Observational astrophysics

(Day 1)

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CAMK/PAN
Geoplanet School 2021/2022

Observational astrophysics

Prerequisites

None, but if you have problems to follow the lectures, do let me know.

Reading material

Available in advance.

Check the lecture's website:

https://events.camk.edu.pl/event/27/

Slides

Not available in advance.

After the end of each lecture, they will be made available.

When?

Tuesdays, 11:15am

Large seminar room @CAMK-Warsaw

Zoom link by e-mail

12 meetings of 1h30m

Participation

Is encouraged. Participation and other activities during the lectures will count for the grades (to be explained soon)

What are these lectures about?

- Observational astrophysics
  - Making measurements from astronomical sources
    - Techniques, telescopes and instruments
    - Understanding the errors of those measurements
  - Using the measurements
    - Estimating parameters
    - Testing theories

What to expect?

Goals

- To cover what you need to know to plan, propose, prepare, carry out, and analyse observations.
- Understand the limitations of the data that you want to use, but that was obtained by someone else.
- There will be a focus on near-UV/optical/near-IR wavelengths because:

  1) this is what I know best and

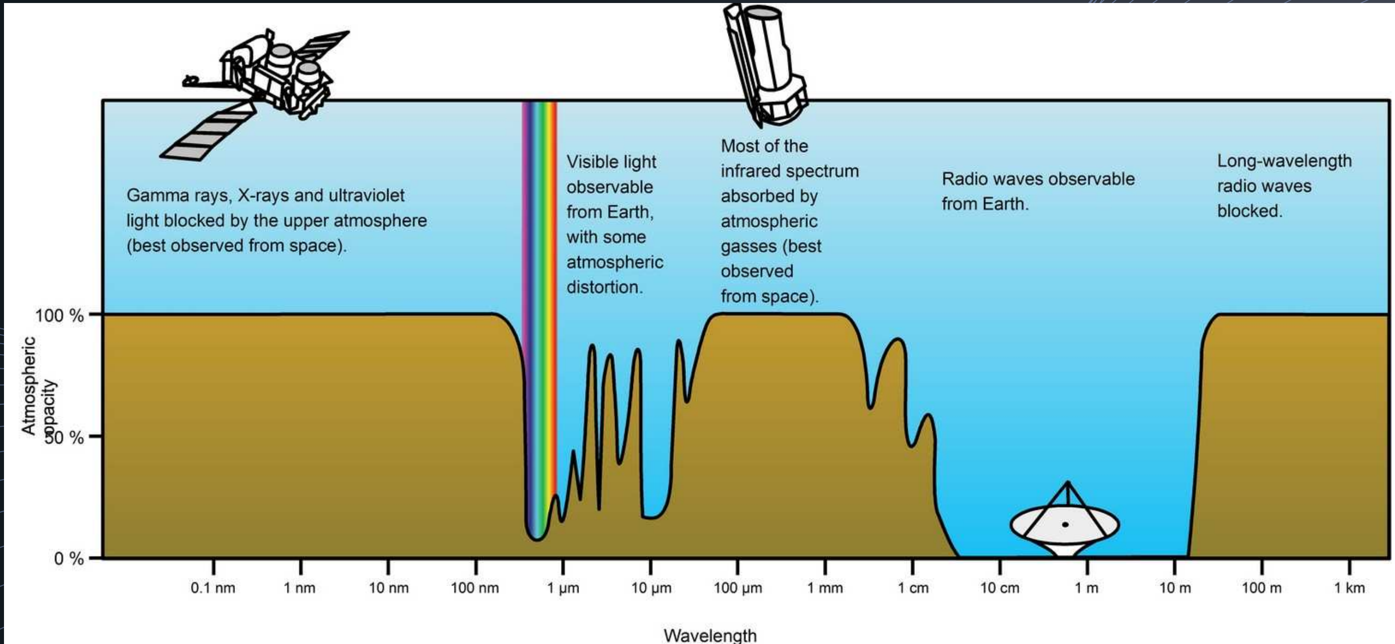
  2) most of the observational facilities in the world cover this wavelength range.

Benefits

- Overview of observing techniques, of modern instrumentation, telescopes, and missions, and tips for writing proposals
- Obvious use for observers
- But also useful for theoreticians/modellers:
  - ➔ Compare/test your model/theory with/to observational data
  - ➔ Motivate your observer colleagues to obtain the right data that you need
  - ➔ Join a proposal, as the provider of models or theoretical background
  - ➔ Work on the science case for a new instrument or mission

Topics that will be covered

- The electromagnetic spectrum
- Effects of the atmosphere
- Astronomical coordinate systems and time

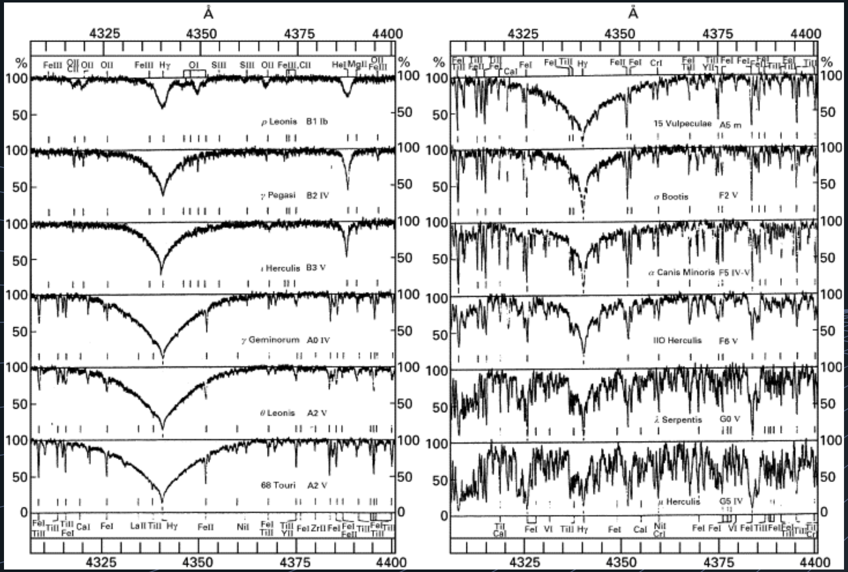


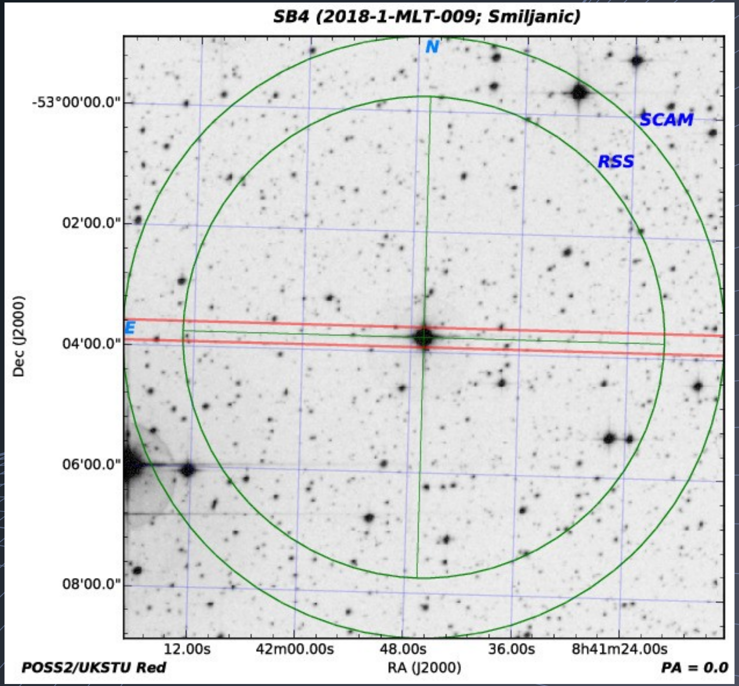
Topics that will be covered

- Telescopes and image formation
- Adaptive and active optics
- Detectors
- Measurements, signal-to-noise, errors

Topics that will be covered

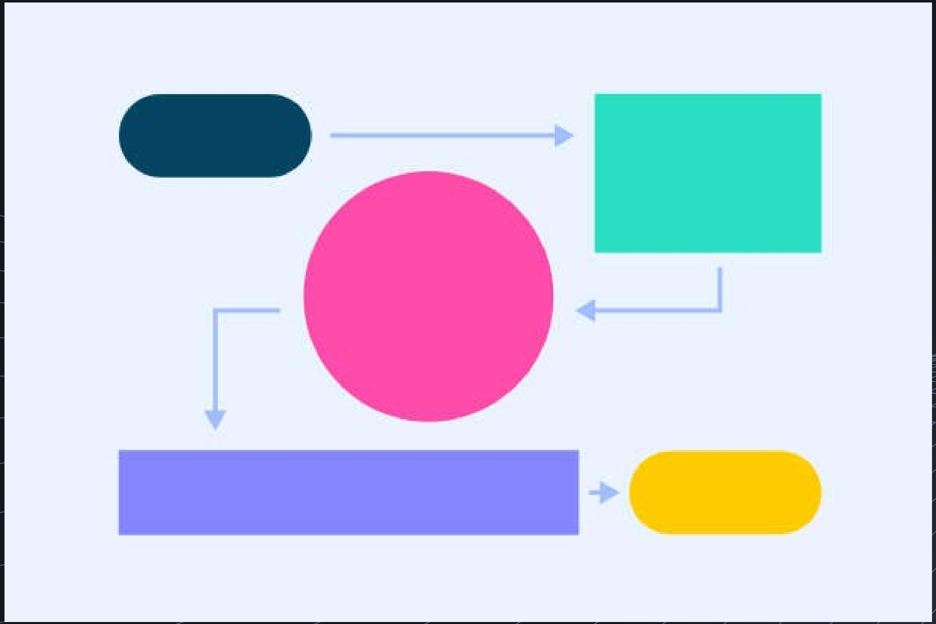
- Photometry
- Spectroscopy
- Astrometry
- Asteroseismology
- Interferometry
- Polarimetry
- Infrared observations





Topics that will be covered

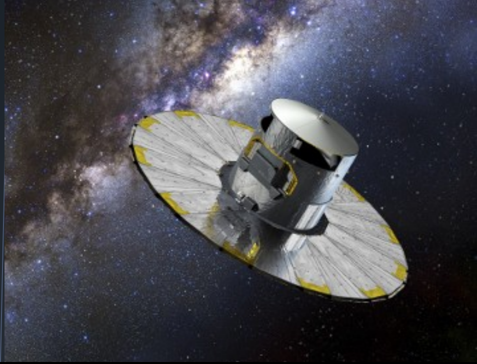
- Writing and evaluating observing proposals

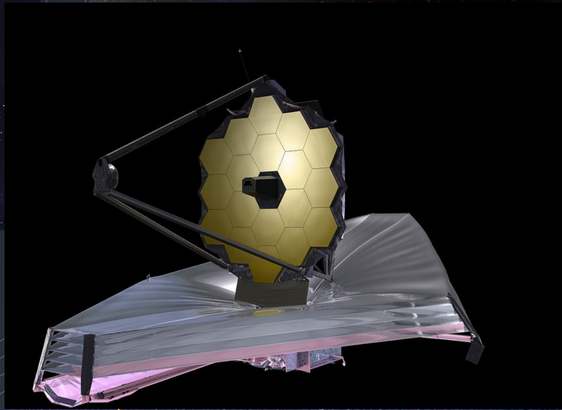


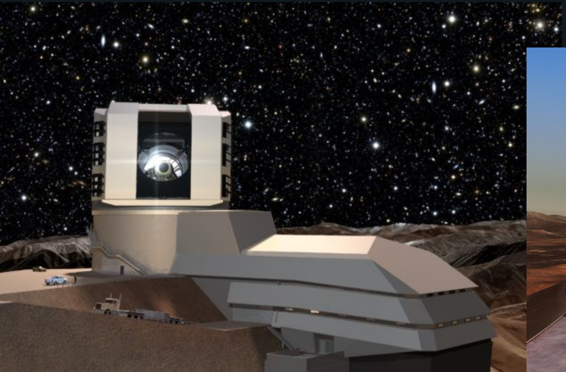
The plan is non-linear...

- Cerro Paranal (VLT, VLTI, VST, VISTA)
- SALT as a comparison

- Cerro Armazones (E-ELT)
- Vera Rubin Telescope (LSST)
- And to space (Gaia, TESS, PLATO, JWST)



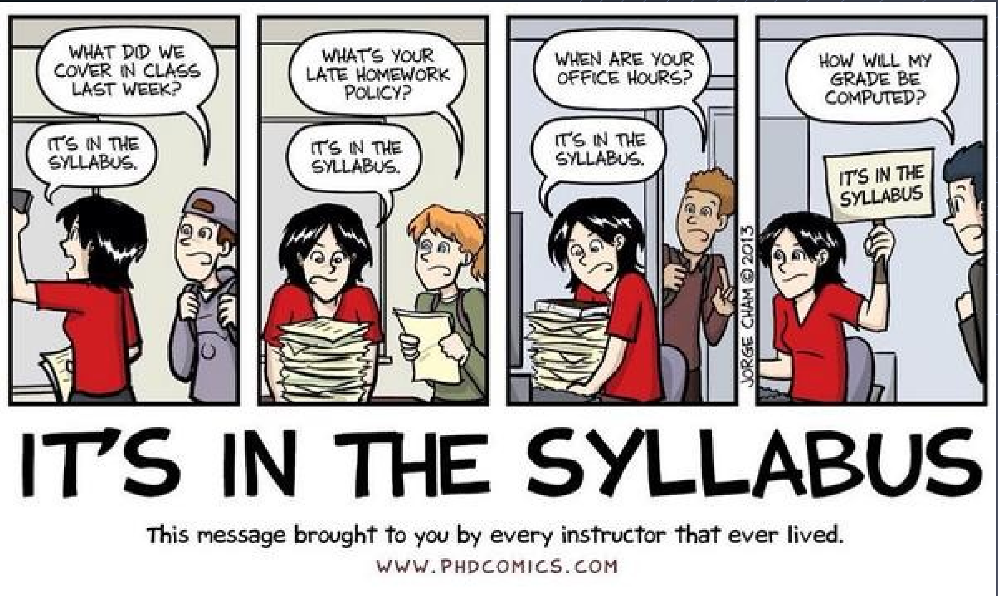




Any question?

The evaluation

How to get ECTS points?



100 points will be distributed

0-20 points	0-10 points	0-20 points	0-25 points	0-25 points
Short seminar	Participation	Data analysis	Proposal writing	Proposal evaluation
5 min, 2-3 slides.	Questions to me and to your colleagues.	Practical exercise with real data.	For the VLT/VLTI.	We will set up mock evaluation panels.

Short presentation (0-20 pts)

How?

- Topics randomly distributed
- One week in advance
- Use any material you would like
- Max 2-3 slides, 5 mins
- Each person presents once
- Three dates set for this,
- In each date 1/3 of the students will present

When?

- See lecture plan
- Meeting #04 (Nov. 16, 2021)
  - Topic: Telescopes
- Meeting #07 (Dec. 07, 2021)
  - Topic: Instruments (Optical and IR)
- Meeting #10 (Jan. 25, 2022)
  - Topic: Instruments (Optical and IR)

Participation (0-10 pts)

How?

- Be active
- Ask questions
- To me and to your colleagues (during their seminars)
- It’s not comparative; I understand participation does not come easy to everyone
- But make an effort!

Practical data analysis (0-20 pts)

How?

- Raw data and calibration files will be distributed
- Either one long slit stellar spectrum or an image of an open cluster in one band
- Return a FITS file with the reduced data product; with reduction info in the header
- IRAF tutorials will be provided
- Data sets can be different for each person

When?

- See lecture plan
- Data sets still to be prepared
- Distributed in advance
- Meeting #08 (Dec. 14, 2021)
  - Detectors and data processing
- Deadline (Feb. 08, 2022)
- Late work will not be graded

Proposal preparation (0-25 pts)

How?

- E-mail alert of a transient event sent on Dec. 07, 2021
- Search information about the object
- Prepare a proposal for follow-up observation
- This task is individual
- (TBD) ESO Phase 1 template
- Use any instrument/telescope at Cerro Paranal
- Points are given not for the science, but for the technical aspects of the proposal

When?

- See lecture plan
- Meeting #07 (Dec. 07, 2021)
  - Writing and evaluation of observing proposals
- Submission deadline (Jan. 14, 2022)
- Late work will not be graded

Proposal evaluation (0-25 pts)

How?

- We will follow (more or less) the procedure of ESO panels
- Each person is a referee of 3 proposals
- You are the primary referee of one
- Comments and grades by Jan. 28, 2022
- Material distributed Feb. 04 to “non-conflicted” people
- I will chair the panel
- (TBD) You will not be present for the discussion of your proposal
- Proposals are evaluated based on what was written

When?

- See lecture plan
- Proposal deadline: Jan. 14, 2022
- Deadline for evaluation: Jan. 28, 2022
- Grades and comments to the panel by Feb. 04, 2022
- Meeting #12 (Feb. 08, 2022)
  - Panel meeting

Any question?

Ethics and feedback

All professional interactions should be conducted with consideration and respect

Our meetings should be inclusive

- Environment for free discussion of ideas
- No one should fear to join the discussion
- Please, contribute to that
- If I am failing (by my own actions, or lack of actions), do let me know directly or anonymously, as you prefer

Conduct towards others

- Have a look at the Ethics Statement of the European Astronomical Society
- Sections: conduct towards others, conflicts of interest, plagiarism, attribution of work, peer review, language

Feedback

- Appreciated during and after the lectures
- In person, by e-mail, or anonymous
- Survey to be set in the Lecture’s website

Any question?

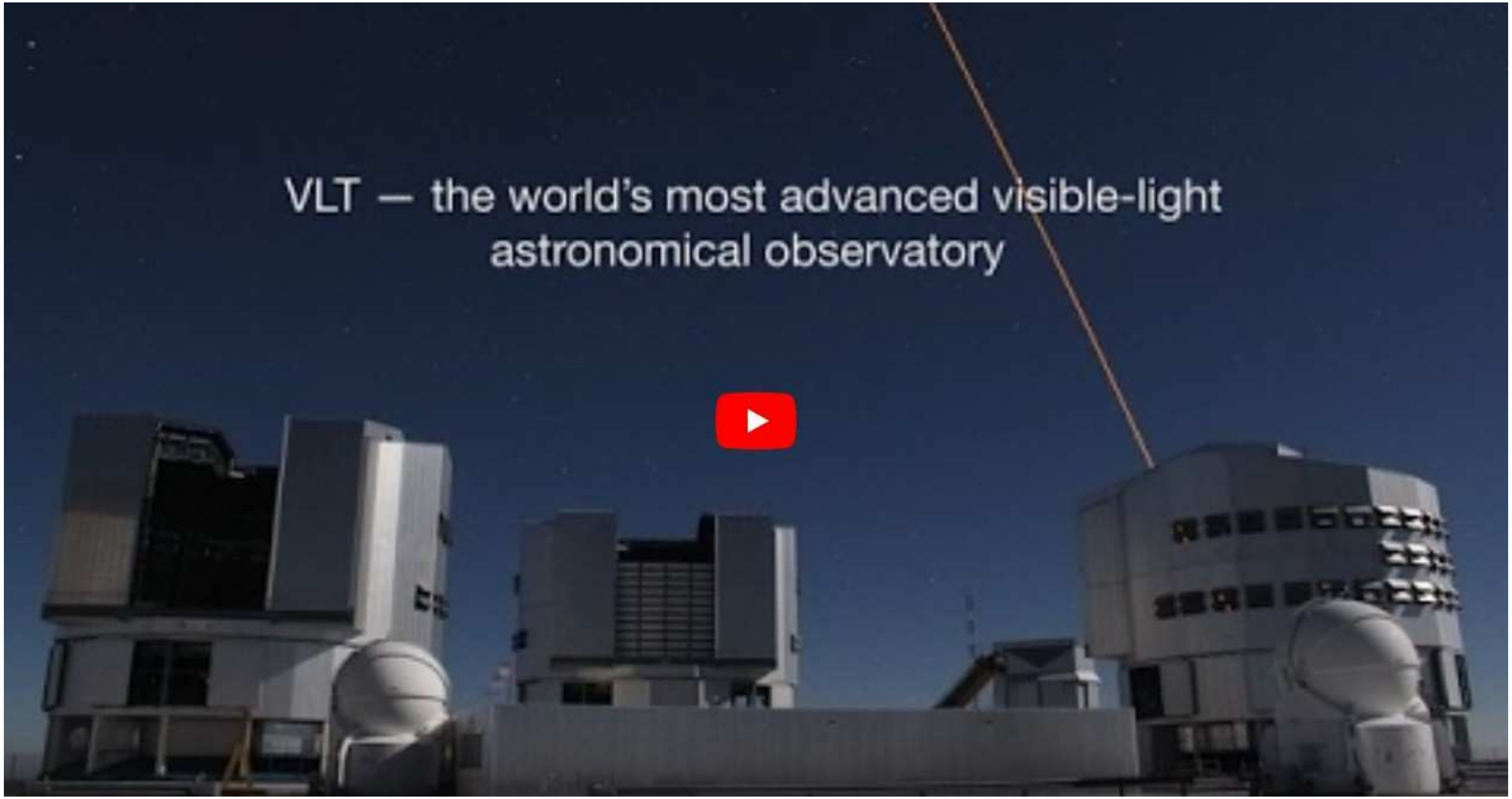
Cerro Paranal Observatory

(Day 01)

(Credit: ESO)

https://www.youtube.com/watch?v=LY_zLR9kE1w

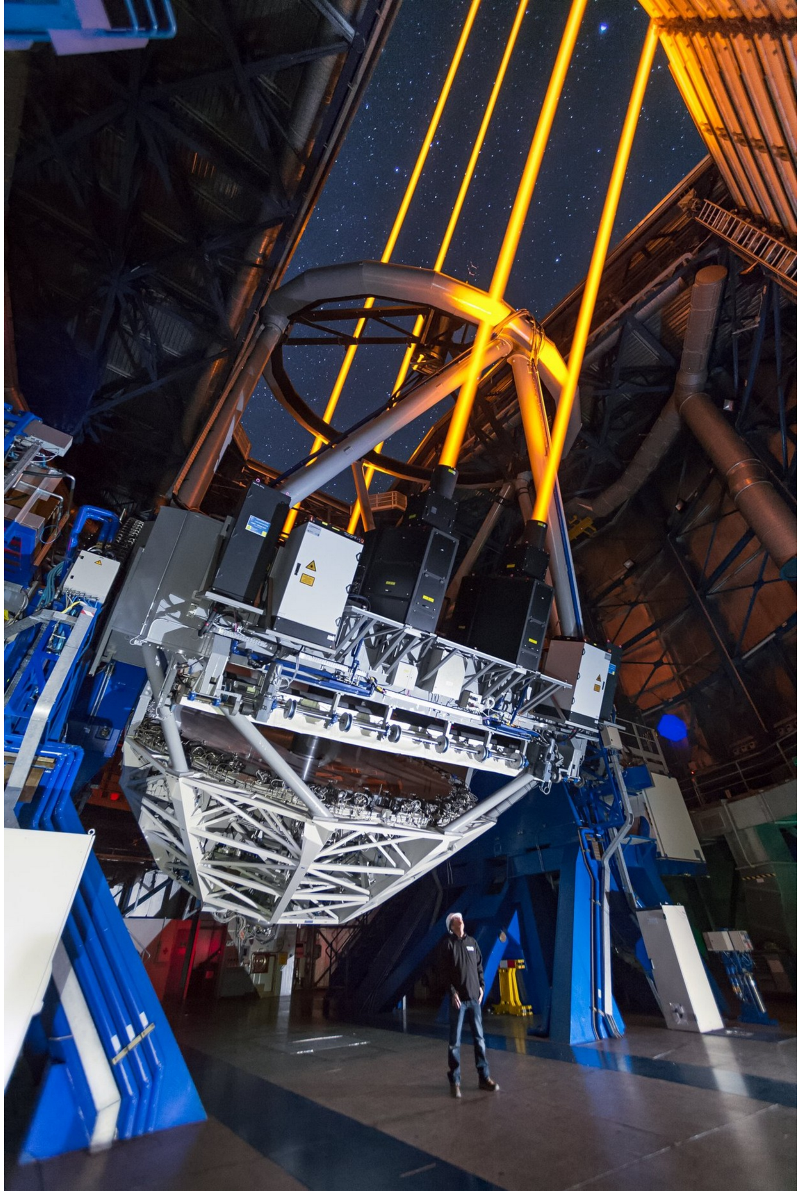
VLT Trailer



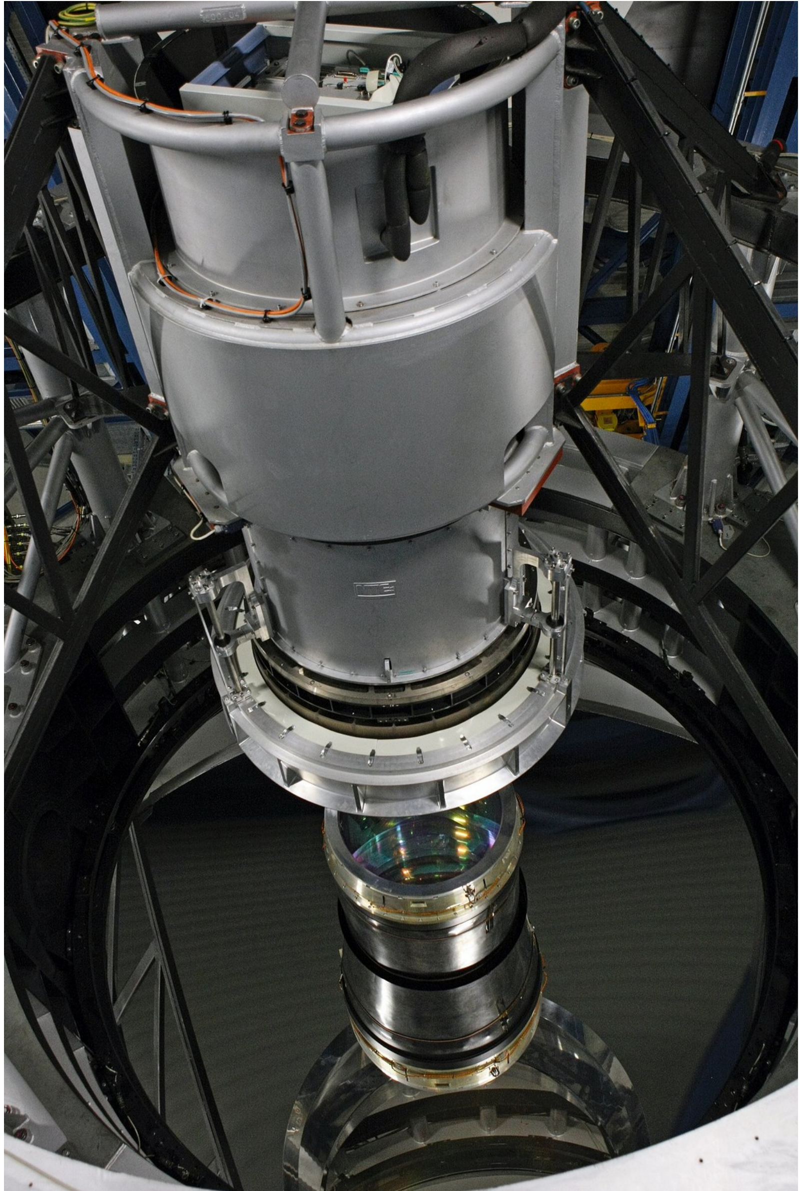
(Credit: ESO)

Paranal Telescopes

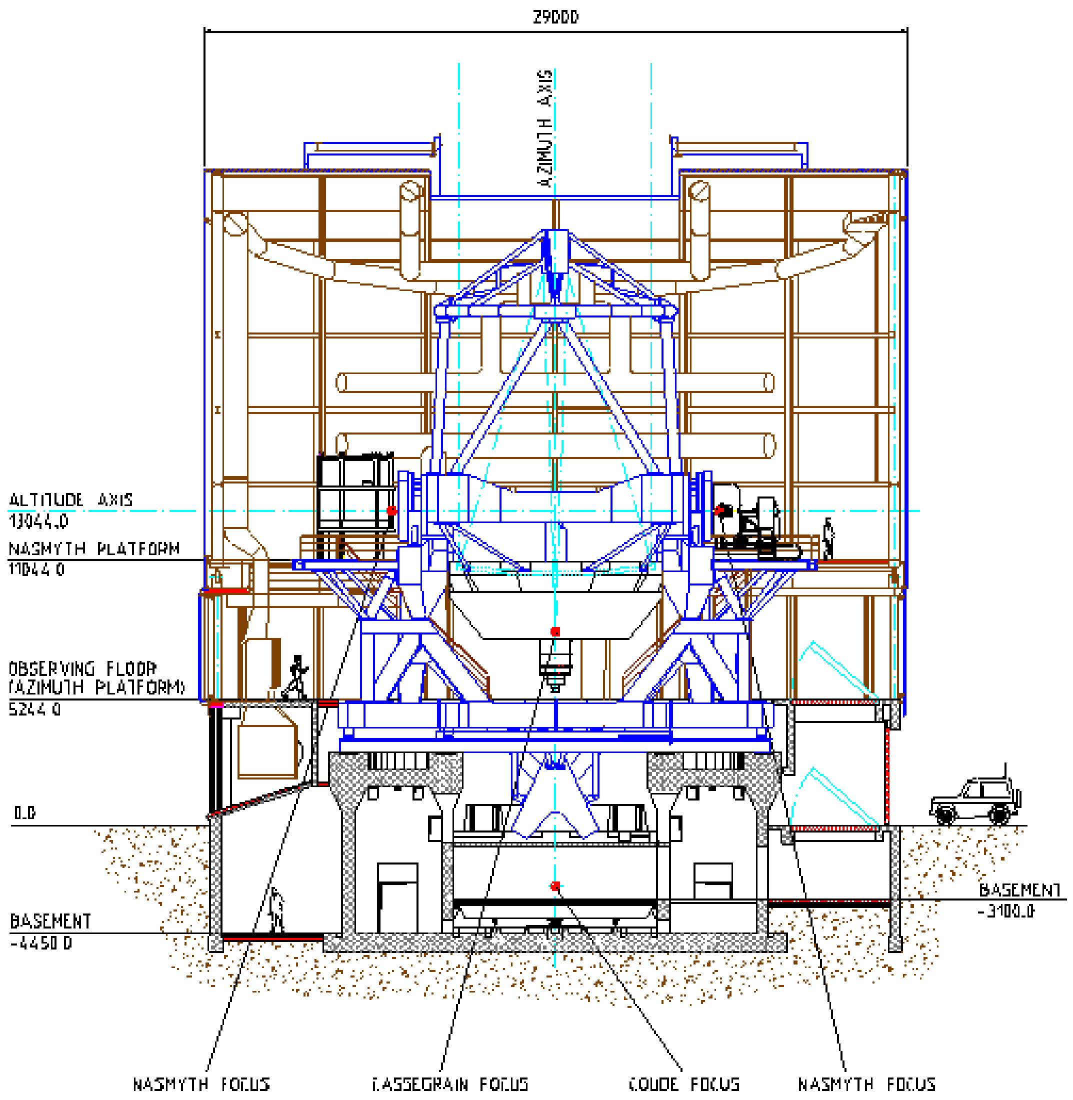
- Four Unit Telescopes (UTs) of 8.2m diameter
  - Antu (UT1, the Sun), Kueyen (UT2, the Moon), Melipal (UT3, the Southern Cross), Yepun (UT4, the Evening Star)
- Four Auxiliary Telescopes (ATs) of 1.8m diameter
- The four UTs can work together as a 16m telescope (e.g. ESPRESSO)
- Very Large Telescope Interferometer (VLTI) – combines UTs or ATs
- VLT Survey Telescope (VST) of 2.6m diameter
- Visible and Infrared Survey Telescope for Astronomy (VISTA) of 4.1m diameter

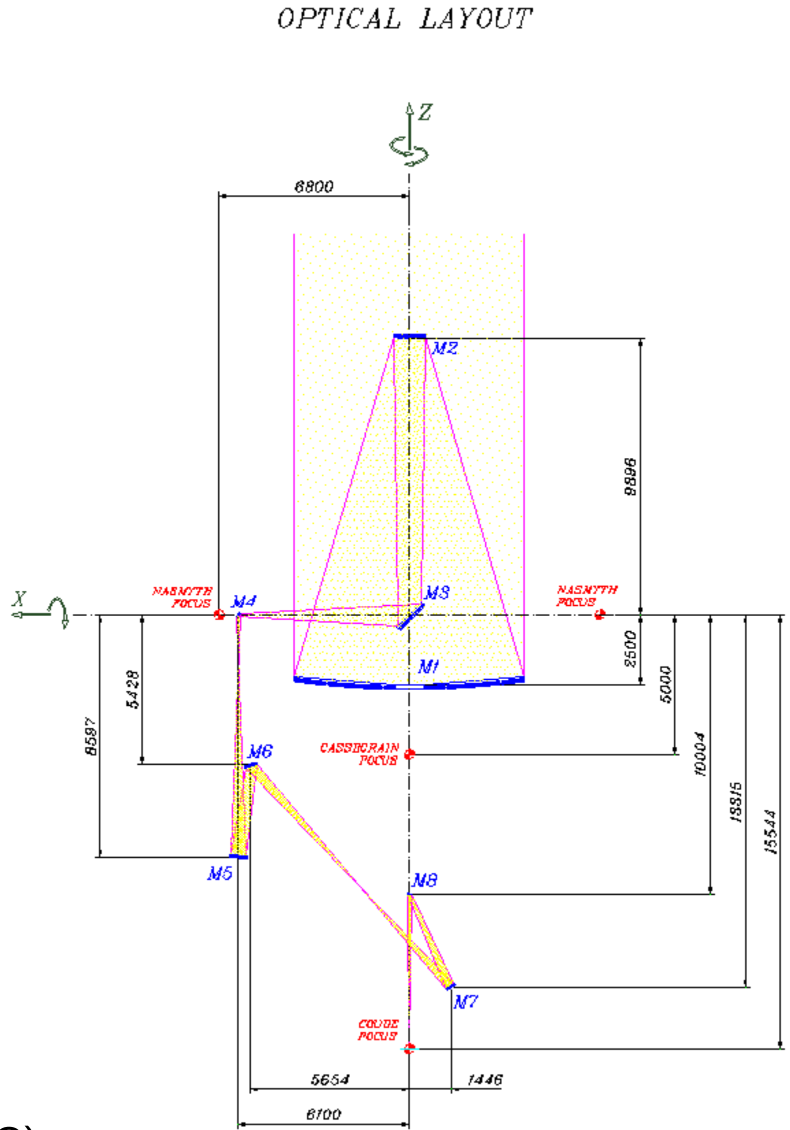


UTs



(Credit: ESO)


29000
AZIMUTH AXIS
ALTITUDE AXIS
13044.0
NASMYTH PLATFORM
11044.0
OBSERVING FLOOR
(AZIMUTH PLATFORM)
5244.0
0.0
BASEMENT
-4450.0
BASEMENT
-3100.0
NASMYTH FOCUS
CASSEGRAIN FOCUS
COUDE FOCUS
NASMYTH FOCUS


OPTICAL LAYOUT
Z
X
6800
M2
9896
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M4
M3
NASMYTH FOCUS
M1
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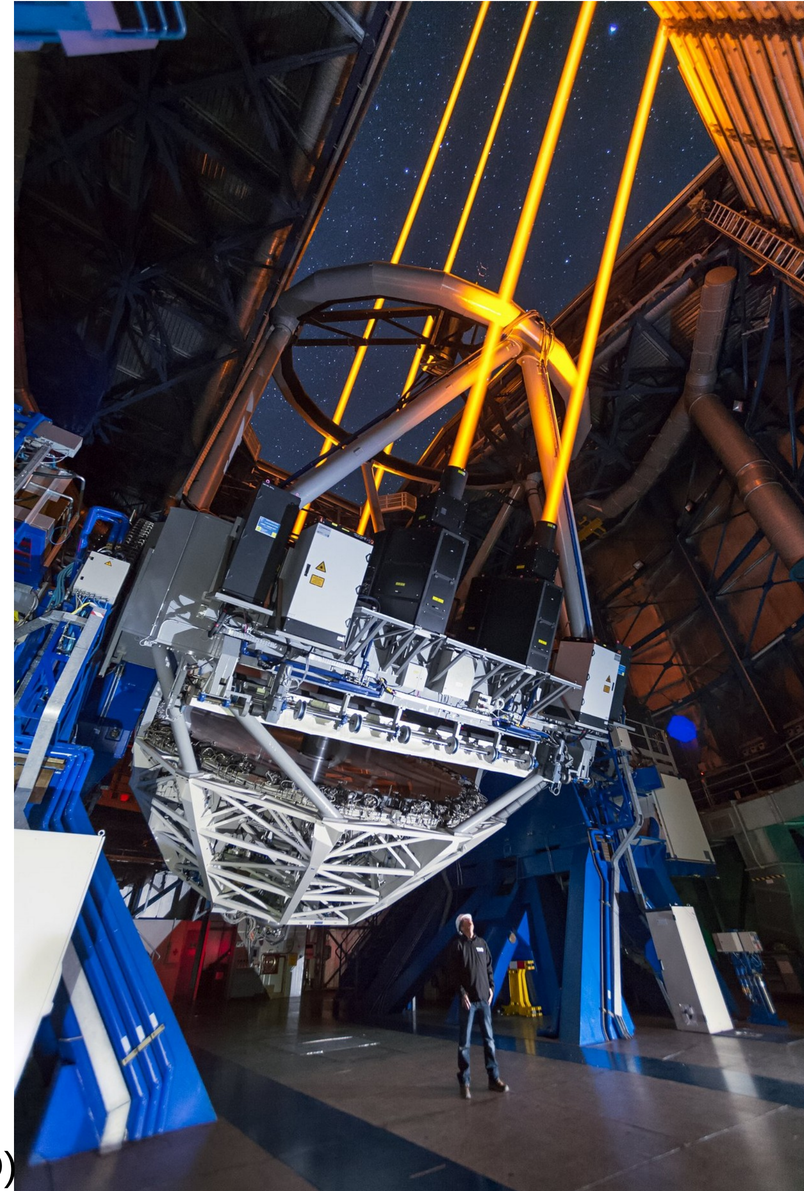
5000
5428
8597
M6
CASSEGRAIN FOCUS
10004
13315
15544
M5
M8
M7
COUDE FOCUS
5654
1446
6100

(Credit: ESO)

UTs

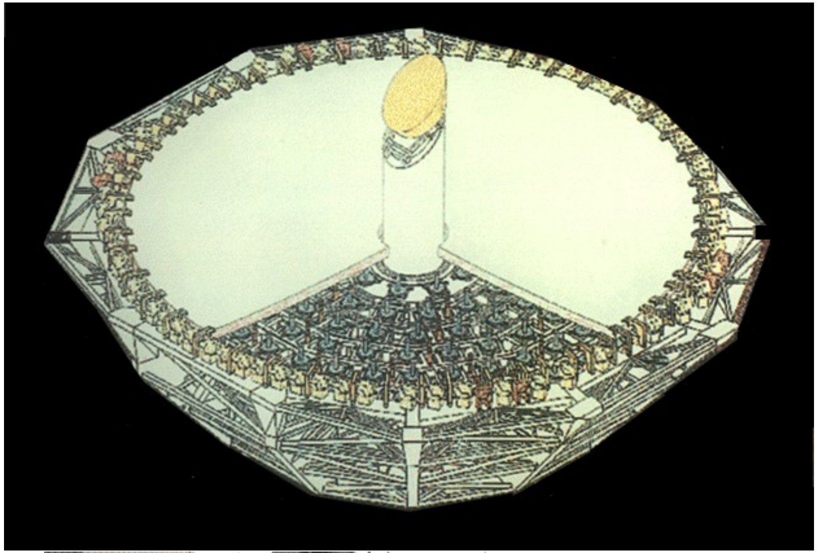
- Alt-azimuth mount
- M1: 8.2m diameter, centre hole of 1m diameter
  - 175 mm thick
  - 150 actuators for active correction
- M2: 1.1m diameter, position and orientation can be slightly modified
  - Corrects optical aberration, pointing, and does chopping (IR observations)
- 4 foci: 2 Nasmyth, 1 Cassegrain, 1 Coude
  - FoV: 20’, 15’, 2’ for each focus
  - 3 instruments + Telescope combination



(Credit: ESO)

UTs

- M3: A tower, mounted at the centre of M1 supports the tertiary mirror
  - Flat mirror, 870 x 1240 mm
  - Rotates along the azimuth axis
  - M3 can be moved away the optical path
- M4-M8: part of the UT structure to create a *coudé* focus (for the VLTI)
- M9-M11: do not move, part of “*coudé* laboratory”
- M12-M20: part of the interferometric tunnel and lab



(Credit: ESO)

UTs

- Each focus has one “adapter-rotator” unit:
  - Field acquisition: provide visual identification of the object to be observed
  - Guiding: measures the position of a reference star (and corrects any error)
  - Wave-front sensing: monitors optical quality changes by gravitational flexure. Used to correct position and shape of the mirrors
  - Rotator: during observations, the field of view rotates. The instrument or beam must rotate to compensate for that movement

(Credit: amos.be)

Questions?

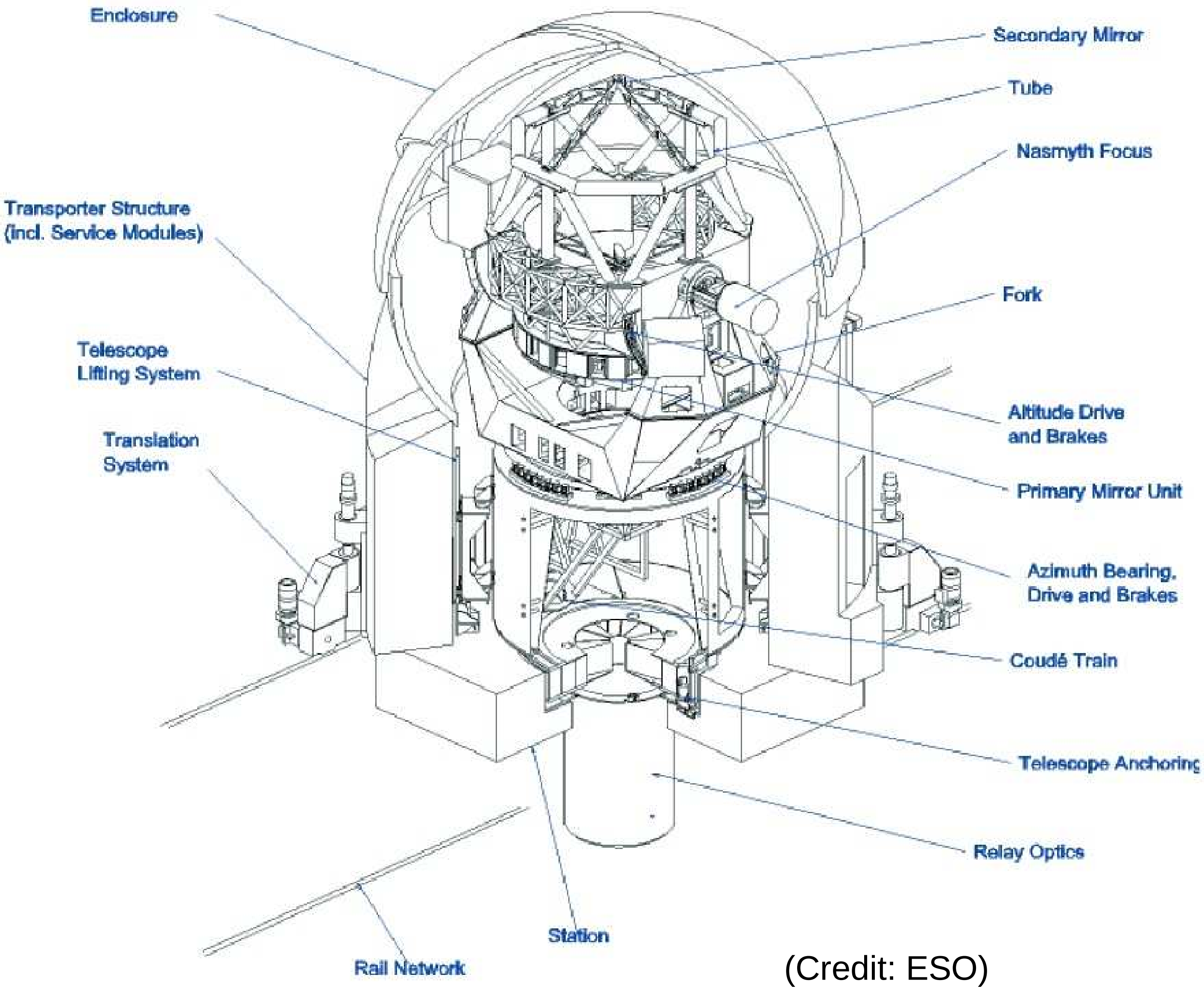
(Credit: Shutterstock)

ATs

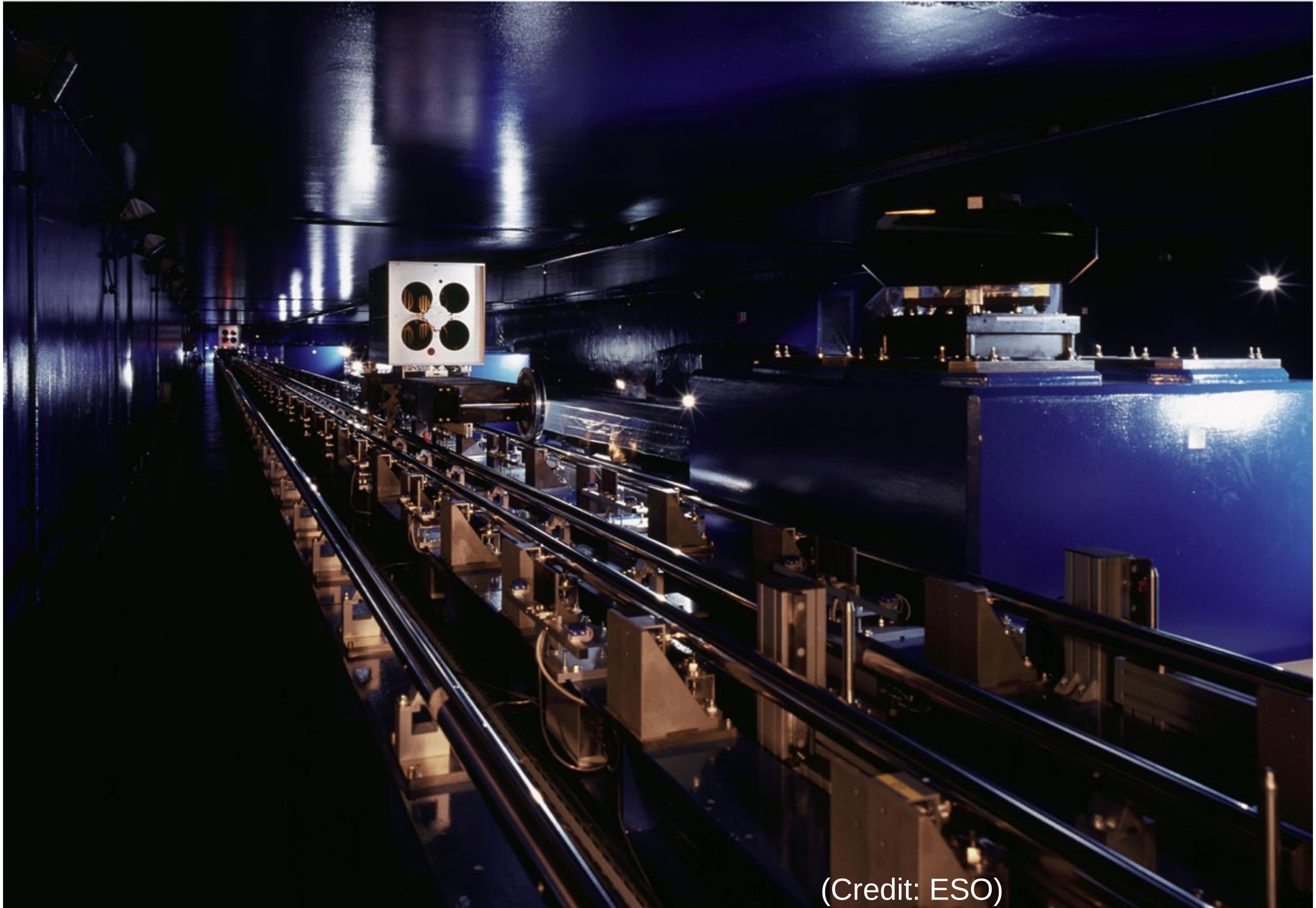
- Four Alt-azimuth 1.8m telescopes (VLTI)
- Platform with 30 positions. Multiple baselines
- Max UT baseline is 130m, Max AT baseline is 202m (~2 mas of angular resolution in K band)
- 11 mirrors, no active optics, M6 with tip-tilt
- M1-M3 like the UT, 5-mirrors *coudé* train (M4-M8) for an underground *coudé* focus
- M9 dichroic mirror, visible to A&G system
- M10-11 (Relay optics) send 18mm beam to the VLTI delay lines

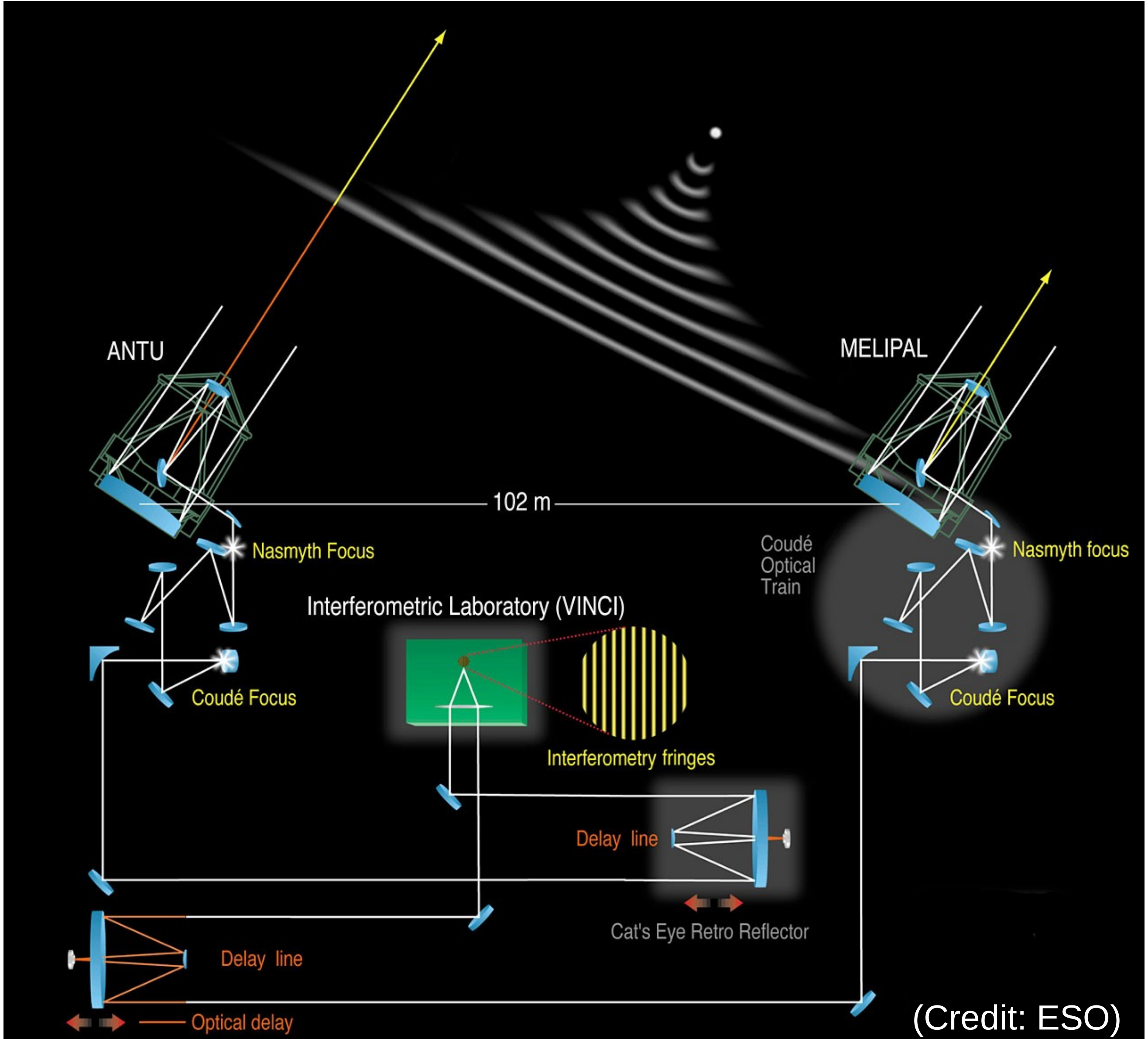
(Credit: ESO)


(Credit: ESO)


Enclosure
Secondary Mirror
Tube
Nasmyth Focus
Transporter Structure
(Incl. Service Modules)
Fork
Telescope
Lifting System
Altitude Drive
and Brakes
Translation
System
Primary Mirror Unit
Azimuth Bearing,
Drive and Brakes
Coudé Train
Telescope Anchoring
Relay Optics
Station
Rail Network

(Credit: ESO)


(Credit: ESO)



ANTU
MELIPAL
102 m
Nasmyth Focus
Nasmyth focus
Coudé
Optical
Train
Interferometric Laboratory (VINCI)
Coudé Focus
Coudé Focus
Interferometry fringes
Delay line
Cat's Eye Retro Reflector
Delay line
Optical delay

(Credit: ESO)

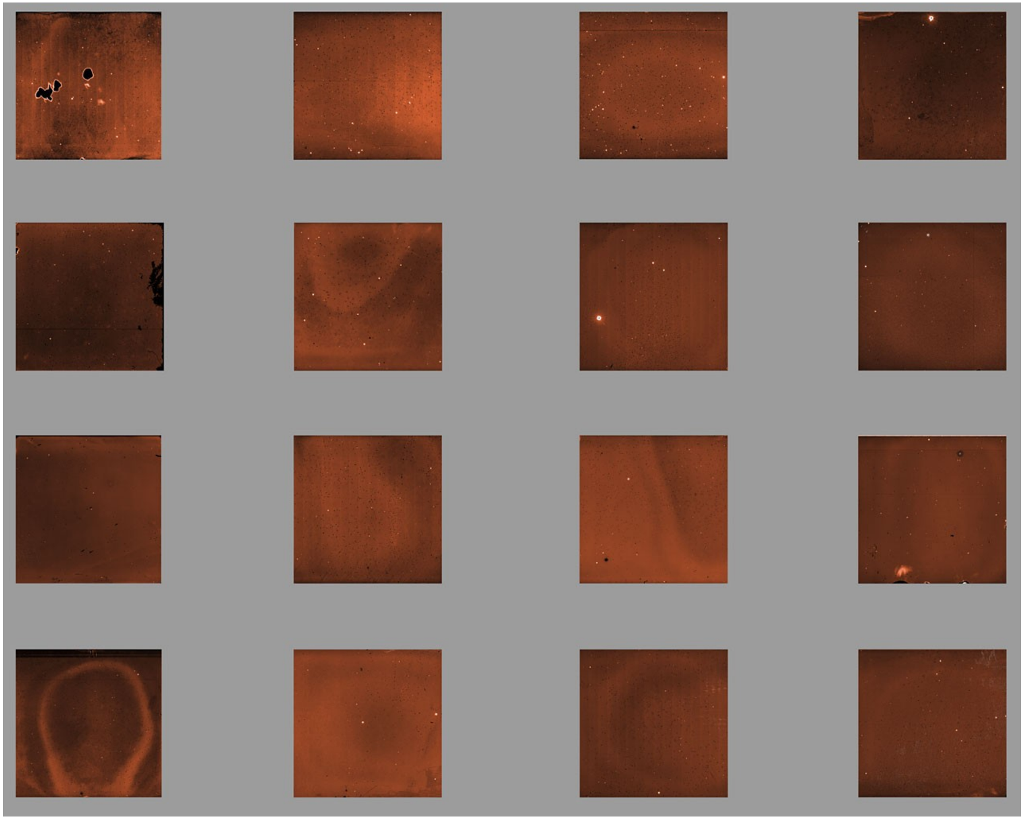
VISTA

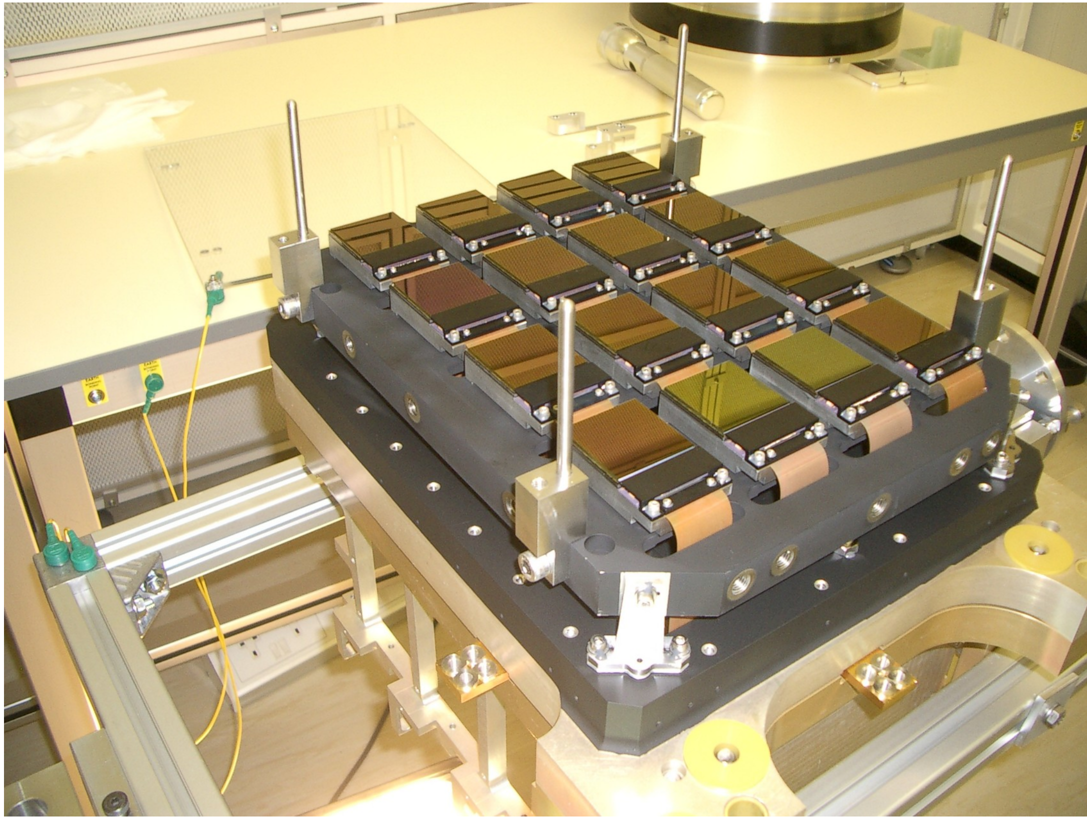
- Alt-azimuth, 4.1m telescope, 2 mirrors
- Near-IR optimized (protected silver coating, 98% reflectiveness)
- One instrument: VISTA InfraRed CAMera (VIRCAM) – 0.9 to 1.2 microns
- Mosaic of 16 detectors
- Can image ~0.6 deg2 non-continous sky in 1 exposure
- 1.5 deg^2 FoV can be achieved in 6 exposures

(Credit: ESO)


(Credit: ESO)

VIRCAM FoV

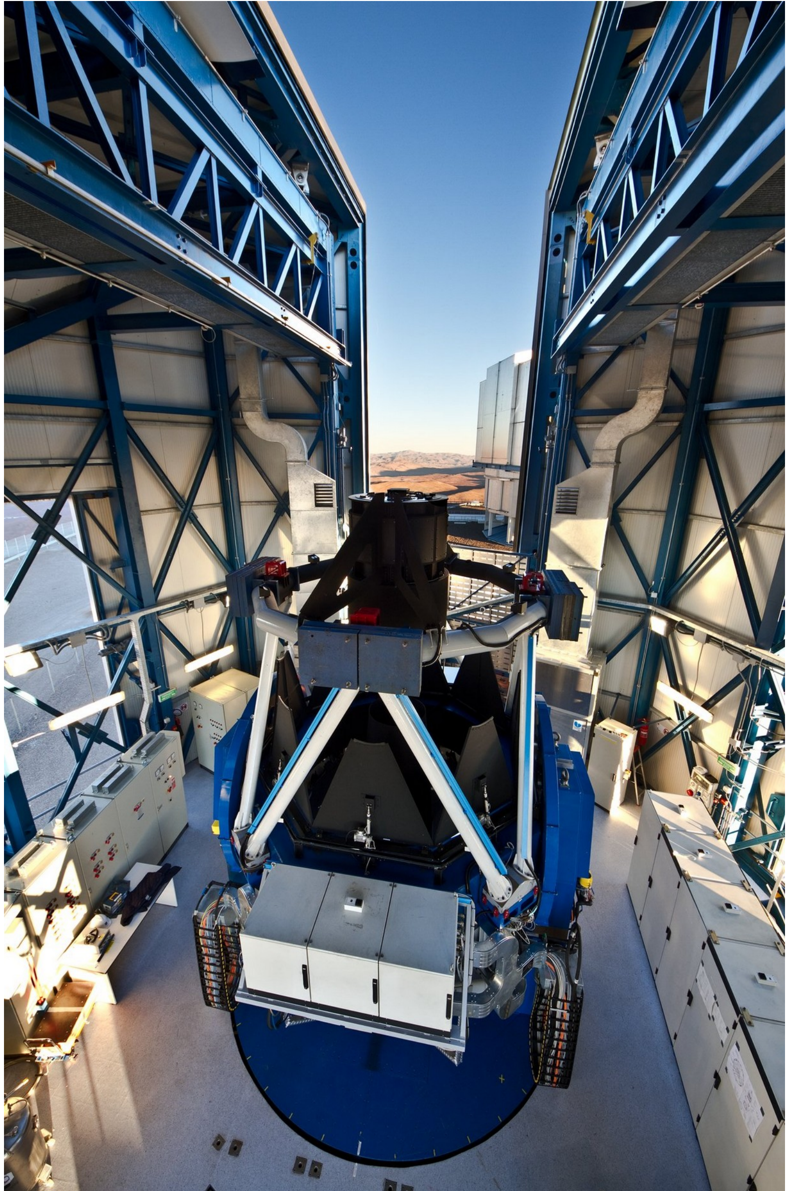




(Credit: ESO)

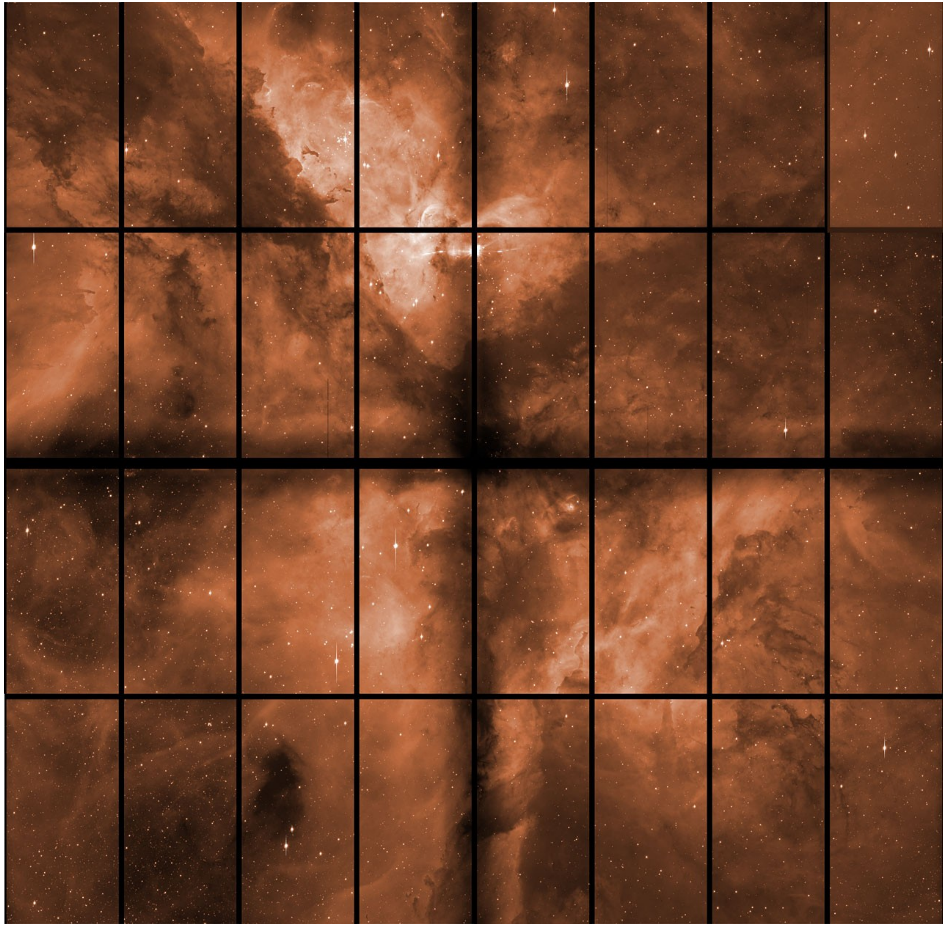
VST

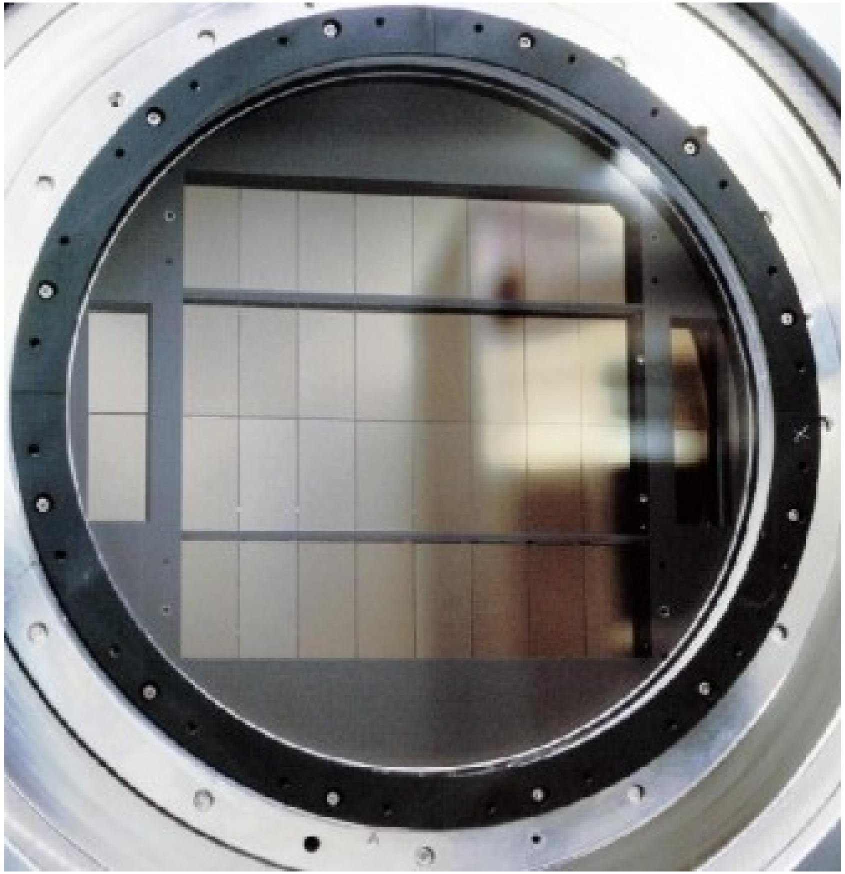
- Alt-azimuth, 2.6m telescope,2 mirrors
- Optical survey telescope: 3500-10000 A
- One instrument: OmegaCAM
- Mosaic of 32 detectors, 12 filters
- 4 additional detectors for guiding/orientation and for image quality monitoring
- 1 deg^2 FoV with 4 exposures
- Different observing modes depending on goal (e.g., stable PSF for precise measurements or field completeness)



(Credit: ESO)

VST





(Credit: ESO)

Paranal: Instruments Summary Table

Instrument	Spectral Coverage	Observing Mode	Spectral Resolution	Multiplex	Note	Telescope
FORS2	optical 330 - 1100 nm	imaging (incl. configurable occulting bars), long slit and multi-object spectroscopy, spectropolarimetry, imaging polarimetry	260 - 2600	yes	Spectroscopy with ~7' long slit, ~20" multi-slit, and laser-cut slit masks; multiple object spectroscopy; RRM	VLT UT1
KMOS	near-IR 0.8 - 2.5 µm	multi-object integral field spectroscopy (24 arms)	1800 - 4000	yes	24-arms Integral Field Spectroscopy; 2.8x2.8", 0.2" sampling IFU over a 7.2' field;	VLT UT1
FLAMES	optical 370 - 950 nm	multi-fibre echelle,integral field spectroscopy	6000 - 47000	yes	132 Medusa fibres; 15 deployable IFUs, one large IFU; GIRAFFE: single echelle order; 8 fibres to UVES	VLT UT2
VISIR	mid-IR: 4.5 - 21 µm	M, N and Q band normal and burst-mode imaging; coronagraphy (Angular Groove Phase Mask, 4-Quadrant Phase Mask); N band low resolution long slit spectroscopy; high-resolution long slit and cross-dispersed spectroscopy	~400, 20000	no	pixel size of 0.045 and 0.076 arcsec in imaging, and 0.076 arcsec in spectroscopy	VLT UT2
UVES	optical 300 - 1100 nm	echelle, image slicer, slit spectroscopy	up to 80,000 (blue arm) / 110,000 (red arm)	no	long slit capability in single order; Iodine cell; RRM	VLT UT2
SPHERE	optical: 500 - 900 nm near-IR: 0.95 - 2.32 µm	high-contrast imaging, dual-band imaging, integral field spectroscopy, differential-polarimetric imaging with or without classical, apodized pupil Lyot coronagraphs, sparse aperture mask	~30, 50, 400	no	extreme AO with optical wave-front sensor; fast star hopping; RRM	VLT UT3
X-SHOOTER	UV-optical-NIR 300 - 2500 nm	echelle, slit and integral field spectroscopy	~5000-17000	no	full spectral coverage with one pointing; slit + IFU; RRM	VLT UT3
CRIRES	near-IR 0.95-5.3 µm	echelle, slit spectroscopy	~50,000-100,000	no	AO assisted, 29 wavelength settings, 0.2"x10" and 0.4"x10" slits, gas cells for precision RV measurements	VLT UT3

HAWK-I	near-IR 0.85-2.5 µm	broand and narrow band imaging, fast photometry	-	-	pixel size of 0.106"; field: 7.5'x7.5', subwindow readout capability; GLAO; RRM	VLT UT4
MUSE	optical 465 - 930 nm	integral field spectroscopy	1770 @ 480nm 3590 @ 930nm	no	IFU size on sky 60"x60" with spaxel size 0.2" (WFM) or 7.5"x7.5" with spaxel size 0.025" (NFM); GLAO, LTAO, no AO; RRM.	VLT UT4
ESPRESSO	optical 380 - 788 nm	fibre-fed échelle spectroscopy	140,000, 190,000, or 70,000 (median)	no	2 fibres (1 object, 1 sky or simultaneous reference); RV precision < 1 m/s (with the ultimate goal of reaching 10 cm/s); 1-UT and 4-UT modes	VLT UT1, VLT UT2, VLT UT3, or/and VLT UT4
GRAVITY	near-IR 2.05 - 2.45 µm	spectro-interferometry	R ~ 20, 500, & 4000	no	4 beam combiner - delivers spectrally dispersed visibilities, differential and closure phases	VLTI - ATs VLTI - UTs
MATISSE	mid-IR 2.8 - 4.1 µm 4.5 - 5 µm 8 - 13 µm	spectro-interferometry	R ~ 30 (covers L&M-band) R ~ 506, 959, 3666 (L or M band) R ~ 30, 218 (N band)	no	4 beam combiner - delivers spectrally dispersed visibilities, differential and closure phases	VLTI - ATs VLTI - UTs
PIONIER	near-IR 1.65 µm	spectro - interferometry	R ~ 5 or 40	no	4 beam combiner - delivers spectrally dispersed visibilities, differential and closure phases	VLTI - ATs VLTI - UTs
VIRCAM	near-IR 0.8-2.2 µm	imaging	-	-	1.5 degree x 1 degree field of view with 0.34" average pixel size	VISTA
OmegaCAM	optical 350-910 nm	imaging	-	-	1 degree x 1 degree unvignetted field of view with 0.21" pixel size	VST

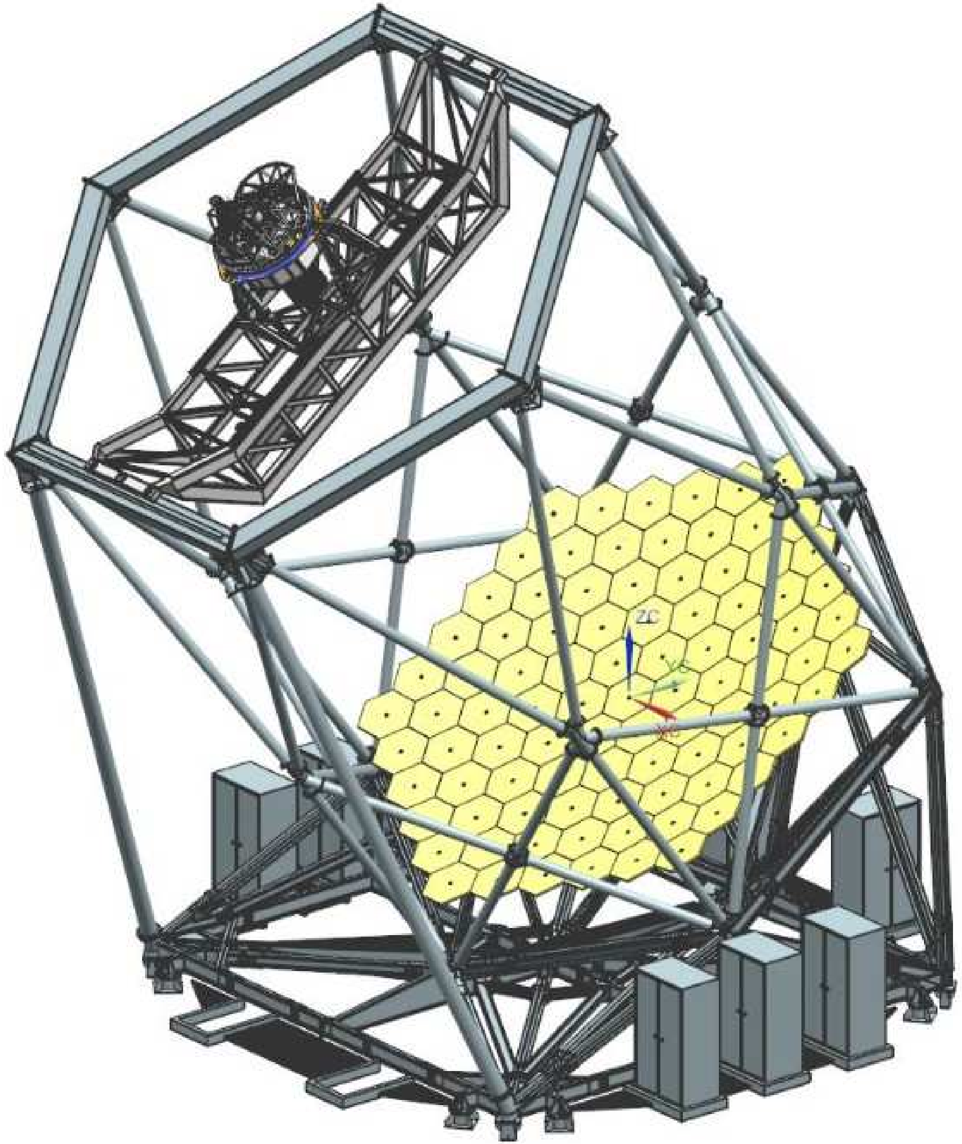
Questions?

(Credit: Shutterstock)

(Day 01)

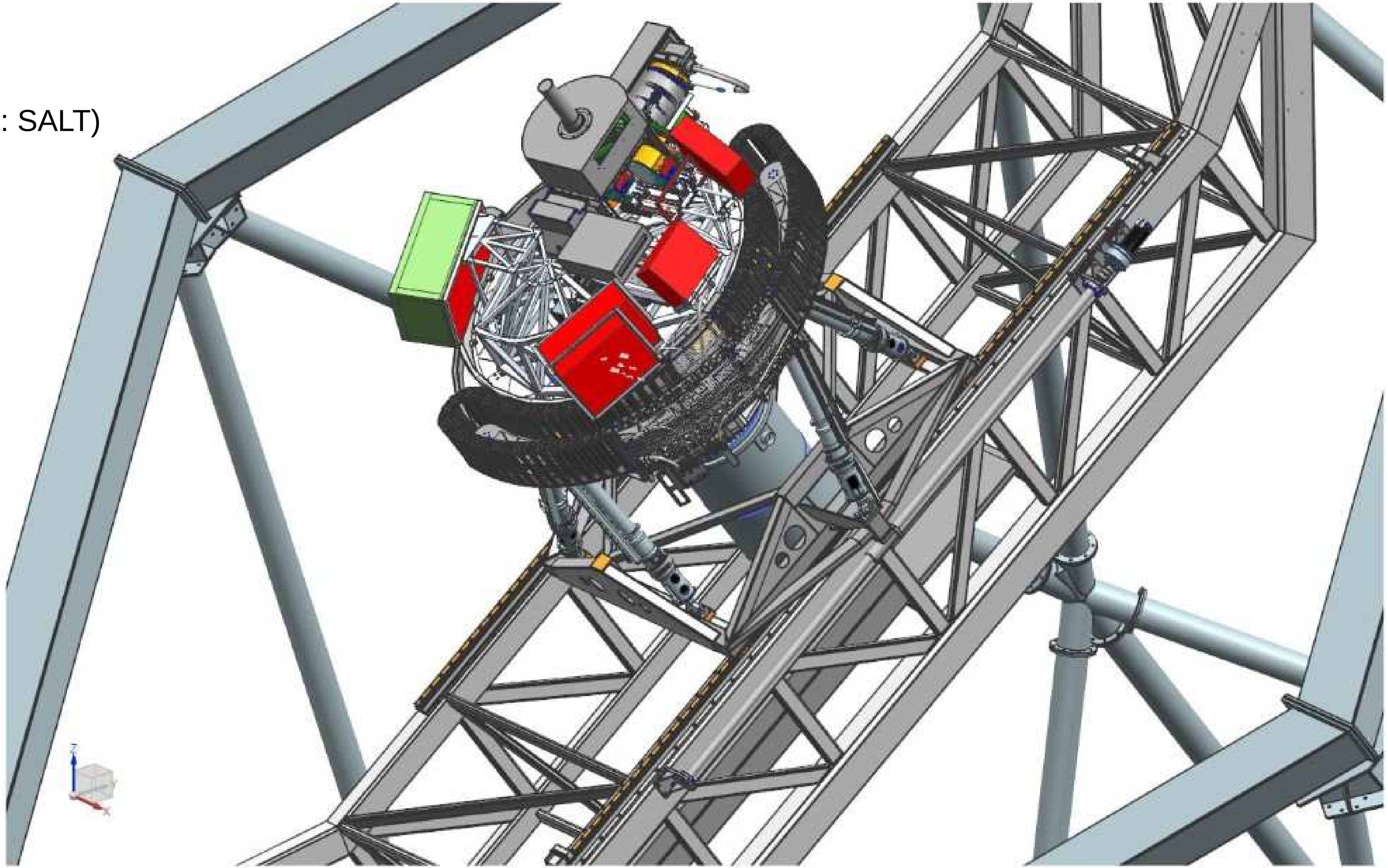
South African Large Telescope

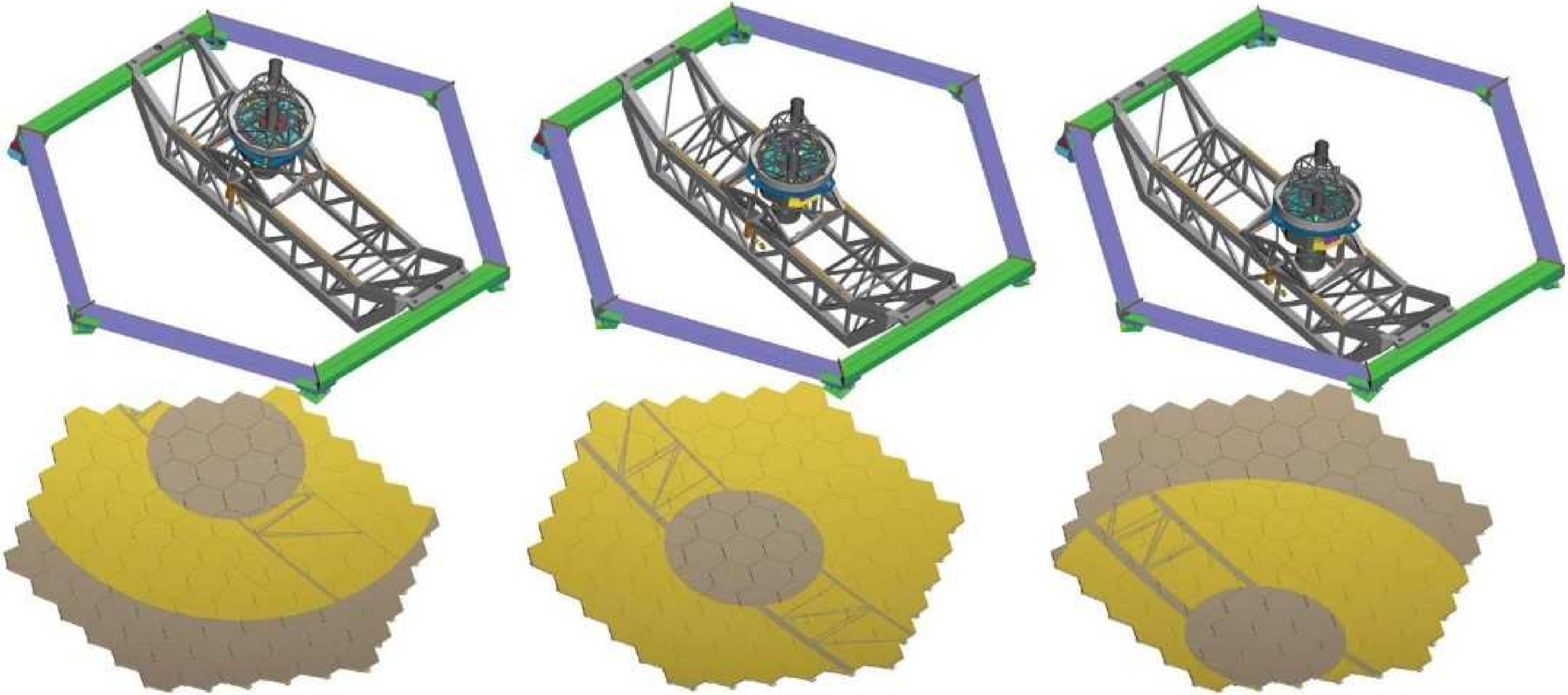
- Hexagonal primary mirror 11m across (equivalent to 9.2m)
- 91 individual 1m hexagonal mirrors, three actuators per mirror
- Fixed-altitude telescope, fixed angle of 37 degrees from the zenith
- Azimuthal rotation for target acquisition
- The target is tracked by moving the instrument at the primary focus
- Visibility time and availability in a night depends on the declination of the object (45 min to ~3h)
- The “pupil” (the area of the mirror that the tracker sees) moves during exposure



(Credit: SALT)

(Credit: SALT)





(Credit: SALT)

Figure 2.3: The pupil (yellow) for three different tracker positions. The grey areas are non-illuminated parts of the mirror.

South African Large Telescope

- About 70% of the sky is observable by SALT
- But each target has its “window of opportunity”
- Instruments can be rapidly changed (less than 80s)
- Considered to be optimal for spectroscopy
- The moving pupil makes absolute photometry/spectrophotometry impossible
- Median seeing ~ 1.5” (0.7” in Paranal)
- Background sky brightness V ~ 22 mag/arcsec^2 (~21.6 in Paranal)
- Airmass of observations: 1.17-1.37

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 exposure 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 exposure 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

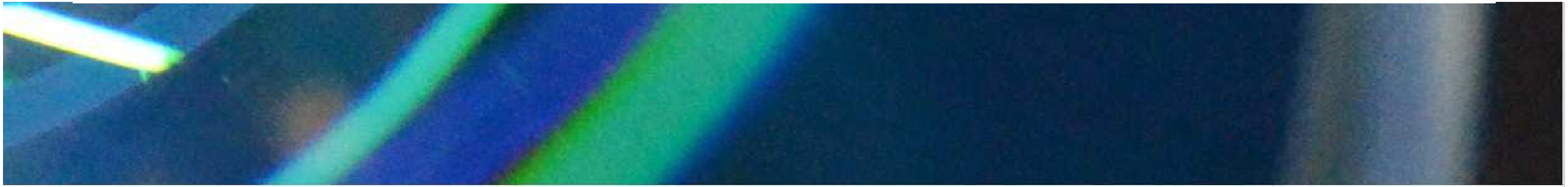
The High Resolution Spectrograph, HRS:

- 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"	

The Berkeley Visible Image Tube (BVIT) Detector

High time resolution observing on the SALT 10m telescope



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**

Questions?

(Credit: Shutterstock)