Technological Development and Needs at ESO

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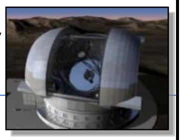
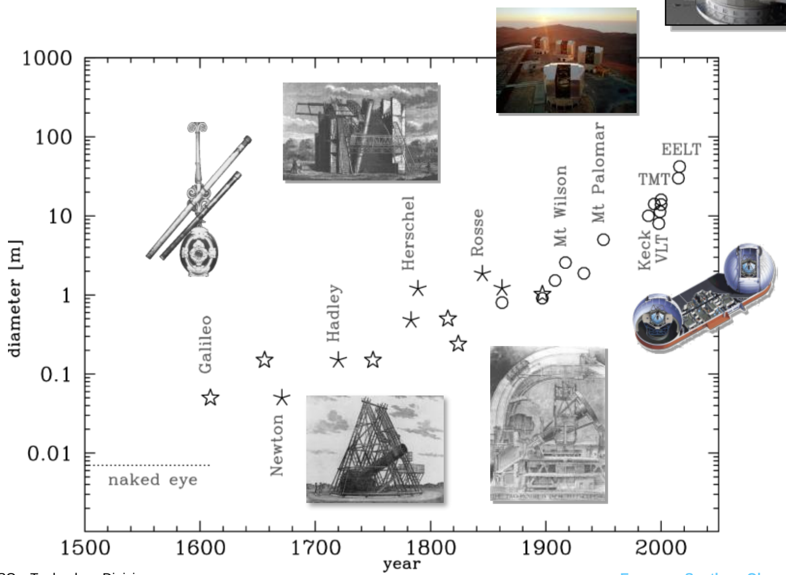
ESO

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.

Technology in Astronomy





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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 larger telescope mirrors, while maintaining optical accuracy.

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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.

Active Optics

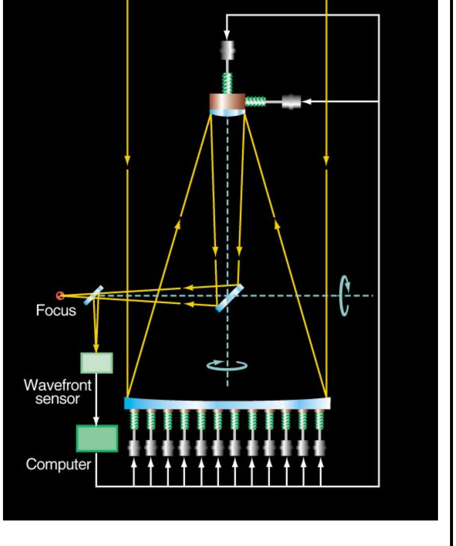
In the past, mirrors over several metres in diameter had to be made extremely thick to prevent them from losing their shape as the telescope panned across the sky. Eventually such mirrors became prohibitively heavy and so a new way had to be found to ensure optical accuracy.

Telescope	Dia/thkn	year
ESO 3.6	6	1960s
ESO NTT	15	1970s
ESO VLT	47	1990s
ESO E-ELT	840	2010s

Principle of Active Optics

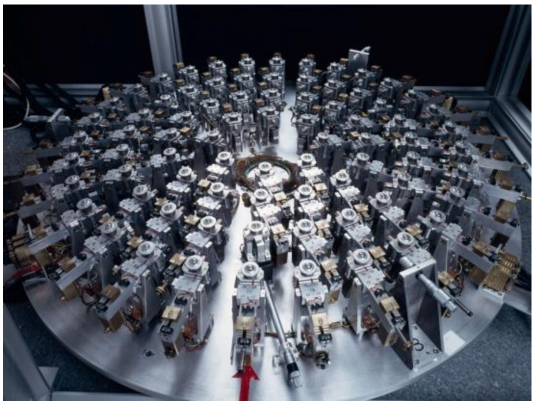
Closed control loop with:

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.



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Active Optics=>The NTT

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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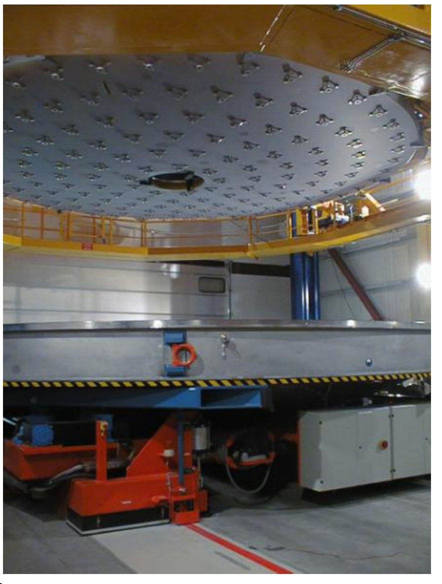
VLT M1 Mirror



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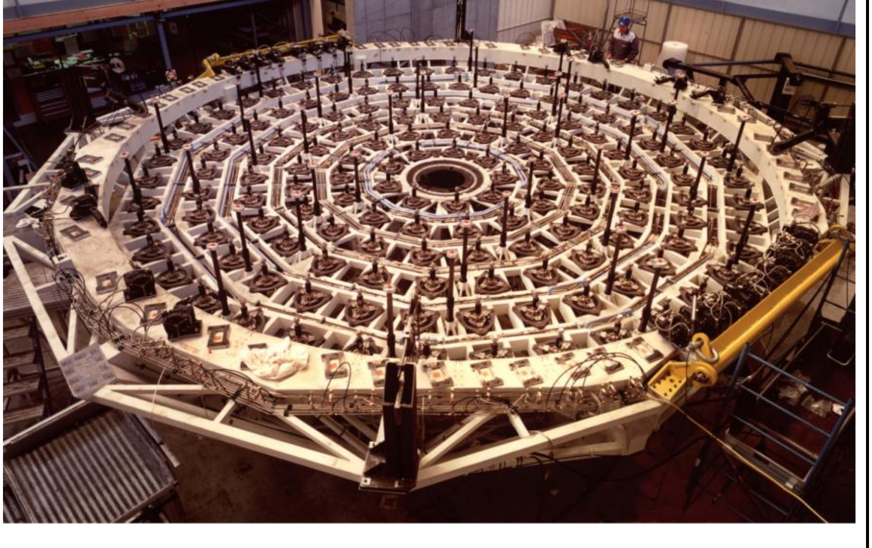
VLT M1 cell



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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

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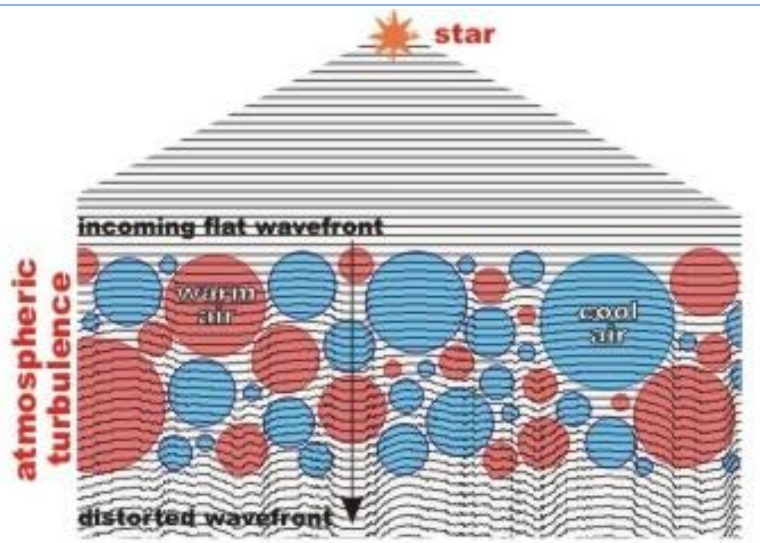
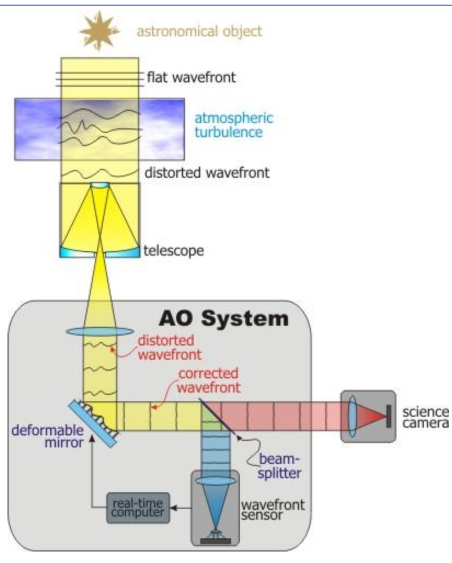
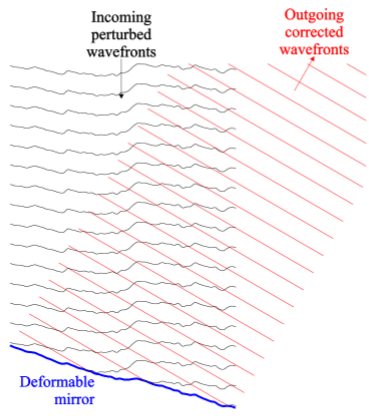


Adaptive Optics principle

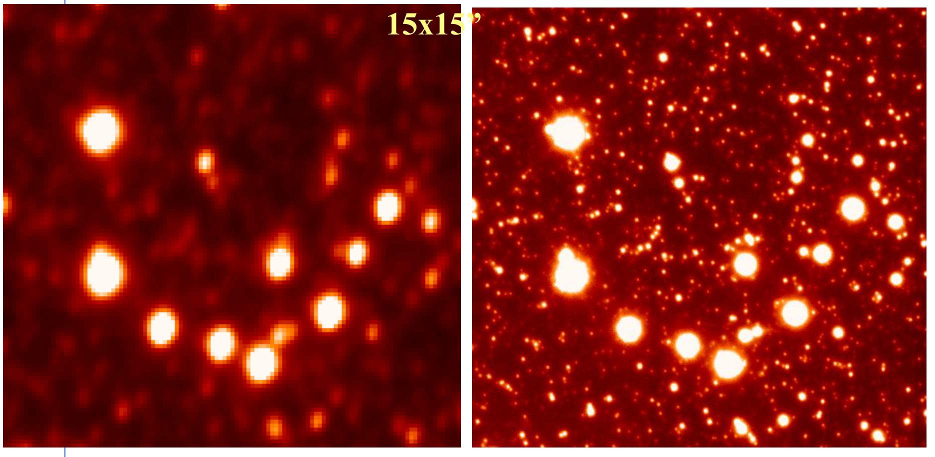




MAD on Nasmyth A UT3 (Melipal)

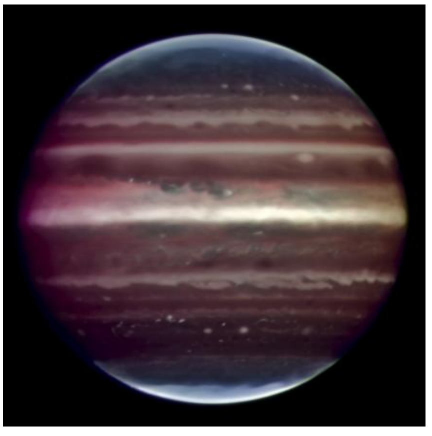
MAD: 2 arcmin FoV, at 2.2µm (K band), using two DMs, a SH WFS (for the Star oriented MCAO reconstruction), and a Multi-Pyramid WFS (for the layer oriented MCAO reconstruction)

An AO milestone: MAD



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

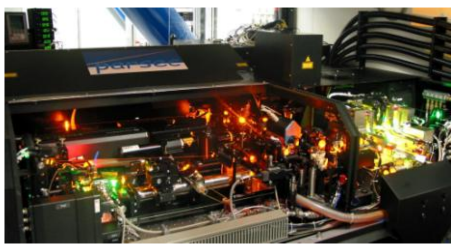
An AO milestone: MAD

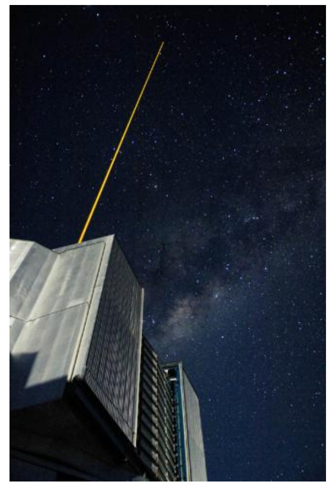


MCAO: 2 Guide "stars" (satellites Europa and Io)
2.14µm + 2.16µm filters
90 mas resolution (300 km at Jupiter)

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

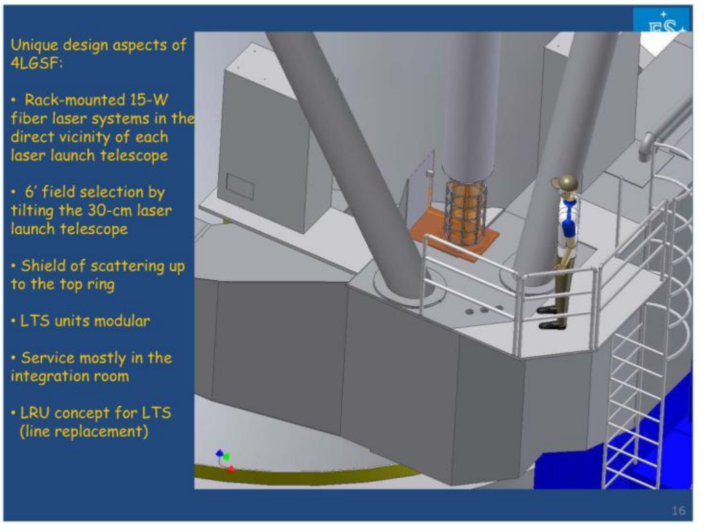




The VLT LSGF at UT4

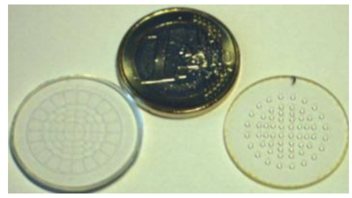
VLT Laser Clean Room

Launching Telescope of 4LGSF

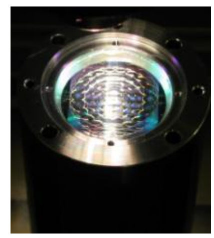


Fiber Laser demo

Special optics for AO

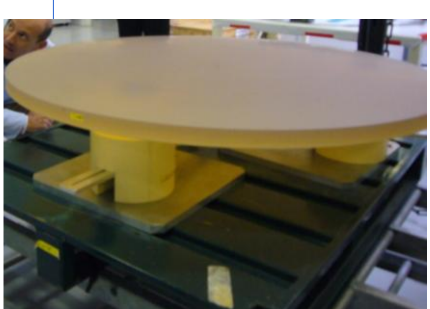


Custom lenslet arrays for MACAO



1.1 m light-weighted reference body
for the VLT Deformable secondary mirror

Thin shells



1.1m Zerodur shell, in manufacturing
at SAGEM

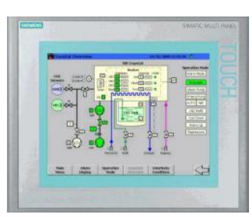
2.6m glass shell, 2 mm thick at SAGEM

Electronics needs

In the aim to support the instrumentation plan of the VLT, we also have to design, develop and produce complete tool chain from motion controllers to test benches. A batch of 50 motion controllers and 10 DC and 10 stepper test benches were produced in 2010.

Industrial Automation (PLC)

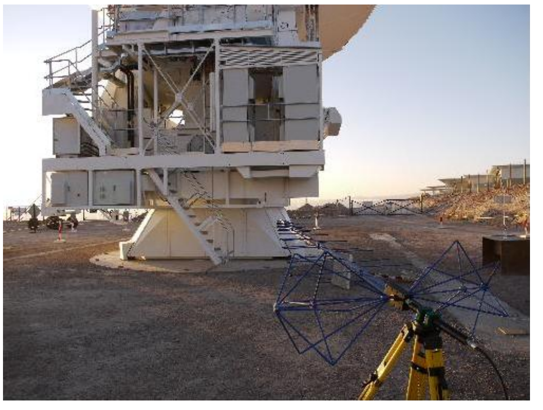
- SIEMENS S7 ESO standard
  - Dedicated to Automation and Safety
- Typ. implementation:
  - X-Shooter Cryo-Controller redesign



Electronics needs

ESO is also providing expertise in the domain of EMC tests, electrical safety and CE marking. This year the effort was mainly concentrated on the first European ALMA antenna acceptance.

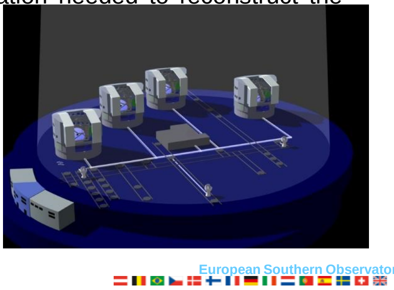
We have now to investigate the use of the WiFi within the telescope area. The uses of mobile phones GSM frequencies is falling in the same frequency band, we will have to investigate if we can allow their use.



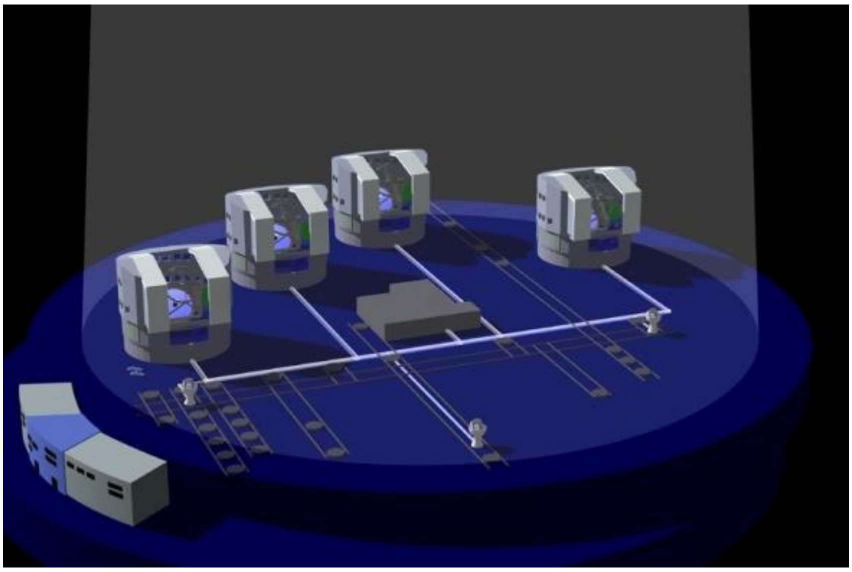
What is the VLTI

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.

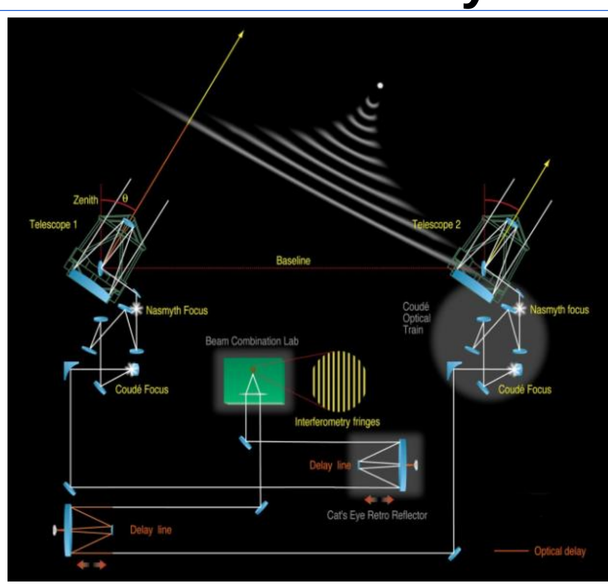
The delay lines help to synchronize the beams, before redirecting them to a central laboratory. The interference fringes produced when the beams are finally recombined provide the information needed to reconstruct the original image in unprecedented detail, giving a picture as sharp as if it had come 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.



What is the VLTI



VLTI Scheme - Subsystems



The VLTI Telescopes

ESO’s Precision Engineering Requirements

- The next generation of big projects are €1B class projects
- ESO’s approach to these projects embodies three major principles
  - Industrial Procurement
  - Exploit and push the current state of the art
    - In terms of industrial capability and design/analysis tools
  - Risk Management

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 x12-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
- Temperature extremes of -20C to +20C
- 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

Antenna top level requirements

- 25 µm rms surface accuracy under all the environmental conditions
- Blind all sky pointing of 2 arcsec rms
- Offset pointing accuracy of 0.6 arcsec over a two degree field
- Tracking of 0.6 arcsec rms
- Pathlength variations less than 20 µm
- Fast position switching 1.5° in 1.5 sec, and
- Able to directly point at the sun

Technology needs

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

Thank you !