Technologies for a future giant optical telescope

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Opportunities for international research cooperation and commercialisation of functional materials
Helsinki, 22 January 2008

Technologies for a future giant optical telescope

- Talk summary
  - What is ESO?
  - Background to the European Extremely Large Telescope (E-ELT)
  - Present activities
  - Time scales
  - Technology examples
- Work of ESO and many collaborating institutions and industrial partners

ESO is ...

- Inter-governmental Organisation
- Estalished by International Convention in 1962

ESO's mission…

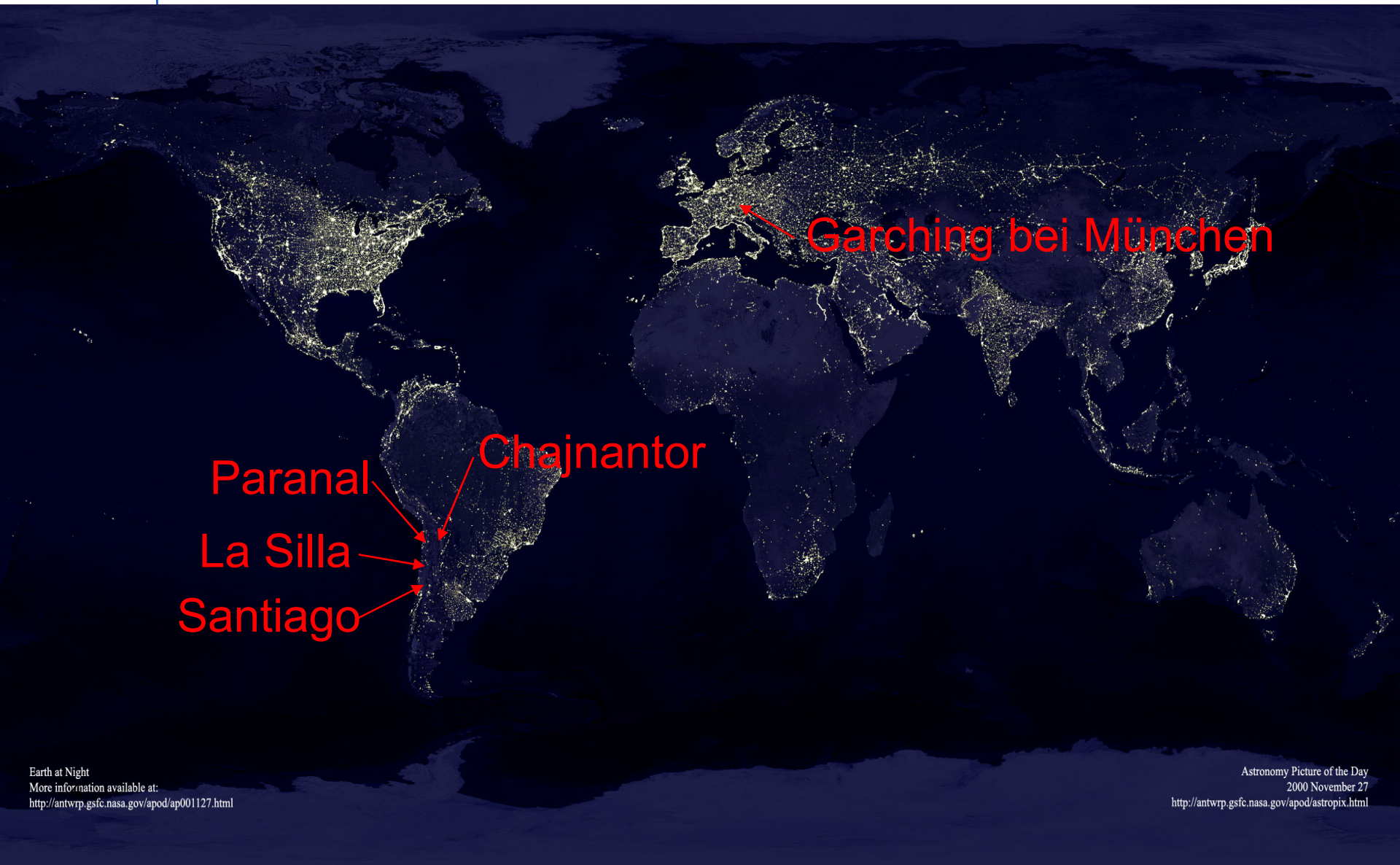
- Provide astronomers in member states (~ 3000) with state-of-the-art observational facilities
- Further and organise collaboration with astronomy and astro-physics in Europe

Budget and Staff ...

- Budget: ~200 Euro
- Staff: 650

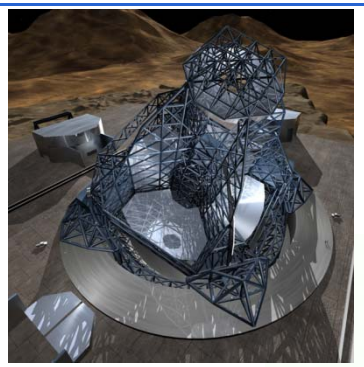
(2006)

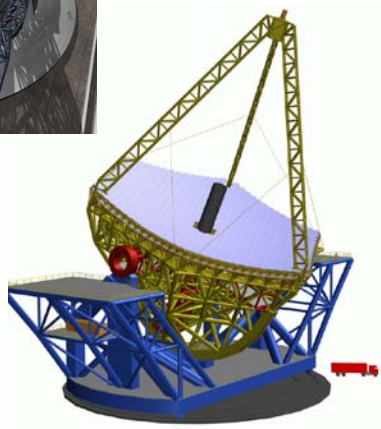
ESO Sites

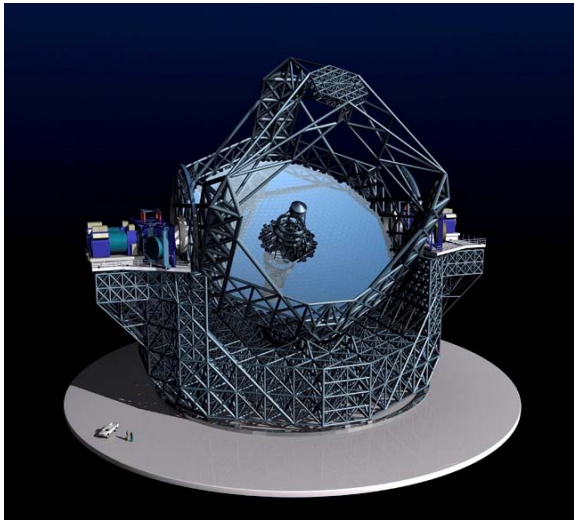

Garching bei München
Chajnantor
Paranal
La Silla
Santiago
Earth at Night
More information available at:
http://antwrp.gsfc.nasa.gov/apod/ap001127.html
Astronomy Picture of the Day
2000 November 27
http://antwrp.gsfc.nasa.gov/apod/astropix.html

E-ELT Background

- OWL 100m Design Study (1997 - 2005)
  - Why have telescopes only increased by a factor of two in diameter every 50 years?
  - What are the physical limits?
  - Can we break the cost scaling laws (D^2.6) ?
  - Can a 100m optical telescope be built for 1000 M€ ?
- Swedish 50m telescope design study
- OWL Concept review (November 2005)
  - No show stoppers but high risk of not being completed on time on in budget
  - Recommended to explore the possibility of building a 30 – 60 m telescope at a cost of 650-750 M€ in a competitive time scale
  - 5 Working groups set up (Science, Instruments, Site, Design and Adaptive Optics)
- E-ELT baseline design accepted at the Marseille meeting (November 2006)
  - 42m diameter, 5-mirror design
  - Approval to start Phase B







Present activities (1)

FP6 Activities

- Technology oriented, design independent
- 30 partners, 11 countries, 30.5 M€ (8.4 M€ from FP6)

- ELT Design Study (EC Research Infrastructures Action)
  - Mechanical studies
  - Enclosure concepts and wind studies
  - Adaptive optics
  - Integrated modelling
  - Wavefront control
  - Advanced adaptive optics
  - Optical fabrication
  - Instrumentation (point designs)
  - Site characterisation
- Other FP6 activities (JRA)
  - Second generation Adaptive Optics
  - Fast Optical Detectors and Fast readout high performance optical detectors
  - Smart focal planes and VPG development

Present activities (2)

ESO Funded Activities (ESO and collaborating institutions)

- E-ELT Phase B
  - Requirements definition, system engineering
  - Mechanical design (internal and industrial studies)
  - Industrial study contracts
  - Optical design, adaptive relay unit industrial studies (M4 & M5)
  - optical manufacture studies
- VLT Activities
  - VLT Adaptive Optics Facility (inc. DSM and 4-laser guide star system)
  - Second generation VLT Instruments, inc. SPHERE (exo-planet finder with extreme AO), MUSE/GALACSI & HAWK-I/GRAAL (with ground layer AO)
- Other In-house developments and studies
  - Electronics standards, time standards, product testing (incl. cryo testing), control architectures, technology demonstrators, ...
- Other industrial and academic studies and developments
  - Fibre lasers, Laser components, PC hollow core fibres, ...

E-ELT Schedule

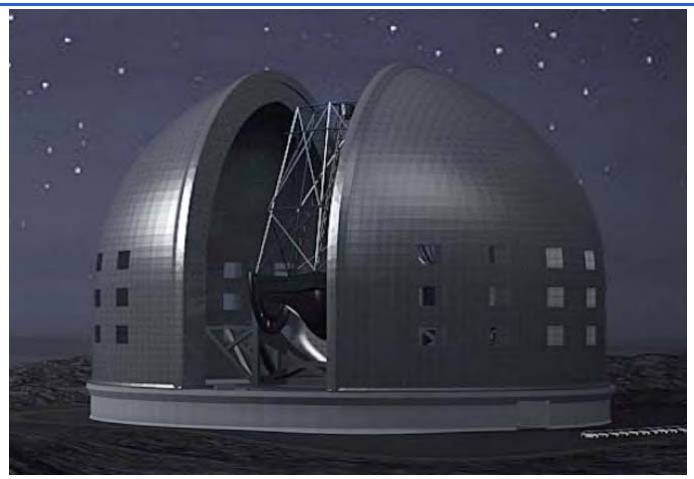
- Time scales
  - E-ELT Phase-B
    - Fully funded (~ 50 M€)
    - Jan 2006 – December 2010
    - In 2010:
      - All FP6/7 studies completed
      - Design concept agreed
      - Site agreed
      - All important technical specifications defined
  - Construction phase: 2011 – 2018
    - Subject to funding being available
    - First science 2015 - 2016
    - Timescale compatible with JWST

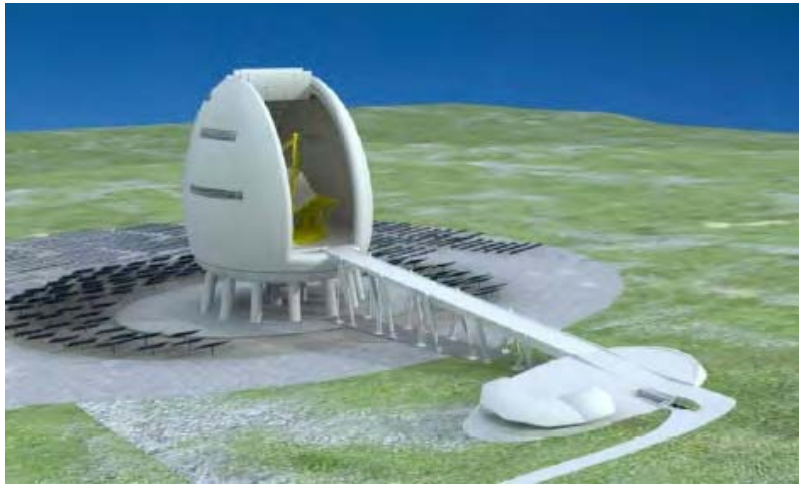
Some key developments & technologies

- Enclosure concept studies
- Mirror Actuators
- Mirror Metrology
- Wind analysis & control
- Mirror Phasing (APE)
- Friction and other drive systems
- Optical fabrication
- Adaptive optics
- Fast optical detectors
- Fibre lasers
- Instrumentation developments & concepts

Enclosure concept studies

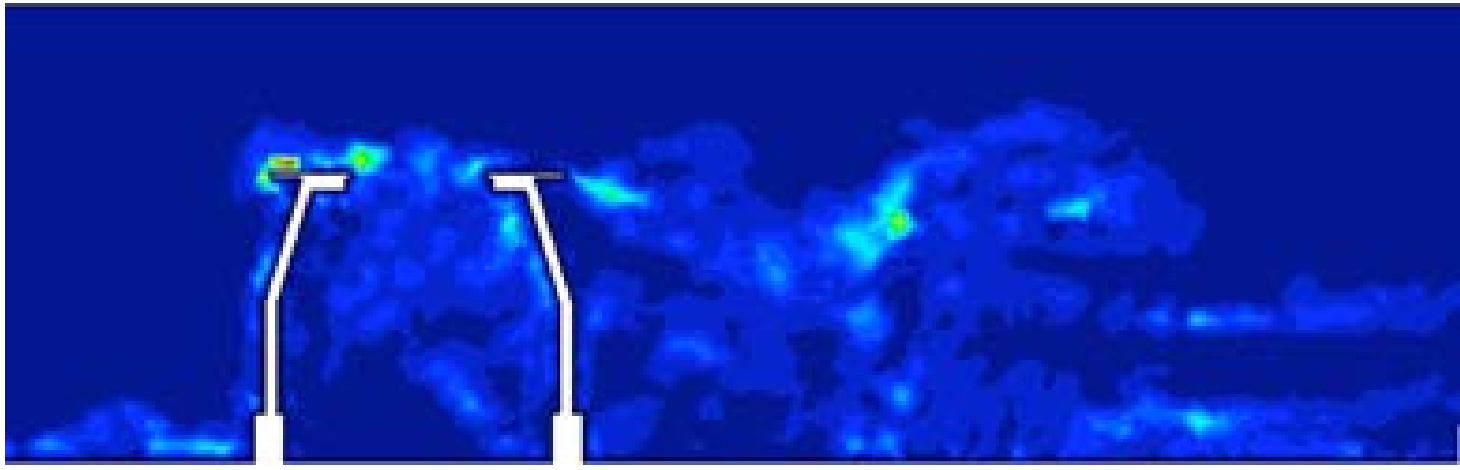
- 4 concepts evaluated (Sliding enclosure, eye-lid, e-BAT and box-type
- Evaluated for cost, reliability, maintainability, protection from wind and stray light, safety, etc.





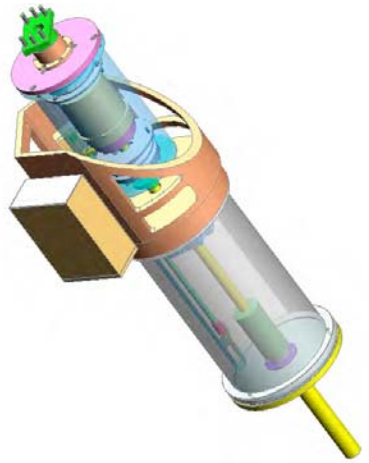
Enclosure concept studies

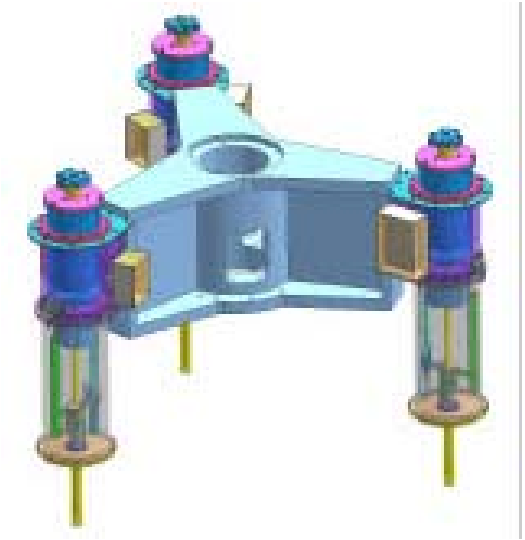
- 4 concepts evaluated (Sliding enclosure, eye-lid, e-BAT and box-type
- Evaluated for cost, reliability, maintainability, protection from wind and stray light, safety, etc.
- Turbulence evaluated with Large eddies simulator, CFD modelling and wind tunnel (ITER and Boundary Layer WT)

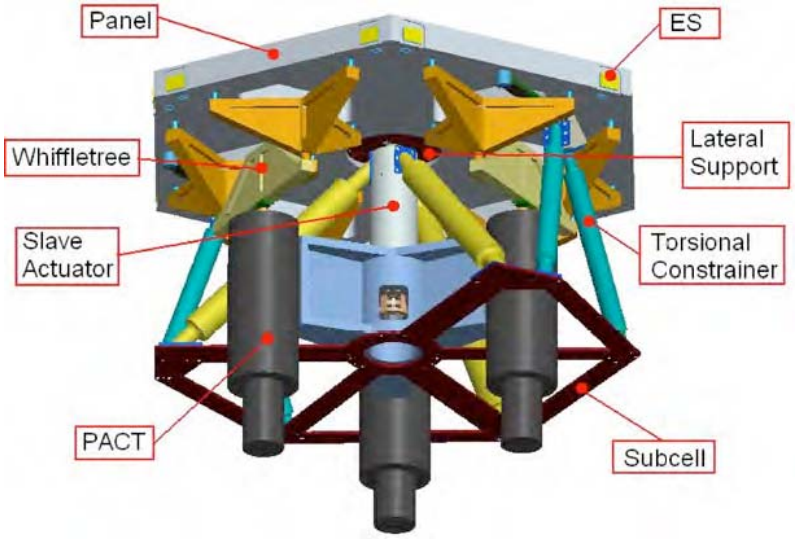


Mirror Actuators

- E-ELT M1 position actuators designed and prototyped
- Dual-stage (voice-coil and stepper)
- Max stroke of 150mm for mirror segment removal
- Closed loop position accuracy of 5nm with variable load up to 1700 N
- Production of 18 units for WEB

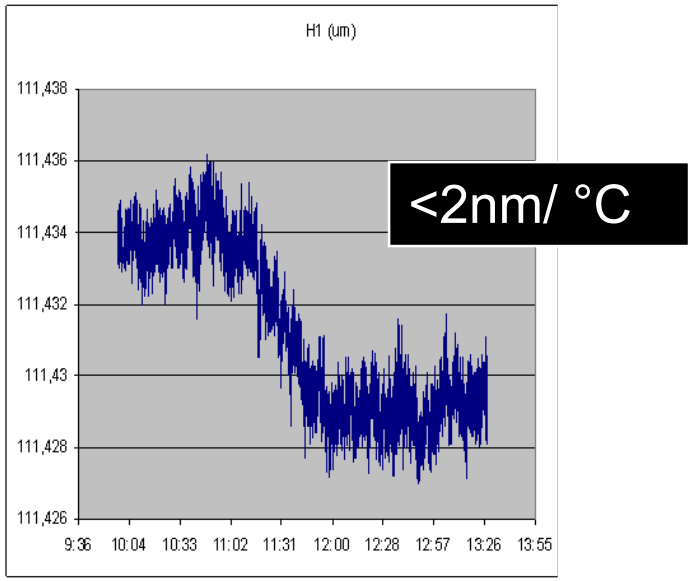


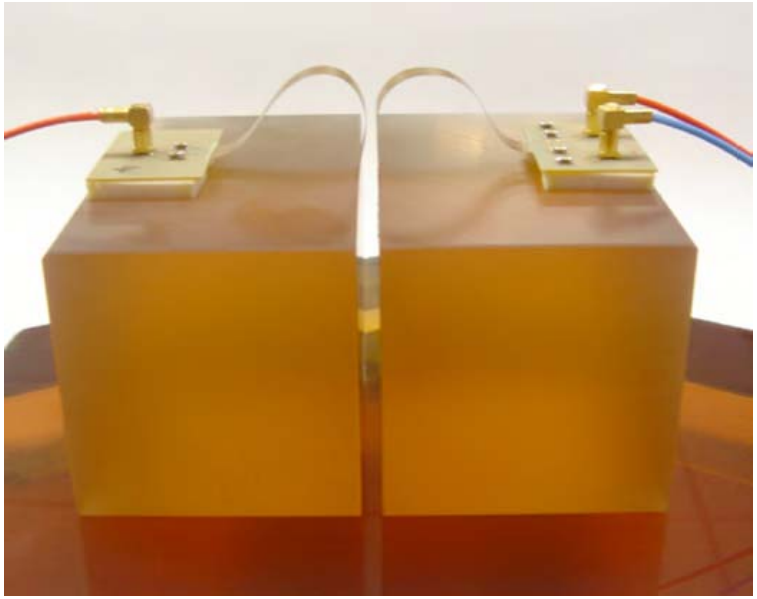




Mirror metrology

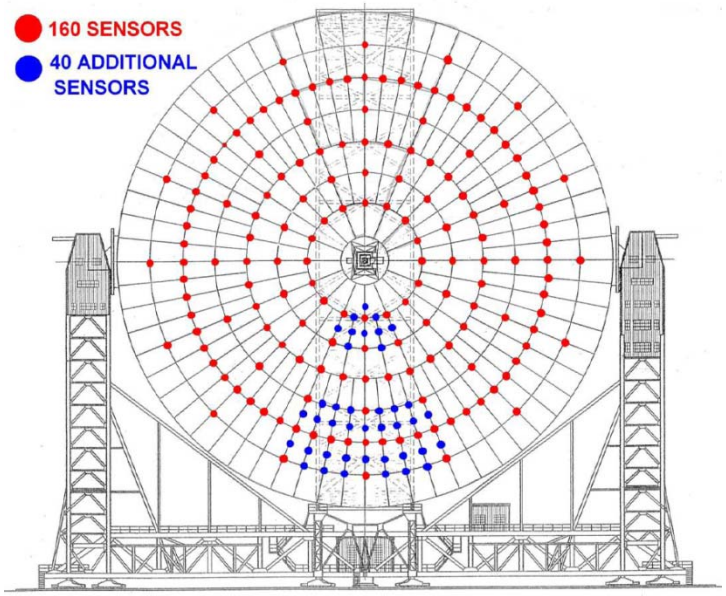
- M1 mirror metrology
  - Capacitive and inductive sensors compared
  - Evaluation of stability, sensitivity to mirror misalignment and deformation of segments, cross talk, noise etc.)
  - High stability test bench has been developed
  - Hardware units produced for integration in the WEB project

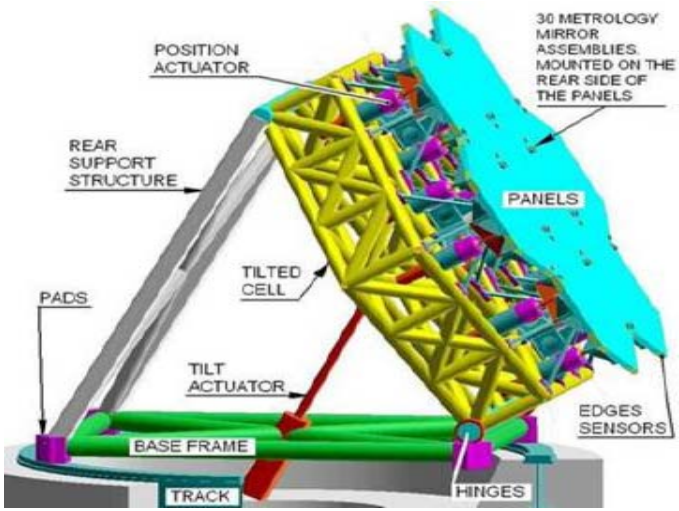


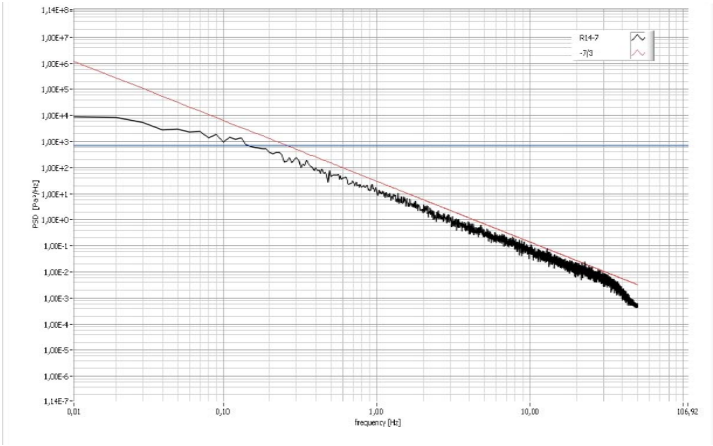


Wind analysis and control

- **Jodrell Bank wind measurements**
  - 200 wind pressure sensors mounted on surface
  - 40 mounted closer together to measure short range correlation functions
- **VST enclosure measurements**
- **WEB** (Wind Evaluation Breadboard)
  - Dev. of position control architectures for wind rejection

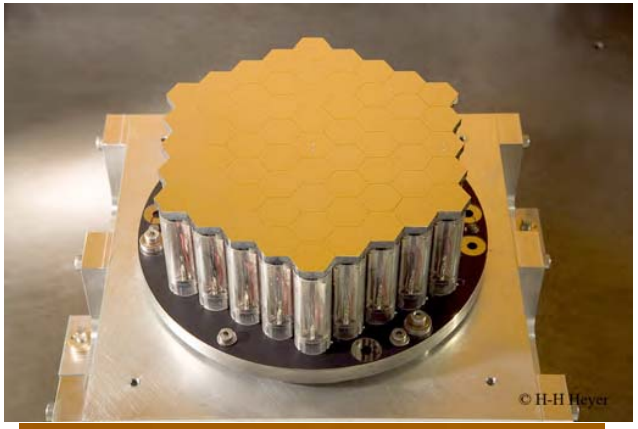


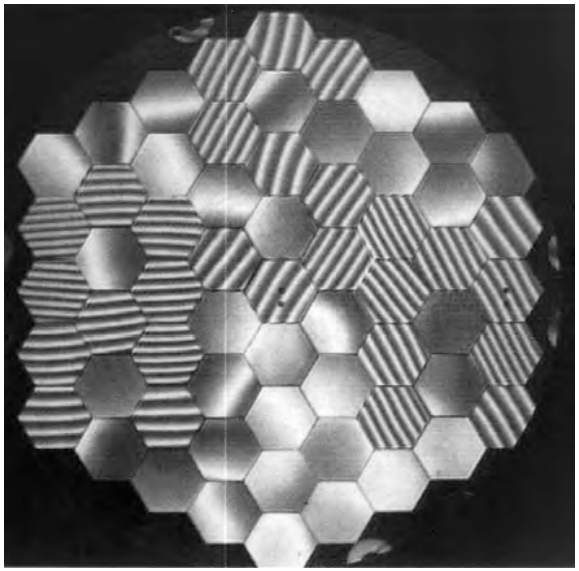




Active Phasing Experiment (APE)

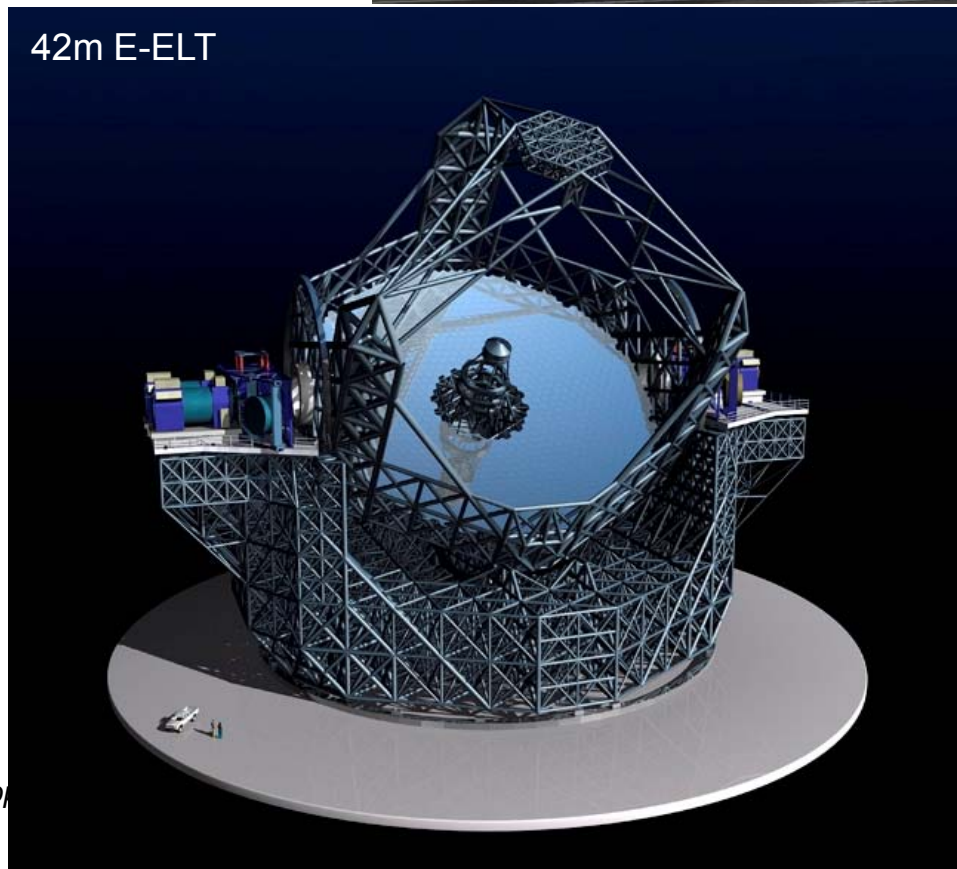
- Designed to test 4 different phasing technologies for segmented mirrors (DISPSI, ZEUS, PYPS & SHAPS)
- A 61-element prototype constructed with internal metrology
- To be installed and tested on the VLT in 2008





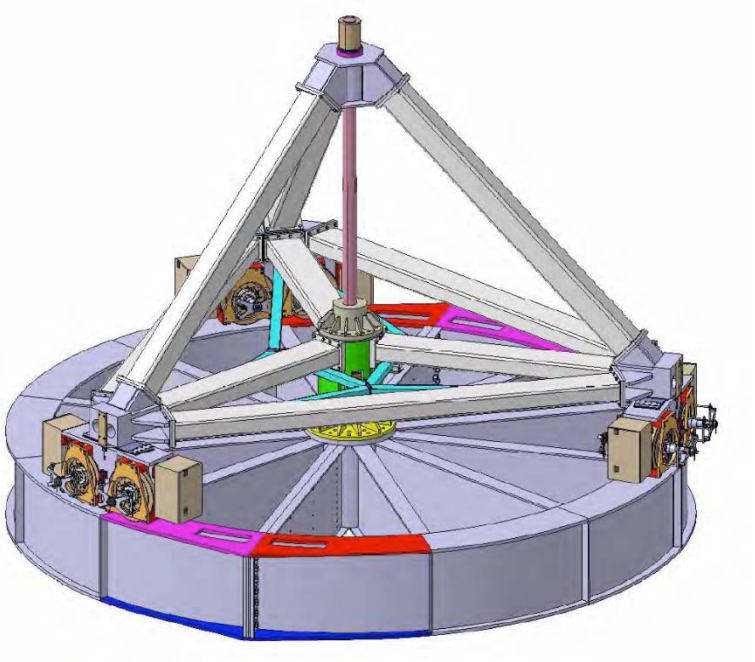
Mechanical Design Studies

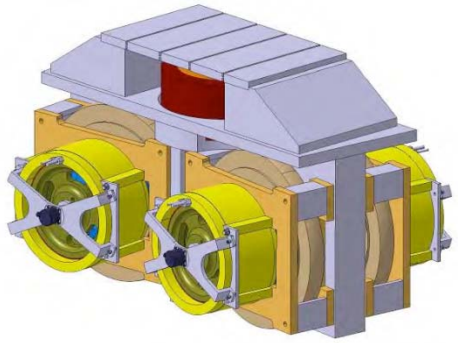
- OWL 100m concept design
- E-ELT 42m mechanical design
  - ESO Baseline design
  - Two industrial studies
- Mechanical technology studies (FP6)
  - Composite materials
  - Structural ropes
  - Magnetic drives
  - Magnetic levitation
  - Friction Drives >>

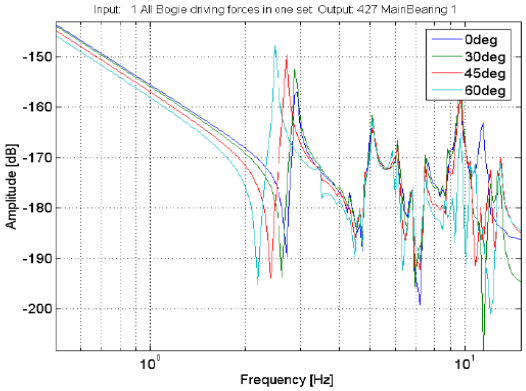


Friction Characterisation Breadboard

- Concept evaluation for friction driven bogies
- 7m Diameter test rig, including wind disturbance and track misalignment generators
- Evaluation of stiffness, stick slip, tracking, pointing, sensitivity to track misalignments, sensitivity to wind disturbances and RAMS aspects
- Prototype not yet as stiff as required

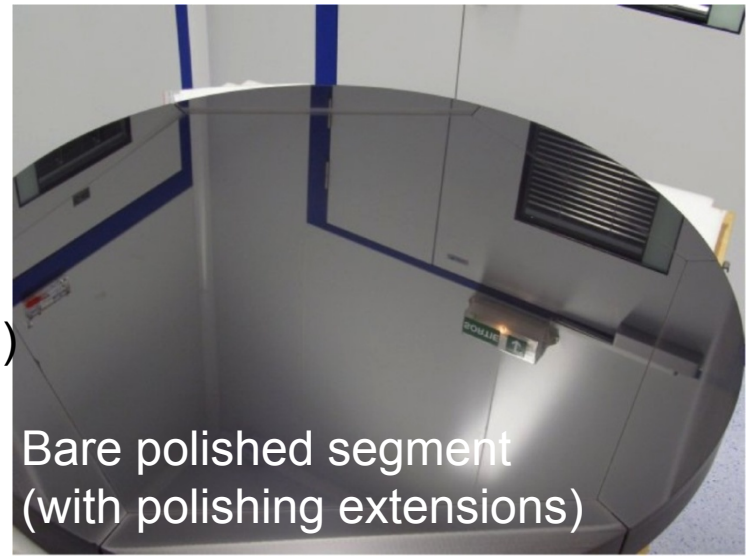


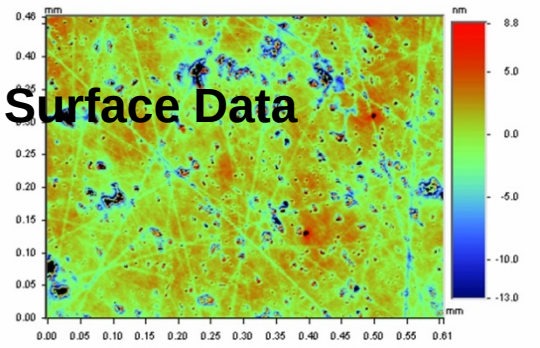




Optical Fabrication Studies – M1

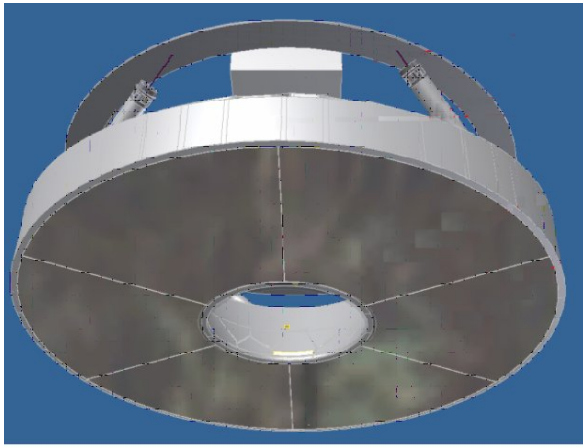
- Manufacture and testing of 1m-class SiC flat segments
- Qualification of SiC as an affordable alternative to Glass
- Investigation of over-coating technologies (CVI, ICVI, metallic, Si, ...)
- Investigation of polishing techniques (edge control)
- Production of flat segments for WEB
- ESO contract for the production of 7 figured segments in Zerodur, Astrosital, ULE + another material

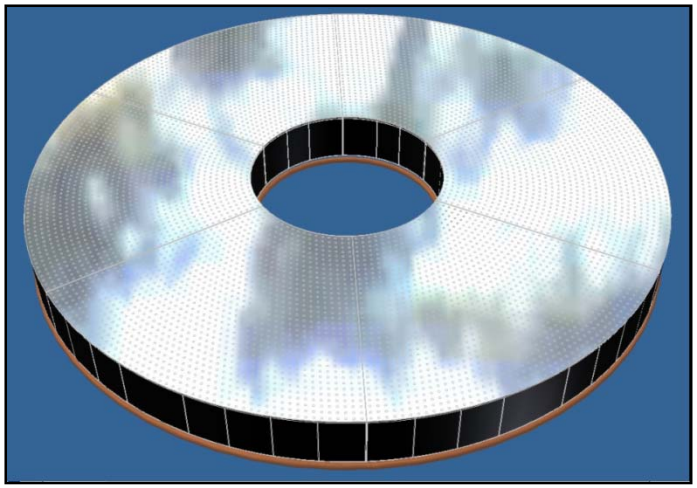


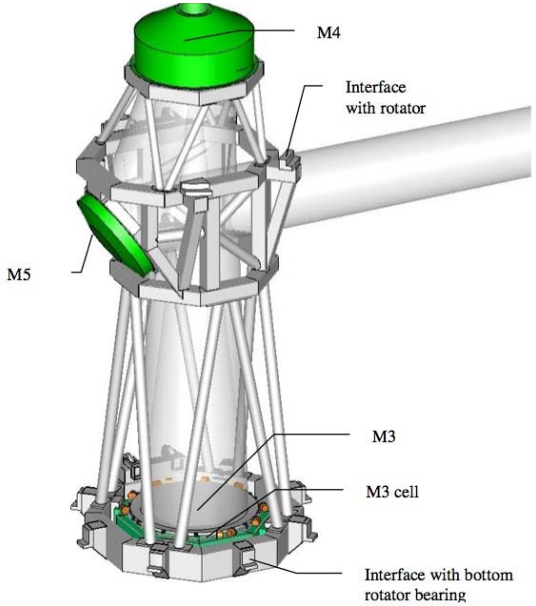


Optical Fabrication studies M2 – M5

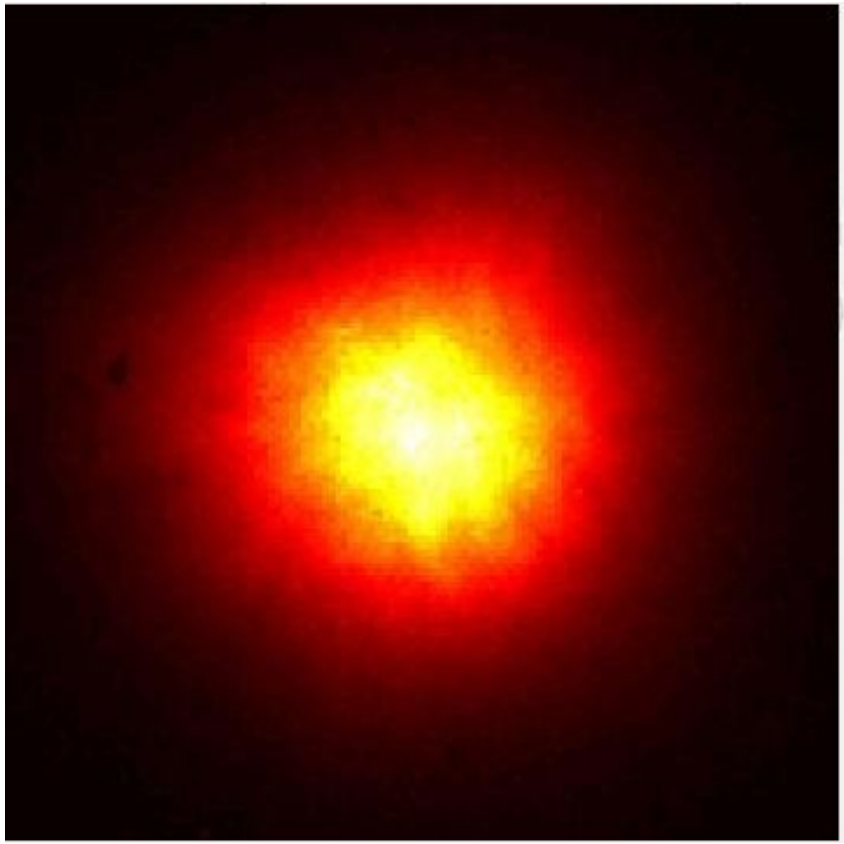
- Several industrial feasibility studies completed
- M2 6m convex (current technology)
- M3-M5 Adaptive Optics Relay Unit
  - M3 4.2m
  - M4 2.5m deformable
  - M5 2.7m tip-tilt
- VLT: 1.2 deformable M2 in manufacture

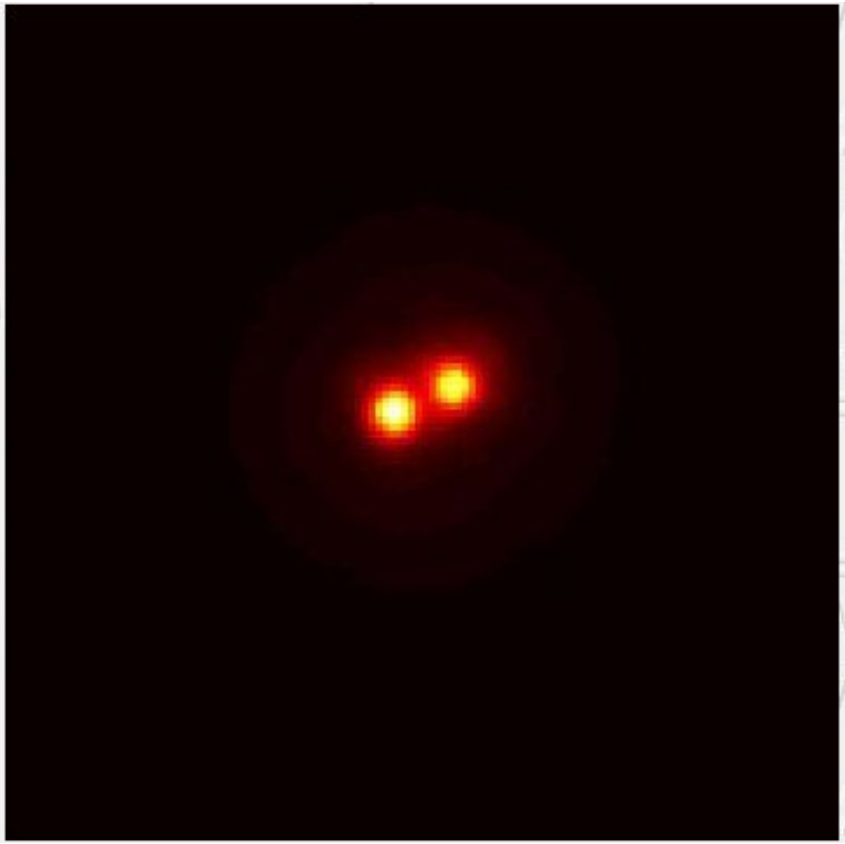






Adaptive Optics





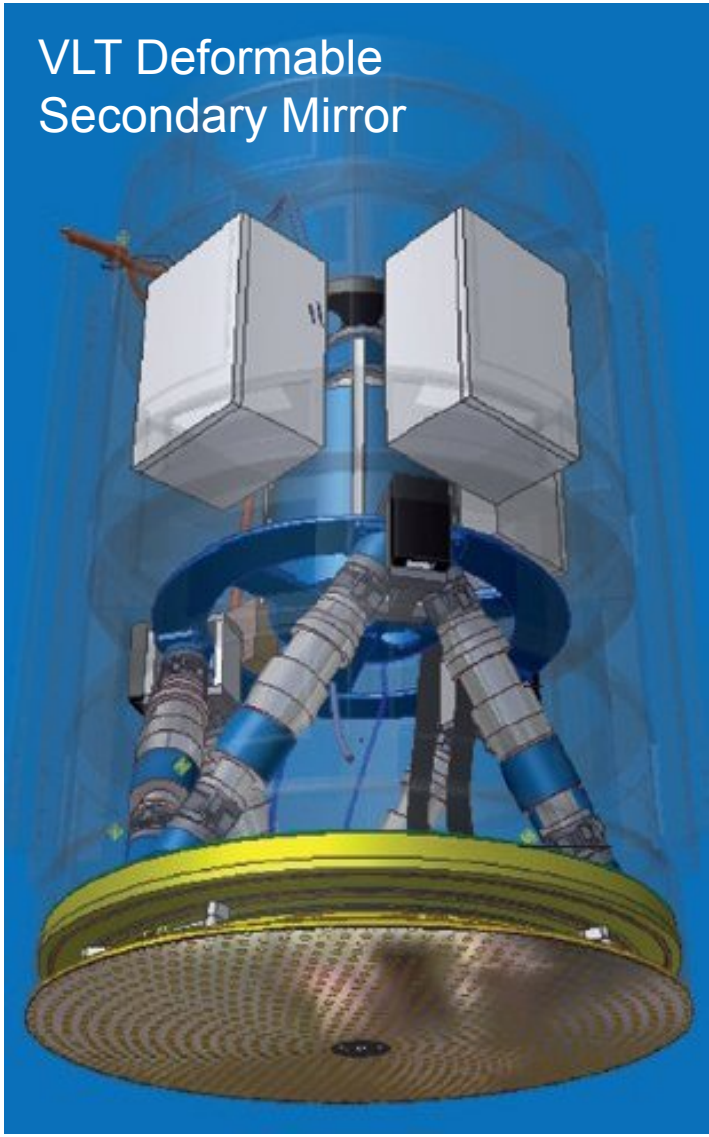
Non-AO

AO

Picture from SINFONI on VLT: 0.75 arcsec seeing, binary separation 0.12 arcsec

Adaptive Optics

- **E-ELT AO Concept developments**
  - Single Layer AO (SLAO)
  - Ground Layer AO (GLAO)
  - Laser Tomography AO (LTAO)
  - Multi- Conjugate AO (MCAO)
  - Extreme AO (XAO)
- **Novel AO Concepts**
  - Dynamic refocus of a pulsed LGS (comparison of techniques, scaling to an ELT)
  - Centroid algorithms and static optical compensation (LGS Elongation)
  - Differential focal and spot anisoplanatism (Cone Effect)
  - Pseudo Infinite Guide Stars (PIGS)
- **Large, high density deformable mirrors**
  - 1371 Actuator DM for SPHERE
  - Deformable large thin shells
  - 1.2m Deformable mirror upgrade for M2 of VLT UT4 (Part of the VLT AO Facility) 1170 actuators, 29mm pitch, 80 Hz



Overview of AO possible performance

	Category #1	Category #2	Category #3
Corrected FoV (diameter)	Small (Isopl. Angle, i.e. 20" with 0.8 of max Strehl)	Medium (1')	Large (5')
Performance metric	70% Strehl (K) 33% Strehl (J)	50% Strehl (K) 11% Strehl (J)	16%(K), 5% (J) EE in 50mas (4 x seeing)
Obs. λ range	R–N	J–N	J–N
PSF uniformity	low	high	medium
Potential systems	SCAO (1DM, 75% Strehl*, NGS, low sky coverage)	MCAO (2 DMs, several LGS)	GLAO (1 DM, several LGS, special LTAO mode)
	LTAO (1DM, 60% Strehl, several LGSs high 'sky coverage')	MCAO (3 DMs, several LGS), larger FoV	MOAO (1-2 DM, several LGS , restricted to 'islands', better Ensquared Energy)
	XAO (2DM, bright NGS)		

Sky coverage always 100% (=> LGS required), not fulfilled by SCAO

Wavelength range R–N (deviations above due to performance)

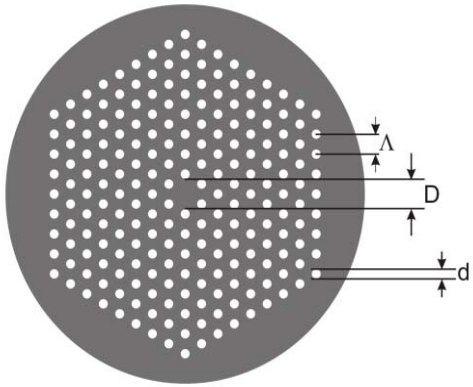
All numbers in 0.5" seeing and with 42-m telescope

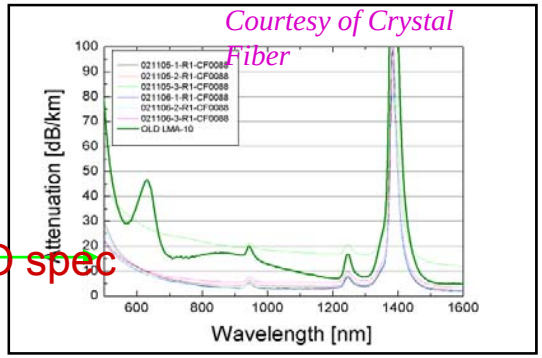
Laser Guide Stars

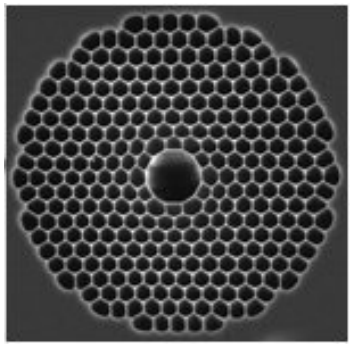
- **Current VLT LFSF**
  - 10 Watt CW 589 nm
  - 1.1 arcsecond artificial star
  - Fibre optical feed
  - In regular operation since spring 2007
- Raman Fibre Lasers
  - 1178nm frequency doubled
  - 5W currently achieved (7W specified), combined to achieve 20W power (15W launched)
  - Will be used in the VLT 4 LGSF
- E-ELT pulsed lasers
  - Planned for E-ELT
  - Needed to counter large ELT cone effect
  - On-going but delayed due to definition of system requirements

Optical Fibres

- Photonic Crystal fibres
  - Current LGSF uses photonic crystal fibres produced by Crystal Fiber (DK) and Mitsubishi (J)
  - Development contract to give acceptable transmission at 598nm
- Hollow core PC Fibres
  - Potentially allow greater laser power transmission
  - Needed for pulsed lasers
  - Development contract not successful due to pulling problems.

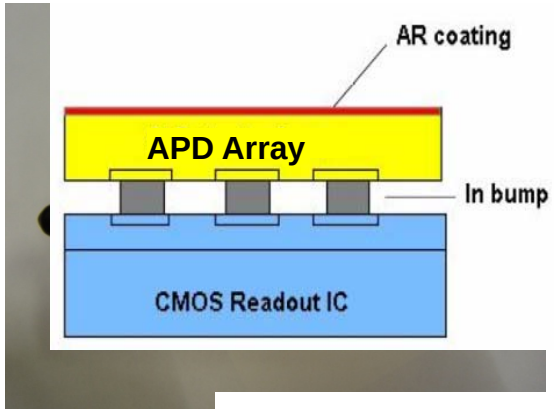






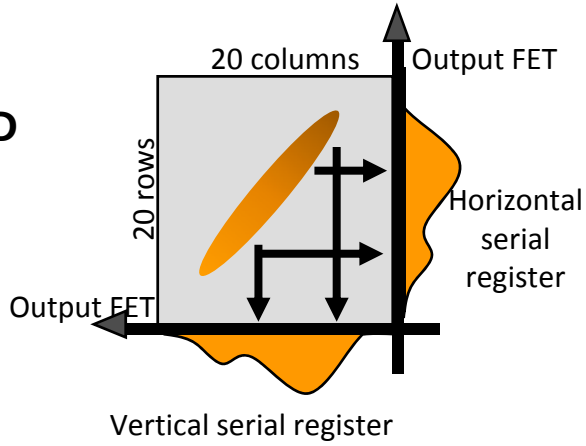
Fast Detectors

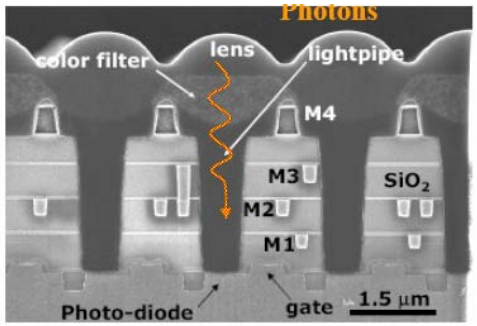
- FP6 fast WFS project
  - 240x240 pixels
  - Based on E2V CCD220
  - Incorporated in OCAM test camera on GTC
  - To be used at ESO for SPHERE planet finder (2nd generation VLT instrument)
- Advanced HD WFS Detector
  - 4 concept studies carried out for a 1600x1600 pixel detector
  - RON <3e- , 700Hz frame rate
  - 3 different approaches proposed
  - Study completed end 2007
  - 2 technology validation studies to start 2008



APD

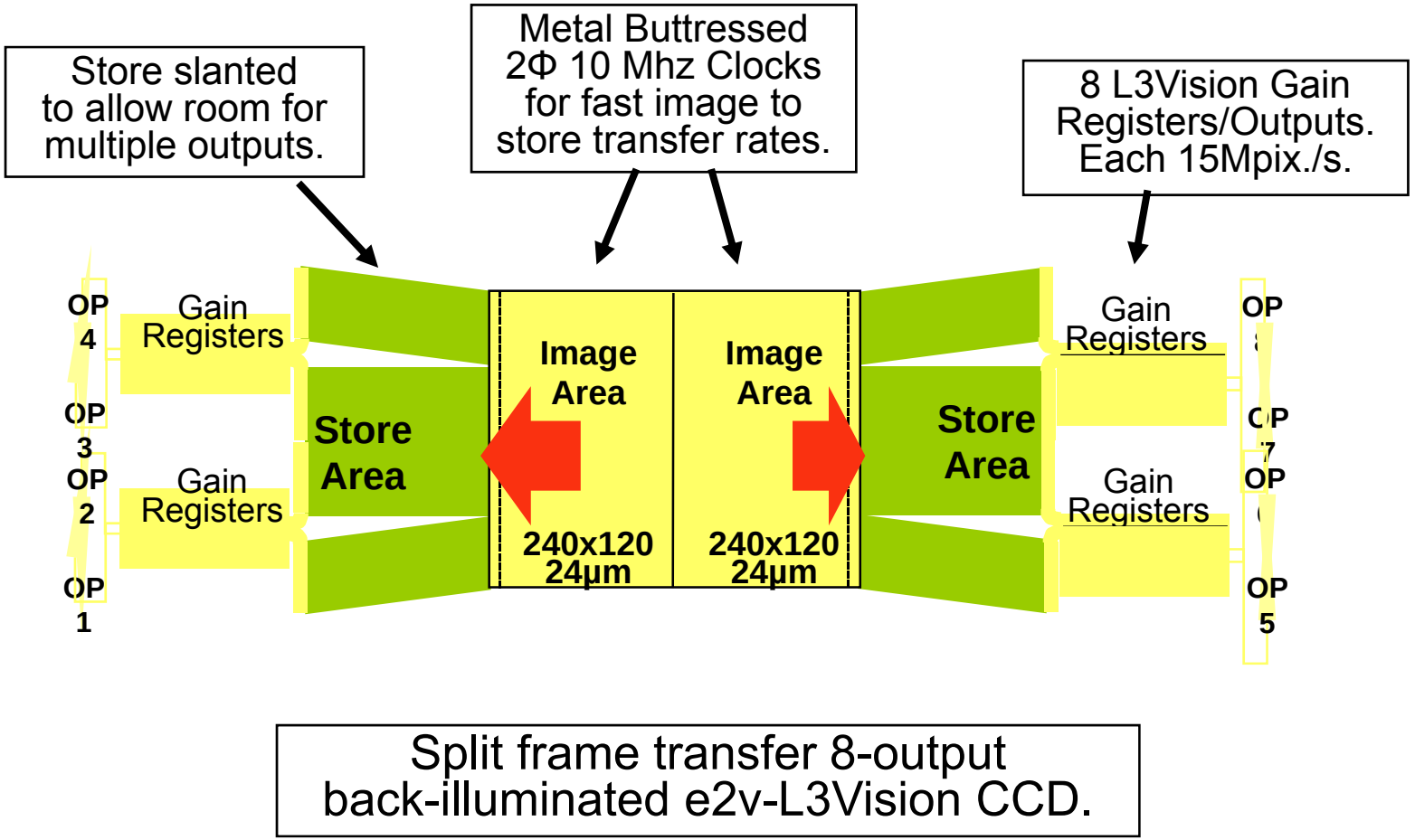
Orthogonal transfer CCD





Monolithic CMOS

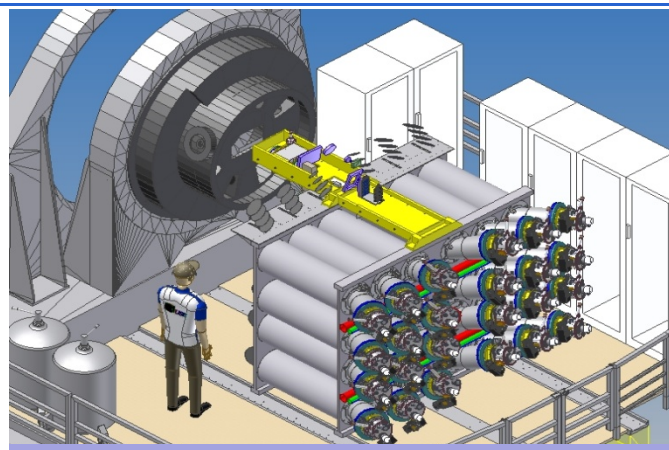
The CCD 220 Design



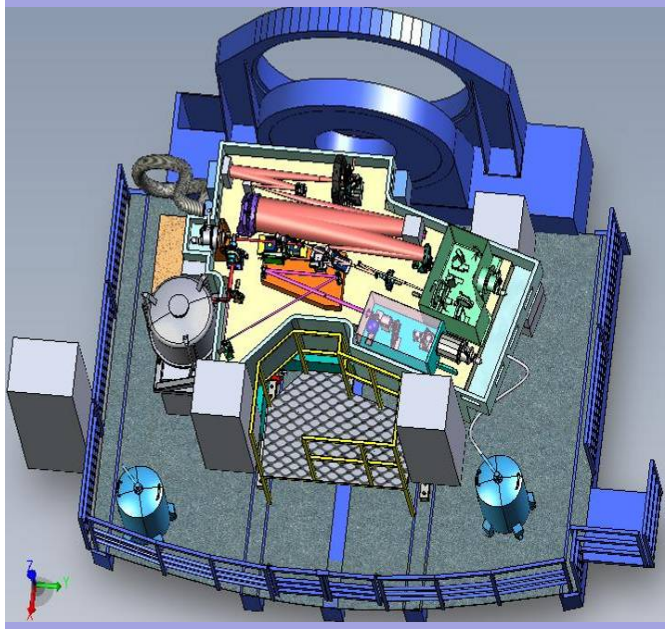
Split frame transfer 8-output back-illuminated e2v-L3Vision CCD.

Instrumentation

- ESO/FP6 AO technology prototypes for incorporation into VLT instruments
  - MAD (Multi (dual) conjugate AO Demonstrator (In operation since mid-2007)
  - MUSE (GALACSI)
  - HAWK-I (GRAAL)
  - SPHERE (Planet finder instrument with eXtreme AO)
- FP6 concept studies for E-ELT instruments



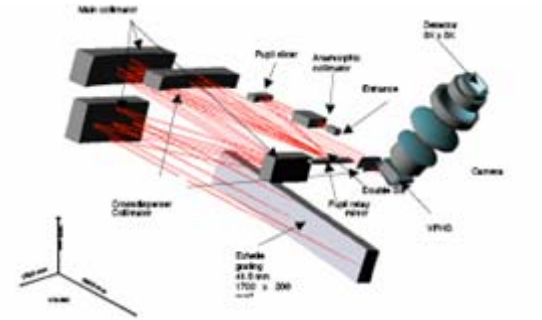
GALACSI-MUSE



SPHERE

Examples of E-ELT instrument concept studies

SCELT



CODEX (HiSPEC Visual)

HiSPEC IR

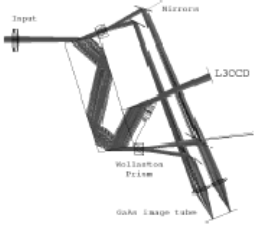
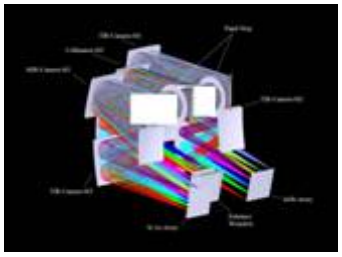
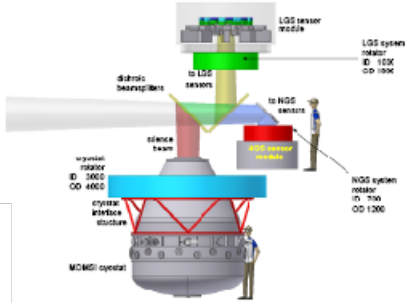


Figure B.2 GASP polarimeter, Zemax ray traces [6], courtesy of P. Collins

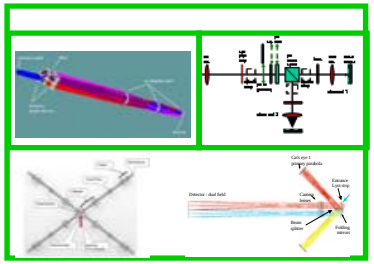
HiTri

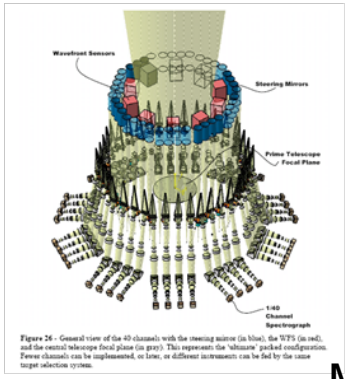


Planet Finder - EPICS



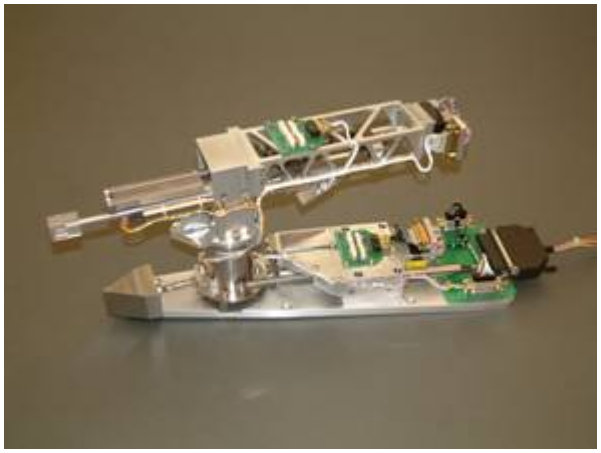
MOMSI



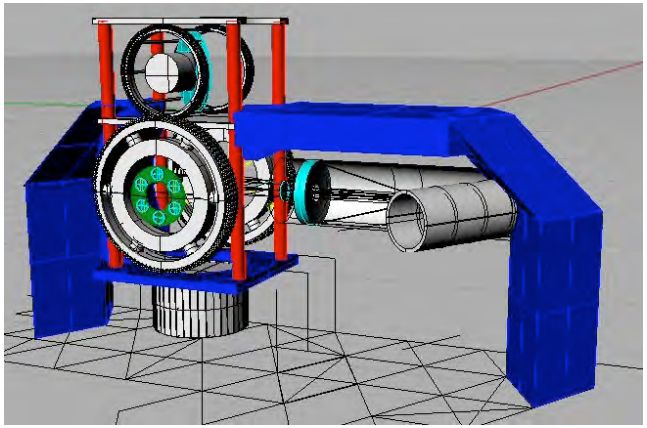


MIDIR

Many other activities ...



Smart focal planes



Subsystem design

Site testing