



Technological Developments and Needs at ESO

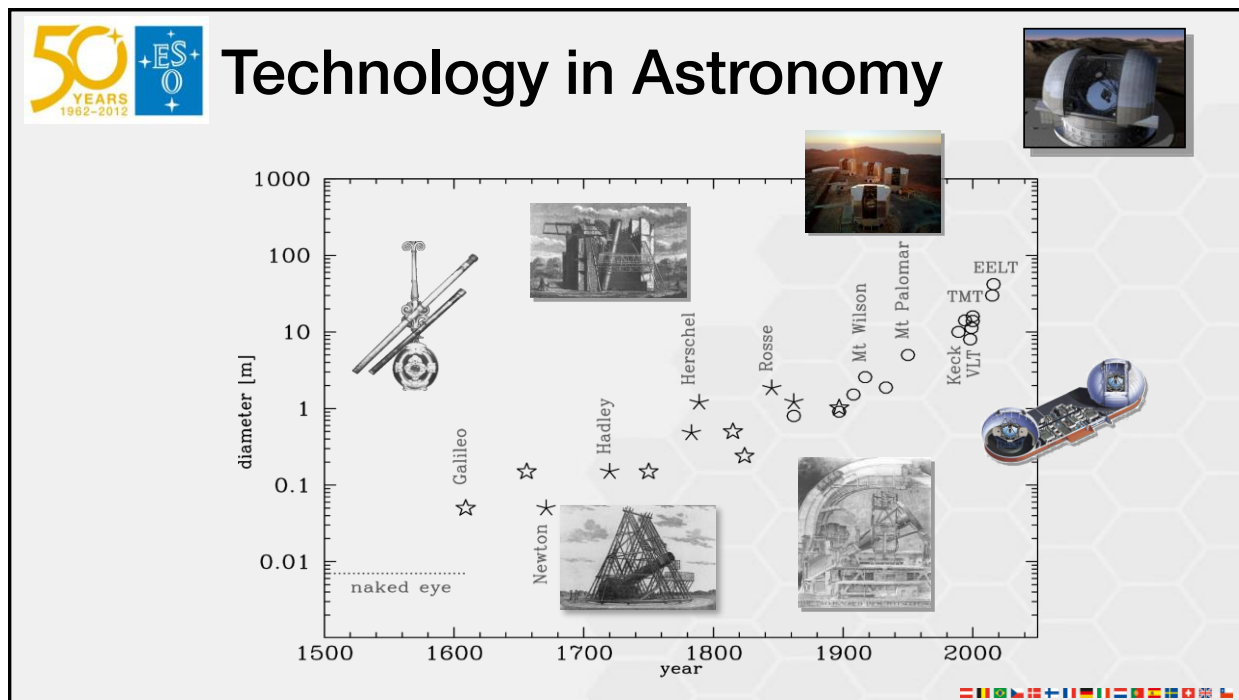
Roberto Tamai
Head of Technology Division
ESO



Technology in Astronomy

- From a small, manually pointed device for visual observations (around 400 years ago) to a large, sophisticated, computer-controlled instrument with full digital output.
- Two properties have been particularly important:
 - the light-collecting power, or diameter of the telescope's mirror (allowing for the detection of fainter and more distant objects), and
 - the image sharpness, or angular resolution (allowing smaller and fainter objects to be seen).
- The European Southern Observatory (ESO), as a worldwide leader in astronomy, has developed, together with industry, several advanced technologies that have enabled the construction of ever bigger telescopes, while maintaining optical accuracy.





50 YEARS 1962-2012 ESO

Technology in Astronomy

ESO has contributed to the progress of several technologies applied to the modern astronomy to improve the image sharpness, among these:

- **ACTIVE OPTICS**, now in use in most modern medium and large telescopes. It preserves optimal image quality by pairing a “flexible” mirror with actuators that actively adjust the mirror's shape during observations.
- **ADAPTIVE OPTICS**, the bigger a mirror, the greater its theoretical resolution, but even at the best sites for astronomy, large, ground-based telescopes observing at visible wavelengths cannot achieve an image sharpness better than telescopes with a 20- to 40-cm diameter, due to distortions introduced by atmospheric turbulence. One of the principal reasons for launching the Hubble Space Telescope was to avoid this image smearing.
- **INTERFEROMETRY**, the combination of the light collected by two or more telescopes can boost the resolution beyond what a single telescope can accomplish. ESO has been a pioneer in this field with the Very Large Telescope Interferometer (VLTi) at Paranal.



Active Optics

Optical telescopes collect light from the cosmos using a primary mirror. Bigger primary mirrors allow astronomers to capture more light, and so the evolution of the telescope has often followed a "bigger is better" mantra.

In the past, mirrors over several metres in diameter had to be made extremely thick to prevent them from losing their shape as the telescope panned across the sky. Eventually such mirrors became prohibitively heavy and so a new way had to be found to ensure optical accuracy.



Active Optics

Optical telescopes collect light from the cosmos using a primary mirror. Bigger primary mirrors allow astronomers to capture more light, and so the evolution

Telescope	Diameter (m)	Thkn (cm)	Dia/thkn	Year
ESO 3.6	3.6	60	6	1960s
ESO NTT	3.6	24	15	1970s
ESO VLT	8m class	17	47	1990s
ESO E-ELT	40m class	5	800	2010s

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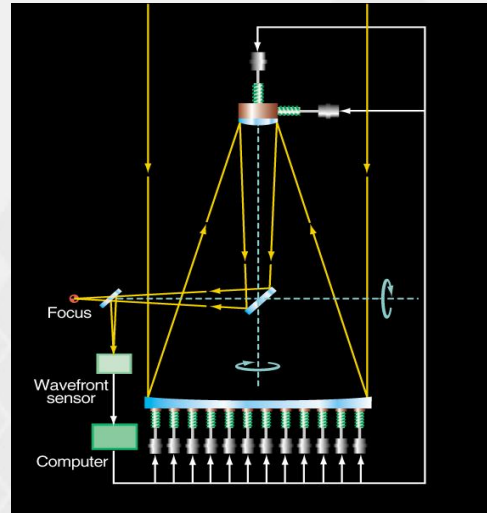




Principle of Active Optics

Closed control loop with:

1. Measurement of wavefront error generated by the telescope itself
 - Integration times of 30 sec to partially average out errors introduced by the atmosphere
 - Modal analysis using optical aberrations and elastic modes of the flexible meniscus mirrors
2. Correction of the errors by the optical elements of the telescope
 - Rigid-body movements of the mirrors
 - Deformation of the mirrors by adjusting the support forces



Active Optics → The NTT

A computer-controlled **active** optics system was first developed at ESO in the 1980s.

The first major telescope to benefit from this revolution in telescopic techniques was ESO's New Technology Telescope (NTT) at the La Silla Observatory.

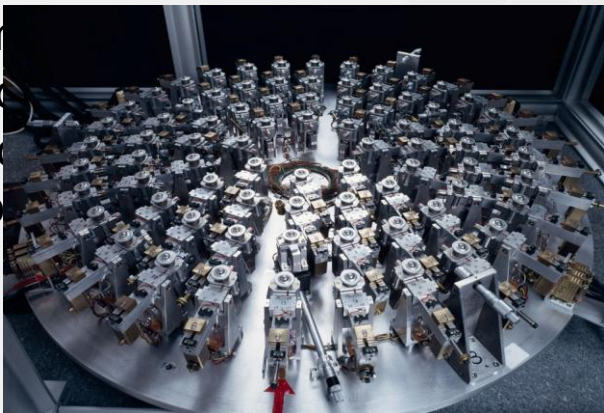




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The first major
revolution
New Technology
Silla Observatory



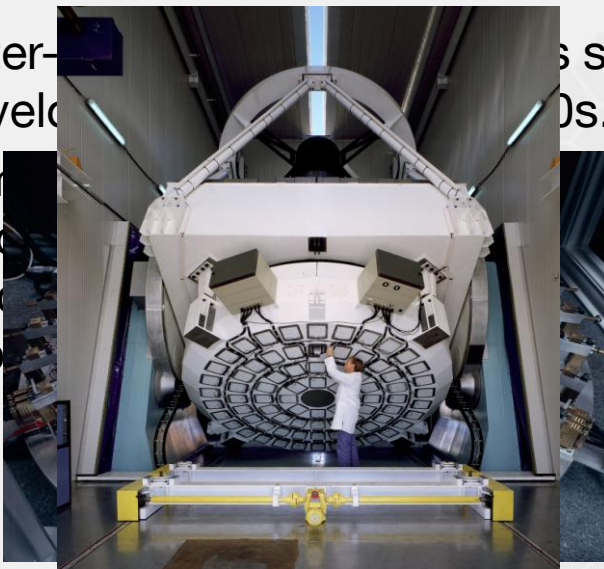
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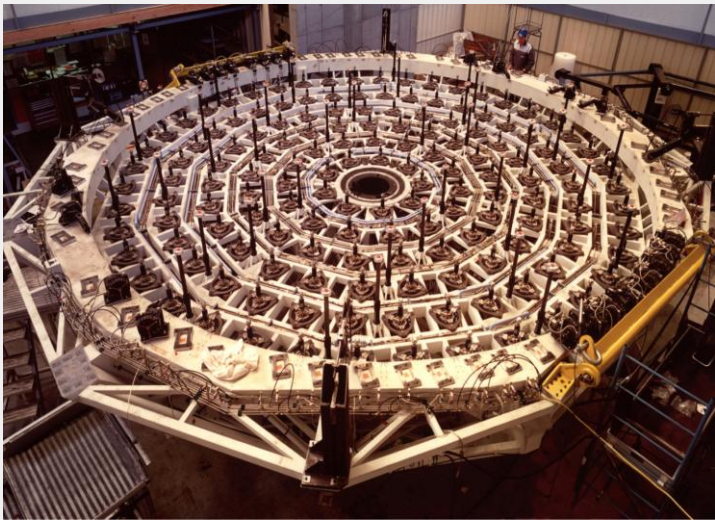




VLT M1 Mirror



VLT M1 cell





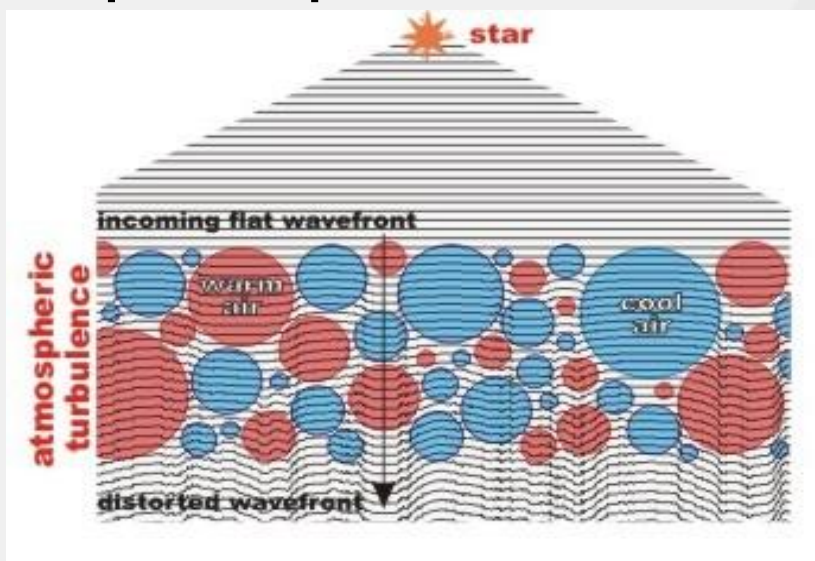
Adaptive Optics

However, Active Optics does not correct for the turbulence in the atmosphere, which is done by a separate and much faster adaptive optics system.

A distinction is made between active optics, in which optical components are modified or adjusted by external control to compensate slowly changing disturbances, and adaptive optics, which applies to closed-loop feedback systems employing sensors and data processors, operating at much higher frequencies.

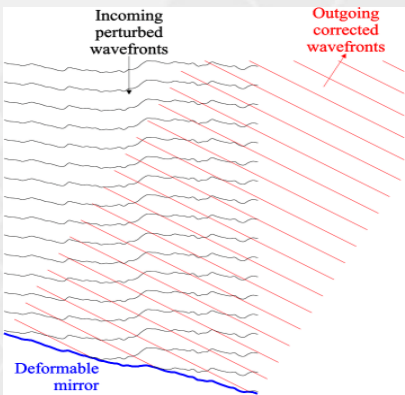
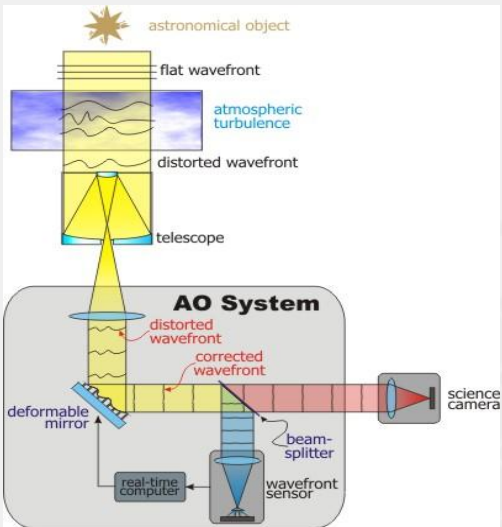


Adaptive Optics

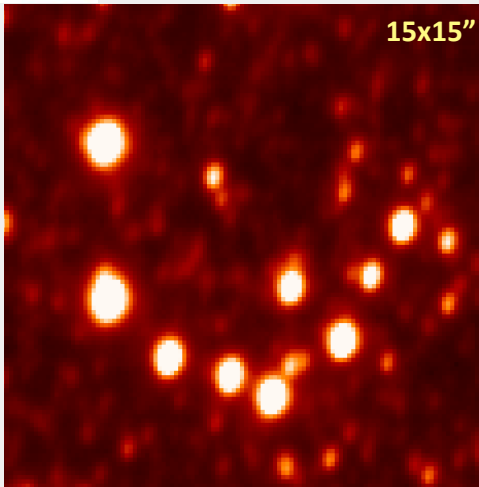




Adaptive Optics principle



An AO milestone: MAD



MCAO: 3 Guide stars at 2'
K-band, FWHM: 100-120mas, Sr: >20%
0.7" seeing, Exposure 360 s

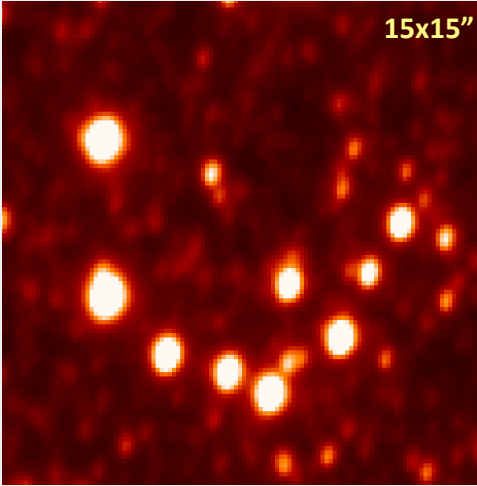


50 YEARS 1962-2012

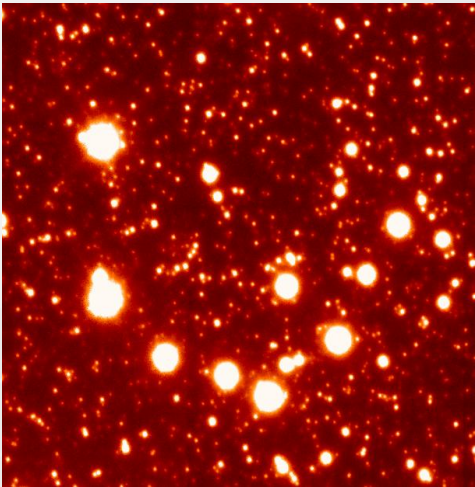
ESO


An AO milestone: MAD

15x15"



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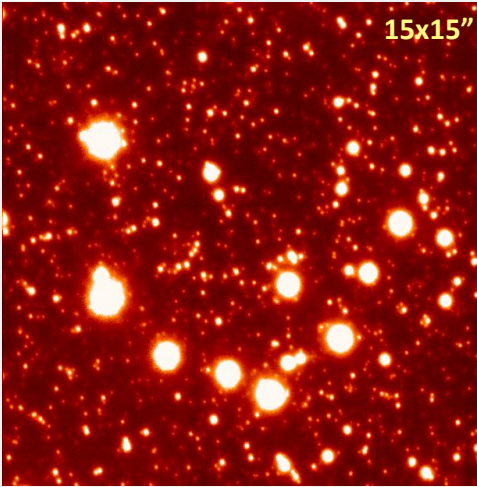


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ESO

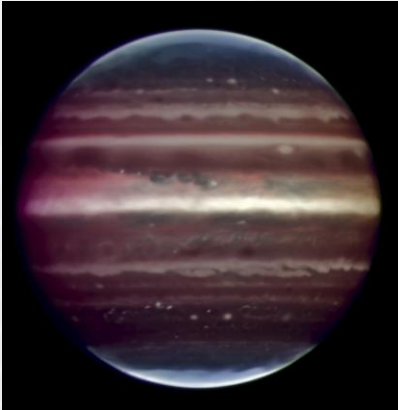
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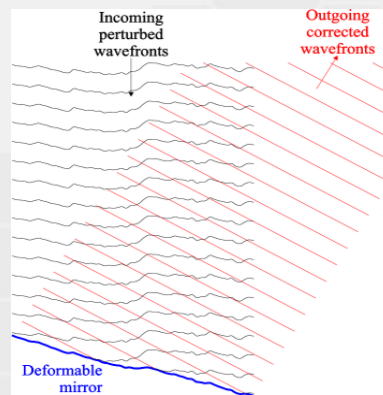
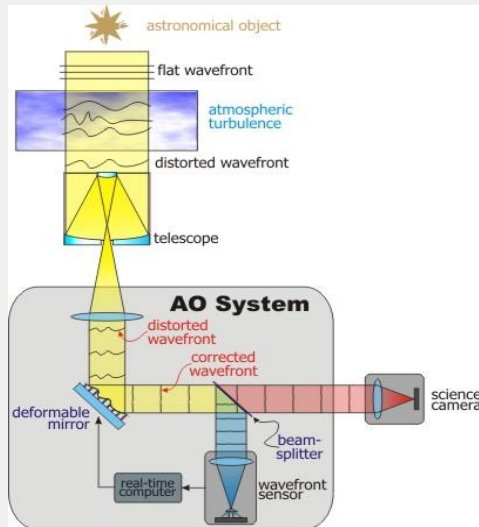
MCAO: 2 Guide "stars" (satellites Europa and Io)
2.14μm + 2.16μm filters
90 mas resolution (300 km at Jupiter)





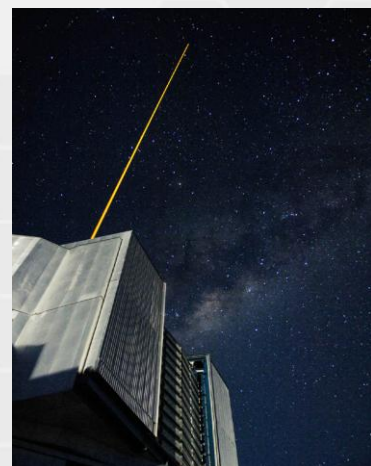
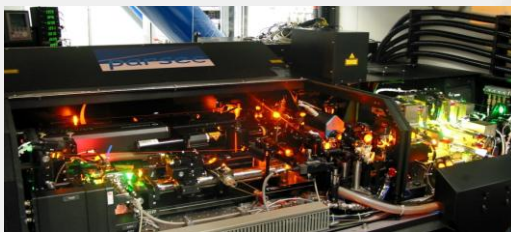


Adaptive Optics principle



Laser for Adaptive Optics

- Laser guide stars are artificial stars generated by exciting atomic sodium in the mesosphere at a height of 90km
- This requires a powerful laser beam launched from the telescope
- The yellow wavelength (589nm) is the colour of a sodium street lamp





The VLT LGSF at UT4



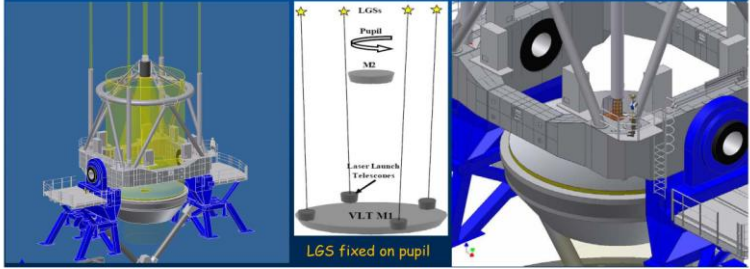
VLT Laser Clean Room





4 Laser Guide Stars Facility

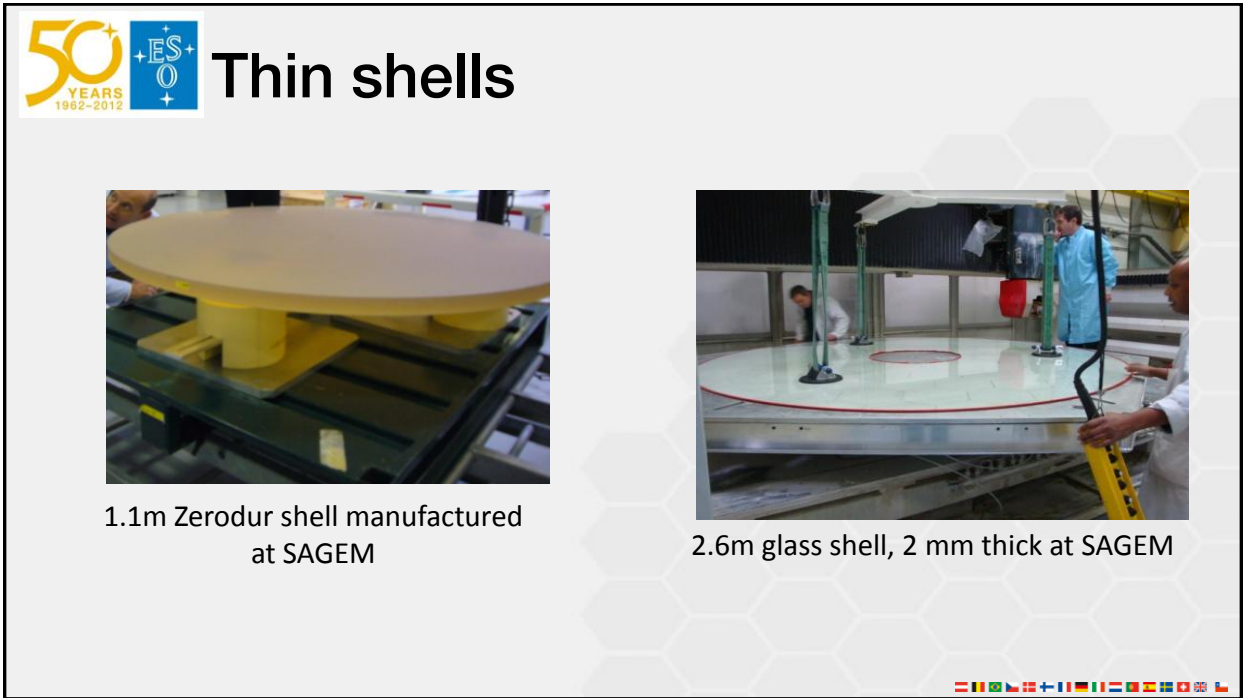
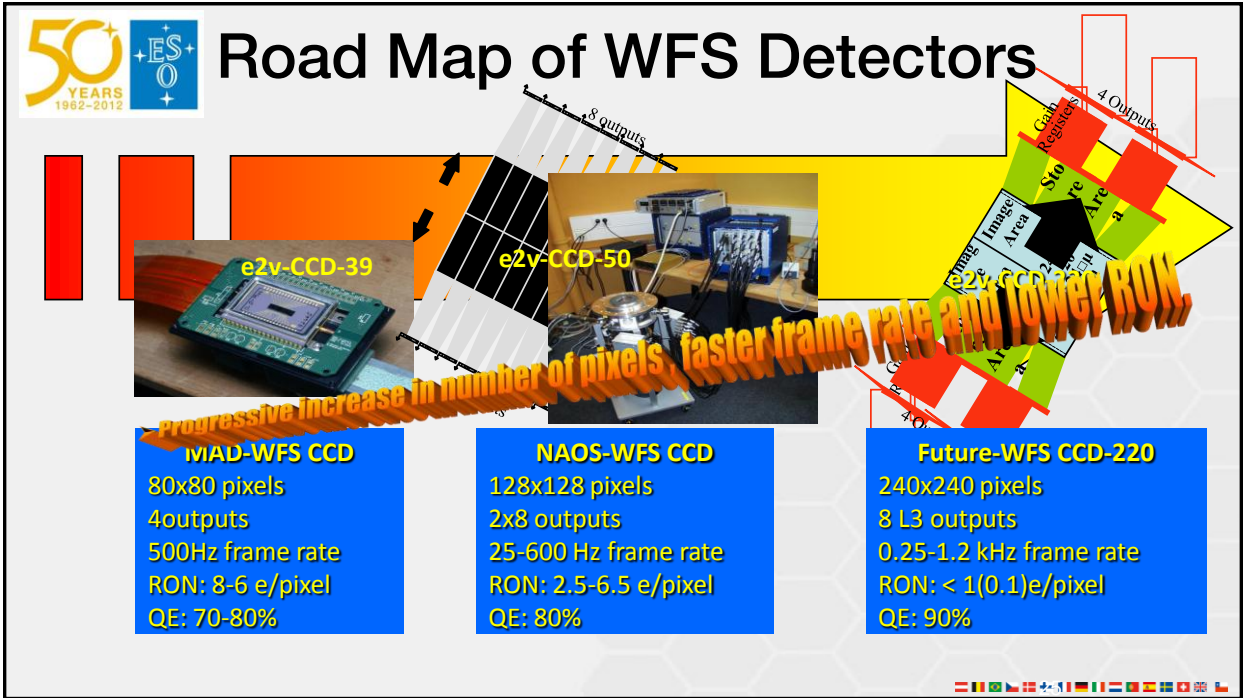
- 4 LGS, off axis up to 330"
- 2.5-5 Mphot/sec/m²
- LGS FWHM <1.2" on WFS
- Central LGS also operational
- 4LT mounted on UT4 Centerpiece
- Will Serve 2nd Gen AO systems on UT4
- Galacsi-MUSE and GRAAL-HawKI
- PDR in Jan 2008
- Commissioning in 2011-2012 (TBC)



Fiber Laser demo

589nm 20W
fiber laser
demo @ESO
Optical Lab
11.12.09







VLT – Main axes drive system

VLT is well known for its excellent tracking performance. The four main contributors to this success are:

1. Direct drive motors
2. Collocated encoders
3. Hydrostatic bearing system
4. Innovative control algorithms

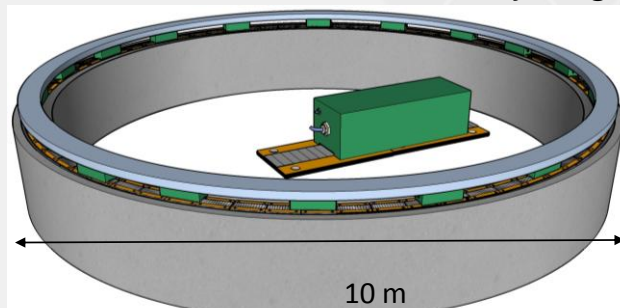


VLT – Direct drive motors

VLT was the first telescope to use large diameter direct drive motors; Altitude 2m and Azimuth 10m.

When designed in the beginning of the 1990s, this was a relatively new technology.

Such large motors have to be assembled by segments





VLT – Direct drive motors

- In comparison, they out-perform traditional gear or friction coupled drives due to their high stiffness and lack of backlash.
- Additional advantages are no maintenance, alignment or wear.



VLT altitude motor



VLT - encoders

- Direct drive motors offers the possibility to use collocated encoders. This is optimal from a controls point of view and superior to gear-coupled drive systems.
- The VLT encoders are high quality tape encoders with the same diameter as the motors. These are mounted together on the same structure and have an accuracy of 0.1 arcsecond.





VLT – Hydrostatic bearing system

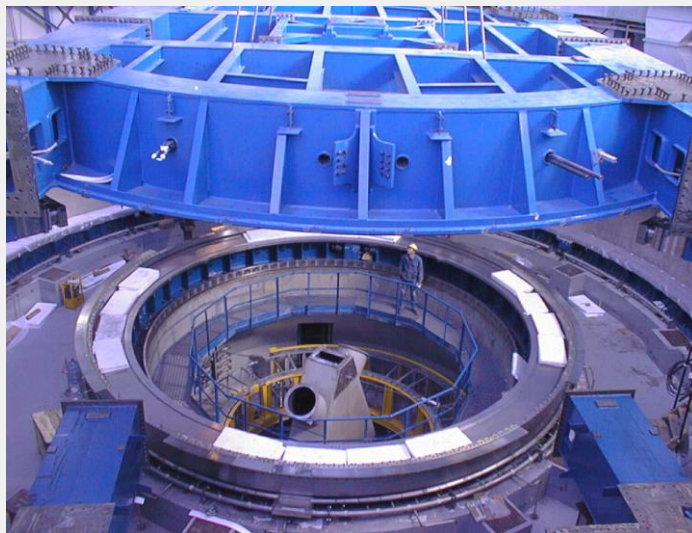
The VLT main axis use hydrostatic bearing systems.

This allows the entire telescope structure to float on an oil film of thickness 50 μm .

The result is not only very low friction (one person can move it) but also the fact that the absence of stick-slip friction make the system practically linear. Again a huge advantage for the control.



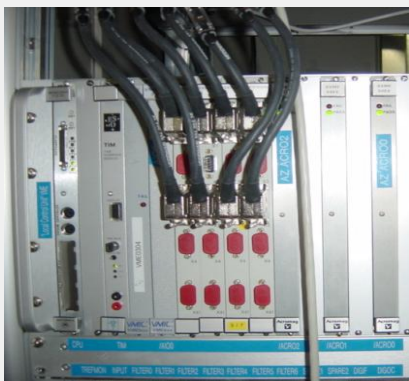
VLT – Hydrostatic bearing system





VLT – Innovative Control Algorithms

First telescope with entire control system implemented in software



Real-time computer platform

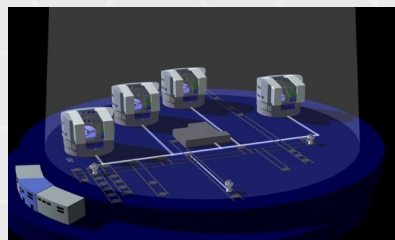


High tech drive technology



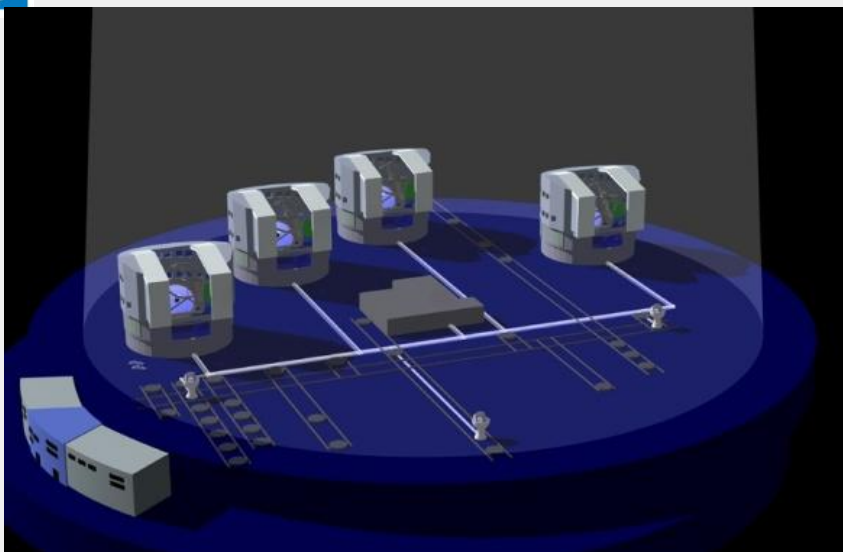
What is the VLTI

The Very Large Telescope Interferometer (VLTI), equivalent to a single instrument with a mirror 16 m in diameter, combines the light from the four big Unit Telescopes and from several moveable 1.8-m Auxiliary Telescopes, spaced across baselines of up to 200 m, by way of the Interferometric Tunnel. Inside this 130-m-long underground cavern, the light beams gathered by the telescopes are passed through delay lines to compensate for the slightly different path-lengths they have taken in reaching the instruments.





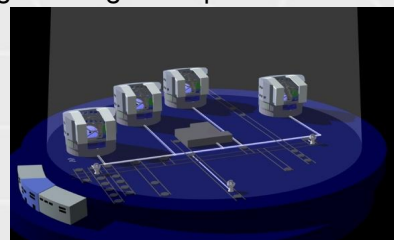
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What is the VLTI

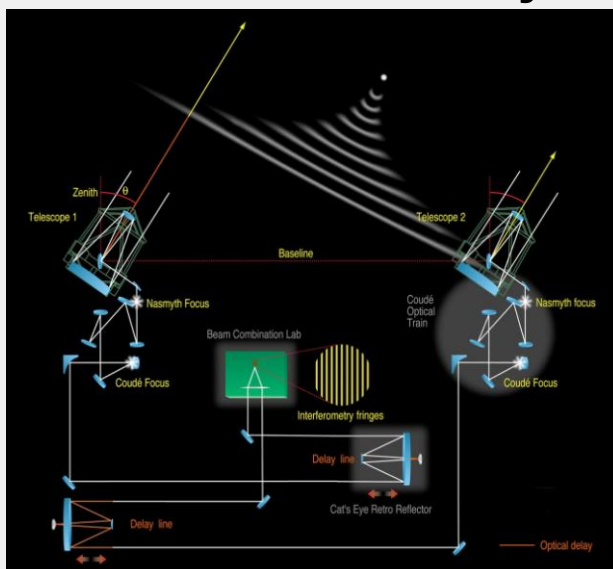
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The delay lines help to synchronize the beams, before redirecting them to a central laboratory. The interference fringes produced when the beams are finally recombined provide the information needed to reconstruct the original image in unprecedented detail, giving a picture as sharp as if it had come from a single telescope 200 m across. This gives the VLT a maximum angular resolution of about 0.001 arc-second at 1 micron wavelength (in the near- infrared), which is equivalent to about 2 meters at the distance of Moon.



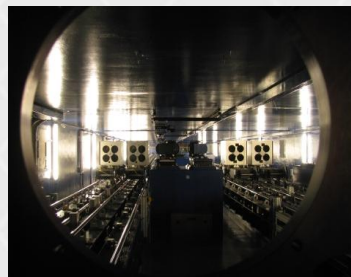


VLTI Scheme - Subsystems



VLTI main Delay Lines (DL)

- Compensate for
 - Earth rotation => slow (5mm/s), large amplitude (length=60m)
 - atmospheric turbulence => fast (corrections at $> 100\text{Hz}$) and small ($20\mu\text{m}$) but with high accuracy (15nm) => needs a laser metrology
- Cat's eye => beams are stable in tip-tilt but not in lateral position =>
 - Rails have to be maintained straight and flat with an accuracy of $< 7\mu\text{m}$ despite seasonal variations => daily maintenance (measurement of the flatness & correction of supports)
 - Wheels and bearings have to be round and centered => regular maintenance.





The ALMA Partnership



- ALMA is a global partnership in astronomy to deliver a truly transformational instrument
 - Europe (ESO)
 - North America (US, Canada, Taiwan)
 - East Asia (Japan, Taiwan)
- Located on the Chajnantor plain of the Chilean Andes at 5000-m (16500')
- ALMA will be operated as a single Observatory with scientific access via regional centers
- Total Global Budget ~\$1.3B



ALMA Antennas

- 66 Antennas delivered by the ALMA partnership
- Three separate companies are constructing the ALMA antennas
 - 25 x 12-m from Europe: AEM – Thales-Alenia Space, European Industrial Engineering and MT Mechatronics
 - 25 x 12-m from North America: Vertex, a part of the General Dynamics Corporation
 - 4 x 12-m and 12 x 7-m from Japan: MELCO, part of the Mitsubishi Electric Corporation





ALMA Environmental Conditions

- Continuous day and night operation at the Array Operations Site (AOS) 5000m in the Atacama desert
- Under strong wind conditions of 6 m/s in the day and 9 m/s at night (survival 65m/s)
- Temperature extremes of -30C to +40C
- Temperature gradients of $\Delta T \leq 0.6C$ in 10 minutes; $\Delta T \leq 1.8C$ in 30 minutes, and
- In a seismically active region



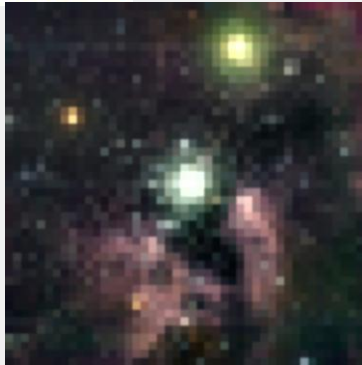
ALMA High Altitude “Qualification Tests”



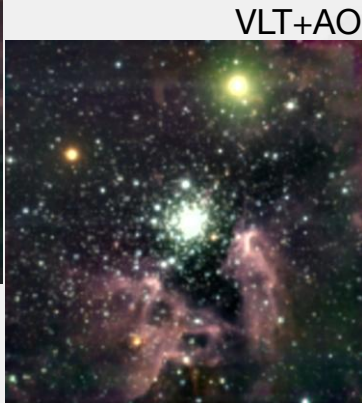




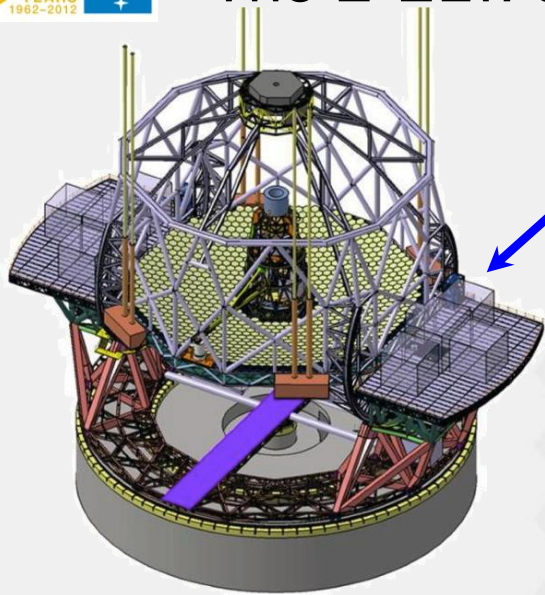
Spectacular Resolution



HST

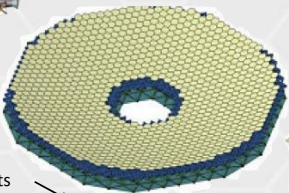
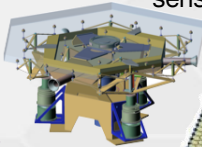


The E-ELT: overview

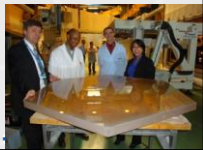
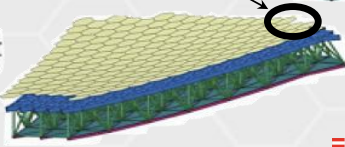


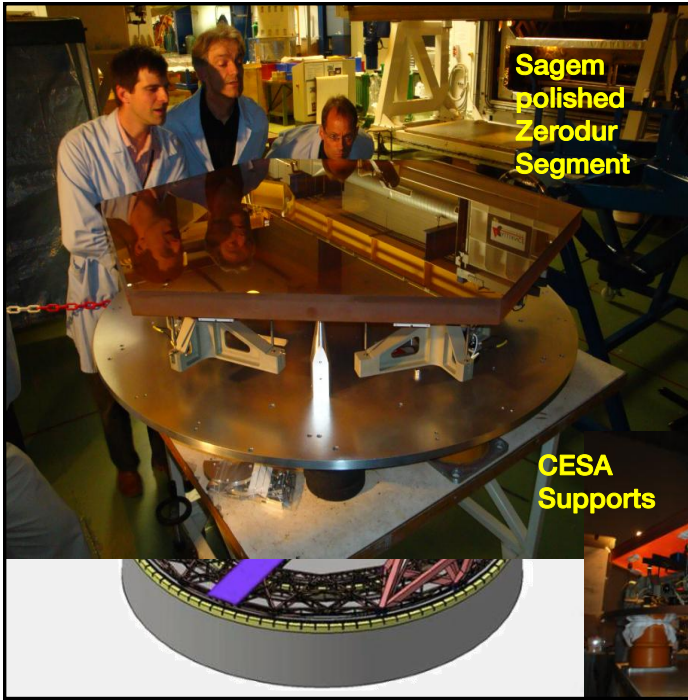
39m Primary Mirror

- 798 segments mirror (6 families of 133+1/family)
- 2 x 7 prototypes FEEDs
- prototype support, PACTs, edge sensors



Prototype segments





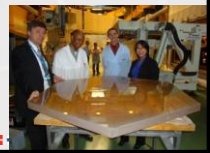
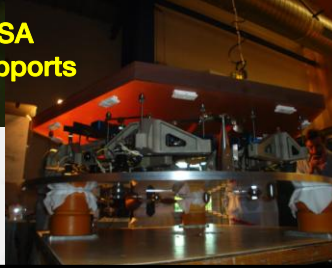
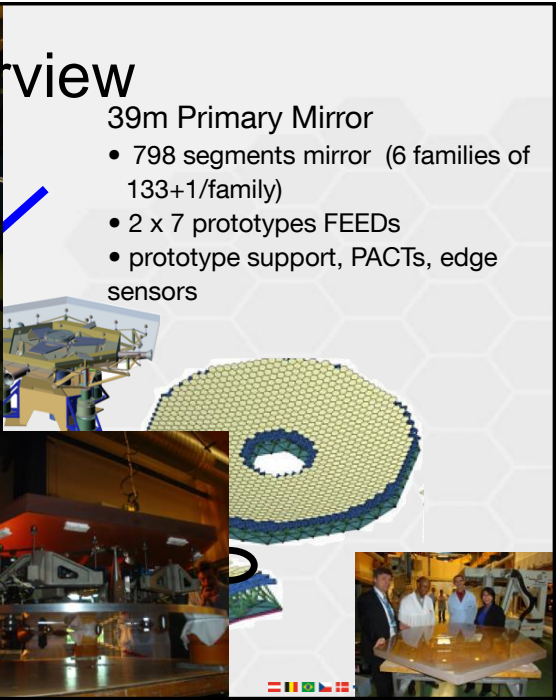
Sagem polished Zerodur Segment

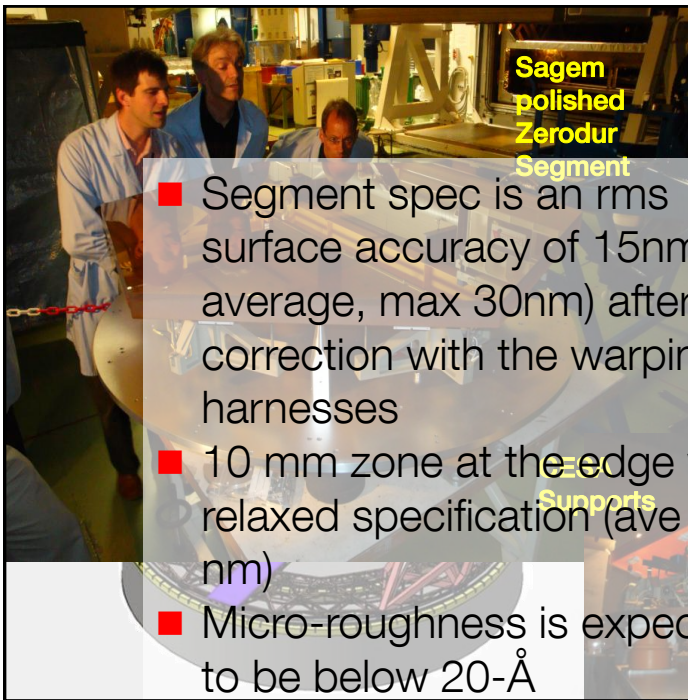
CESA Supports

Overview

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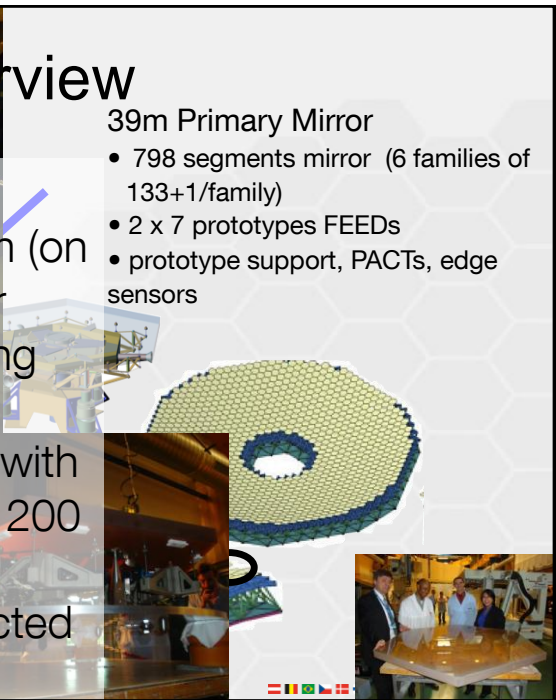
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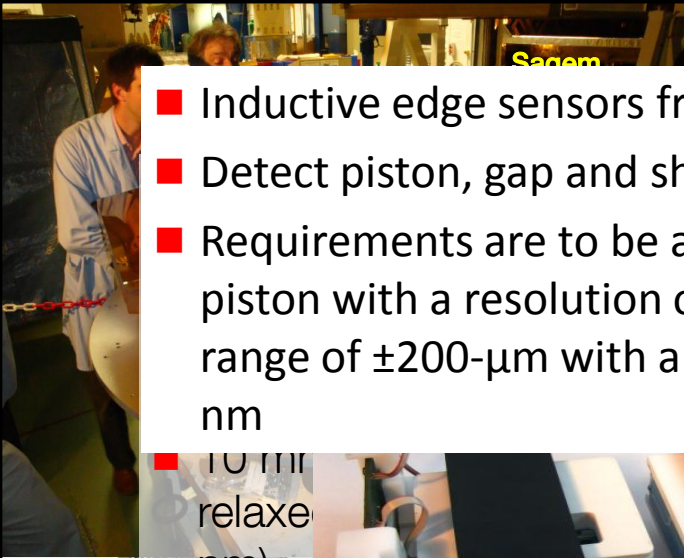
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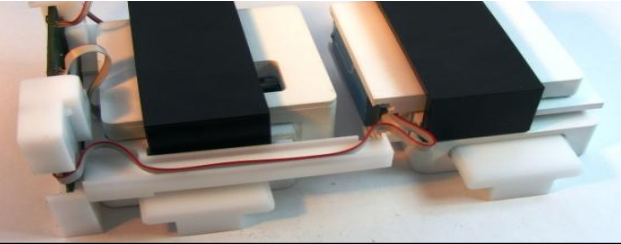
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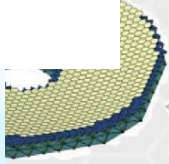


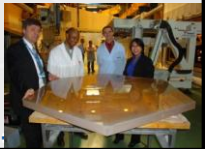
- Segment spec is an rms surface accuracy of 15nm (on average, max 30nm) after correction with the warping harnesses
- 10 mm zone at the edge with relaxed specification (ave 200 nm)
- Micro-roughness is expected to be below 20-Å



- Inductive edge sensors from micro-Epsilon
- Detect piston, gap and shear
- Requirements are to be able to measure piston with a resolution of 0.5-nm over a range of $\pm 200\text{-}\mu\text{m}$ with a repeatability of 1-nm
- 10 mm relaxe (nm)
- Micro-to be



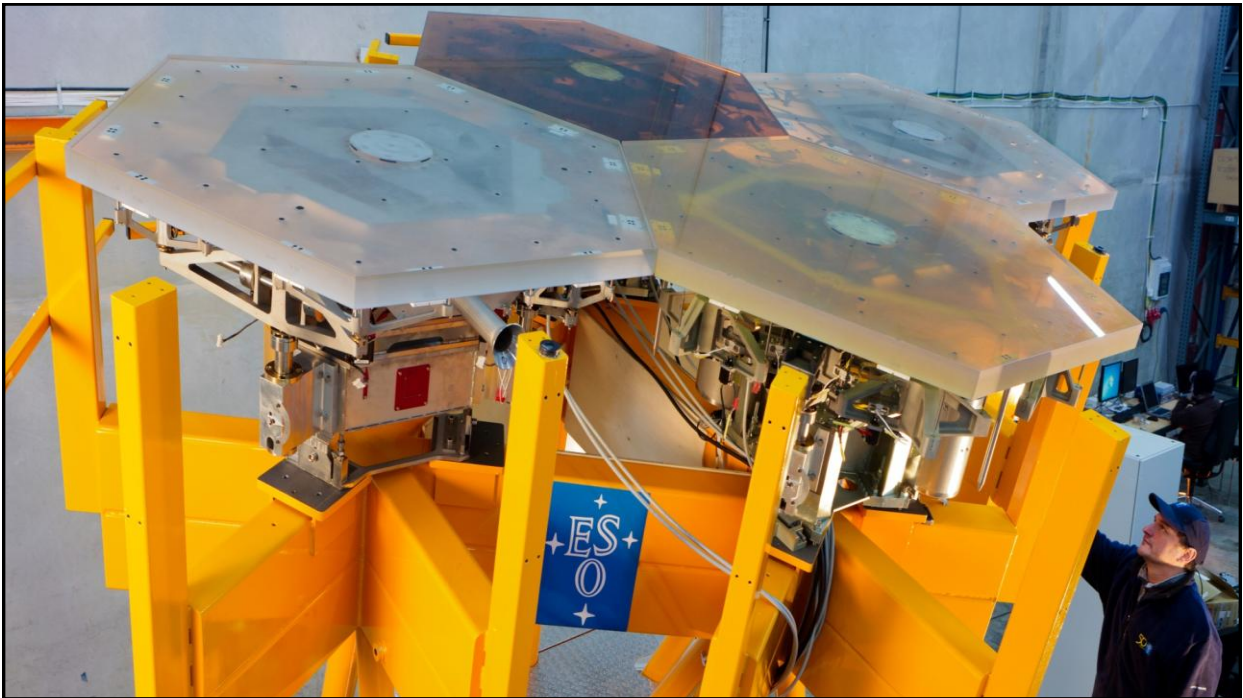




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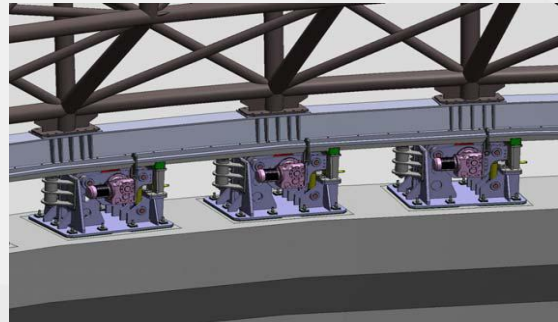
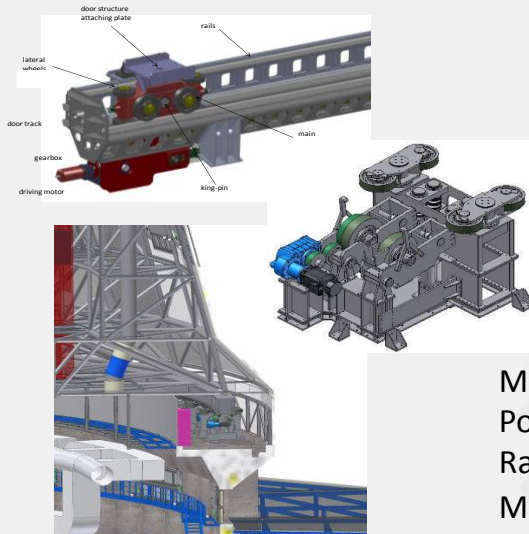
Ds

ACTs, edge





Dome drive system

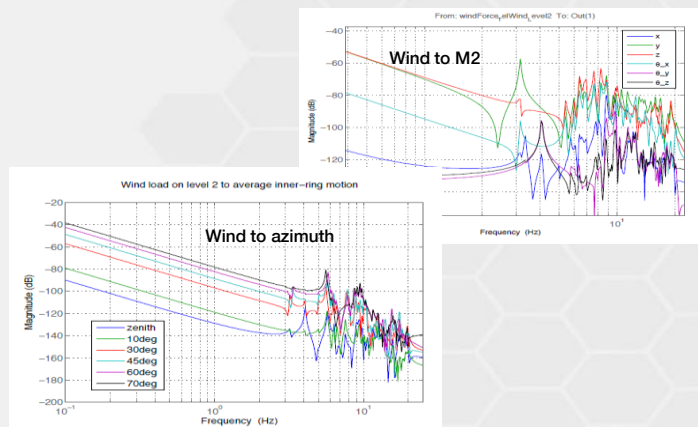


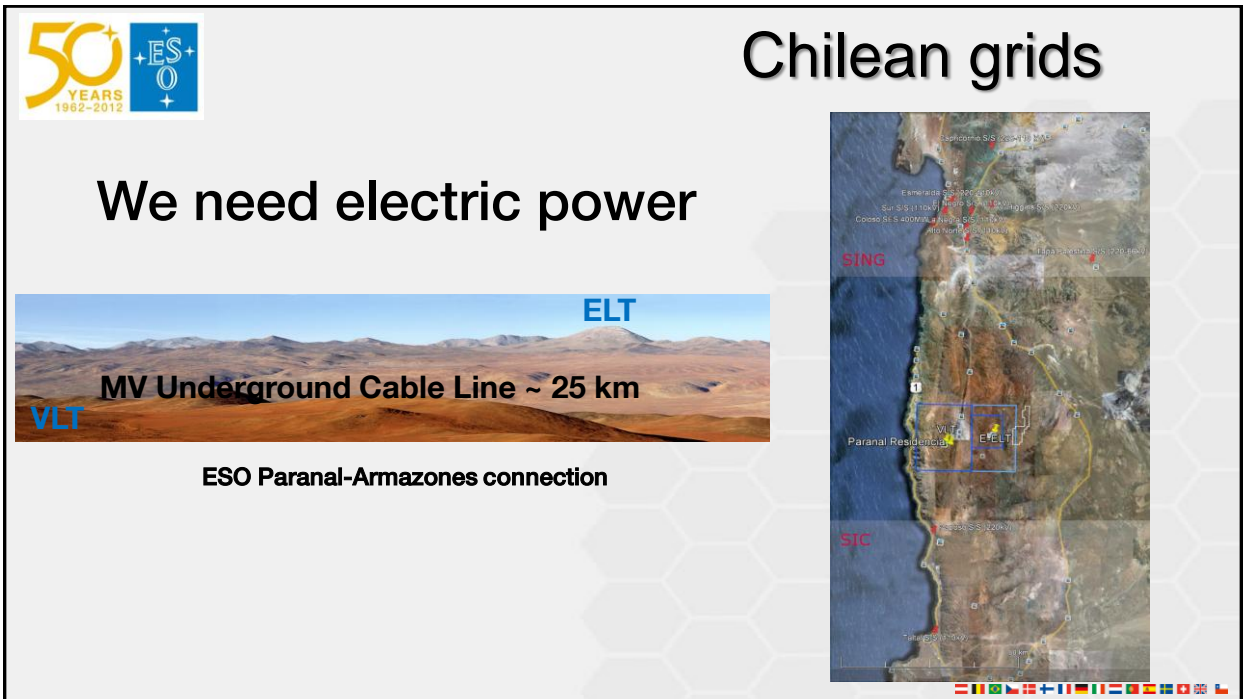
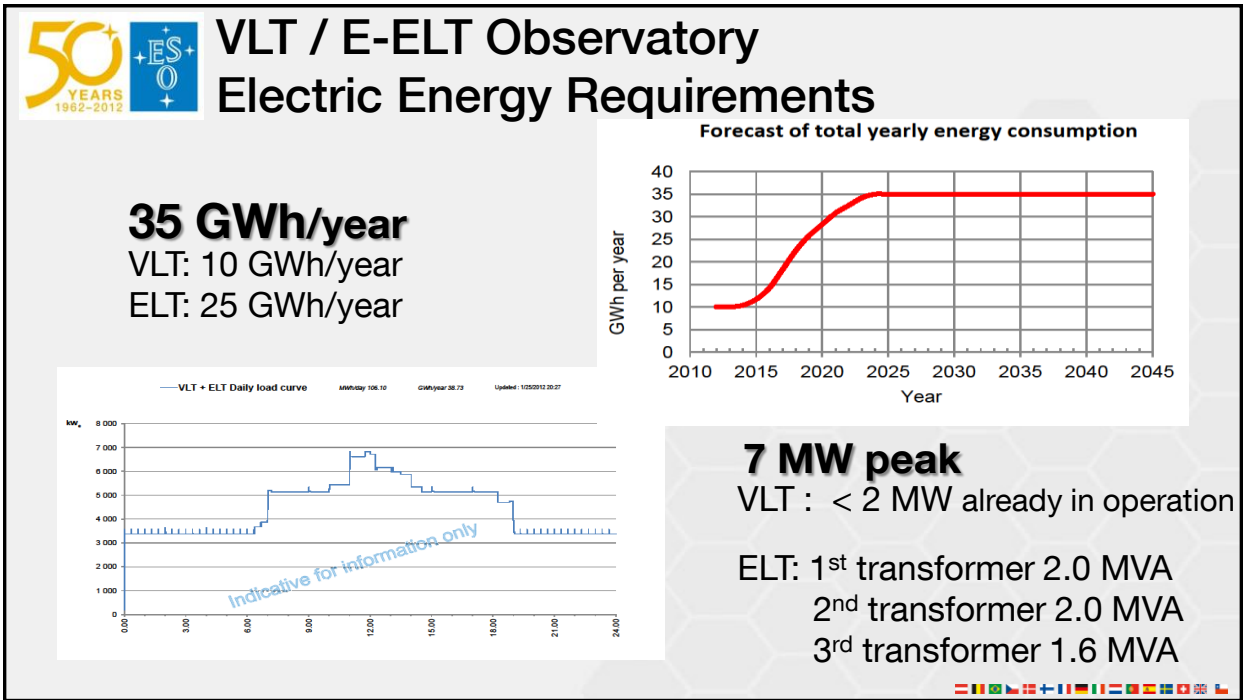
Maximum operational speed = 2 deg/s
Position resolution shall be 0.003 deg
Rail Diameter = 96 m
Mass around 4700 tonnes

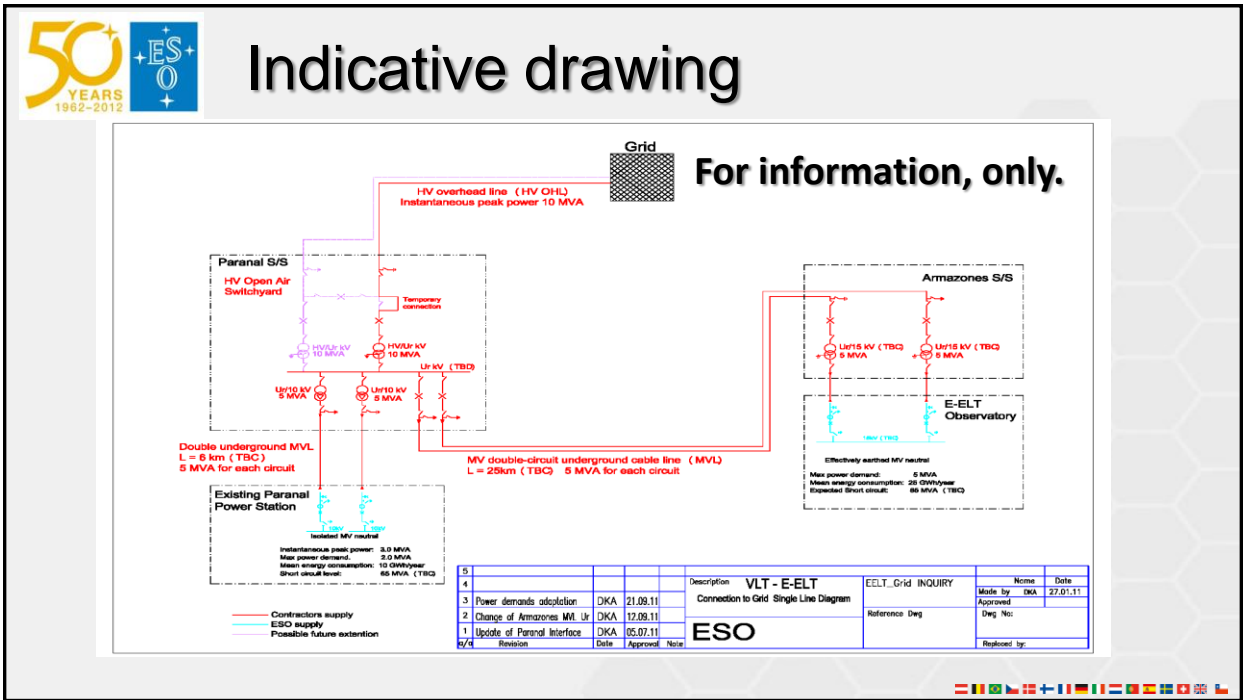



Telescope structure

- Precision control of large flexible structures
- Drive and encoder diameters of 30 m
- Sub-arcsecond precision
- Complex plant transfer functions
- Co-location of drive motors and encoders improves controllability but not always possible










The existing Paranal power generating syst.



A power generating station is currently operating at Paranal, which is used to supply the power demand of the VLT Observatory.

This station is currently comprised of:

- one multi-fuel turbine-generator set (rated about 2.6 MW_e at the site);
- three diesel-generator sets (3x 856 kW_e).

All generators are directly connected to the MV (10 kV) distribution network of Paranal.



Technology needs in Astronomy

- Optics
- Detectors
- Mechanical structures
- Cooling and chiller system
- HVAC
- Cranes and handling equipments
- Mirror coating facilities
- Actuators
- Controllers
- SW
- Power grid connection and generation systems
- Power distribution
- Transportation of goods
- Waste and chemicals treatment
- (Pulsed) laser at specific frequency/wavelength
- Consultancy (RAMS, PA, QA)
-



Thank you!

