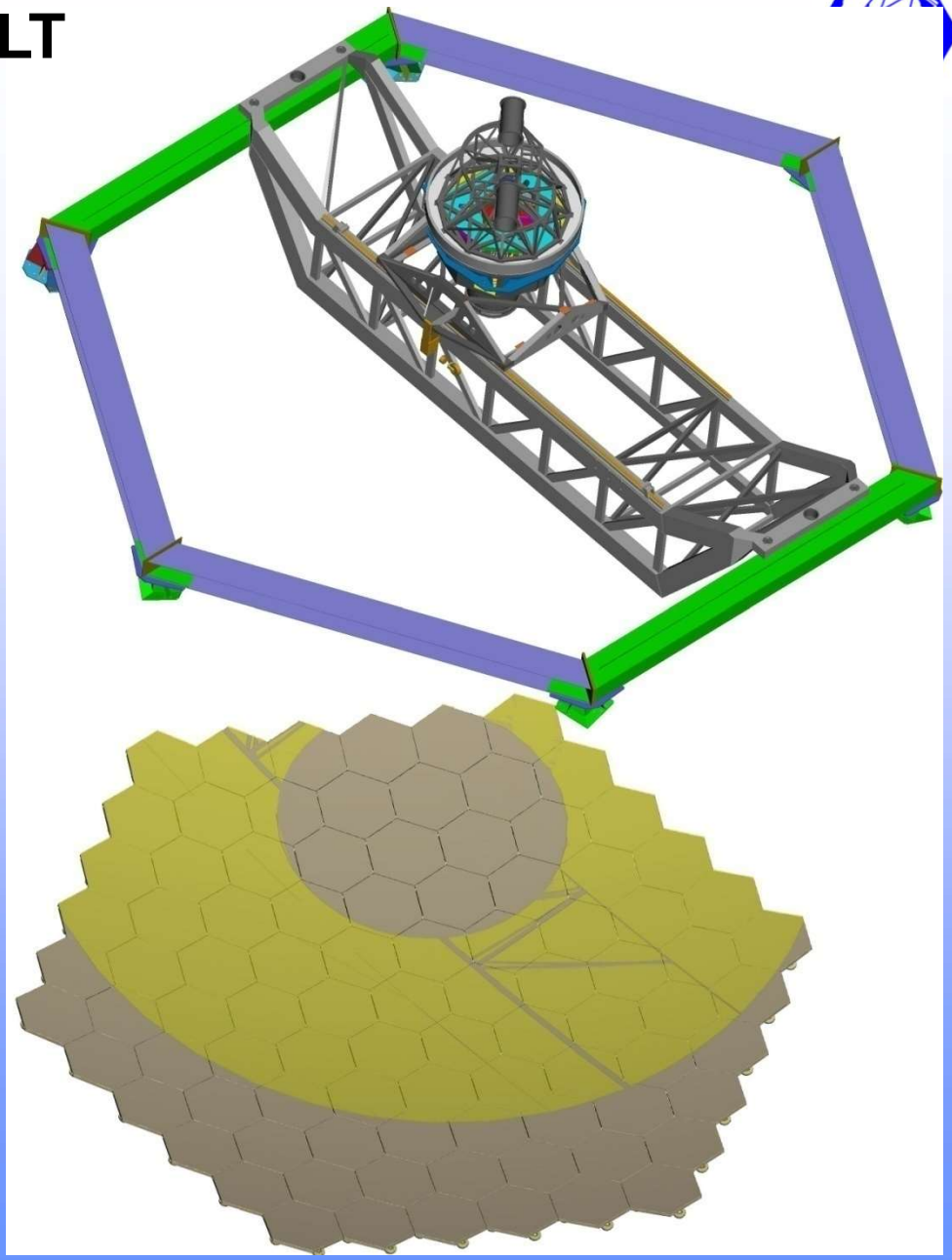
SALT/HET Tracking Principle

Tracker off-centre and pupil partially on primary mirror array. At worst extreme, still a ~7 metre telescope.

With tracker and 11-m pupil centred on primary mirror array and central obstruction (from SAC optics), equivalent to a 9 metre telescope.

Pupil is always underfilled
Pupil is baffled at exit pupil
- **controls stray light**
- **used to simulate pupil for calibrations**





How SALT Observes: Restricted Viewing Window

Annulus of visibility for SALT:

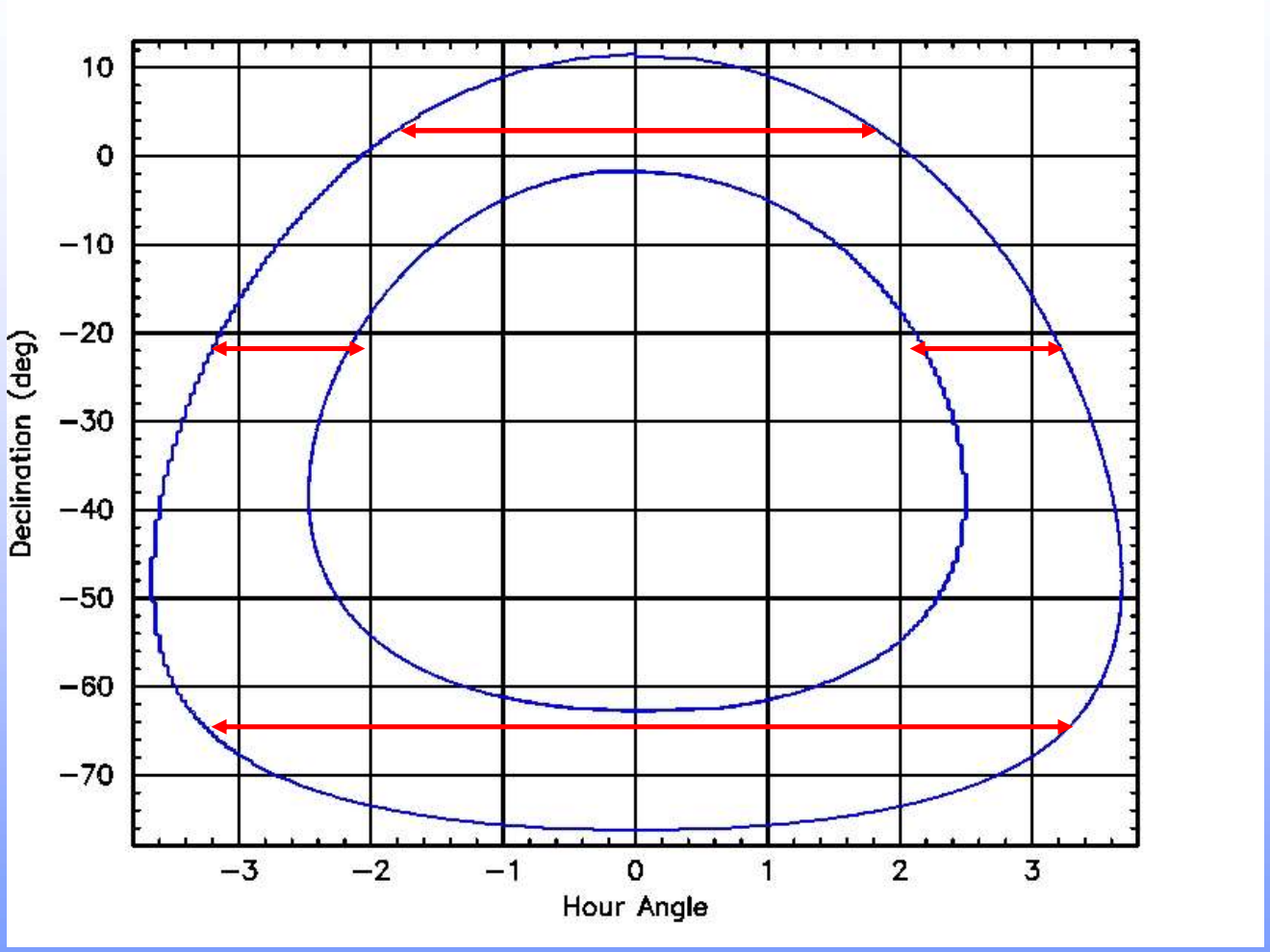
Annulus represents 12.5% of visible sky

Declination range: +10º to -75º

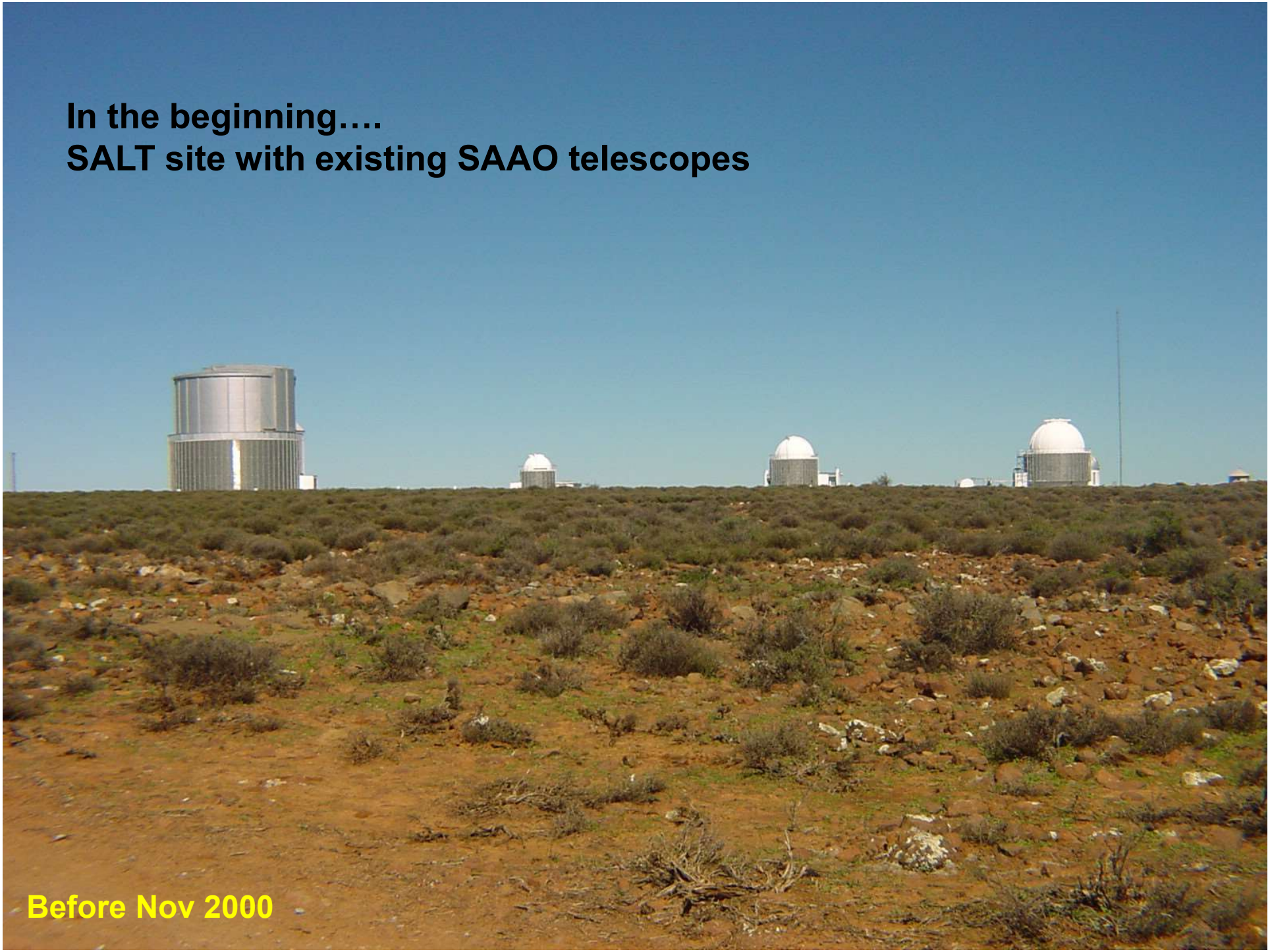
Observation time available = time taken to cross annulus

***But* tracker only has limited range ⇒**

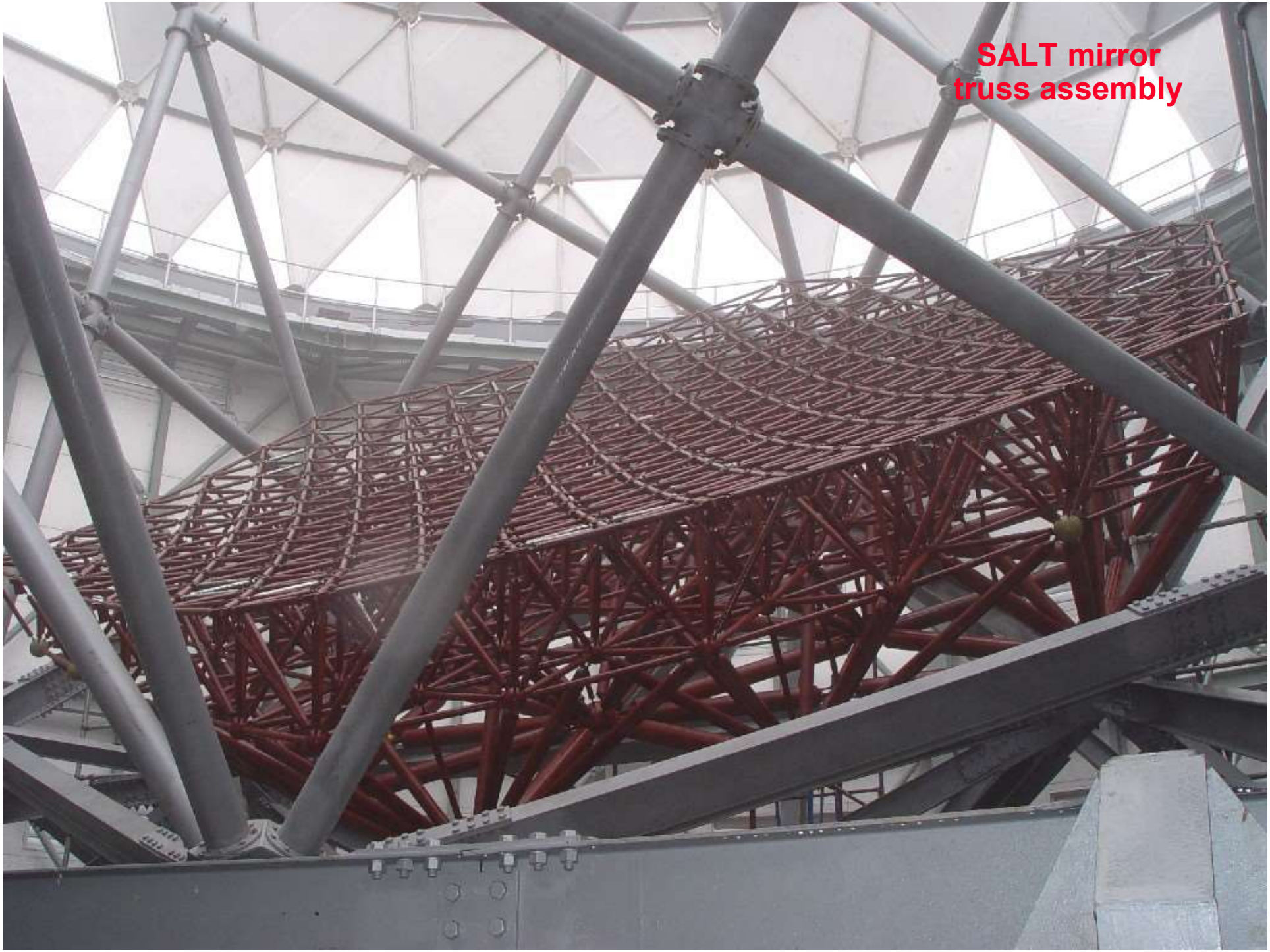
Additional azimuth moves needed to achieve full obs. time

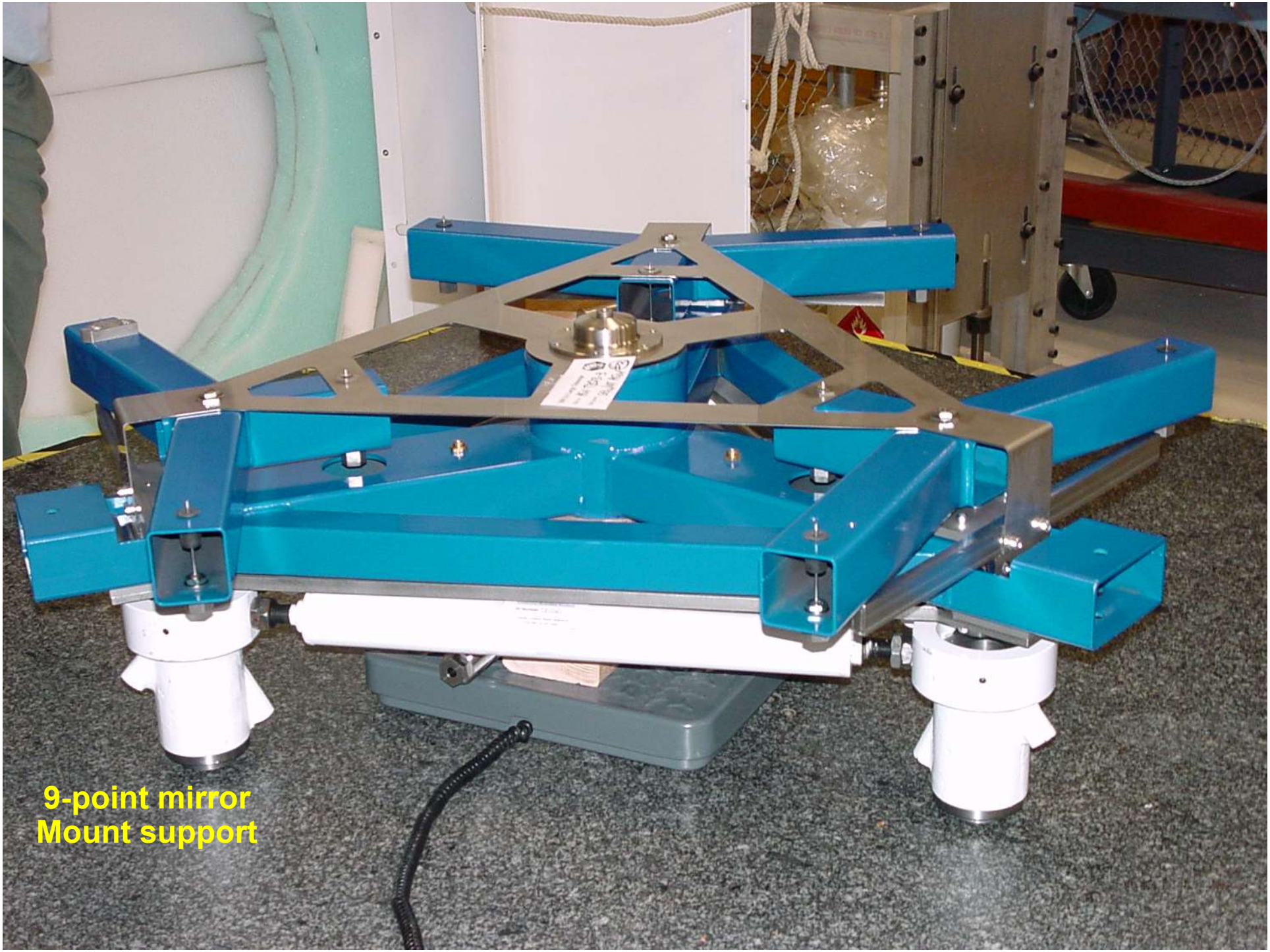


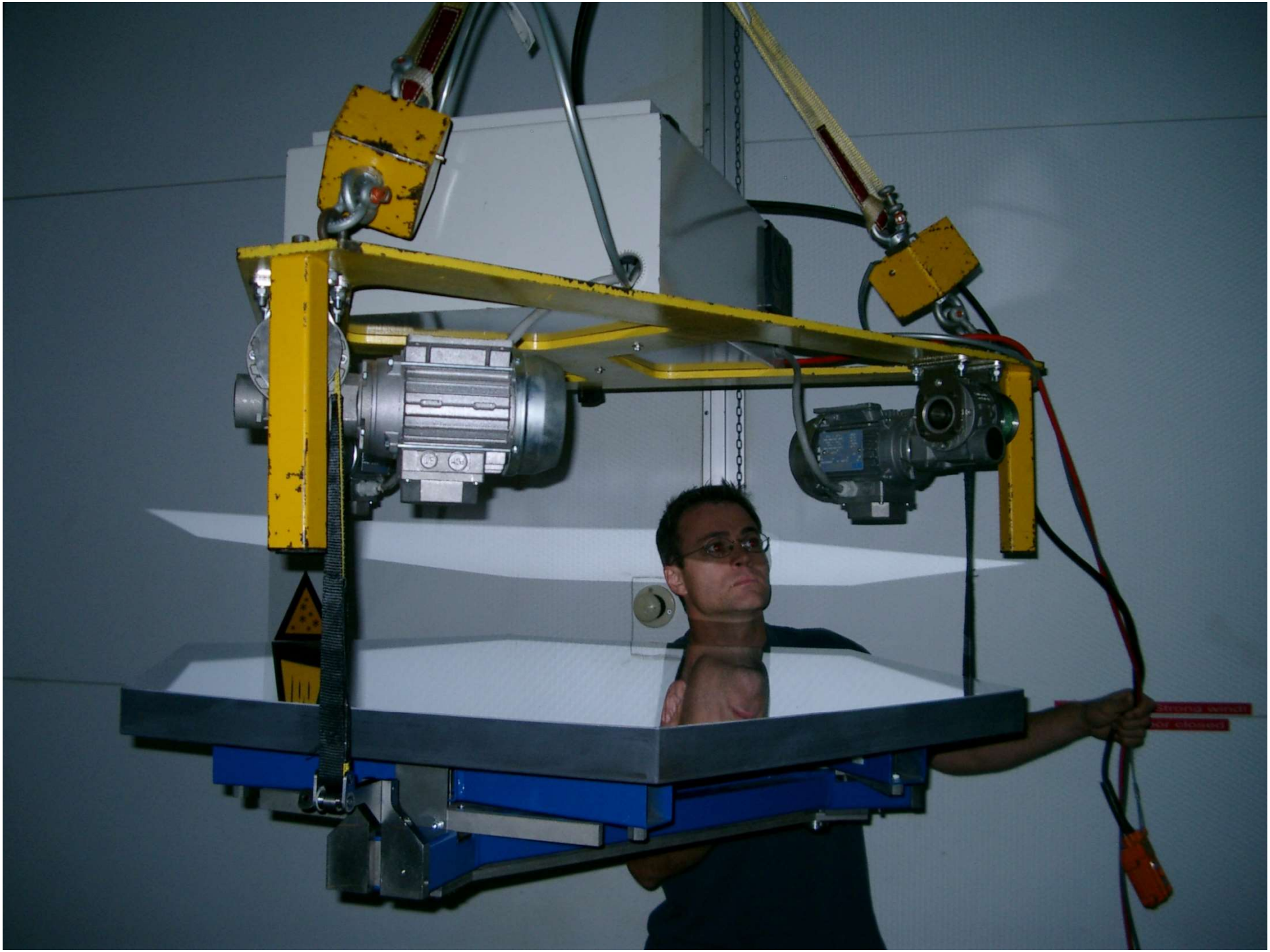
Implies that all SALT observations have to be queue-scheduled


In the beginning….
SALT site with existing SAAO telescopes
Before Nov 2000


Oct 2002


SALT mirror
truss assembly


9-point mirror
Mount support



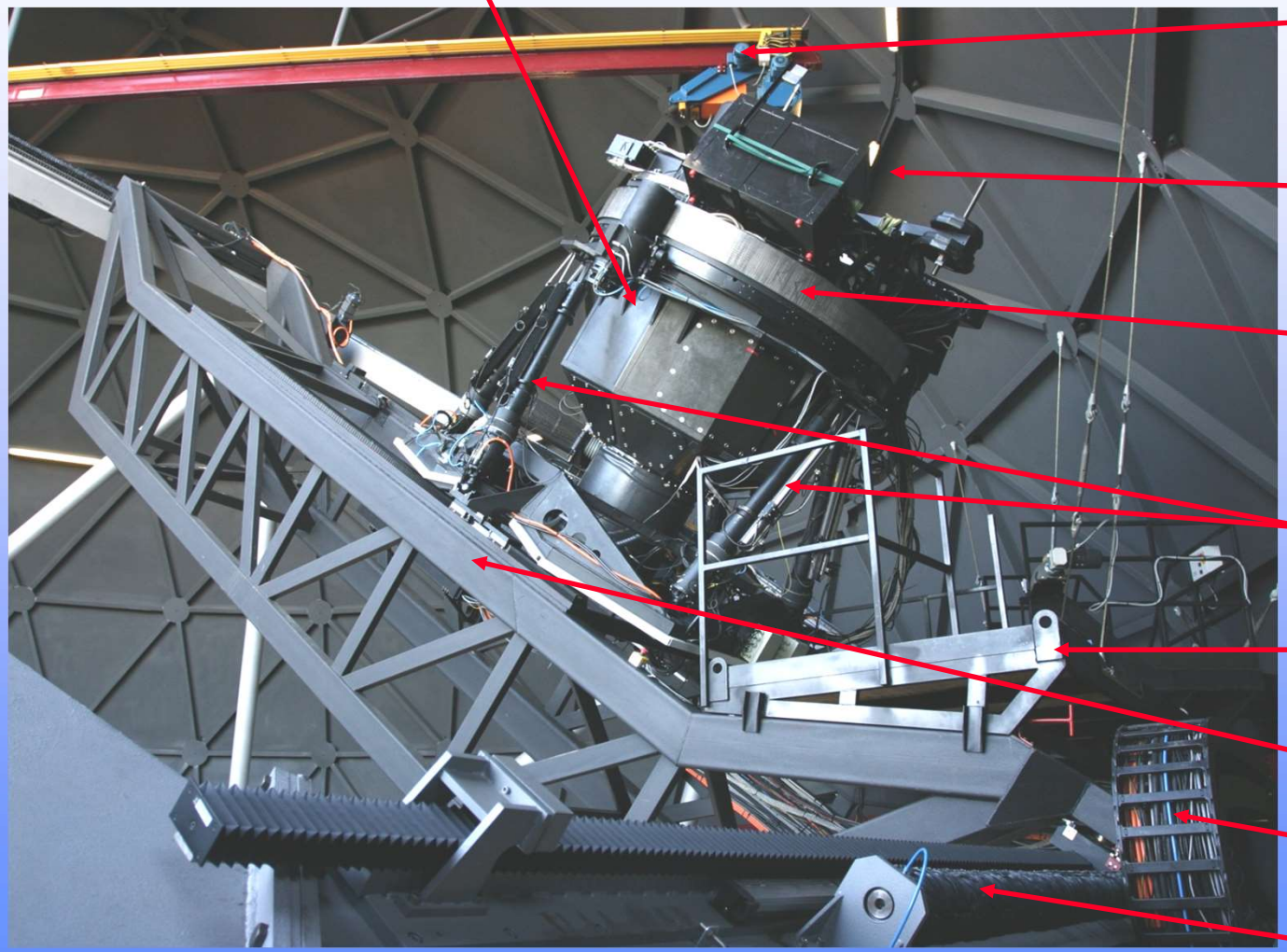

Prime Focus Tracker lift:
Sept 2003
COLONIA

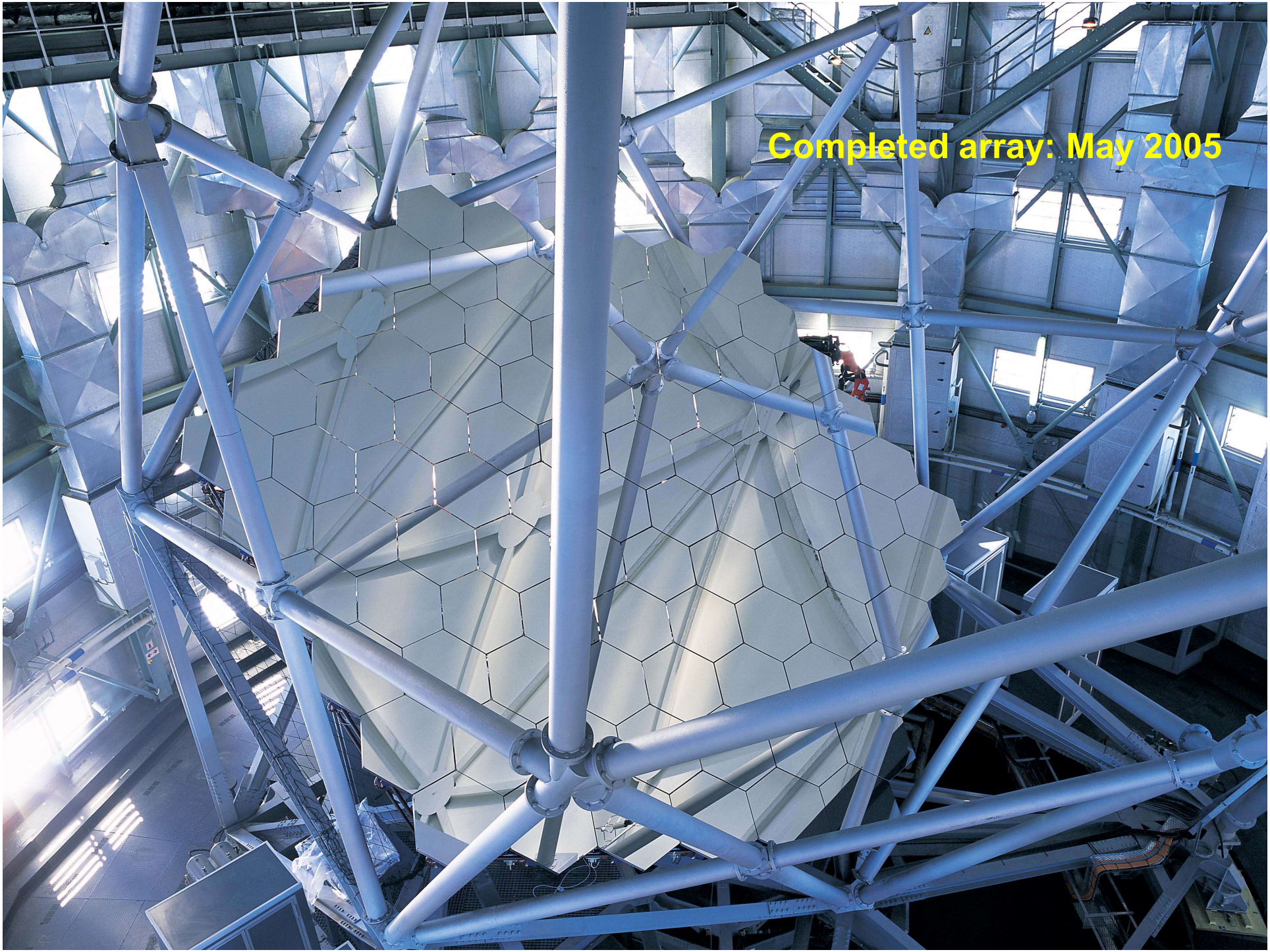
Completed Telescope
(May 2005)

- Dome
- Shutter
- Tracker & Payload
- Structure
  - TUBE
  - BASE WEDGE
  - MIRROR TRUSS
- Facility Building
  - CAT-WALK ACCESS
  - AIR CONDITIONING DUCTS
  - VENTILATION LOUVRES
- Primary Mirror Array

SALT instruments are all mounted on Prime Focus Payload

Payload structure (rotating & non-rotating components) made of carbon composite




Completed array: May 2005

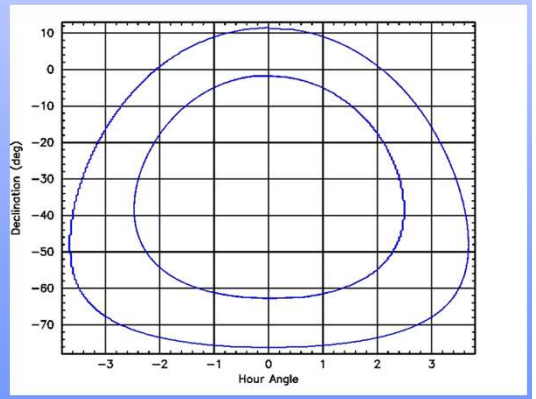
SALT Inauguration: 10 Nov 2005
Opened by the South African President, Thabo Mbeki

~2000 people attended the inauguration, reflecting the high profile of the project

Enjoyed media attention….

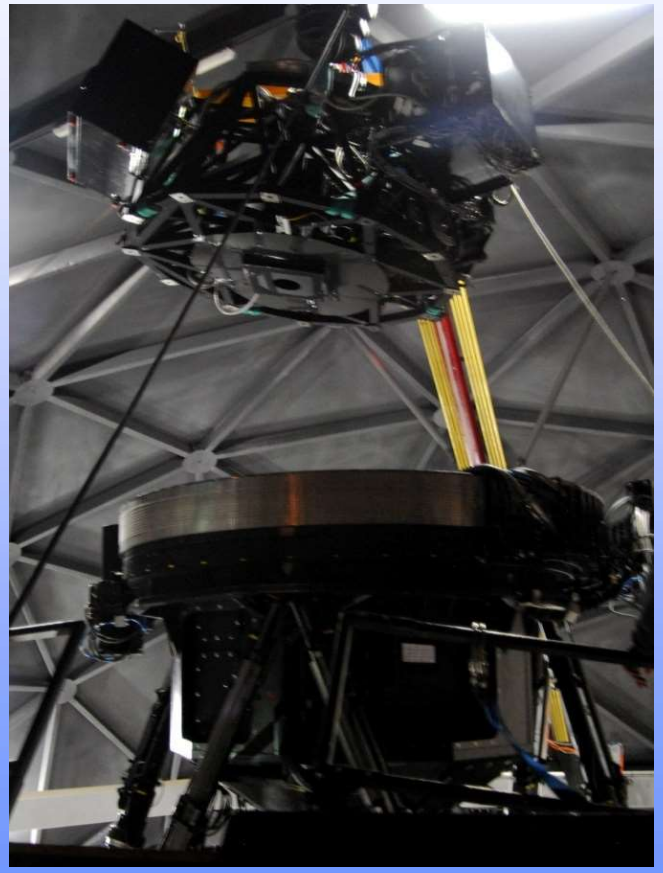
Key Numbers for SALT

Aperture	7 – 8.3 m effective filled aperture (moving 11 m pupil) 92 x 1.2 m hexagonal segments 8 arcmin FoV
Wavelength range	320 – 900 nm (visible); 800 – 1700 nm (NIR)
Instrument suite	*Robert Stobie Spectrograph (RSS)* ● Low- medium res (R ~ 350 – 9000) longslit & MOS ● Polarimetric modes (linear, circular, all-Stokes) ● Fabry-Perot etalons for imaging spectroscopy *SALTICAM* ● Visible imaging camera with multiple filter sets ● High speed (~10 Hz) capability *High Resolution Spectrograph (HRS)* ● Fibre-fed single object (+ sky) ● Three resolution modes (R ~15,000, 34,000, 70,000) ● High stability modes (ThAr, iodine, laser freq comb) *NIR IFU spectrograph (commissioning in 2022)* ● ~25 arcsec IFUs (212 fibres); R ~2000 – 5200
Other relevant facts	Can access +11° < Dec < -76° (restricted viewing annulus on the sky)

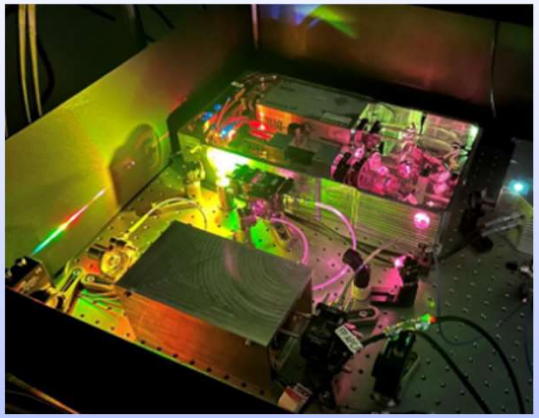


Current SALT Instruments

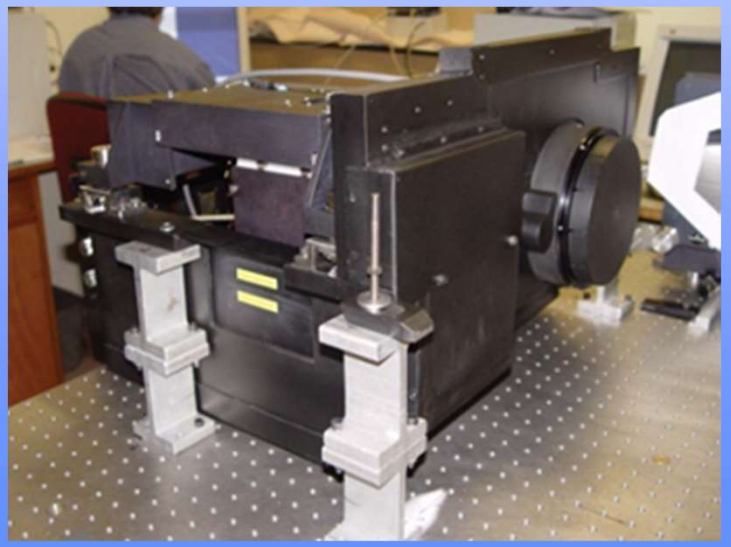
- Prime Focus Spectrograph (RSS)
  Spectrograph (HRS)



- HRS: High Resolution

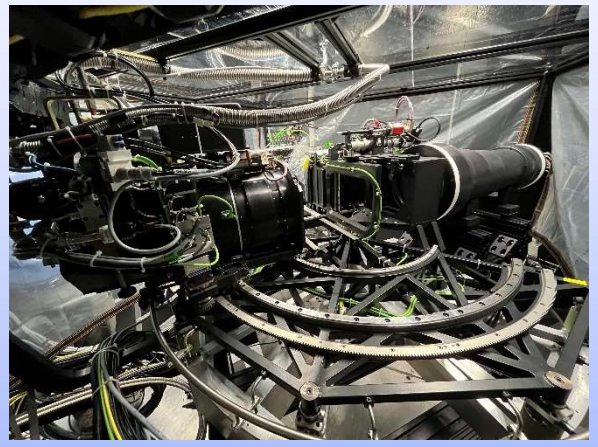


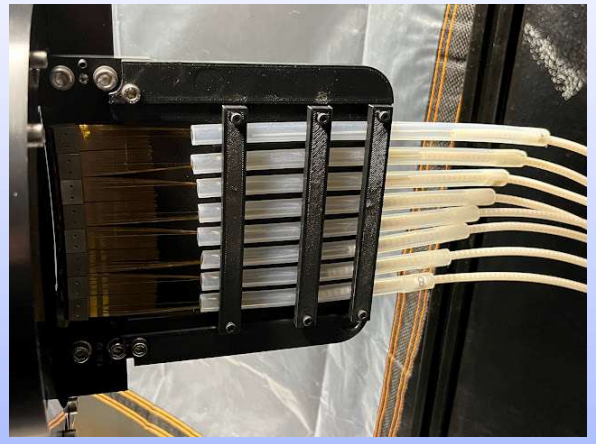
- SALT Imaging Camera (SALTICAM)



Current SALT Instruments

- **NIRWALS: Near IR IFU Spectrograph (800 – 1700 nm). Completed in 2023.**





- medium resolution (~2000-5200)
- Fed by 25 arcsec IFUs (212 fibres)
- Inside cold room (-40°C)

Future SALT Instrument

- **RSS Dual: UV/VIS + Red (320-900nm)**

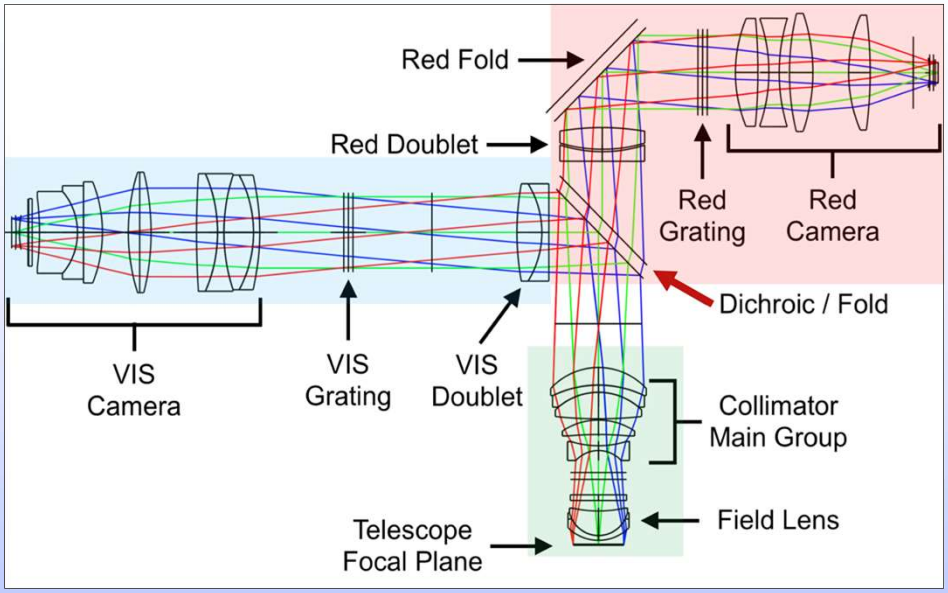
Adding new efficient Red arm (R ~ 2000)

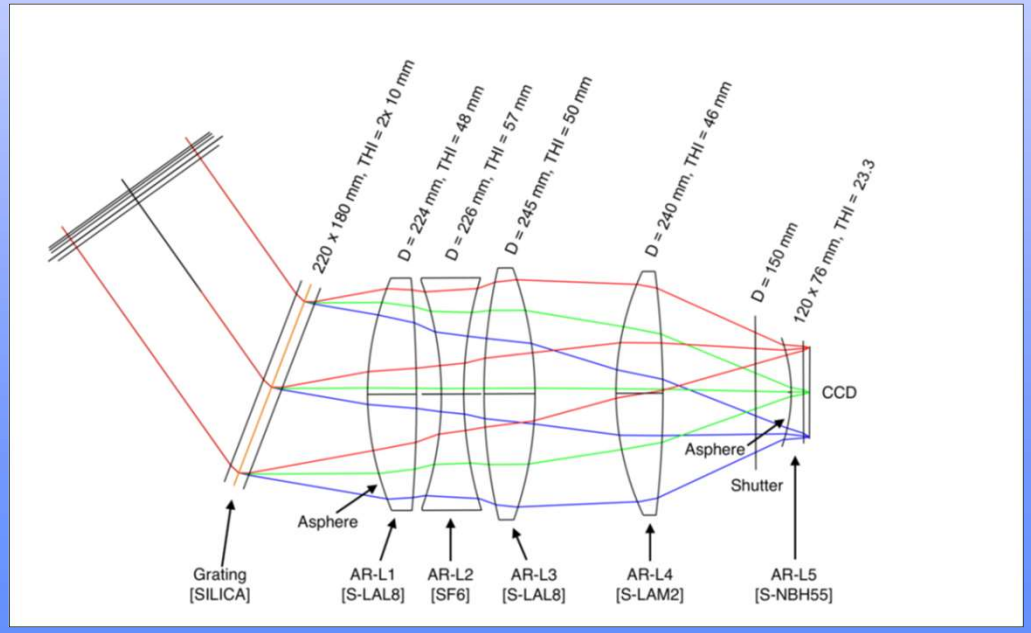
Interchangeable fold/dichoic (split @634nm)

56% peak efficiency (excluding. telescope & slit losses)

Optical & mechanical design complete; blanks procured

Expected completion in 2026

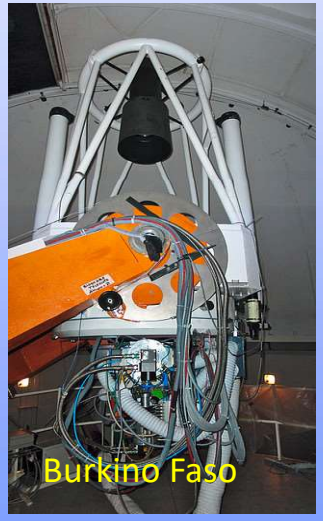


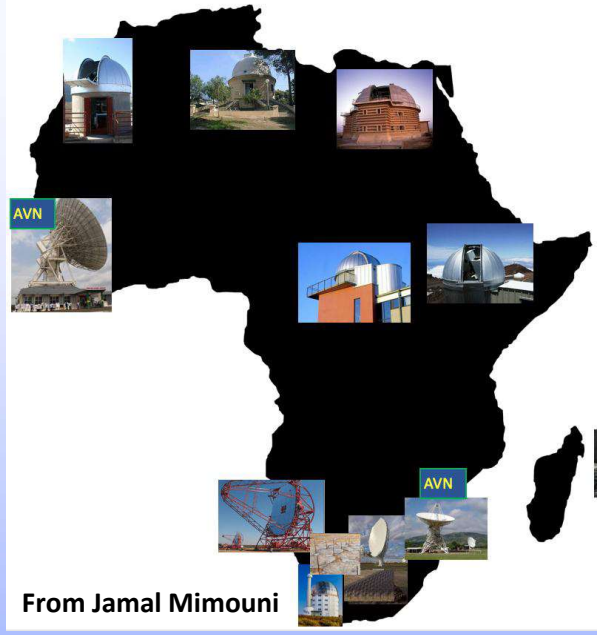


The Future: An African-wide Network

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 (e.g. Kenya)
- Train young scientists/engineers
- Need for maximize sky coverage (in position & time)

Potential Examples:

1. Kottamia Observatory, Egypt

- An old (1955) 74 inch (1.9-m) telescope, but well instrumented and capable
- Could be a great asset in the AIOS network

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*

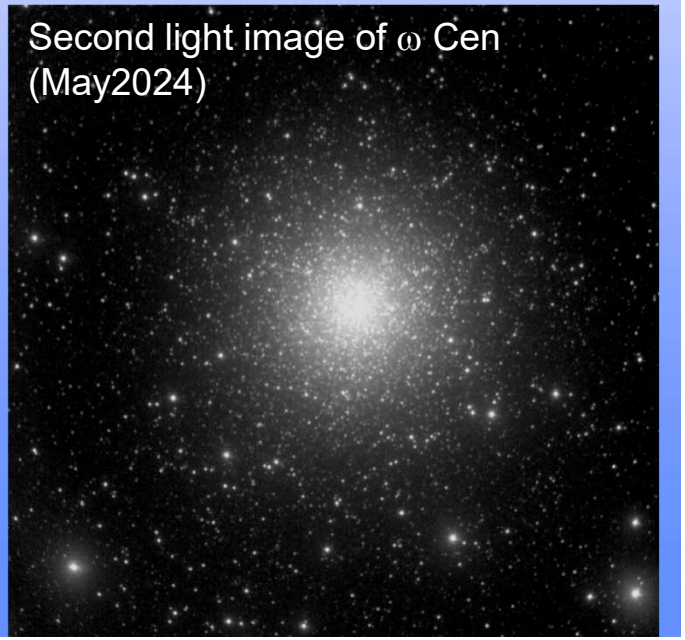
Potential Examples:

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 have full remote operation capability in 2025


Site visit Nov 2023


Second light image of ω Cen (May2024)

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

Kenya Telescope Developments

- Aim to establish a research grade 1-m class telescope on good site (northern Kenya mountains, like Mount Nyiro)
- In 2011 started a site selection process (interrogating meteorological satellite date, installing weather stations)
- Installed AWS on Warges in 2014 (too humid & cloudy)

The Kenyan Optical Telescope Initiative

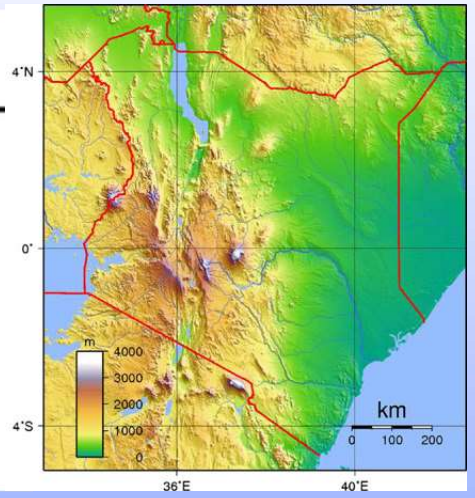
- Began in 2011 as a SA-Kenya bilateral project to look for potential sites for an optical telescope
- Preliminary analysis of existing satellite met data (~30 year)

Theor Appl Climatol (2016) 124:425–449
DOI 10.1007/s00704-014-1366-x

ORIGINAL PAPER

Search for an astronomical site in Kenya (SASKYA) using climate reanalyses and high-resolution meteorological model data

Edward Graham · Richard Vaughan · David A. H. Buckley · Koi Tirima



- Pre-selection of promising sites in northern Kenya (Lake Turkana region)
- Purchase of Automated Weather Stations (AWS)
- In 2018 project became part of a wider optical astronomy development program in Kenya, supported by the UK STFC office under the *Global Challenges Research Fund (GCRF)*
- Supported through the Edinburgh *Astronomical Technology Centre*

Kenyan Optical Telescope Initiative (KOTI)

- **Three meetings held:**
  - July 2018, Edinburgh
  - Oct 2018, Cape Town
  - Feb 2019, Nairobi (wrap up)
- **Site visit by helicopter to 3 potential sites**
  - Ol Donyo Nyiro, Ol Donyo Kulal & Chalbi desert
- **Hike to Ololokwe (south east, near Archer's Post)**
- **One has now become the preferred site, namely Ol Donyo Nyiro (2752-m)**
  - Anecdotally perhaps the best equatorial site on Earth for optical telescopes

- **Program roadmap being developed:**
  - Site testing (install AWS and borrowed Atmoscope (from Namibia following CTA site testing)
  - Developing model for both research telescope and also teaching/outreach telescopes
  - Look at potential for capacity and skills development in establishing an optical observatory

Kenyan Optical Telescope Initiative (KOTI)

The Vision

- **See astronomy embedded in Kenya in research, education at all levels, public awareness and tourism**
- **A research observatory. Initially a single 1-m class telescope, but with expansion capability**
- **Smaller telescopes for training and outreach *(linkage to "Travelling Telescope" initiative; development of astronomy visitors centre near Nairobi; the TBI astronomy initiative)***
- **Opportunities for capacity building in STEM subjects *(including climatology, Earth resources)***
- **Opportunities for school and university students to participate in astronomical activities *(associated with tertiary institutions)***
- **Training opportunities for students and others in astro-tourism *(telescopes at game parks)***

Aim to engage in global multi-wavelength astronomy and leverage unique geographical advantage (both hemispheres, good astro climate). Sites could become important part of a world-wide network supporting transient astronomy.

The End

The future is in our hands!