FACT SHEETS

AFRICA'S

GIANT EYE ON THE SKY

Inspiring society by exploring the Universe

S·A·L·T

SOUTHERN AFRICAN LARGE TELESCOPE

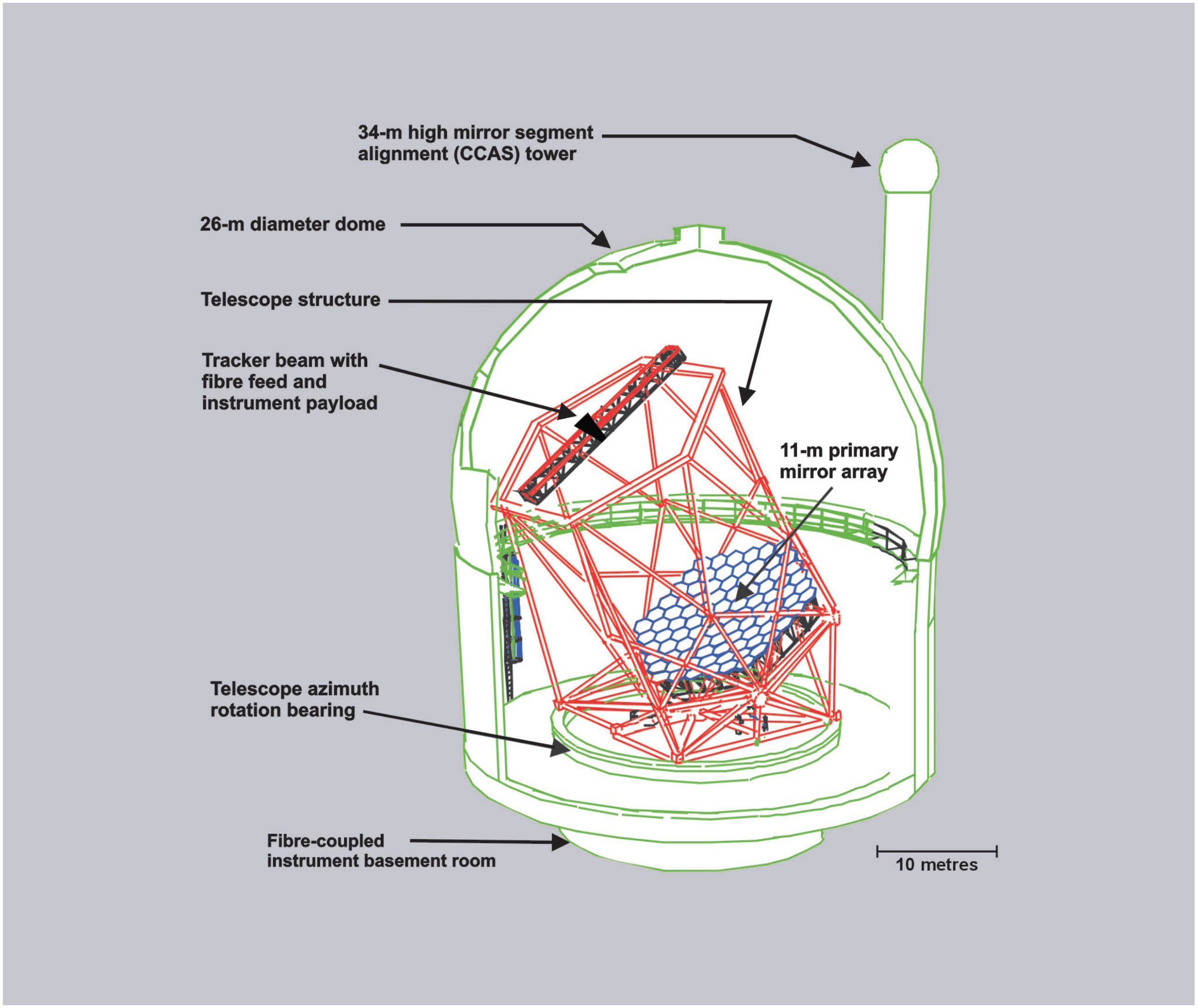
INTRODUCTION

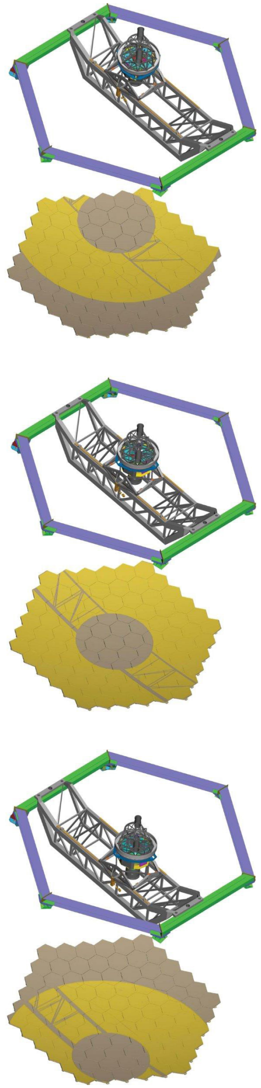
The Southern African Large Telescope (SALT) is the largest single optical telescope in the southern hemisphere, and amongst the largest in the world. It has a hexagonal primary mirror array 11 metres across, comprising 91 individual 1-metre hexagonal mirrors. It is the non-identical twin of the Hobby-Eberly Telescope (HET) which is located at McDonald Observatory in West Texas, USA. HET and SALT represent a new paradigm in the design of optical telescopes. The light gathered by the huge mirror is fed into a suite of instruments (an imager and two spectrographs in SALT's case) from which astronomers infer the properties of planets, stars and galaxies, as well as the structure of the Universe itself.

SALT's queue-scheduled mode of operation allows rapid response (often within a day or two). This, together with the fact that the full range of instruments is available at all times, allows observers to quickly switch between observing modes, depending on the specific science requirements. This capability makes SALT a powerful instrument for transient follow-up work, as was demonstrated with the first multi-messenger event GRW20170817.

SALT is located about 400 km from Cape Town in the Karoo semi-desert in South Africa, near the village Sutherland. It is one of the darkest astronomical sites in the world and is ideally placed (in longitude) between the other large optical observatories of the southern hemisphere (in Chile and Australia) to allow continuous coverage for time-critical observations.

IN PICTURES





The pupil (yellow) for three different tracker positions. The grey areas are non-illuminated parts of the mirror

SALT FACTS

- SALT is a fixed-altitude telescope, but due to a moveable tracker it can still observe 70% of the accessible sky.
- The design was based on a modified version of the Hobby-Eberly Telescope (HET) in Texas, USA.
- Construction started in 2000, first-light was achieved five years later and SALT entered full science operation in 2011.
- The total telescope cost, including its instruments and operations, was approximately US$32 million, of which South Africa contributed a third and the international partners provided the balance.
- The primary mirror is fixed at an angle of 37 degrees with respect to the zenith, compared to the HET's 35-degree tilt.
- The tracker is a robot that carries the science instruments (the so-called 'payload'). It is located in the prime focus and tracks the target across the primary mirror.
- Targets with declinations between +10 and -75 degrees can be observed by SALT, but the time that they are observable for depends on their declination.
- The structure with all its control cables and cooling pipes is capable of rotating 480° to ensure shortest-path rotation between two nearby scheduled observations.
- The primary mirror measures 11 metres in diameter and consists of 91 interchangeable hexagonal mirror segments, with a spherical figure.
- Each mirror segment is a hexagon 1 metre wide across the flats and is ion-polished to better than 19 nm rms.
- Three actuators (precision "pistons") on each of the 91 mirror mounts are used to position the individual mirror segments accurately.
- An optical wavefront sensor positioned in the Centre of Curvature Alignment System tower (CCAS) is used to align all of the mirrors to the ideal spherical surface once a week.
- Edge sensors, which detect changes in relative positions of the mirror segments, provide data on mirror misalignment approximately every 60 seconds. Detected displacements are corrected in a closed-loop control system which adjusts the mirror actuators to compensate for shifts due to temperature changes.
- SALT's primary mirror edge sensor system can keep the mirror segments well aligned for a week over a temperature range of up to 20 degrees Celsius.

- As part of the SALT design, the pupil (that is, the view of the mirror as the tracker sees it) moves during the course of an observing track, resulting in a constantly-changing collecting area for the telescope (see figure on page 3)

- The annual operating cost is currently US$3.3 million, which is distributed between the nine international SALT partners based on their respective shares in SALT.

- With a publication rate of 49 refereed papers in 2017, SALT is one of the most cost-effective large telescopes.

- Researches not affiliated with one of the partner institutions can purchase their own SALT time. The price is ~2200 US$/h or 2900 US$/hr for high priority time (with the guarantee of being fully observed); a limited amount of Director's Discretionary Time is free to every researcher.

- The first generation instrumentation includes a low to medium resolution imaging spectrograph/spectropolarimeter (the Robert Stobie Spectrograph, RSS), an acquisition and imaging camera (SALTICAM) and a fibre-fed high-resolution spectrograph (the HRS).

- A high time resolution photon-counting camera (the Berkeley Visible Image Tube camera, BVIT) was added to the instrument suite as a visitor instrument.

- In 2019 SALT will acquire a fibre-fed near-infrared spectrograph, the wavelength range of which will be 0.85 microns – 1.7 microns.

- A new low-resolution, high-throughput optical spectrograph (MaxE) is in the design phase.

- All of the science instruments are permanently mounted on the telescope, so SALT can switch between instruments in less than 80 seconds.

- SALT observations are fully queue scheduled. They are carried out by a team of SALT astronomers and SALT operators on behalf of the SALT user community.

- All science targets are assigned a priority class, which determines the likelihood of the object being observed and under what sky conditions that observation will be attempted.

- Director's Discretionary Time (DDT) proposals may be submitted throughout the year, not just during the regular proposal calls issued every six months.

- Data is transferred to Cape Town each morning by fibre-link, then processed and sent to the PIs, who typically receive it less than a day after their observations were taken. Data products can be made available within an hour of a high-priority target being observed.

SITE FACTS

- The observing site is about 400 km north-west of Cape Town in the Karoo desert, 20 km from the small town of Sutherland.

- SALT is located at -32˚22'33.0" (South) and -20˚48'38.9" (East), at an elevation of 1783 m above sea level.

- Although the site's median seeing is 1.5 arcseconds, it is one of the darkest observatory locations in the world (V = 22.0 mag/sq.arcsec at zenith during dark time and Solar minimum).

- About 40% of the observing time is lost due to weather in Winter, and 35% in Summer.

INSTRUMENT FACTS

SALTICAM:

- SALTICAM was designed and built by the SAAO Instrumentation group.
- It was the first-light instrument.
- SALTICAM serves as the acquisition and imaging camera for the telescope.
- SALTICAM offers full-frame, frame-transfer, slot-mode (high-speed) and drift-scan imaging modes.
- The detector consists of two 2048 x 4096 pixel CCDs.
- The science field-of-view is 8 arcmin in diameter.
- The pixel scale is 0.14 arcsec/pixel.
- In slot-mode, SALTICAM can provide sampling at a rate of 20 Hz over an 8x120 arcsec slot.
- The filter magazine holds eight filters at a time and the complete suite includes Johnson-Cousins, Sloan and Stromgren sets.

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Field-of-view	**8' (science)**
	10' (guide star)
Wavelength range	**320 nm – 950 nm**
Number of CCD chips	**2**
Pixel dimensions	**15 x 15 µm**
CCD format per chip	**2048 x 4102 px**
Area per chip	**30.7 x 61.5 mm**
Plate scale (imaging)	**0.14 "/px**
Pre-binning	**1x1, 2x2, ... 9x9**
Read-out capabilities (amplifier per chip)	**2**
Mosaicing	**2 x 1 mini-mosaic**
Charge transfer efficiency (CTE)	**> 99.99%**
Quantum efficiency (QE)	**>40% @ 350 nm ~80% @ 500 nm >45% @ 900 nm**
Full well	**164 and 172 ke^-/px**
Dark current	**<1 e^-/px/hr @ 160 K**
Read-out noise	**3.3 e^-/px @ 100 kHz (slot mode)**
Read-out speed	**100 – 300 kHz (frame transfer time)**
Minimum expousure time	**0.05 s @ 9x9 (slot mode)**

The Robert Stobie Spectrograph, RSS:

- The Robert Stobie Spectrograph (RSS) is named after the SAAO Director who secured the funding to make SALT a reality.
- It was designed and built by the University of Wisconsin-Madison as their in-kind contribution to the SALT partnership.
- RSS has several modes: long-slit (LS), multi-object (MOS), Fabry Pérot (FP), spectropolarimetry (Pol) as well as direct imaging.
- The spectrograph operates in the visible range and is sensitive to wavelengths between 320 nm (the atmospheric cut-off in the ultraviolet) and 900 nm.
- The RSS has a suite of six transmissive diffraction gratings with different wavelength ranges and resolutions. The individual gratings have 300, 900, 1300, 1800, 2300 and 3000 lines per mm. The lowest resolution 300 l/mm is a surface-relief grating, while the other five are volume-phase holographic gratings.
- The grating in use can be rotated with respect to the beam to change the wavelength range of the spectrum. The camera barrel (+ detector) is then articulated to twice the angle of the grating, to maximise the efficiency of the grating.
- To reduce the amount of light lost to reflections at each optical surface, several of the RSS lens groups contain optical coupling fluid.
- The Fabry-Pérot mode provides two-dimensional imaging spectroscopic capabilities over the whole field of view. The system consists of three etalons with gap spacings of ~0.6 nm, ~2.8 nm, and ~13.6 nm, also referred to as low, medium and high resolution.
- The polarimetric modes require additional complex optics, including a polarising beam-splitter and a set of half- and quarter-waveplates. The beam-splitter is a 3x3x2 mosaic of Wollaston prisms made of extremely rare and fragile UV calcite, which is birefringent and hence splits the incoming light into "ordinary" and "extraordinary" rays.
- The detector system was built by the SAAO Instrumentation group and is a mosaic of three 2048 x 4096 CCDs with 15-micron pixels and a plate scale of 224 microns/arcsec.
- As with SALTICAM, the detector can be used in normal, frame-transfer and slot-mode configurations, the latter two providing higher time-resolution by eliminating dead-time due to the CCD reading out.

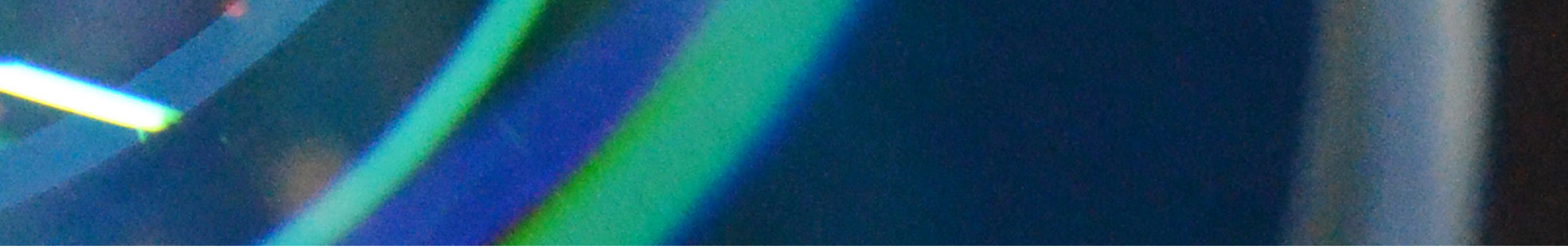
	LS	MOS	FP	Pol
Field-of-view	**8'**	**≤ 8'**	**8'**	**4'**
Wavelength range	**320 nm – 900 nm**		**430 nm – 860 nm**	**320 nm – 900 nm**
Number of CCD chips	**3**			
Pixel dimensions	**15 x 15 µm**			
CCD format per chip	**2048 x 4102 px**			
Area per chip	**30.7 x 61.5 mm**			
Plate scale (imaging)	**0.1267 "/px**			
Plate scale (spectroscopy)	**0.067 "/px**			
Pre-binning	**1x1, 2x2, ... 9x9**			
Read-out capabilities (amplifier per chip)	**2**			
Mosaicing	**3 x 1 mini-mosaic**			
Charge transfer efficiency (CTE)	**> 99.9999%**			
Quantum efficiency (QE)	**>40% @ 350 nm ~80% @ 500 nm >45% @ 900 nm**			
Full well	**150 – 180 ke$^-$/px**			
Dark current	**<1.5 e$^-$/px/hr @ 160 K**			
Read-out noise	**2.8 – 4.4 e$^-$/px**			
Read-out speed	**100 – 250 kHz @ 1x1**			
Minimum expousure time	**0.05 s**			
Spectral resolutions: Low resolution (LR) Medium resolution (MR) High resolution (HR)			**320 – 7700 1250 – 1650 9000**	
Slit sizes	**0.6", 1.0", 1.25", 1.5", 2.0", 3.0", 4.0"**	**≥ 1.5"**	**0.6", 1.0", 1.25", 1.5", 2.0", 3.0", 4.0"**	**0.6", 1.0", 1.25", 1.5", 2.0", 3.0", 4.0"**

INSTRUMENT FACTS

The High Resolution Spectrograph, HRS:

- The High Resolution Spectrograph (HRS) was built by Durham University's Centre for Advanced Instrumentation and installed on the telescope in 2013.
- The instrument is fibre-fed from the prime focus with 50-m long object and sky fibres for each mode.
- HRS permits high-resolution spectroscopy from 370 to 890 nm, divided into blue and red channels at a cross-over wavelength of 555 nm.
- The optical bench is inside a 3-m long stainless-steel vacuum tank that rests on vibration isolators and is kept in a temperature controlled room to maximise the wavelength stability of the instrument.
- The HRS offers low (LR), medium (MR) and high resolution (HR) modes with resolving powers of 15000, 40000 and 65000, respectively
- An additional high-stability mode (HS; at the highest resolution) uses a double-scrambler to limit effects of fibre illumination; it also offers the choice between an iodine cell and the simultaneous injection of Thorium-Argon arc light into the sky fibre (to be used for precision wavelength calibration for exoplanet science).
- Two sizes of fibres are used: with 500 and with 350 micron cores, subtending approximately 2.2" and 1.6" on the sky, respectively, to match the typical site seeing.
- The LR mode uses unsliced 500 micron fibres, while the MR, HR and HS mode fibres have Bowen-Walraven slicer optics that reformat the fibres into narrow slits to increase the resolution for those modes. MR employs sliced 500 micron fibres, while HR and HS modes use sliced 350 micron fibres.
- The HS mode's iodine cell can deliver radial velocity precision of the order of 2-3 m/s, sufficient for detecting a planet like Saturn in a solar system like our own.

	BLUE ARM	RED ARM
Wavelength range	**370 nm – 555 nm**	**555 nm – 890 nm**
Number of CCD chips	**1**	**1**
Pixel dimensions	**15 x 15 µm**	
CCD format per chip	**2048 x 4096 px**	**4096 x 4096 px**
Area per chip	**30.7 x 61.4 mm**	**61.4 x 61.4 mm**
Pre-binning	**1x1, 2x2, 3x3, 8x8, 3x1**	
Read-out capabilities (amplifier per chip)	**1**	**1**
Charge transfer efficiency (CTE)	**99.999%**	**100.00%**
Quantum efficiency (QE)	**49.3% @ 350 nm 78.2% @ 400 nm 86.4% @ >500 nm**	**75.3% @ 550 nm 93.1% @ 650 nm 58.4% @ 900 nm**
Full well	**150 ke$^-$/px**	**150 ke$^-$/px**
Dark current	**2.1 e$^-$/px/hr @ 160 K**	**3.1 e$^-$/px/hr @ 160 K**
Read-out noise	**4.3 e$^-$/px @ 400 kHz**	**3.7 e$^-$/px @ 400 kHz**
Read-out speed	**400 kHz**	**400 kHz**
Spectral resolutions: Low resolution (LR) Medium resolution (MR) High resolution (HR) High stability (HS)	** 15 000 40 000 65 000 65 000**	
Fibre diameter	**1.6" and 2.2"**	



BVIT:

- The Berkeley Visible Image Tube camera (BVIT) is a visitor instrument and was built at the Space Science Laboratory of the University of California, Berkeley.
- This auxiliary port instrument is a micro-channel plate, photon-counting detector system designed for microsecond optical photometric imaging.
- Unlike conventional CCD devices, the Super Gen II photocathode has no read noise and is capable of recording photon events in very short time intervals.
- BVIT can handle data rates up to 1.1 MHz.
- Events are time-tagged to 25 nanoseconds.
- BVIT has a 1.9-arcmin diameter field of view.
- BVIT offers a choice of user-selectable UBVR and neutral density filters.

Field-of-view	**1.9'**
Filters	**B,V,R,Hα,ND0 – ND2.0**
Quantum efficiency (QE)	**16% @ 500 nm** **11% @ 750 nm**
Read-out noise	**0 e^-/px**
Spatial resolution	**30 µm**
Minimum expousure time	**25 ns**
Max globale rate	**1.0 MHz**
Max local rate (9” x 9” area)	**100 kHz**

TELESCOPE FACTS

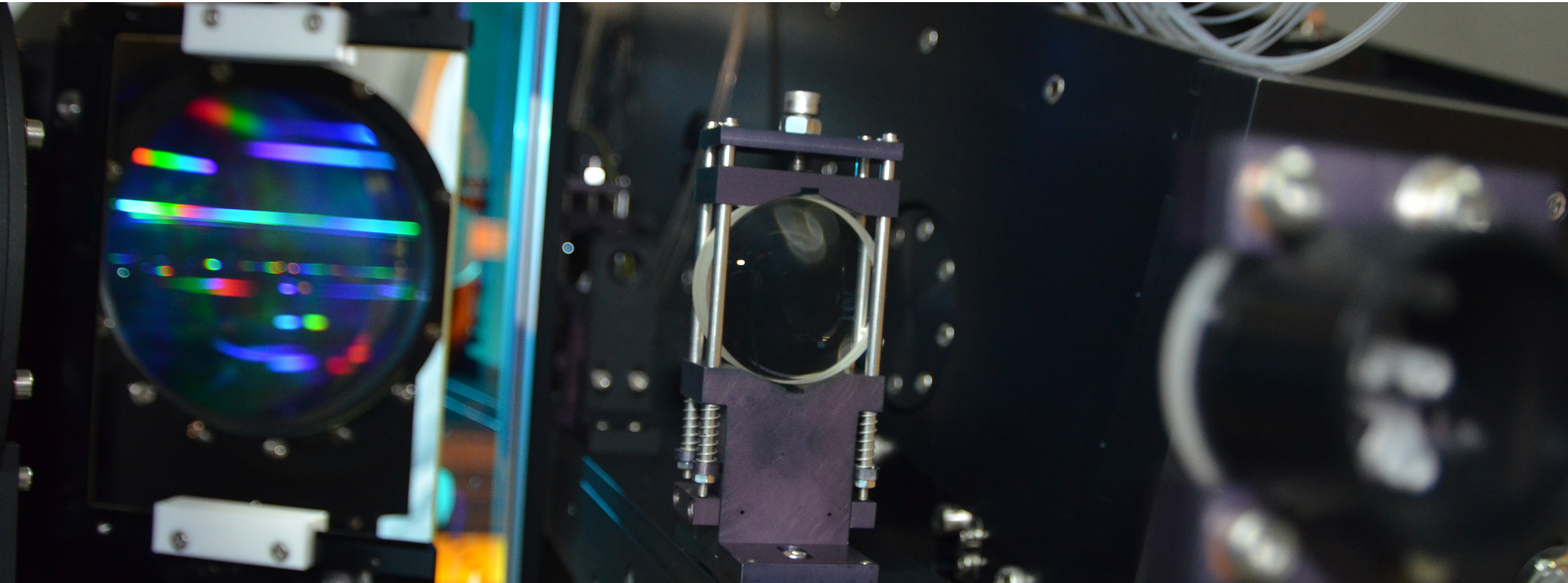
Diameter	**11m**
Focal length	**13.083 m**
Focal ratio	**F/4.2**
Number of hexagonal segments	**91**
Size / weight of segment	**1 m / 100 kg**
Radius of spherical mirror surface	**26.165 m**
Mirrors in spherical aberration corrector (secondary optics)	**4**
(Fixed) elevation of telescope	**53 deg**
Tracker range	**± 6 deg**
Effective diameter range	**7–9 m**
Effective area range	**40 – 55 m^2**
Declination range	**+11deg – -76 deg**
Accessible sky	**~70%**
FoV (at prime focus)	**8'**
Median zenithal seeing	**1.5"**
Maximum sky brightness at site at zenith (V-band)	**22.0 mag/sqdeg**
Airmass range	**1.17 – 1.37**

SCIENCE FACTS

- SALT's forte is rapid follow-up observations of transient objects.
- Due to the dark skies, diffuse low surface brightness objects are ideal for very competitive results.
- Some of the spectroscopic observing modes are rare on large telescopes (e.g., high-speed and Fabry-Pérot imaging spectroscopy).
- Short observing blocks (15 - 30 min) are best suited to allow for SALT's reduced visibility of the sky at any given time.

SOFTWARE FACTS

- SALT uses Labview for the implementation of its control system and is one of the largest Labview deployments worldwide.
- SALT employs a ticket-based software management system that allows the tracking of software issues and facilitates communication with the relevant stakeholders.
- Proposal submission is a two-fold process: the first submission is to request observing time, the second provides detailed instructions for the service observations.
- SALT's control system is assembled from various independent components. The communications between the individual pieces uses NATS which has very small latency times between sending and receiving a message.
- Data from over 10 thousand different sensors and variables are recorded at rates from 20 Hz to 0.003 Hz, with historical data going back to 2008. This can be retrieved and analysed to discover long-term performance trends.



PARTNERS

The current SALT partners are: the South African National Research Foundation, the University of Wisconsin-Madison, Rutgers University, Dartmouth College, Poland (led by the Nicolaus Copernicus Astronomical Centre of the Polish Academy of Sciences), India's Inter-University Centre for Astronomy & Astrophysics, the UK SALT consortium (including the Universities of Central Lancashire, Keele, Southampton, Nottingham, The Open University and Armagh Observatory), the University of North Carolina and the American Museum of Natural History.

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