The European ELT
Phase B Status

Roberto Gilmozzi
E-ELT Principal Investigator

The European ELT

- **A project lead by ESO on behalf of 14 member states**
  - 42m adaptive telescope with segmented primary based on a 5-mirror design
- **Goal of Phase B**
  - Proposal for construction by 2010
- **Schedule:**
  - Detailed design phase until end 2010
  - Start of construction: 2011
  - First light: 2018
- **Cost**
  - Telescope + 1st gen instruments: ~ 950 million Euros
  - Operations (incl new instruments): ~ 35 M€/year
- **Resources**
  - 2007-2009: 57.2 M€ (including 110 FTEs)
  - 2008-2011: 5 M€ for E-ELT related R&D
  - Supporting activities from FP6 (28.8 M€) & FP7 (6.1 M€)

PHASE B STATUS

- **Telescope design being consolidated**
  - BRDv2 → BRDv3 (Review 26-28 Nov 2008)
- **All major telescope subsystems have started their iteration through industrial suppliers**
  - Several reached preliminary design and are moving to next
  - FEED studies ongoing
- **All Phase A instrumentation studies ongoing**
  - 8 instruments, 2 post-focal AO modules
- **Operations scenarios being analyzed**
  - Observing modes
  - Logistics, maintenance, safety
  - Operations costs evaluated
- **Progress of DRM and DRSP**
- **Site Selection Advisory Committe**
  - Nominated to help us select the site
- **Project funding:** Council discussions, EIB contacts
- **Major upcoming reviews:** BRD (05/2009), construction (09/2010)

Historical background

- Precursor (1977): 25m telescope ideas (Meinel et al)
- ELTs as we conceive them today have been around since the late 80s, early 90s: Swedish 25-m telescope
- mid 90s: OWL 100-m & CELT 30-m
- Early 00s: Euro-50, VLOT, GSMT, CELT, OWL, GMT
- In 2004 ESO Council resolved that:
  - *ESO's highest priority strategic goal must be the European retention of astronomical leadership and excellence into the era of Extremely Large Telescopes…*
  - *the construction of an Extremely Large Telescope on a competitive time scale will be addressed by radical strategic planning, especially with respect to the development of enabling technologies and the exploration of all options, including seeking additional funds, for fast implementation*

→ ***ELT effort re-oriented at the end of 2005 towards "the best affordable ELT Facility that can be built on a competitive timescale and with acceptable risks"***

- Mid 00s: consolidation to E-ELT, TMT & GMT

GUIDELINES

Affordable

- Cost ~ VLT, ALMA

Timely

- JWST (≥ 2013) synergy, competitors

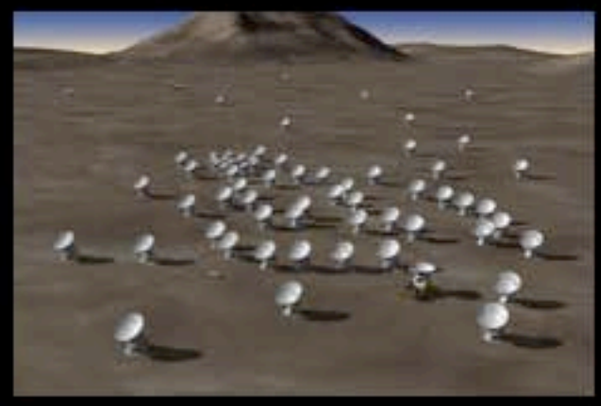
→ First science ~ 2018

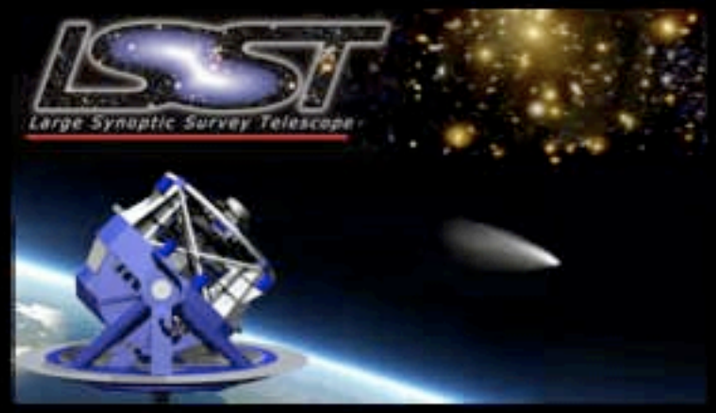
Acceptable risk

- No essential items R&D on critical path
- *Upgrade paths* where appropriate

Synergies

- The 8-10m class Telescopes (VLT/I, ...)
- The JWST
- ALMA
- LSST/Surveys
- SKA / SKA Pathfinders
- ...



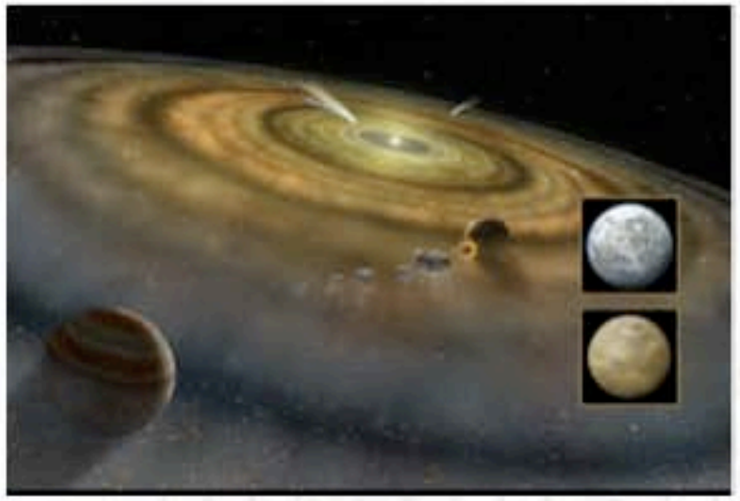


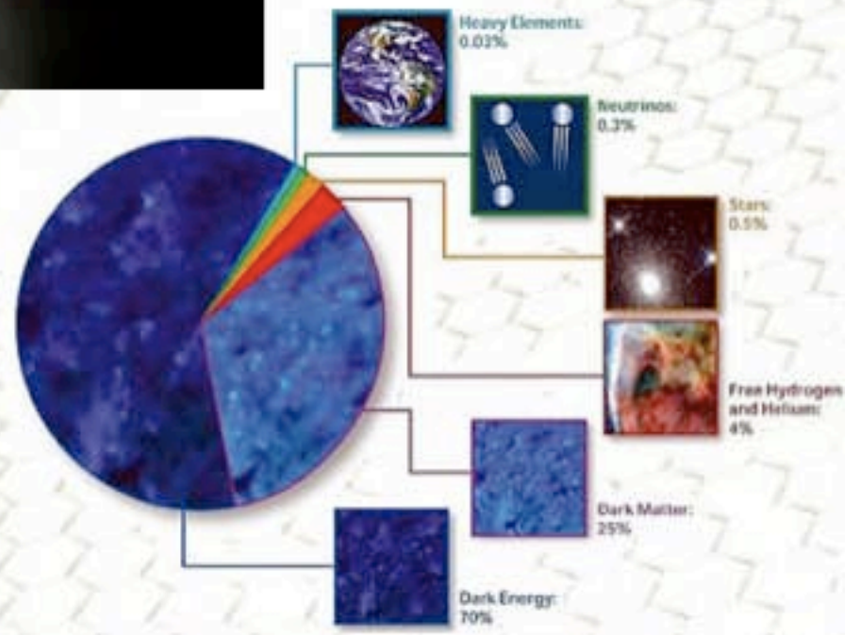
EELT BACKGROUND

- **November 2005:** OWL review concluded that although technically feasible the concept was too risky to conclude on a competitive timescale. The review board recommended that the project advance to phase B but to review high risk areas before doing so
- **January 2006 to April 2006:** The ESO DG called upon the community to establish 5 working groups to create a tool box for the EELT evolution.
- **April 2006 to December 2006:** ESO together with industrial and community support established a new baseline reference design for a 42-m European ELT.
- The design was blessed by the ELT Science & Engineering subcommittee of the ESO STC, the STC, the ESRC & the ESO community at the Marseille meeting.
- The ESO Council launched the phase B detailed design phase of the project in **December 2006** with a three year timeline and a budget of 57.2 Million Euro.

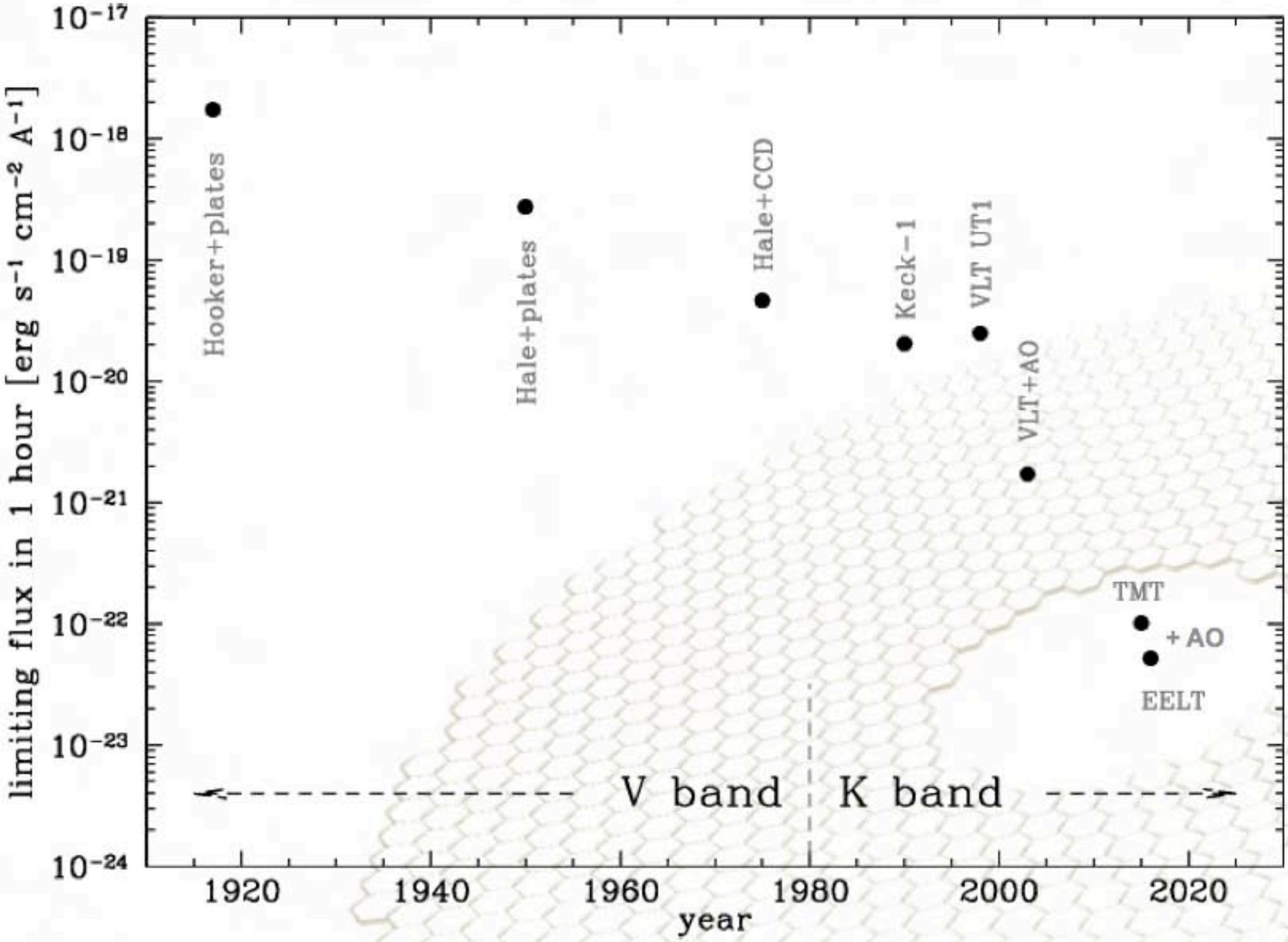
THE DRIVER

- **Planets in other stellar systems**
  - Imaging ***and*** spectroscopy
  - The quest for Earth-like exo-planets
- **Stellar populations**
  - In galaxies inaccessible today (e.g. ellipticals in Virgo cluster)
  - Across the whole history (i.e. extent) of the Universe
- **Cosmology**
  - The first stars/galaxies
  - Direct measure of deceleration
  - Evolution of cosmic parameters
  - Dark matter, dark energy
- **The unknown**
  - Open new parameter space

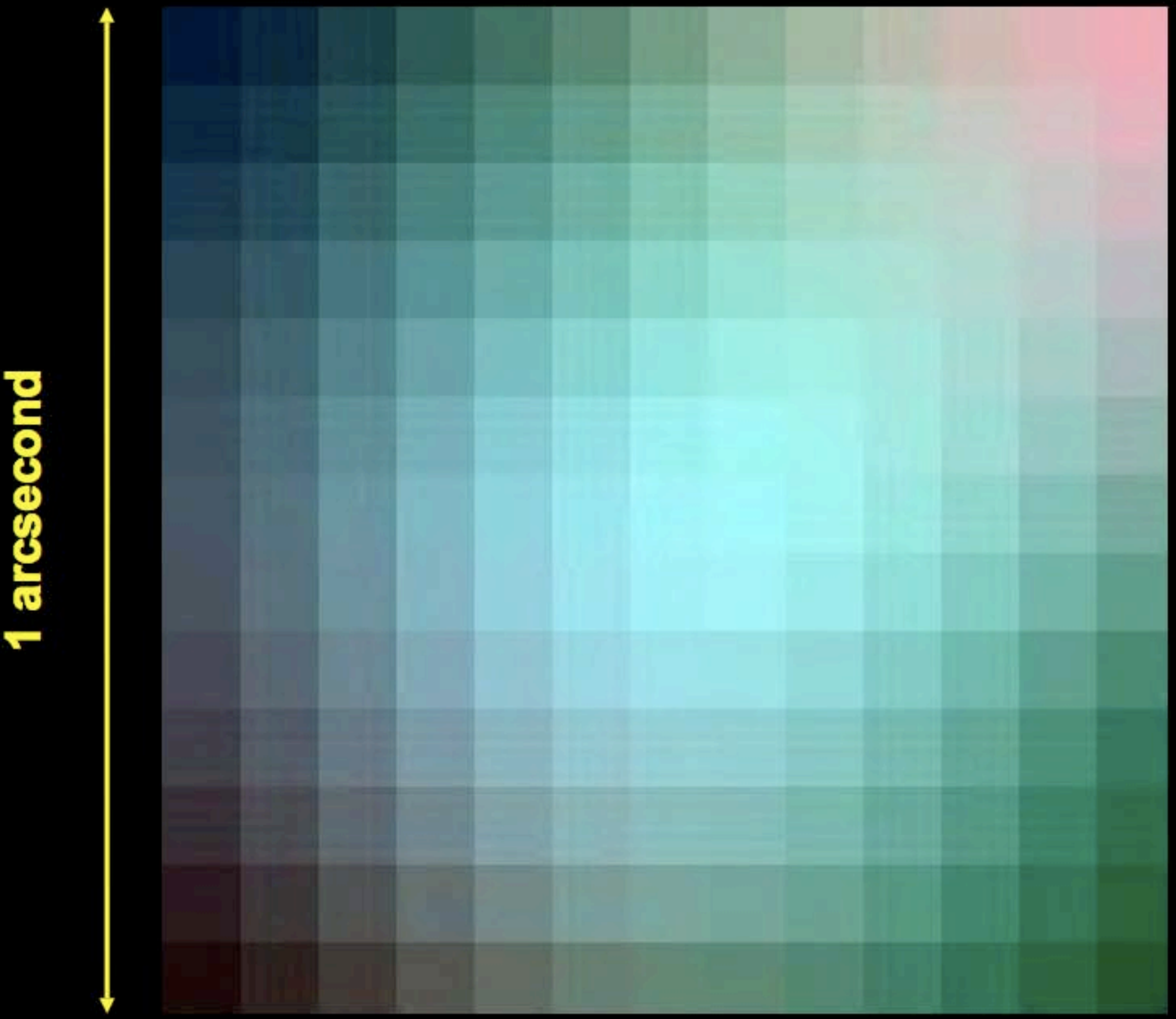




Sensitivity evolution



High spatial resolution



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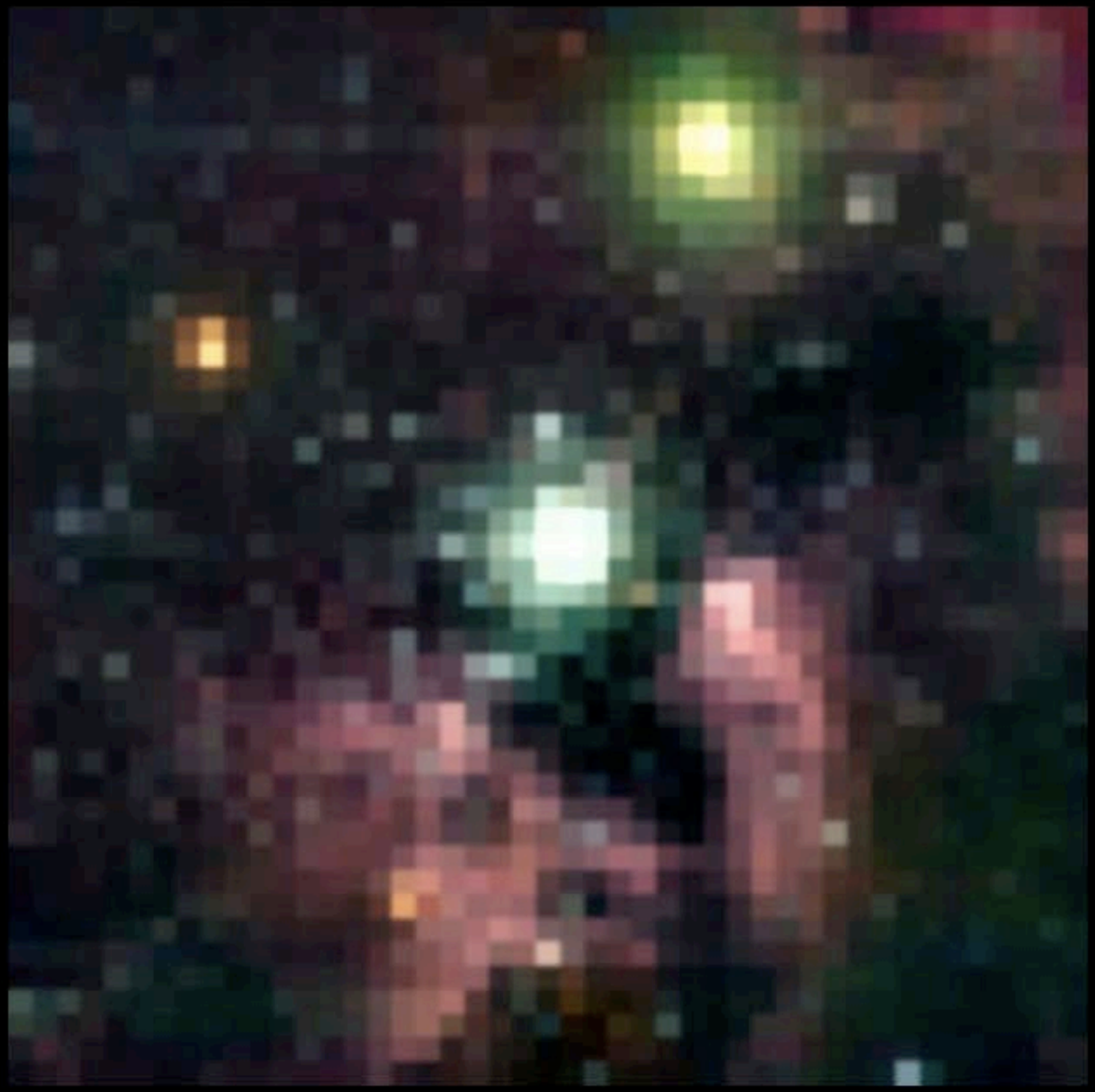
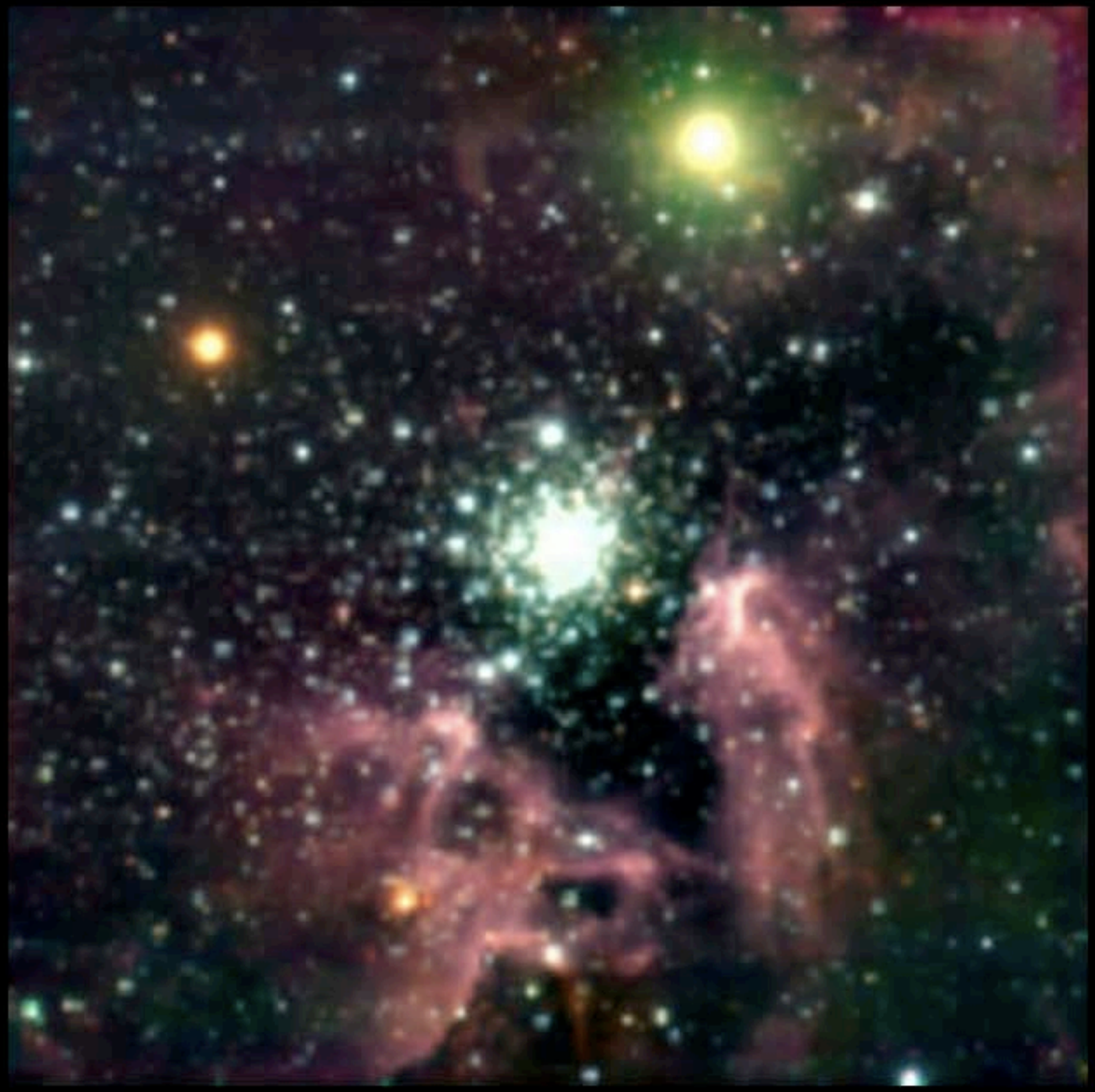


1 arcsecond

HST

HIGH SPATIAL RESOLUTION



1 arcsecond

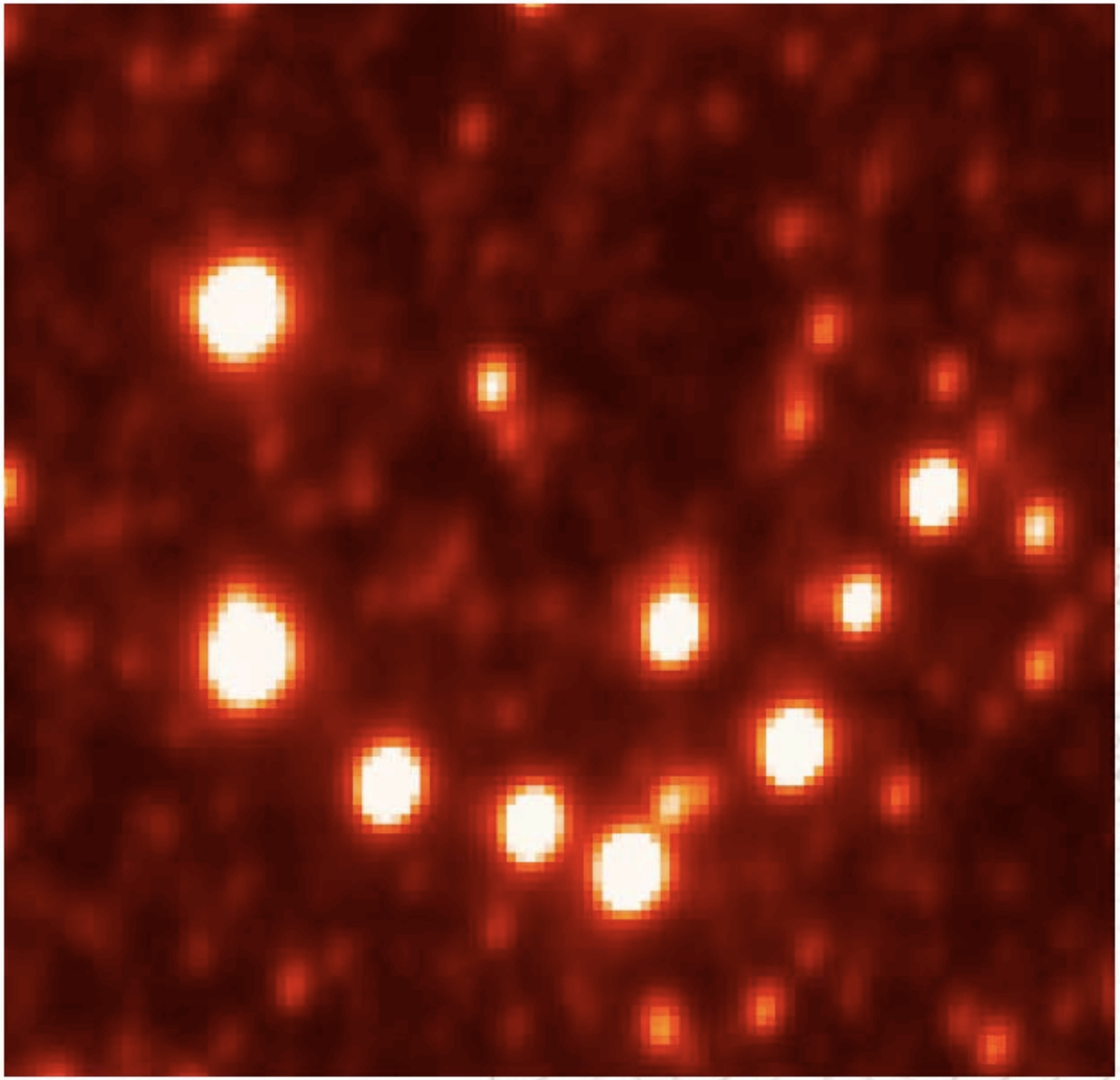
VLT+AO

HIGH SPATIAL RESOLUTION

1 arcsecond

E-ELT

AN AO MILESTONE: MAD

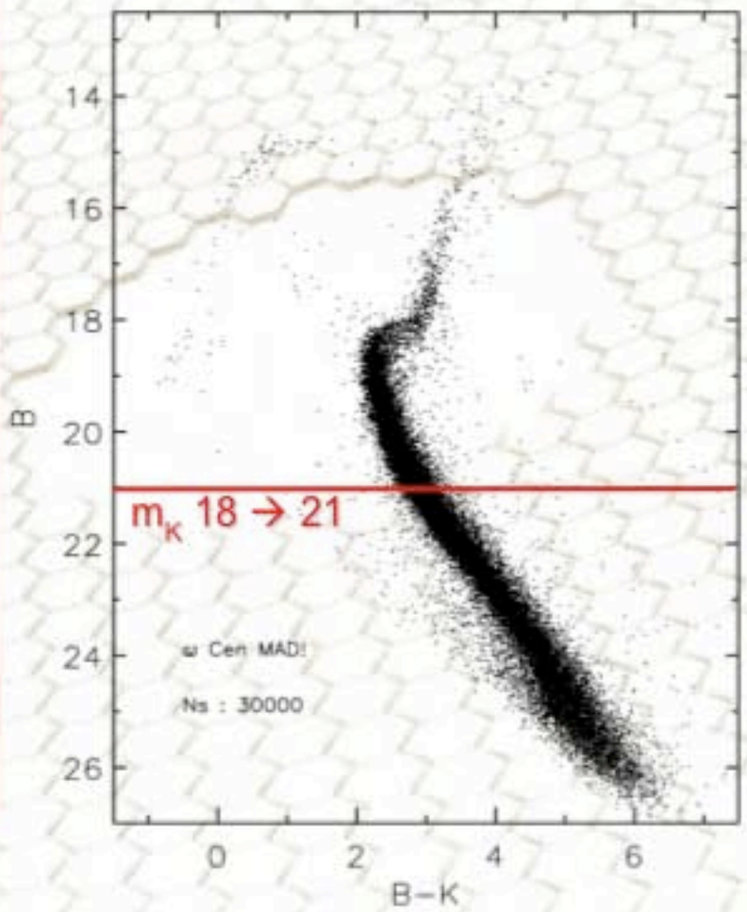


Field: 15x15”

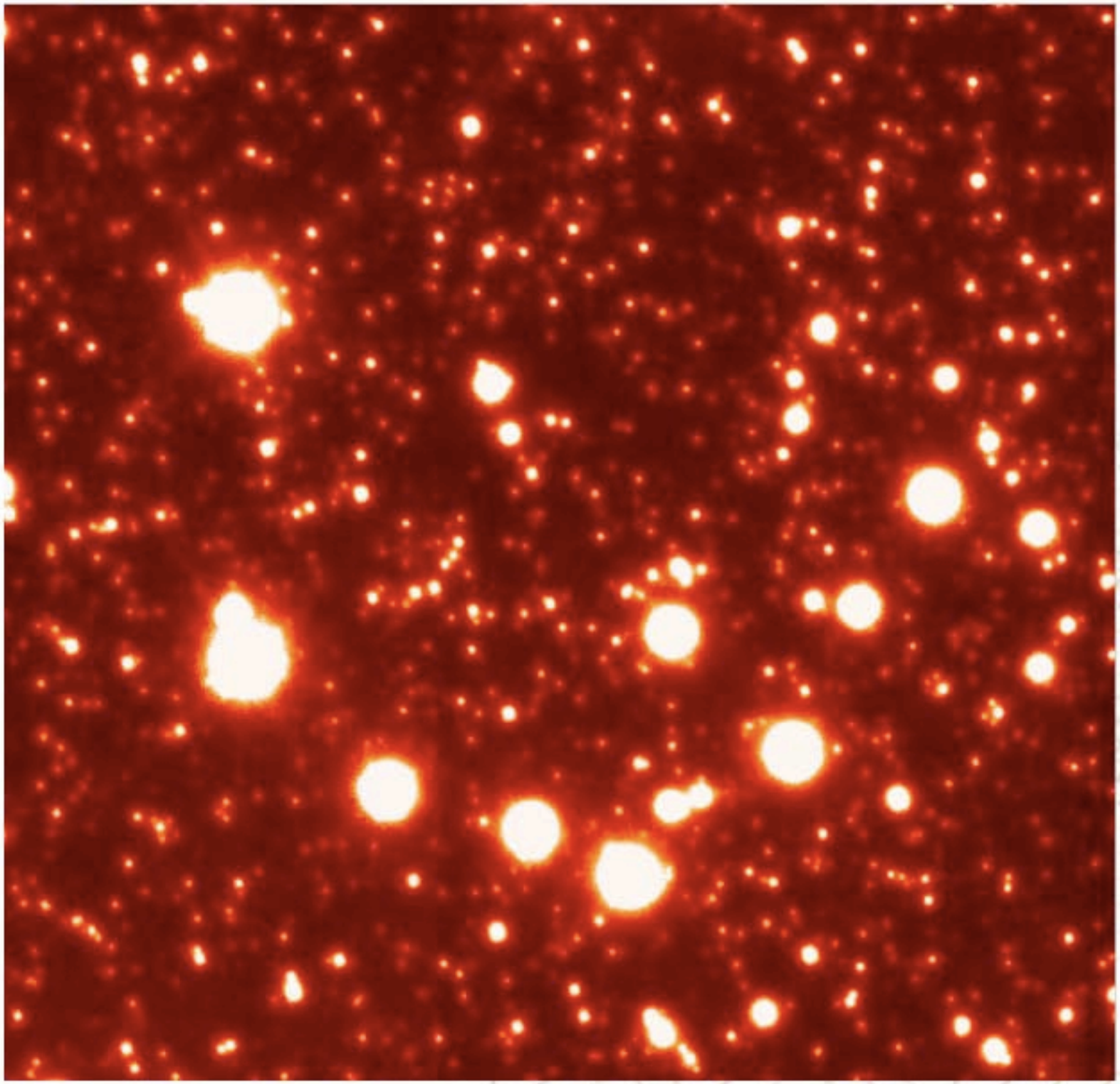
MCAO:

Guide stars at 2’
K-band
FWHM: 100-120mas
Sr: >20%
0.7” seeing
Exposure 360 s

ISAAC seeing: ~ 0.5”



AN AO MILESTONE: MAD



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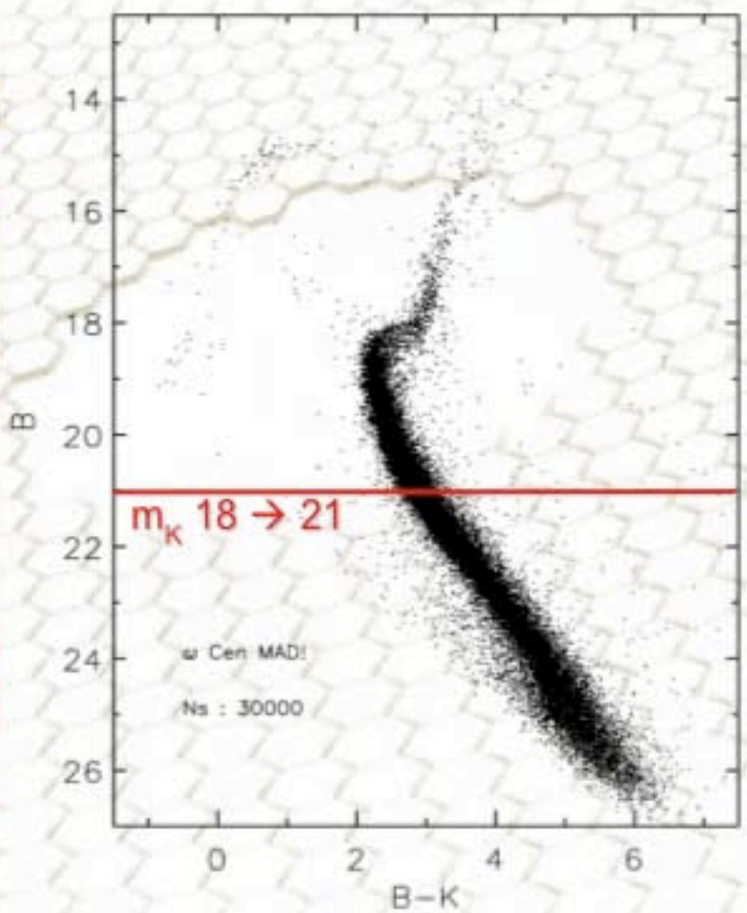
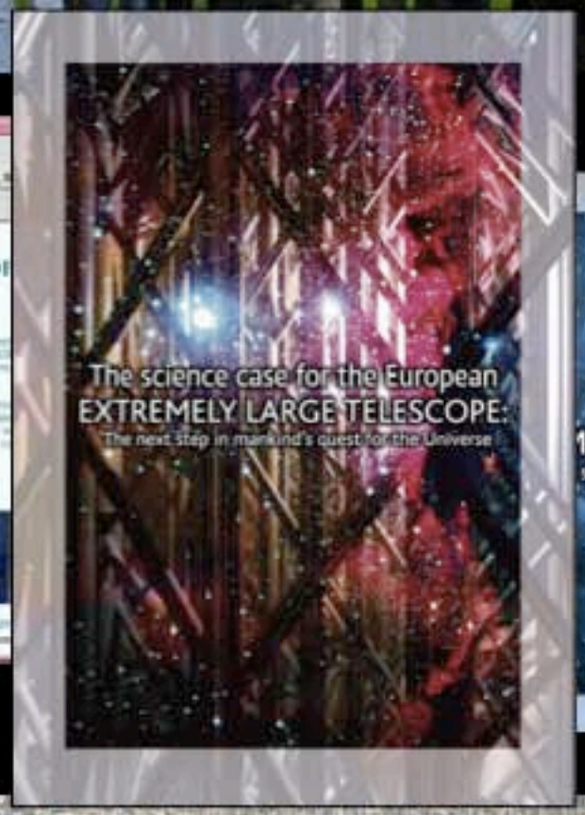


ELT SCIENCE CASE DEVELOPMENT IN EUROPE

Florence 2004

Web site



Marseilles 2003

Science case documents

Marseilles 2006

DRM CASES

Input from: Community, SWG
Simulations: EScO, Community

Stars & Galaxies

* G4: Imaging and spectroscopy of resolved stellar populations in galaxies (demo case)
  - 1- The Resolved Stellar Populations of Elliptical Galaxies
  - 2- The Chemo-Dynamical Structure of Galaxies
  - 3- First Stars relics in the Milky-Way and satellites

* G9: Black holes and AGN
  - 1- A Survey of Black Holes in Different Environments
  - 2- High precision dynamics of black hole/star binaries: a test of General Relativity

Planets & Stars

* S3: From giant to terrestrial exo-planets: detection, characterisation and evolution (demo case)
  - 1- Direct imaging of terrestrial and giant exo-planets
  - 2- Detection of New Earths
  - 3- Rocky planets in the habitable zones of low-mass stars and brown dwarfs
  - 4- Physical properties of Earth-sized planets

* S9: Circumstellar disks
  - 1- Imaging the planet-forming regions of circumstellar disks
  - 2- Dynamics and chemical evolution of circumstellar disks

* S5: Young stellar clusters and the Initial Mass Function
  - 1- Characterising the lowest mass freely floating objects
  - 2- The Centres of Massive Dense Young Clusters: deep ELT infrared imaging and 3D spectroscopy
  - 3- The low-mass Initial Mass Function in the Magellanic Clouds
  - 4- Giant-planet-mass objects in the Large Magellanic Cloud

Galaxies & Cosmology

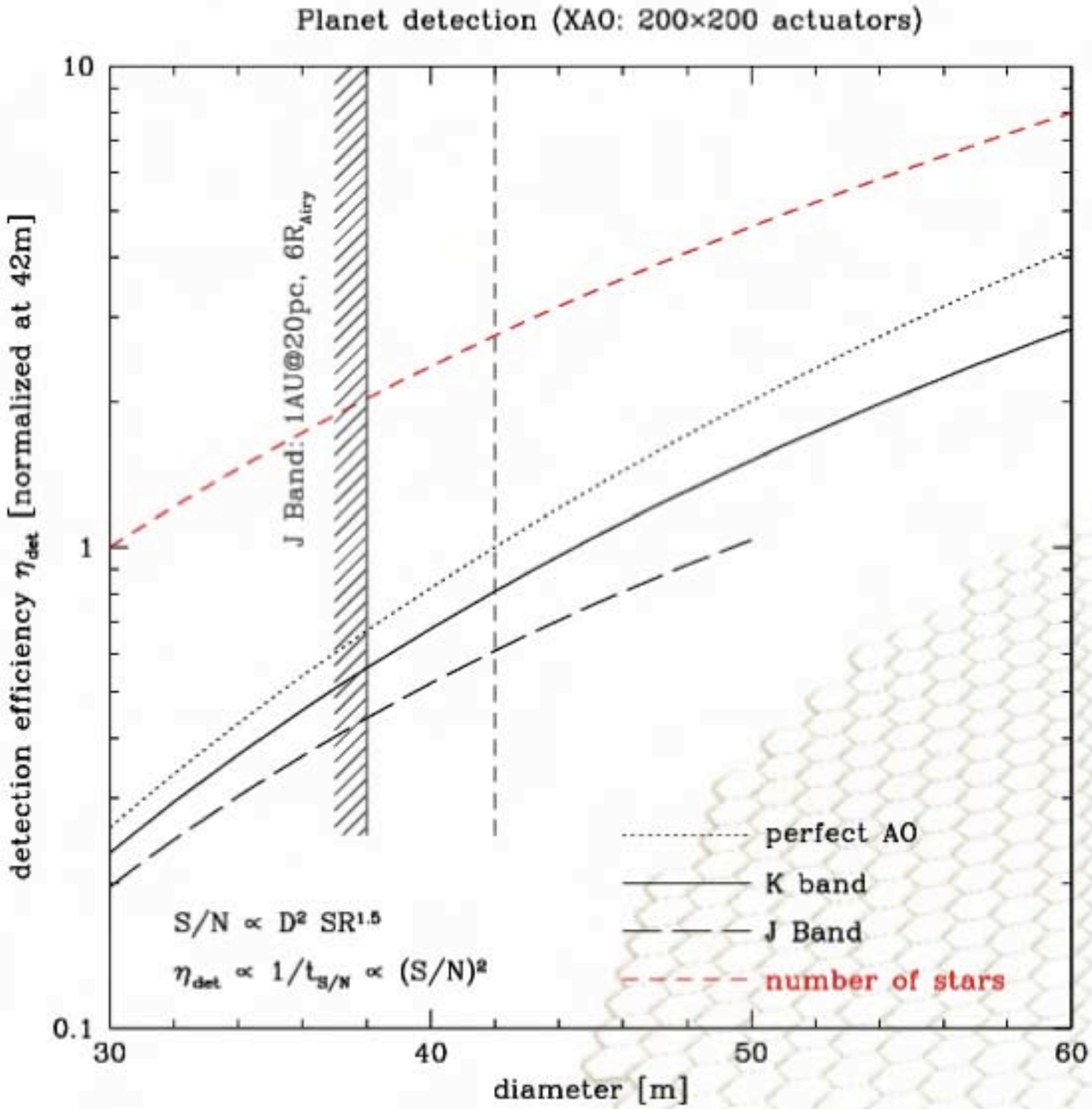
* C10: The physics of high redshift galaxies (demo case)
  - 1- The Physics and Mass Assembly of Galaxies out to z=6
  - 2- High resolution imaging of high redshift galaxies
  - 3- ELT integrated spectroscopy of early-type galaxies at $z > 1$

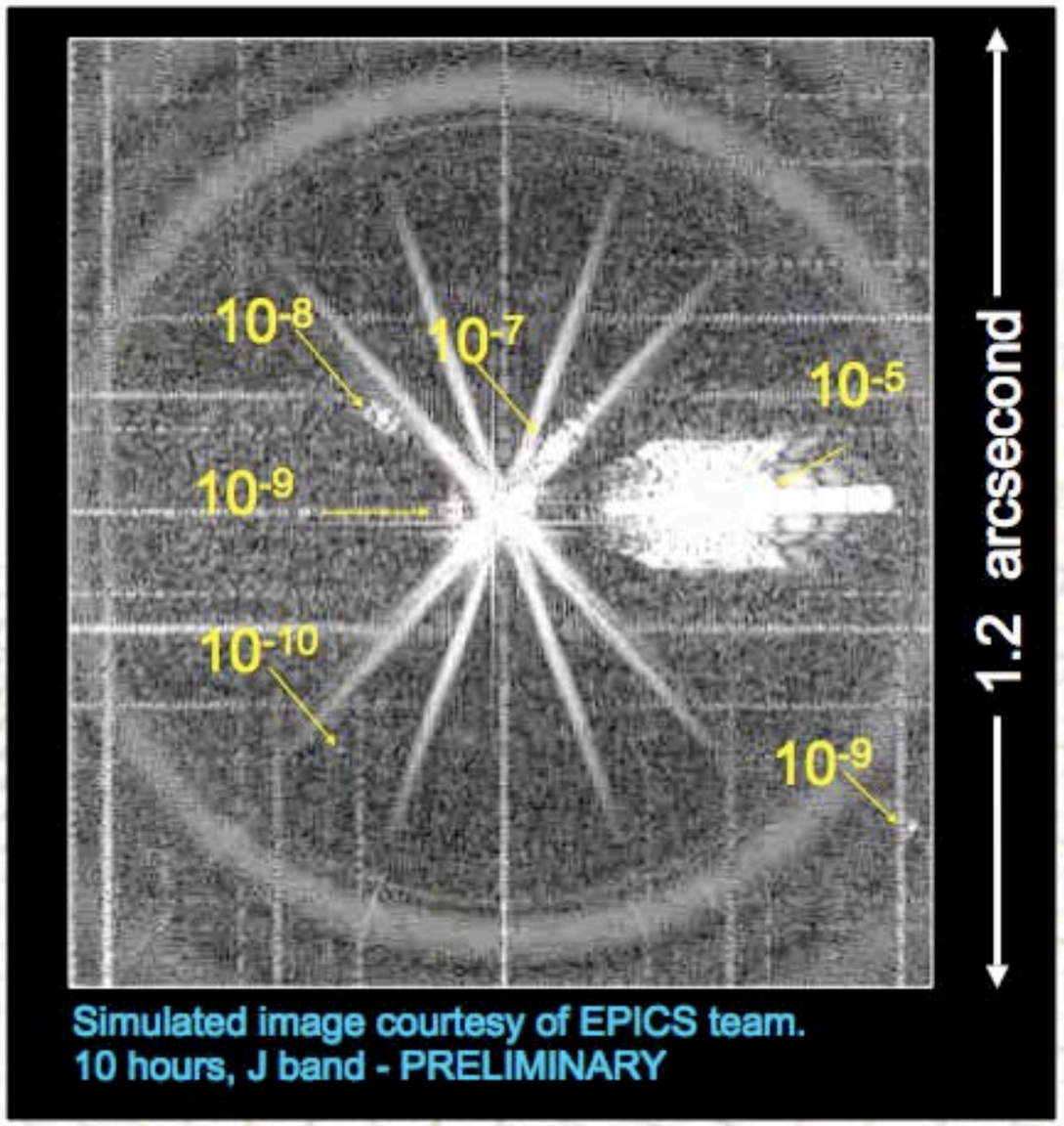
* C4: First light - the highest redshift galaxies
  - 1- The highest redshift galaxies at $z > 6$

* C7: Is the low-density intergalactic medium metal enriched?
  - 1- Is the low density IGM at z=2-3 metal-enriched?

* C2: A dynamical measurement of the expansion history of the Universe
  - 1- Monitoring the redshift drift of the Lyman-forest, a direct measurement of the dynamical evolution of the Universe

EXOPLANET DETECTION





THE SIMULATIONS

Example:
Stellar population
of a galaxy
in a nearby galaxy cluster

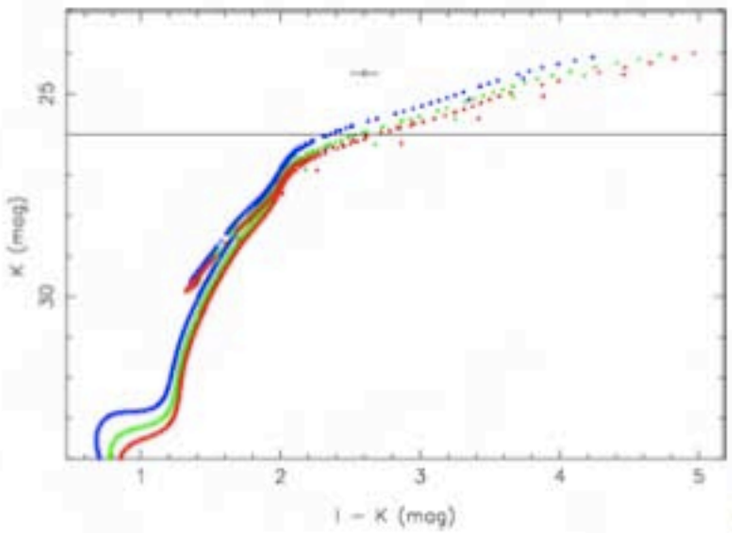
I-band

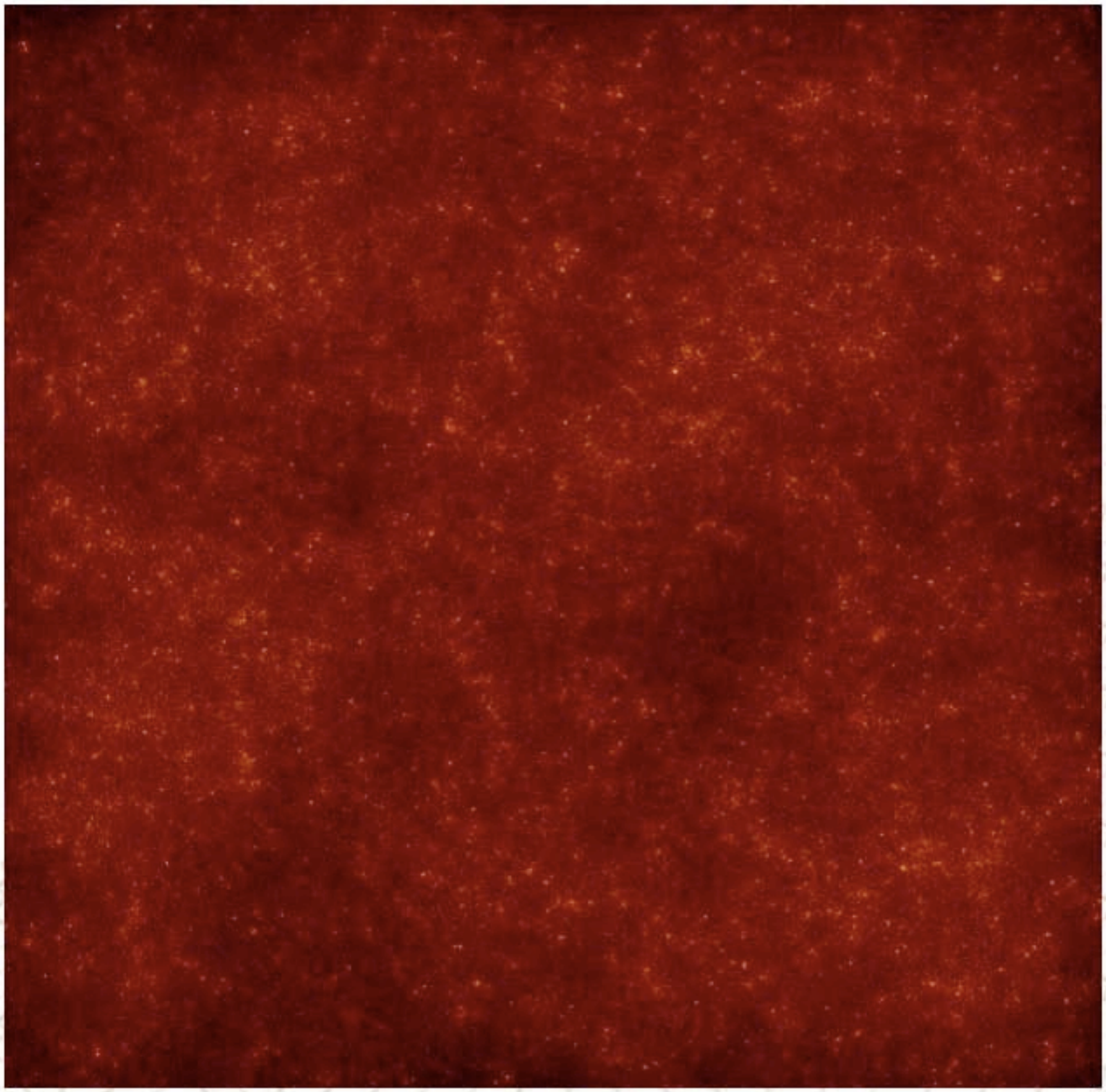
10 hours

3x3 arcsec^2

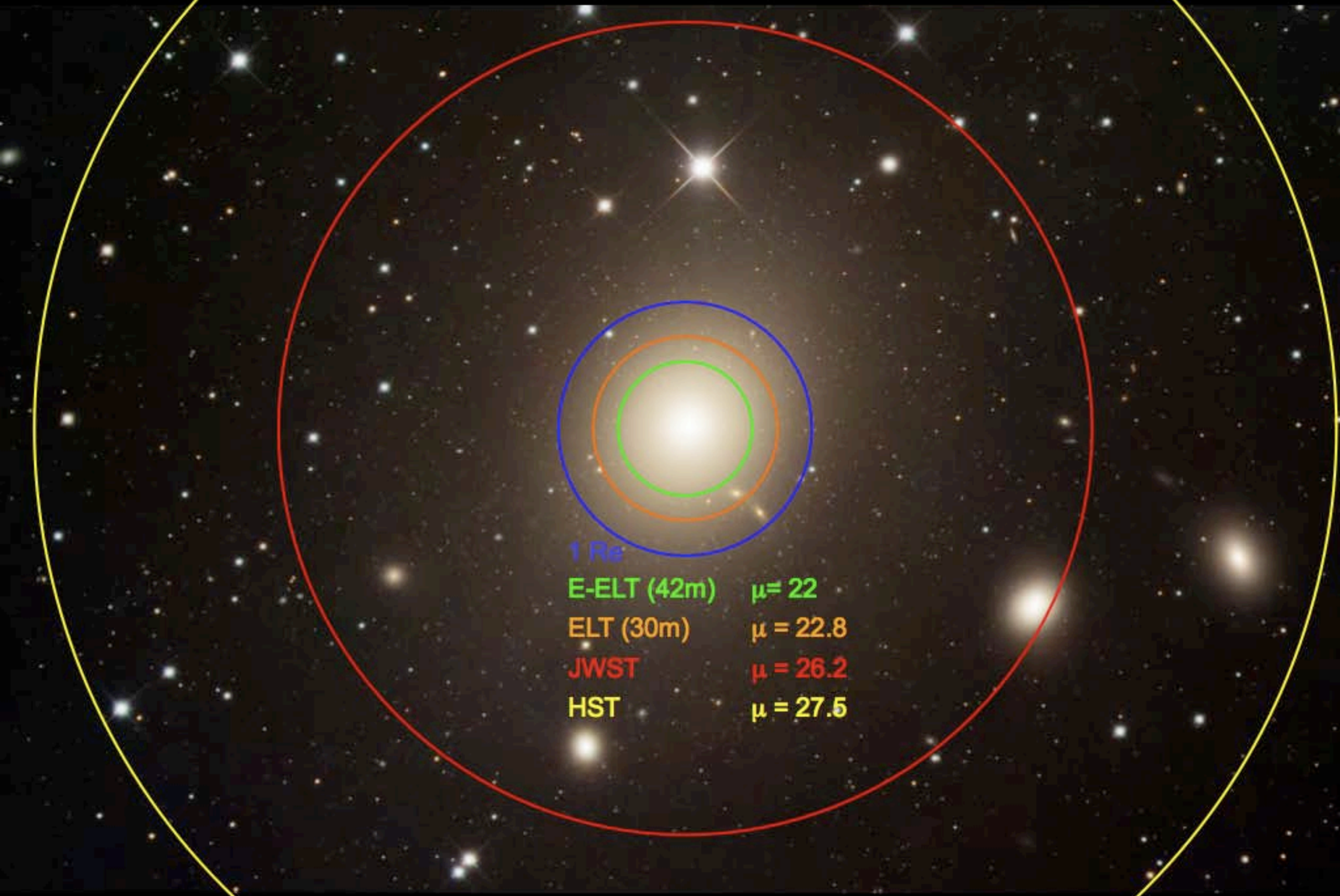
DM = 31.2

μ = 23 mag/arcsec^2

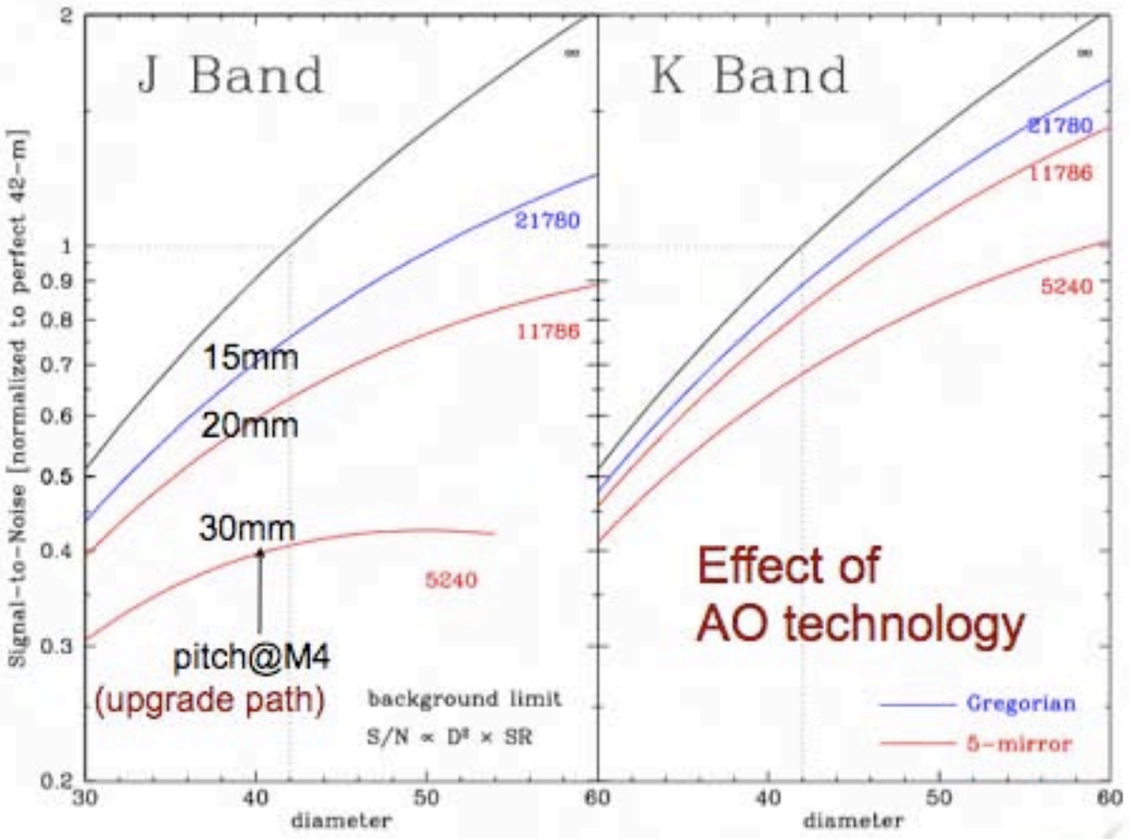


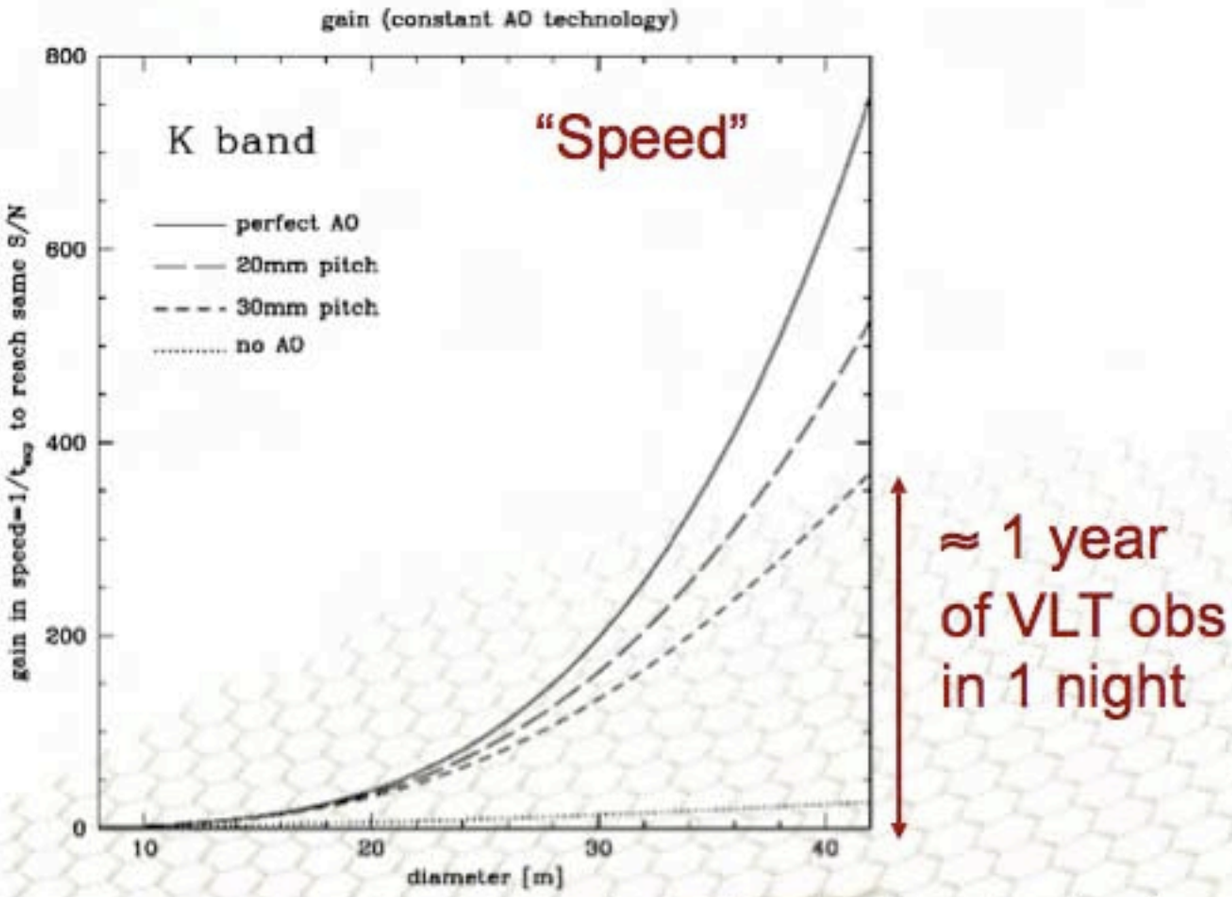


M87 (DM = 31.2)



SUMMARY: POWERFUL PERFORMANCE





$S/N = F / \sqrt{(F+B+\ldots)}$

Flux: $F \propto F_0 \times SR \propto D^2 \times SR$

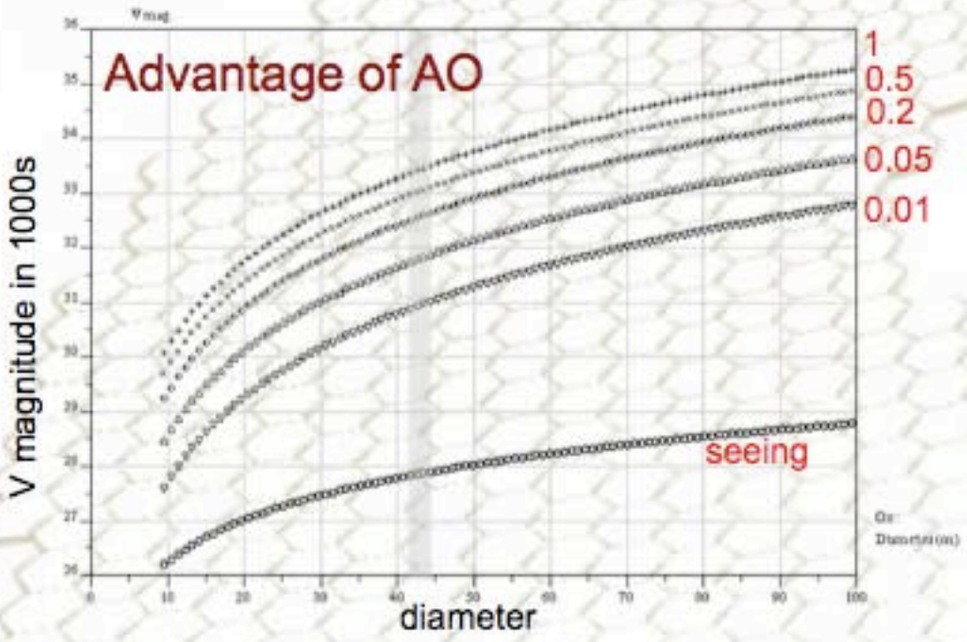
Bgd: $B = sky \times pix^2 \propto D^2 \times D^{-2} \equiv B_0$

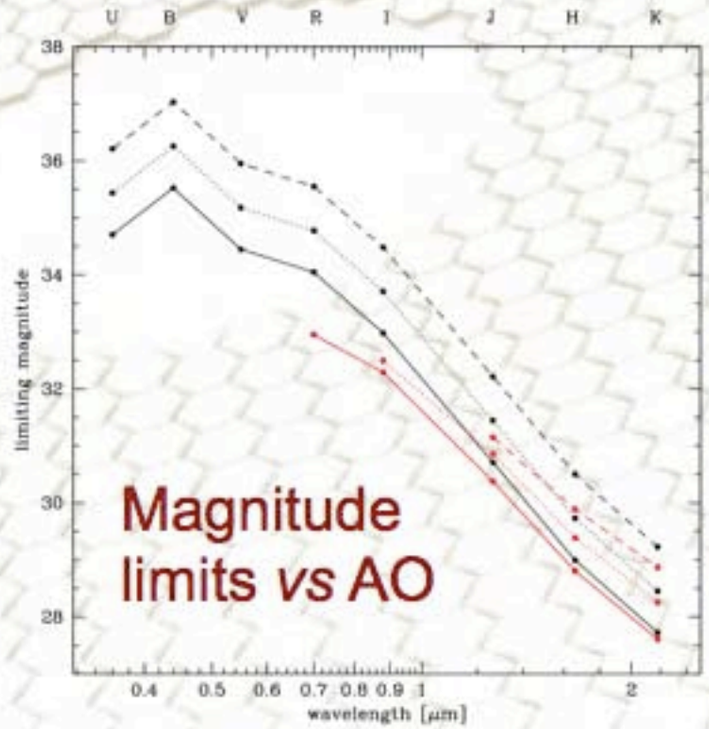
For faint sources:

$S/N \approx F/\sqrt{B} \propto \mathbf{D^2 \times SR}$

For exo-planets:

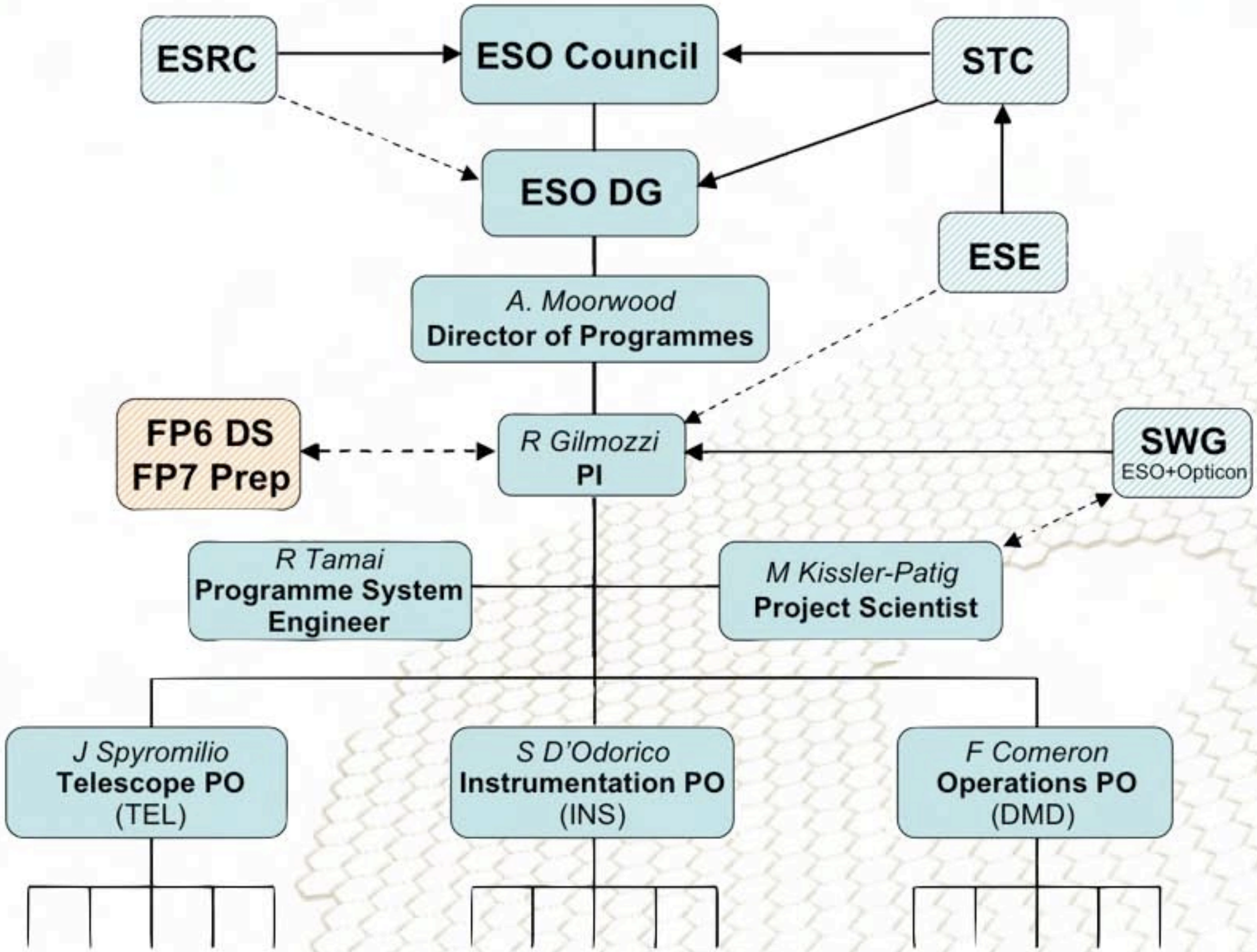
$S/N \approx F/\sqrt{B_\star} \propto \mathbf{D^2 \times SR^{3/2}}$





Status of the Design

Programme Organization



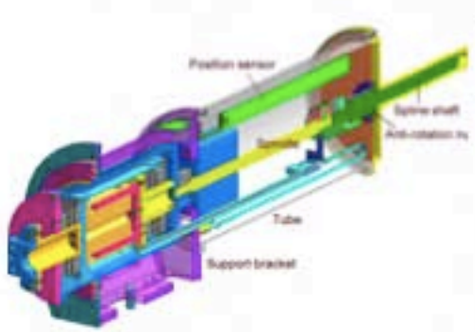
THE FP INITIATIVES

- **FP6: ELT DS**

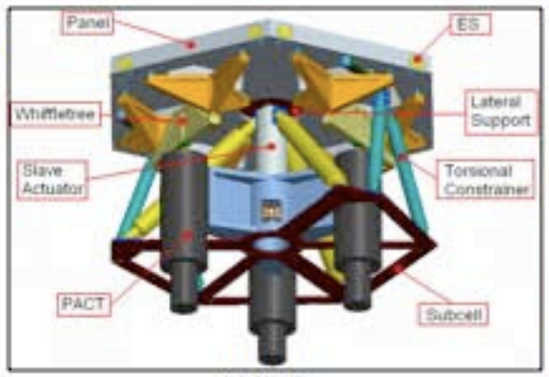
  Foster industrial and academic readiness to build an Extremely Large Telescope

  ➡ **Originally design independent**

  Realigned to the EELT specs after EELT BRD endorsed by ESO's committees and the wider community (Dec 2006)



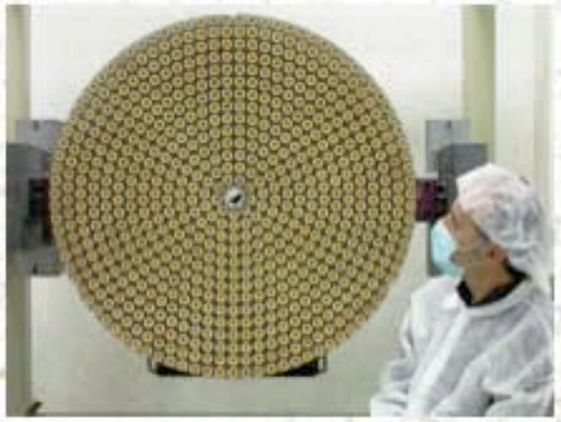
Metrology



WEB


APE


Friction drive BB


Large DMs

- **FP7: EELT Prep**

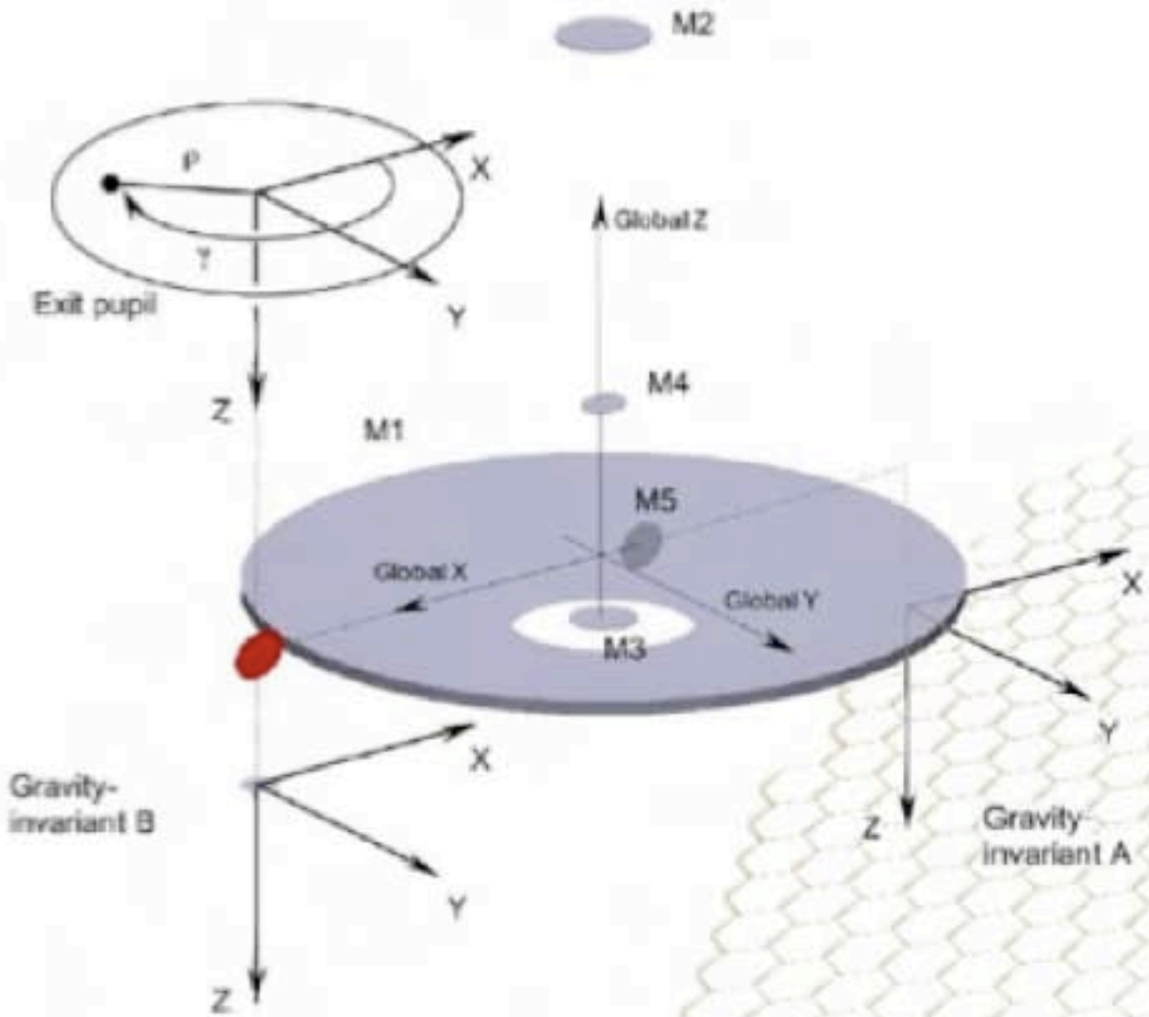
  Support preparedness to start construction phase

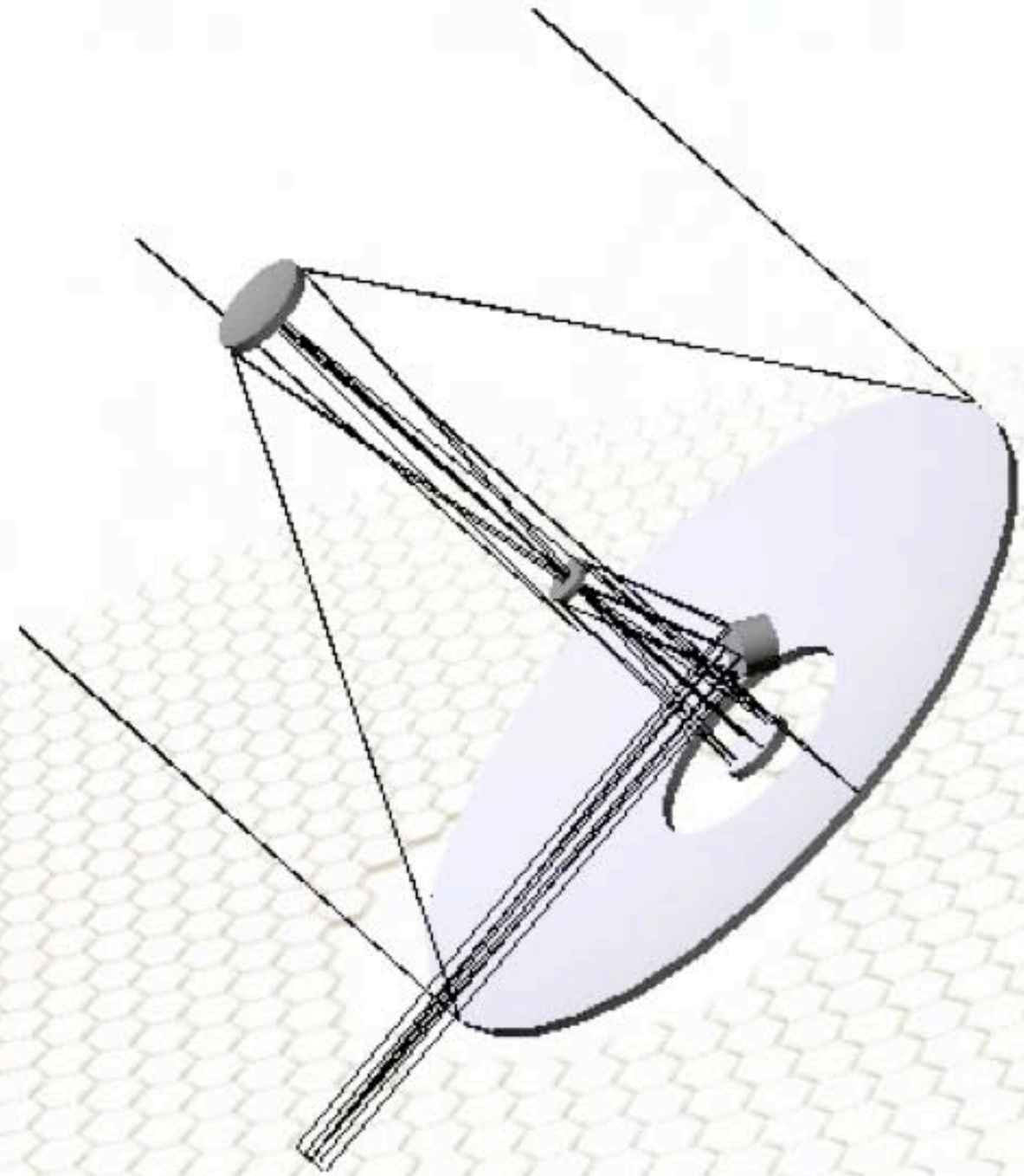
  Funding scenarios, expanded partnership, international cooperation, centers of excellence, science access

  Design Reference Mission

  Upgrade paths

The Telescope

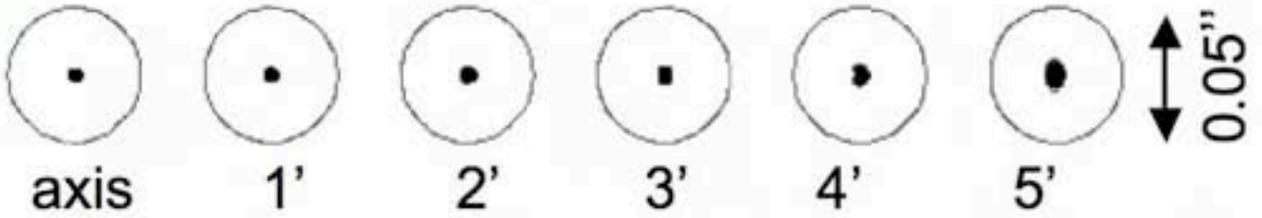


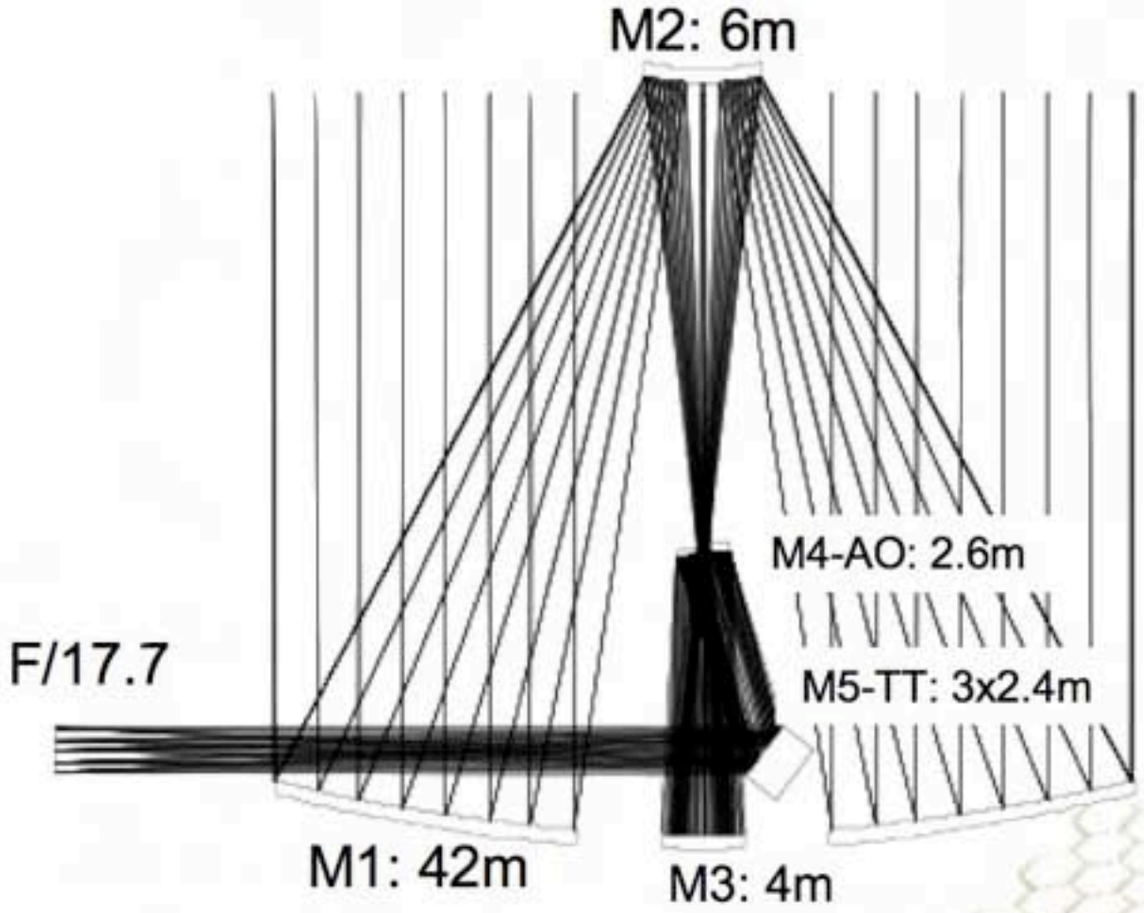


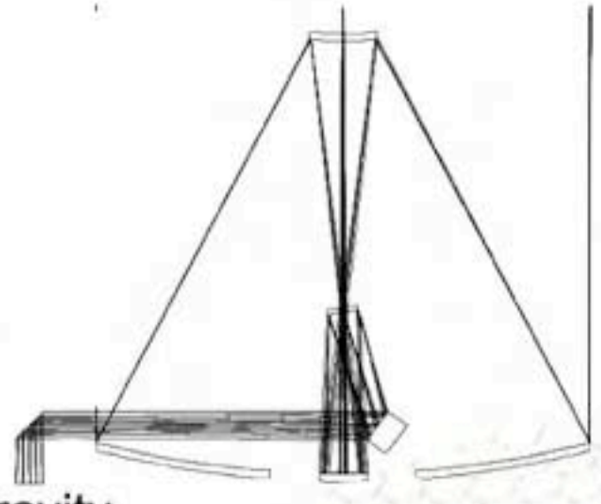
Top Level Requirements

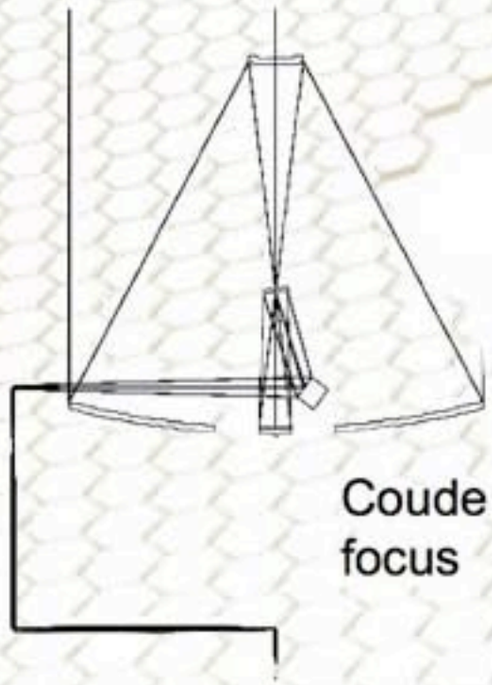
- Diameter: ≥42m (area ≥ 1200 m^2)
  - Alt-Az, F/15 to F/18, fully steerable (0-360,0-90). Operational ZD: 0-70
- Adaptive telescope
  - GLAO correction (≥ 5 arcmin, 90% sky, 80% time)
    - better than 2x FWHM improvement for median seeing conditions
  - Post-focal: SCAO, MCAO, LTAO, ExAO, MOAO, ...
- Science field of view:
  - 10 arcmin unvignetted. Diffraction limited by design
  - 5 arcmin unobscured by guide probes
- Wavelength range: 0.3 − 24 μm
- Transmission @Nasmyth:
  - >50% at >0.35 μm, >60 % at >0.4 μm, >70% at 0.7 μm, >80% at > 1 μm
- Focal stations
  - Two Nasmyth (multiple instruments, including gravity invariant option)
  - At least one Coudé
  - Fixed instrumentation (fast switching: < 10 min same focus, < 20 otherwise)

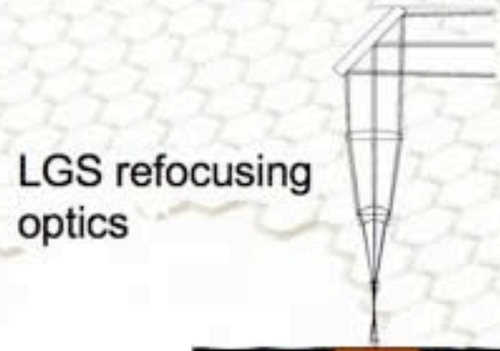
Novel 5-mirror optical design

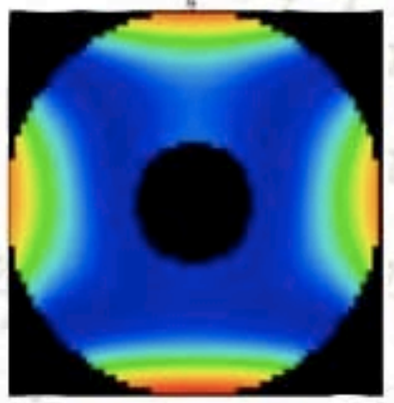










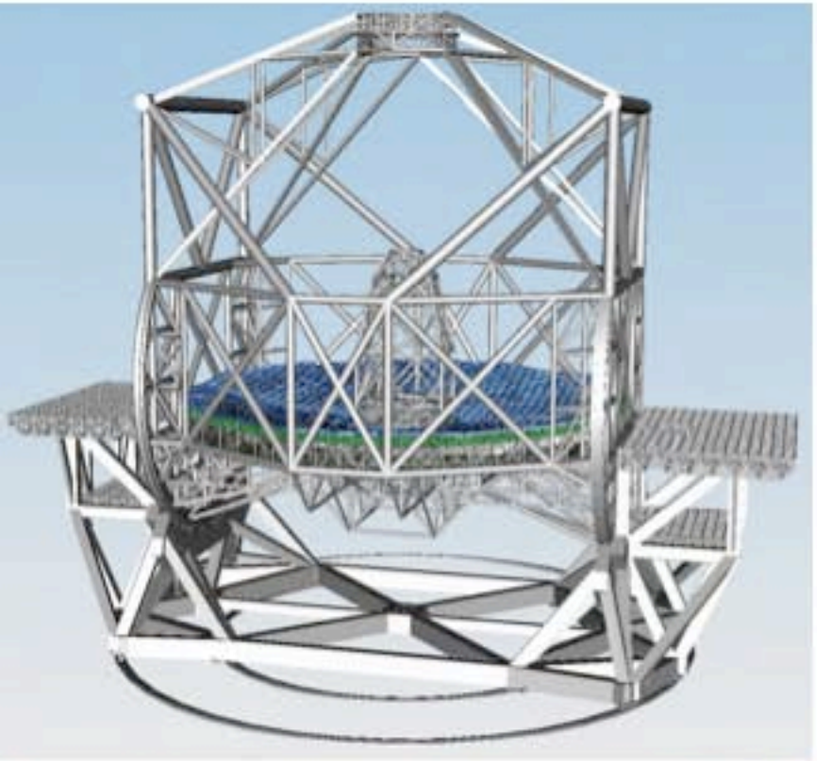


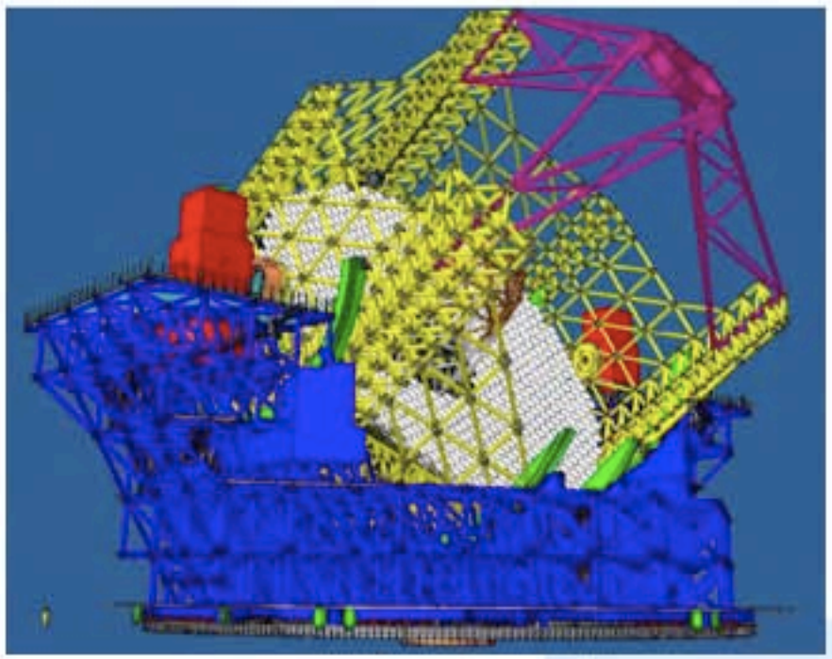
LGS wavefront
4.5' off axis
106 nm rms

Main advantages:

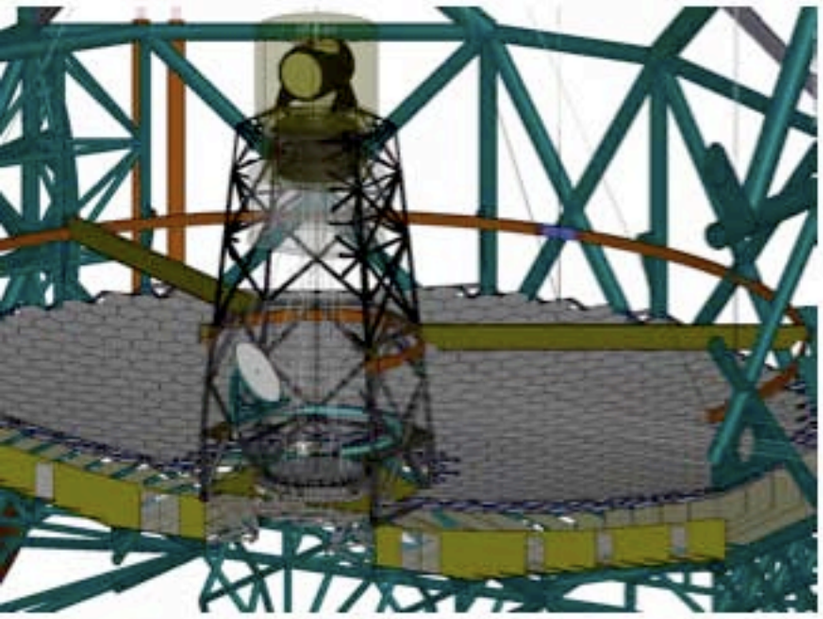
- *image quality*
- *flat, telecentric FoV*
- *zoom capability*
- *laser "friendly"*

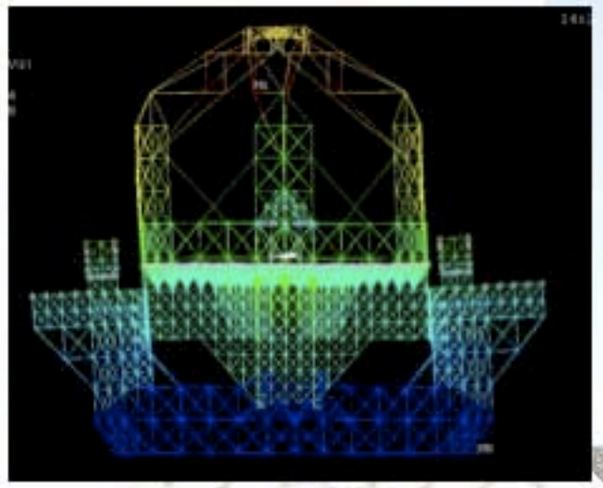
Telescope Mount

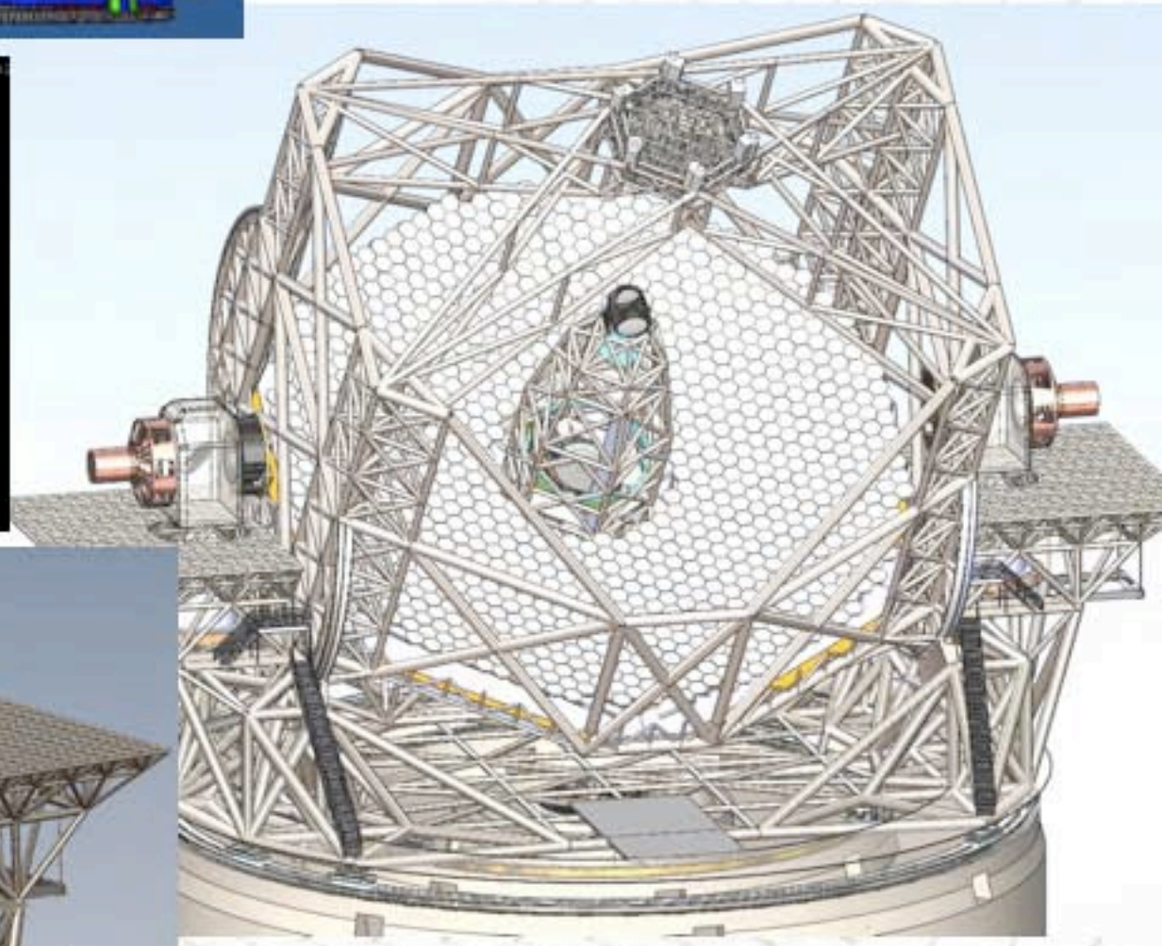


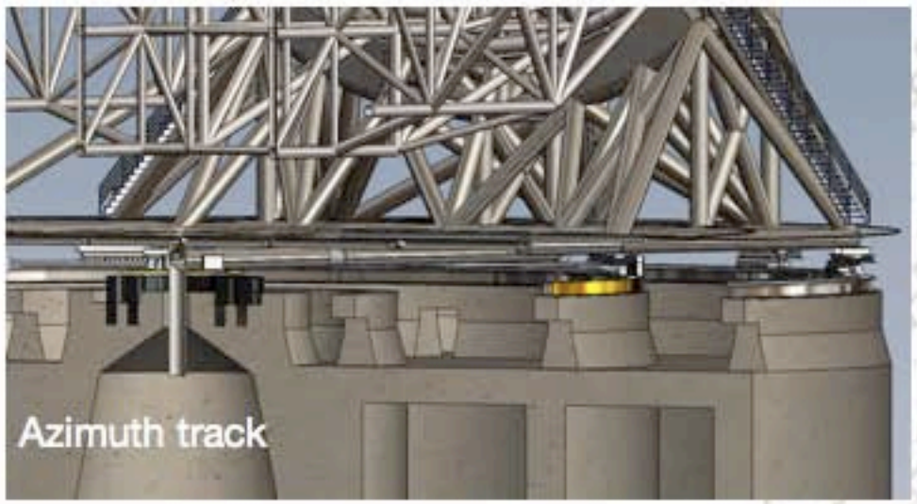


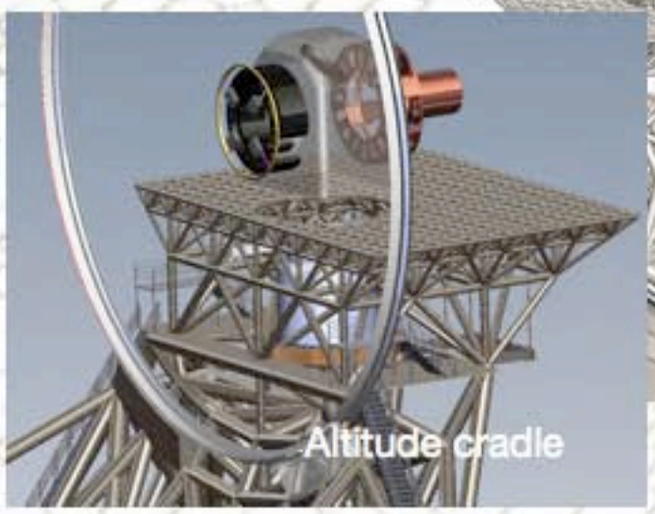
- Two cradle solution
- **Two industrial contracts concluded**
- **FEED ongoing**
- Confirm cost and schedule
- Excellent stiffness (≥3Hz)



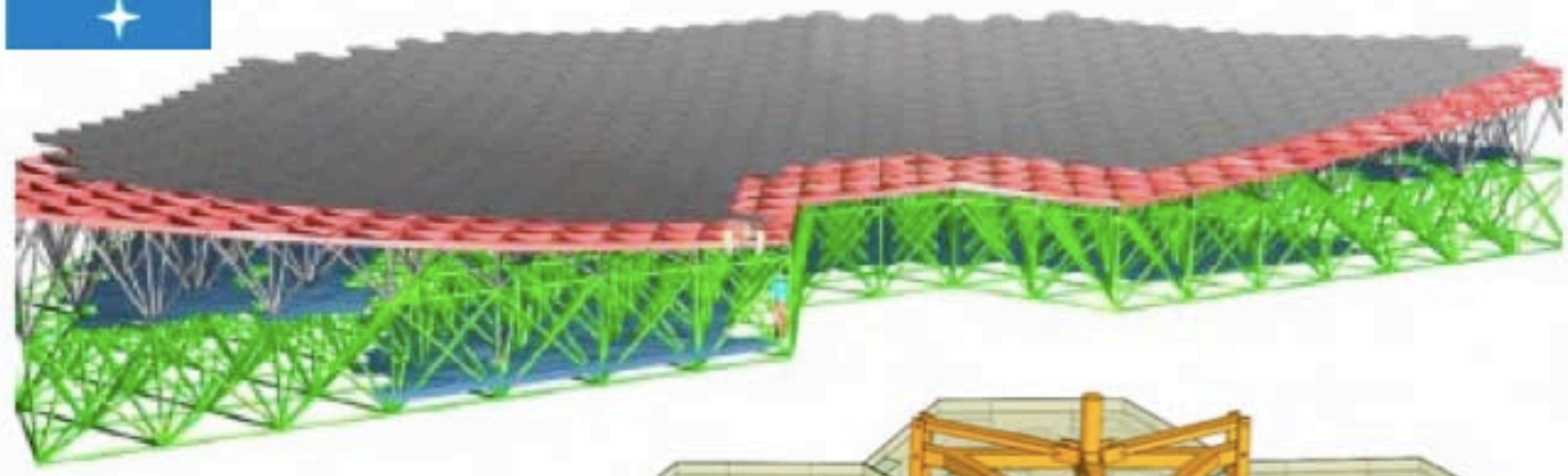






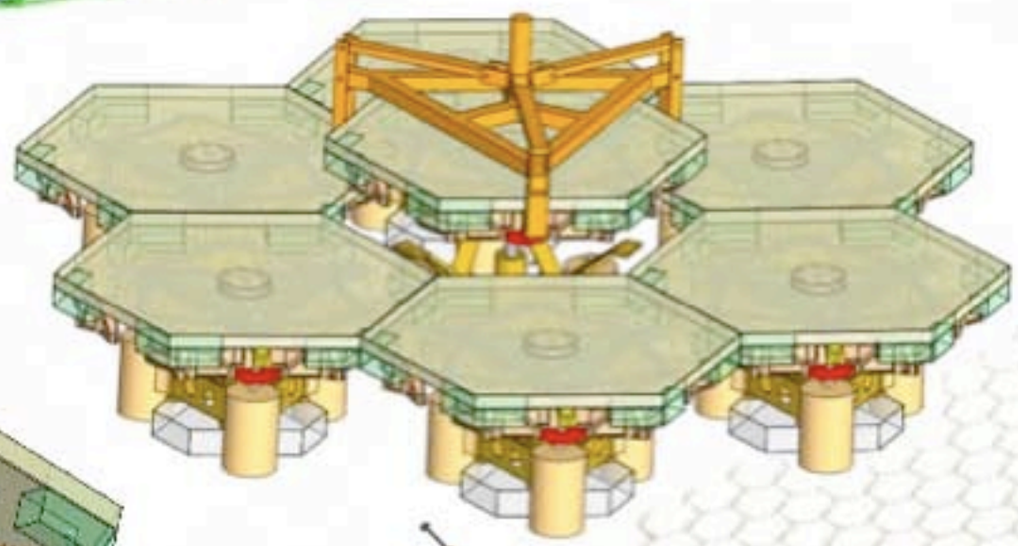


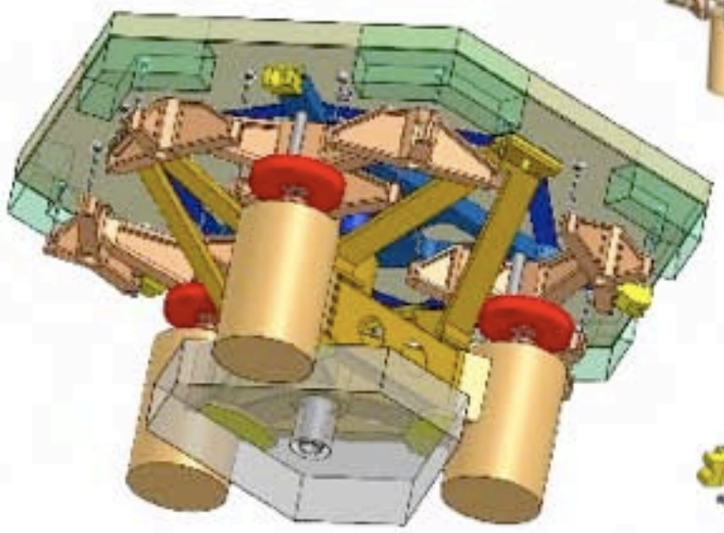
The M1 mirror

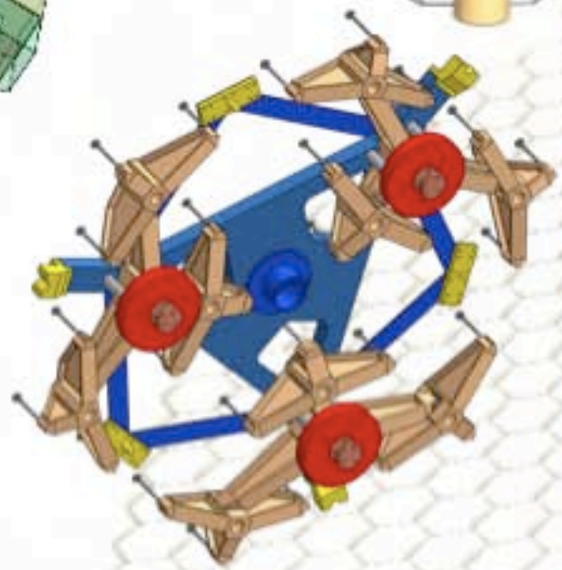


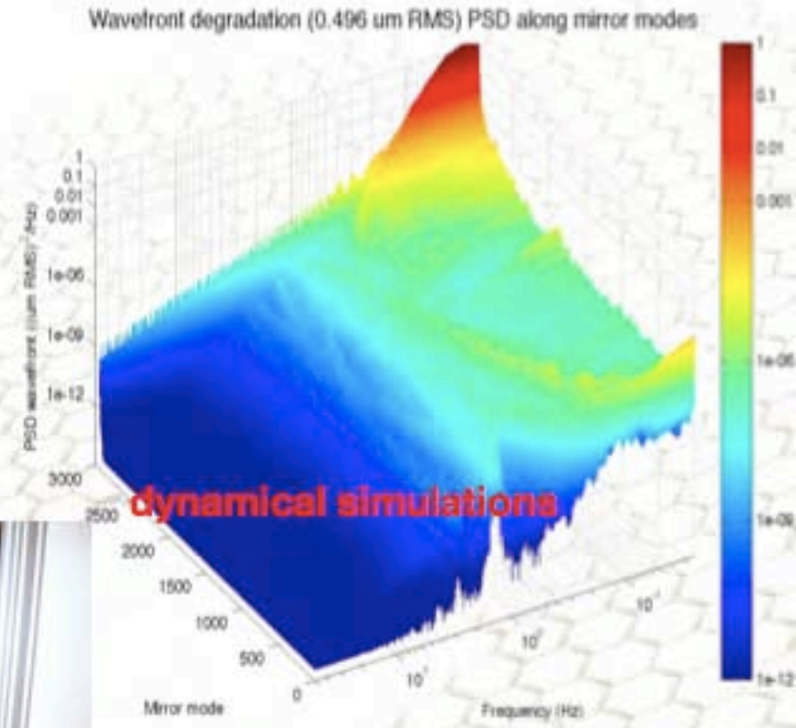
Segment dimensions:
1428.64 mm – 1414.00 mm
(1387.29 - 1427.13 @pupil)
central thickness: 50 mm
gap: 4 mm
bevel 2: mm (goal 1.5)

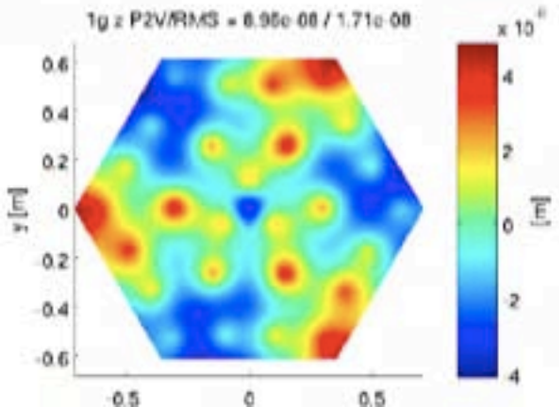
1148 segments:
984 mirror +
1 spare/family







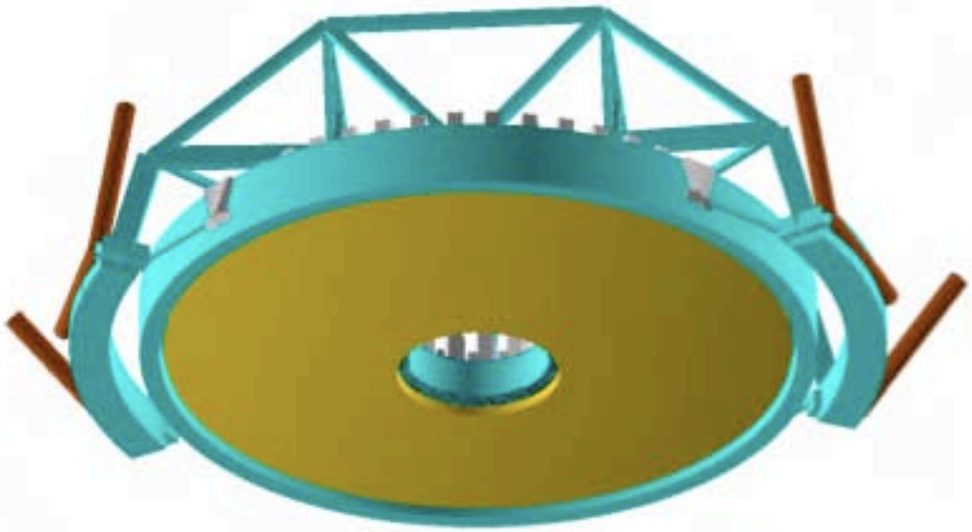


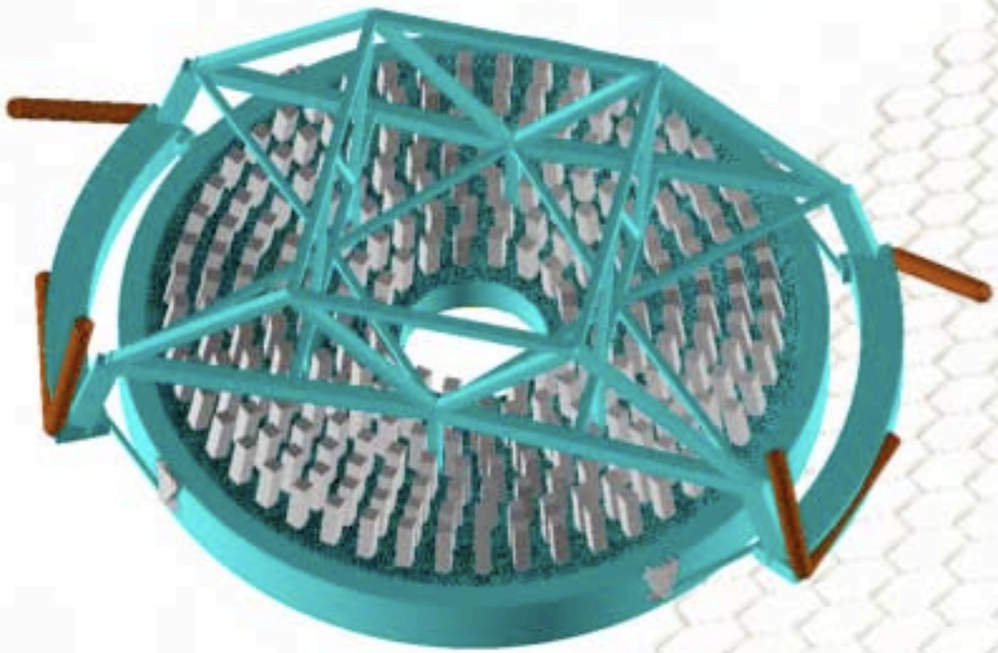


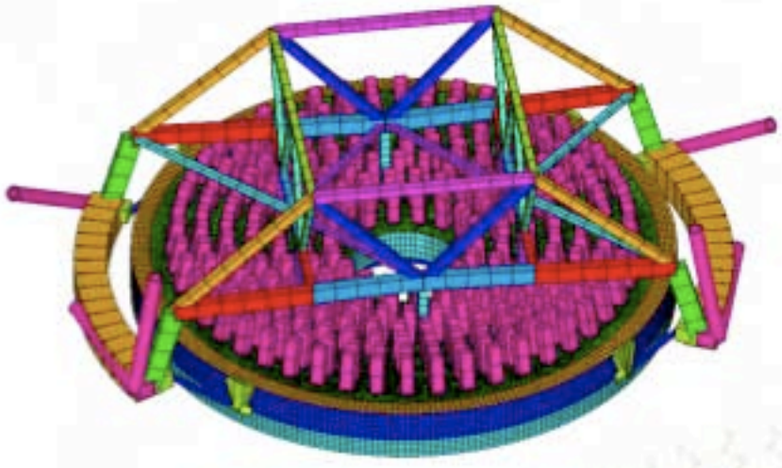
2 x 7 prototype segments being produced by two independent contractors. Production processes being developed under contract to ESO

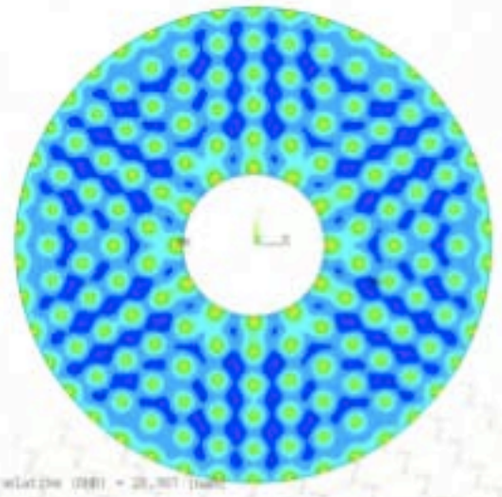
The M2 unit

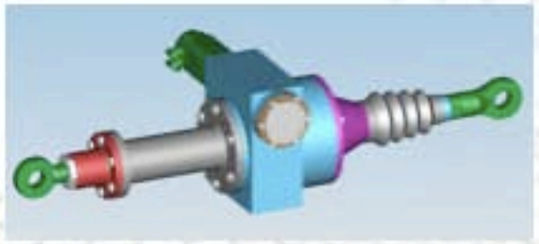
M2 cell design contract ongoing

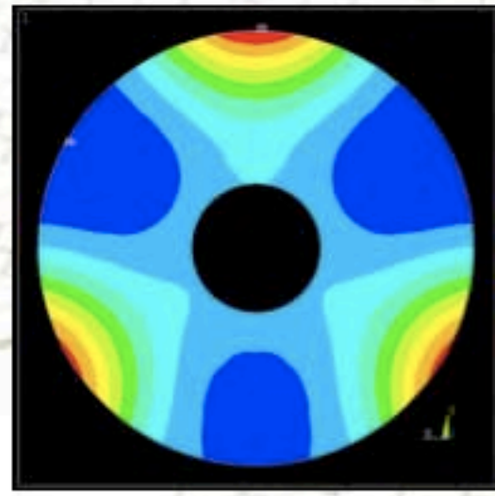


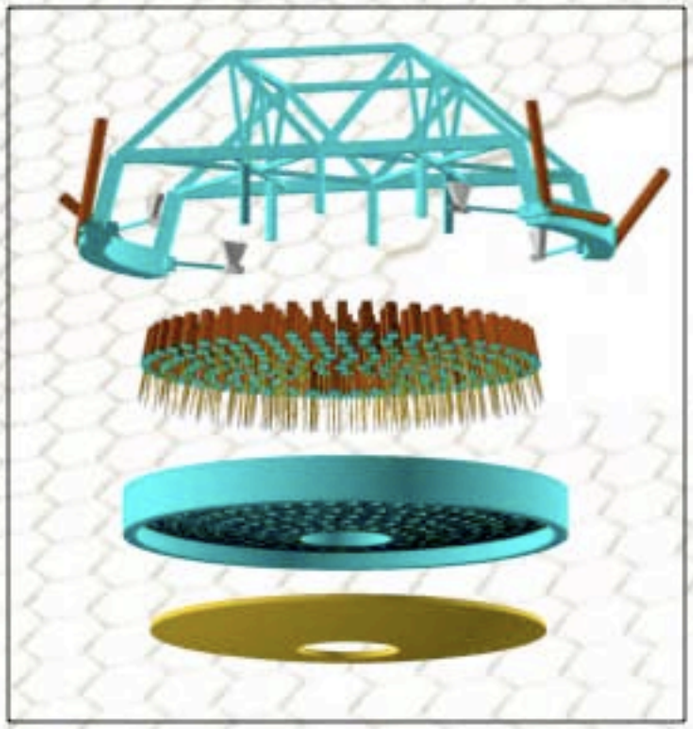


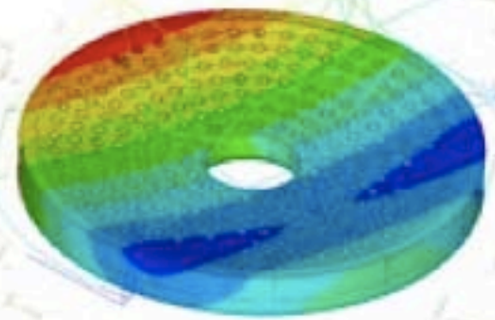






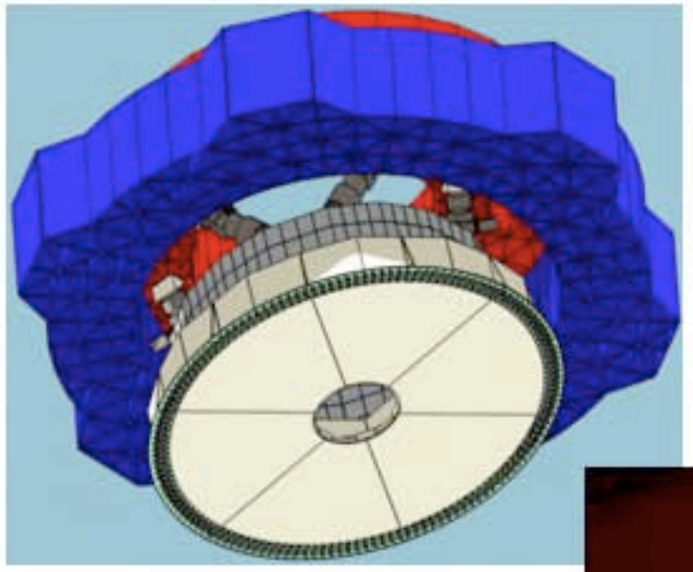




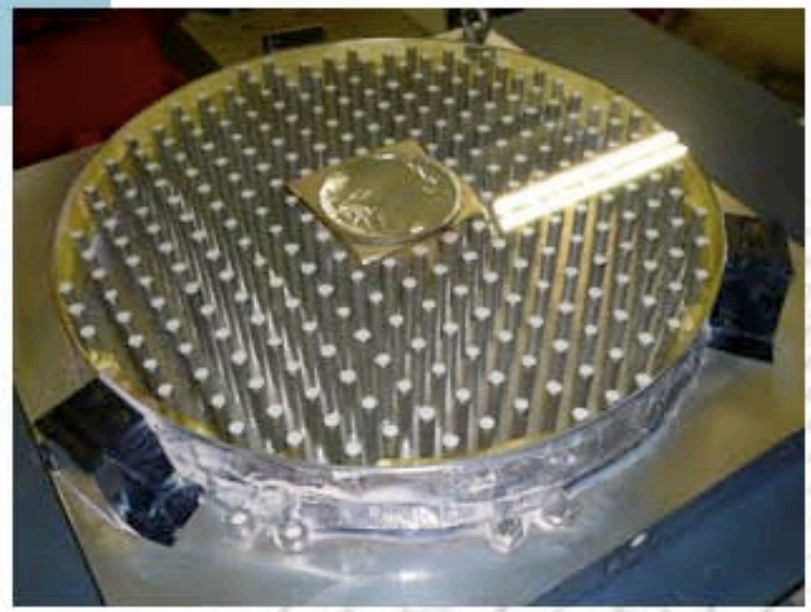


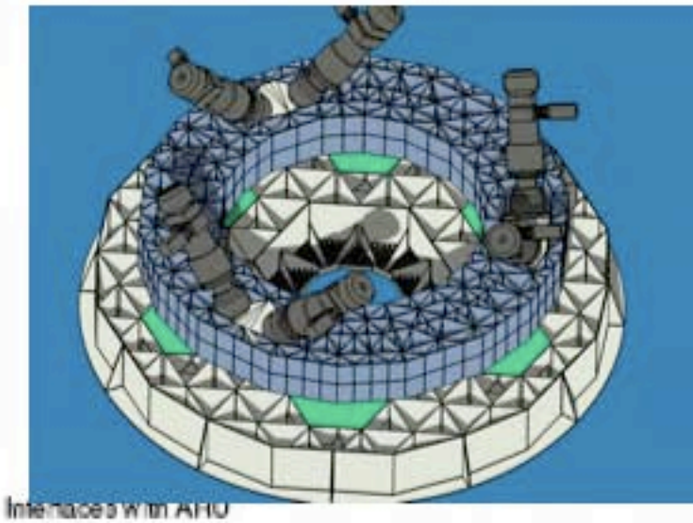
The M4 adaptive mirror

Two industrial studies will deliver working prototypes

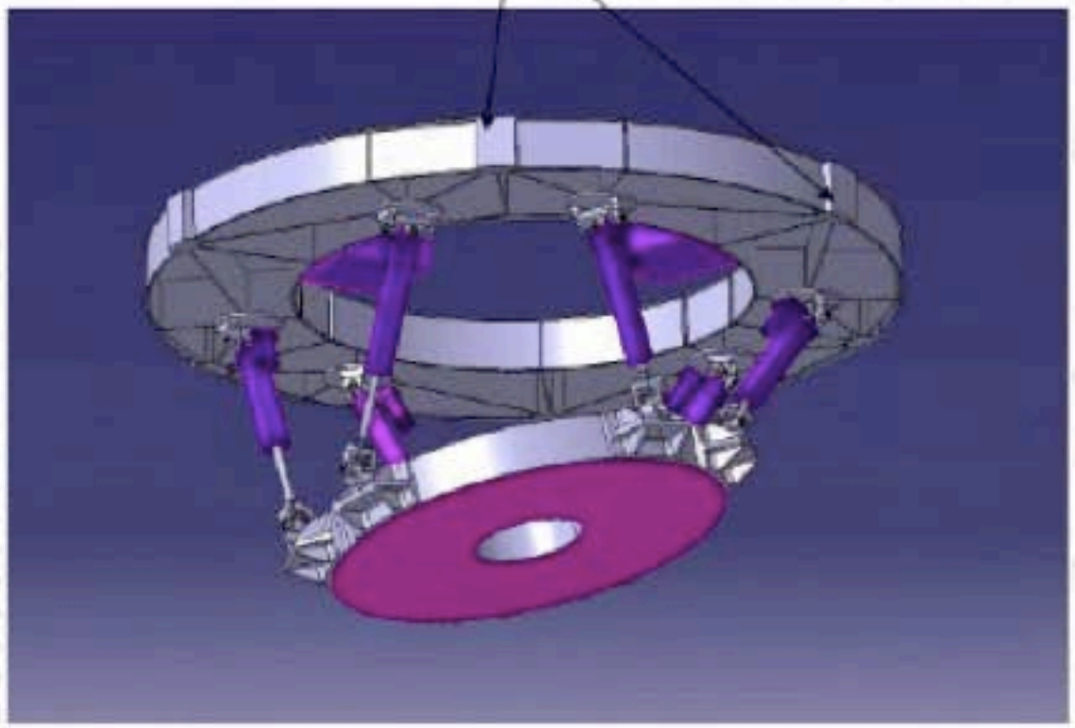


Two contracts running to PDR





Interfaces with AHO

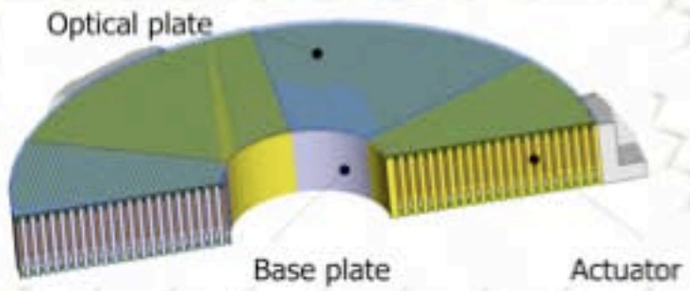


CAD view of the M4 mounting structure holding the 6 feet and the mirror

Specs:

- diameter 2.6 m
- less than 10 tons
- fitting error < 145 nm RMS for median seeing

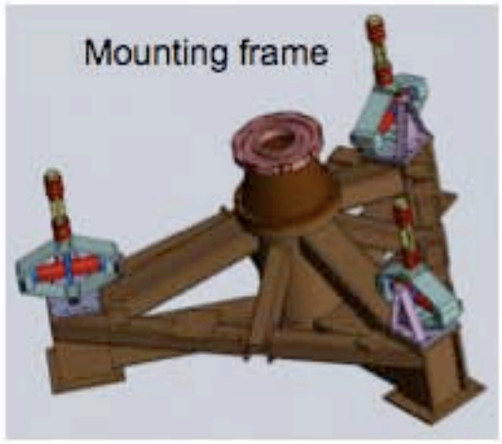
Either voice coil 30-mm pitch or piezo 20-mm pitch, resulting in 6000-10000 actuators

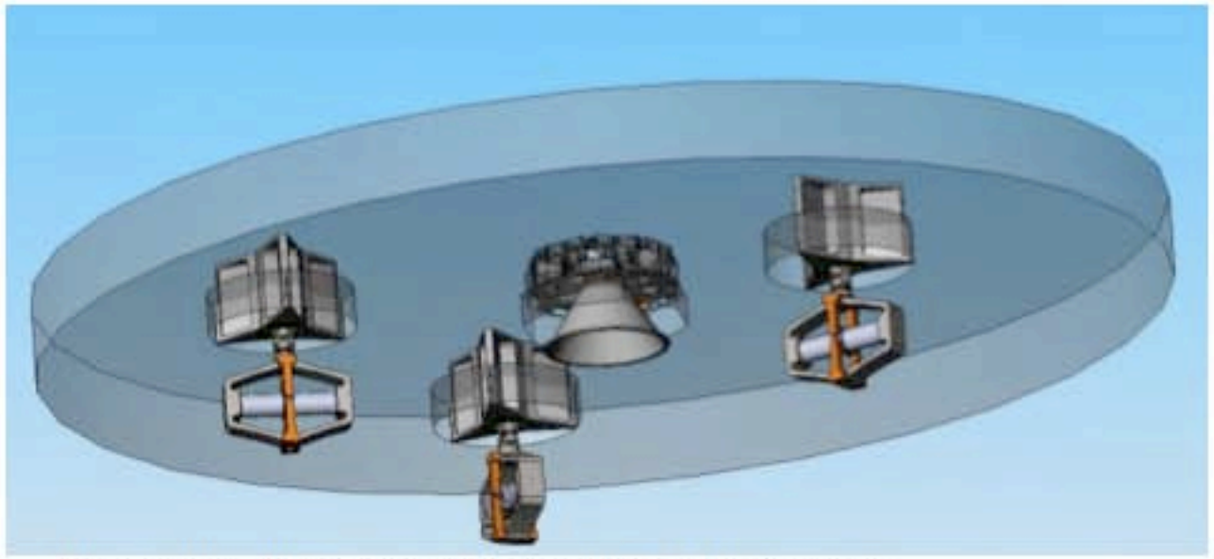


The M5 field-stabilization mirror

M5 field stabilisation unit

Deliverable of industrial electromechanical study: scale 1 prototype





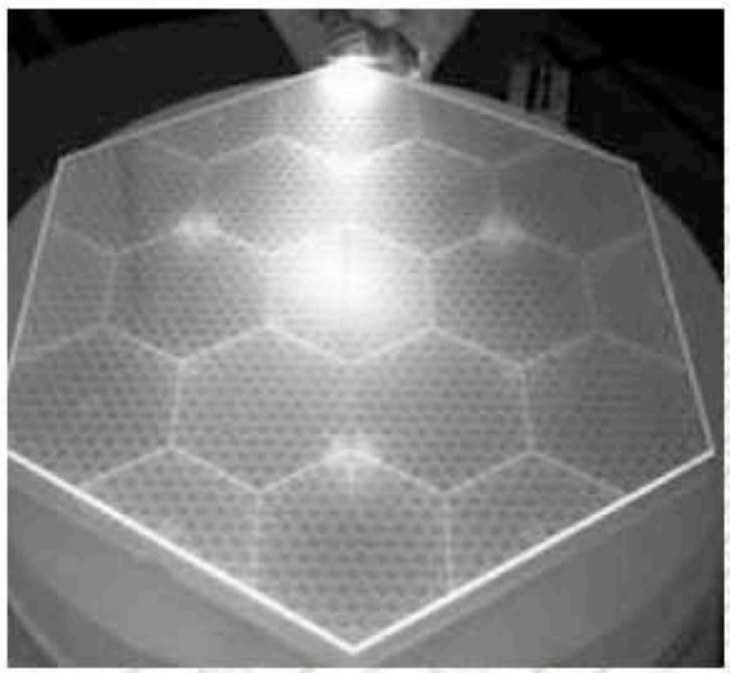
Backside with support elements and actuators

M5 actuator breadboard

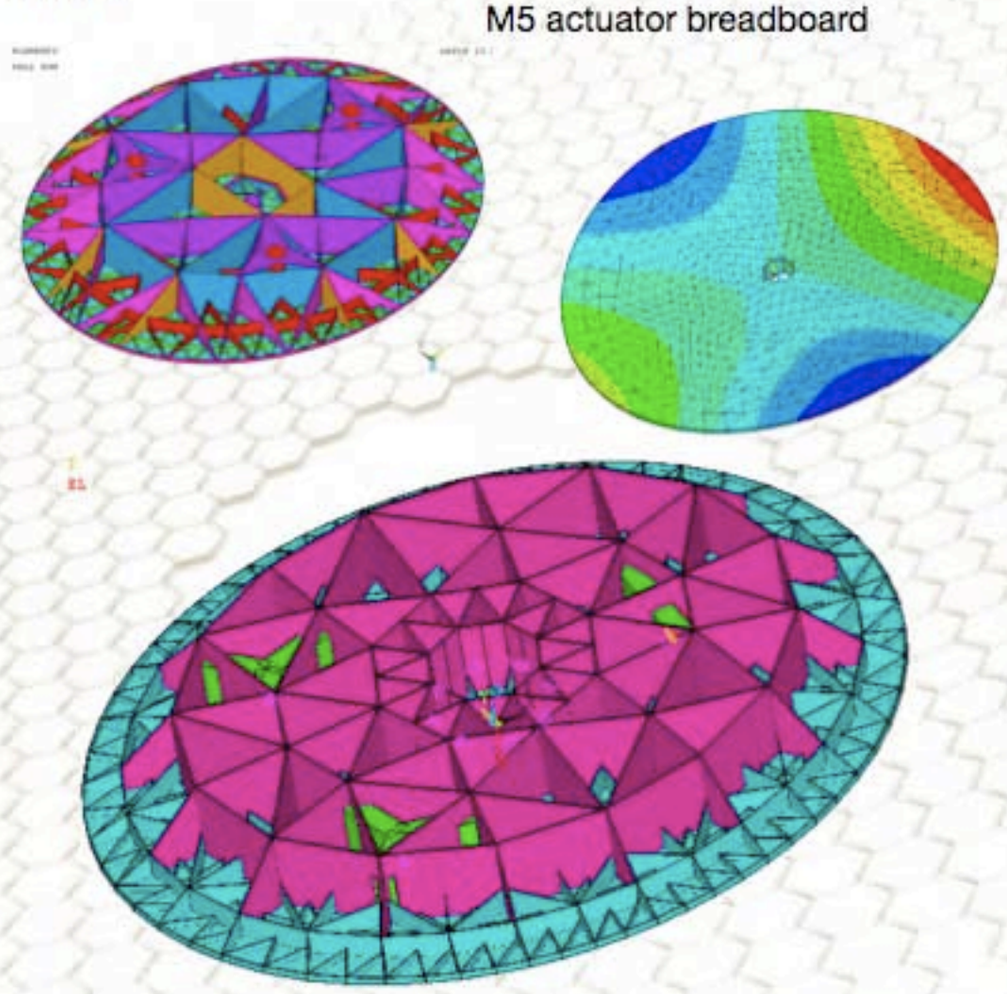
M5 mirror

Flat, 3x2.4m
ultra-lightweight mirror
goal: 40 kg/m^2

Example: ASMD mirror
(1.4 m - JWST study)

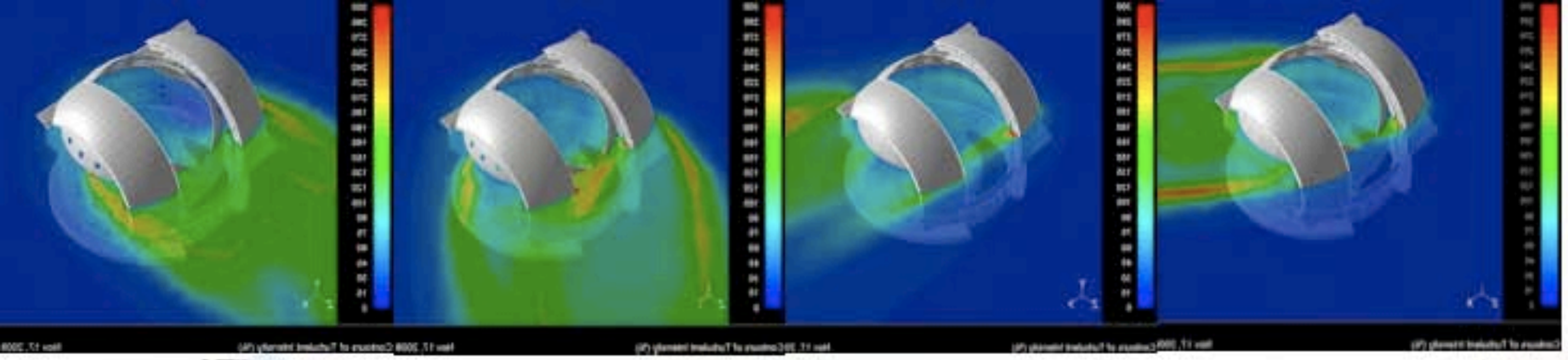


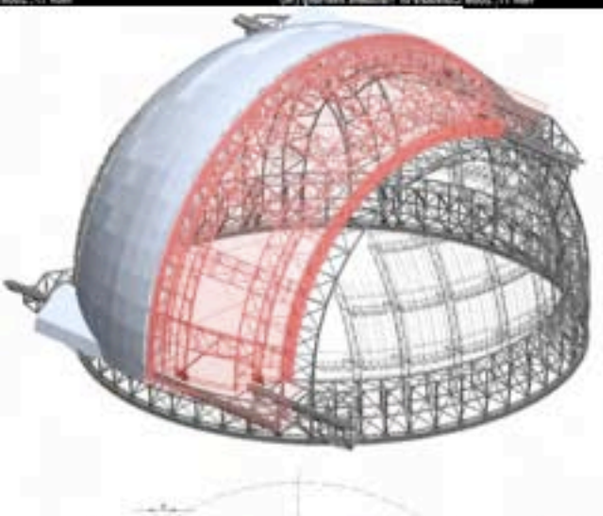
Example: AMSD mirror
Lightweight ULE (JWST)

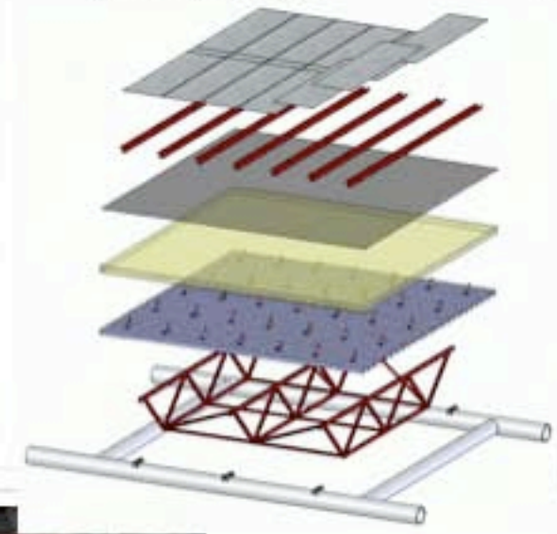


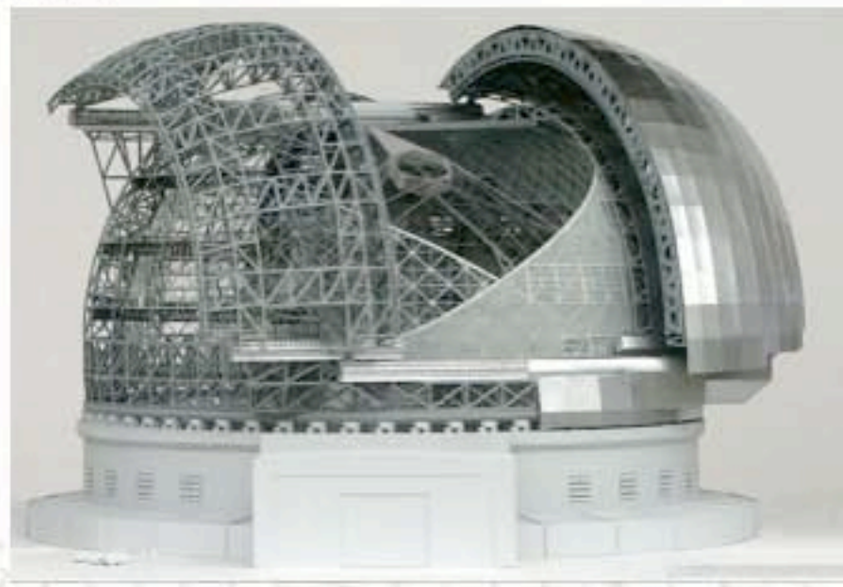
Alternative SiC design (67 kg/m^2) design

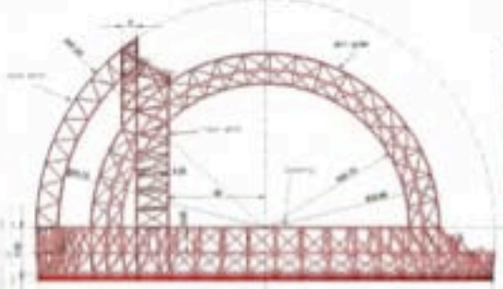
THE DOME

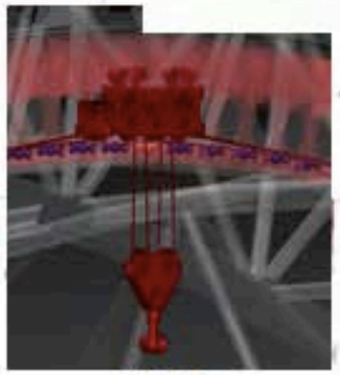




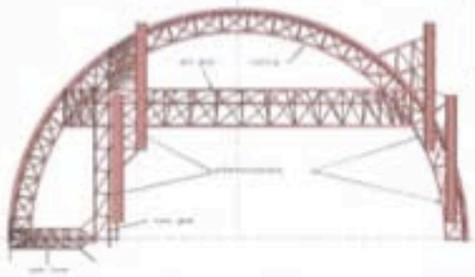


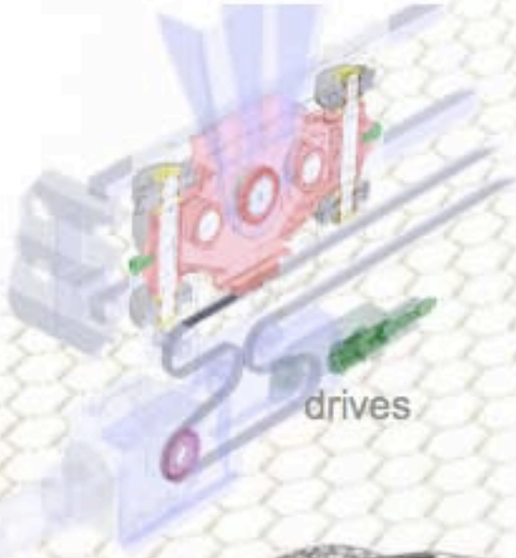






crane





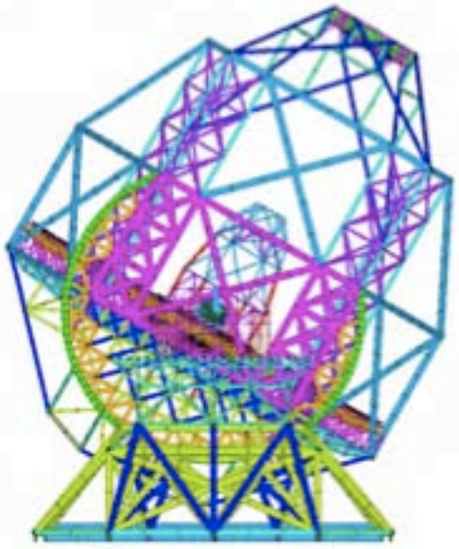
drives

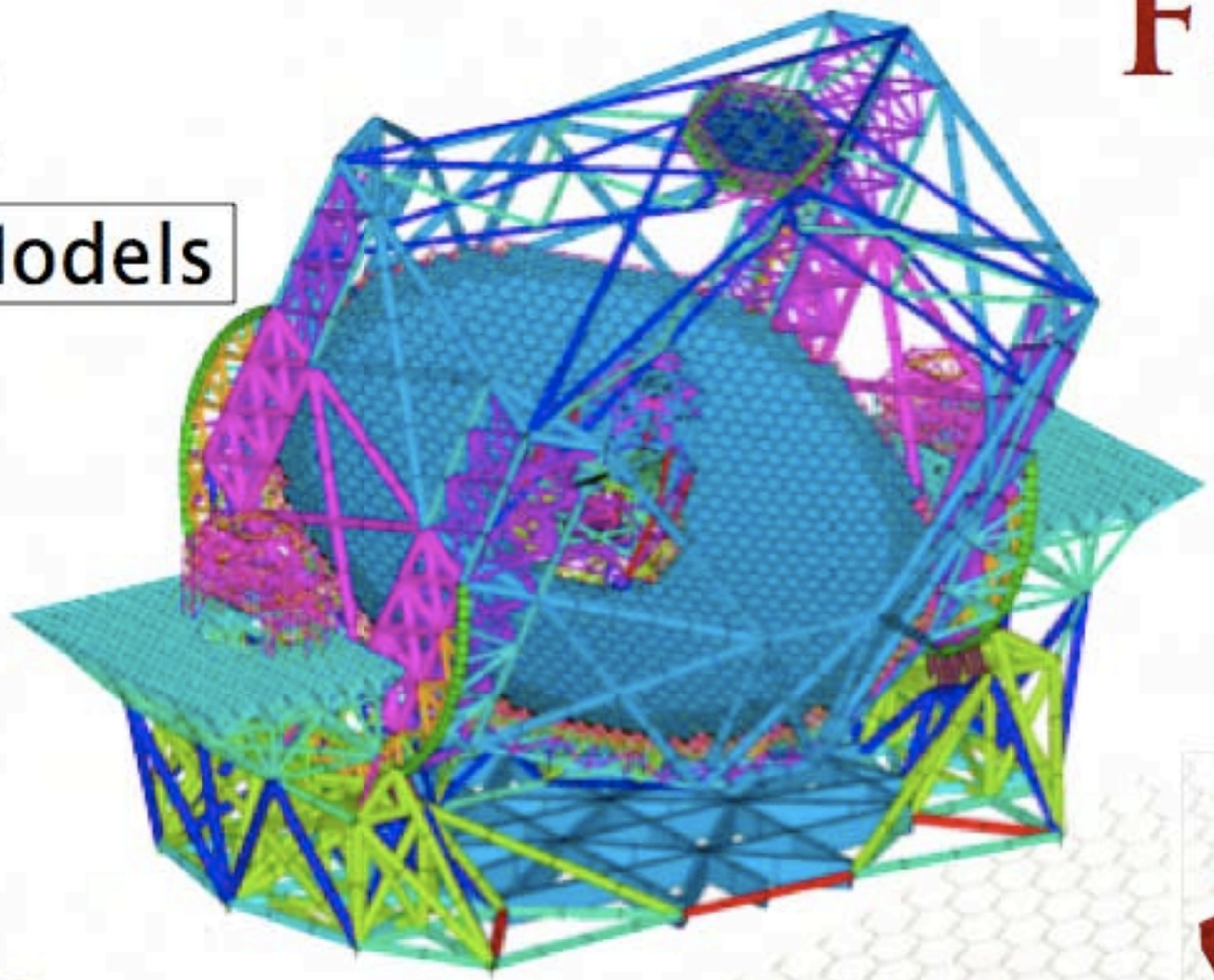
Two preliminary design contracts concluded providing schedule and cost. FEED ongoing

wind screen

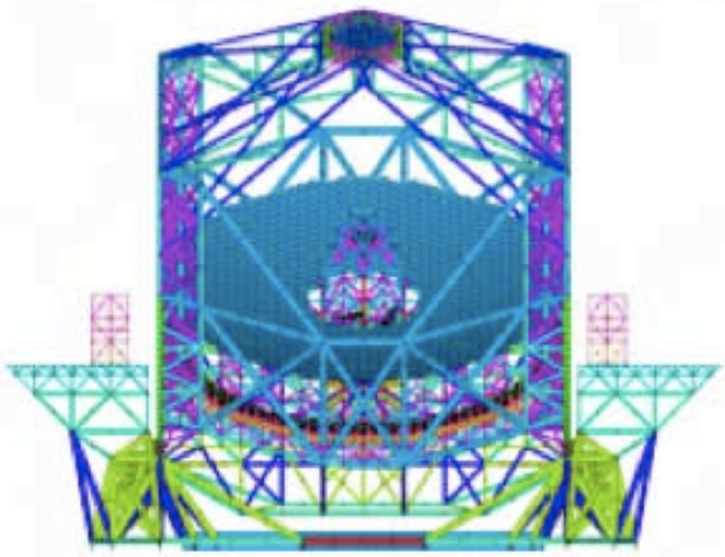
FE Models

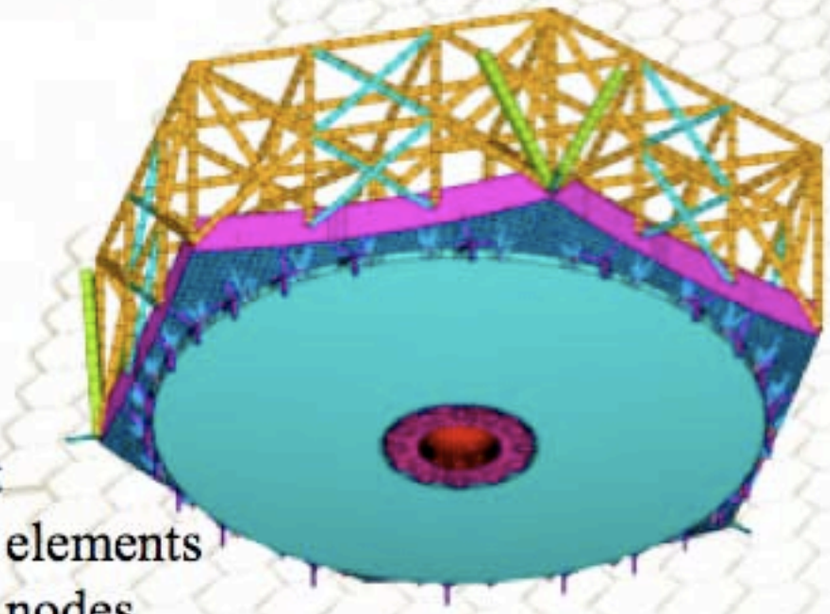
Global FE Models



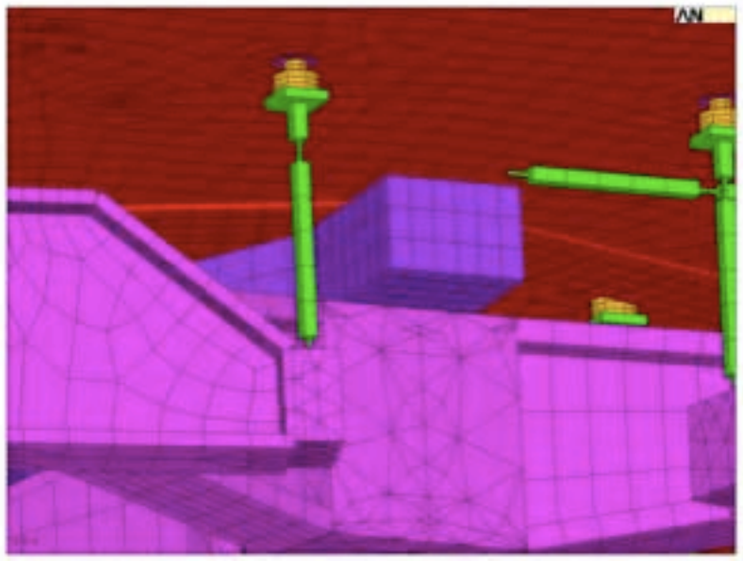


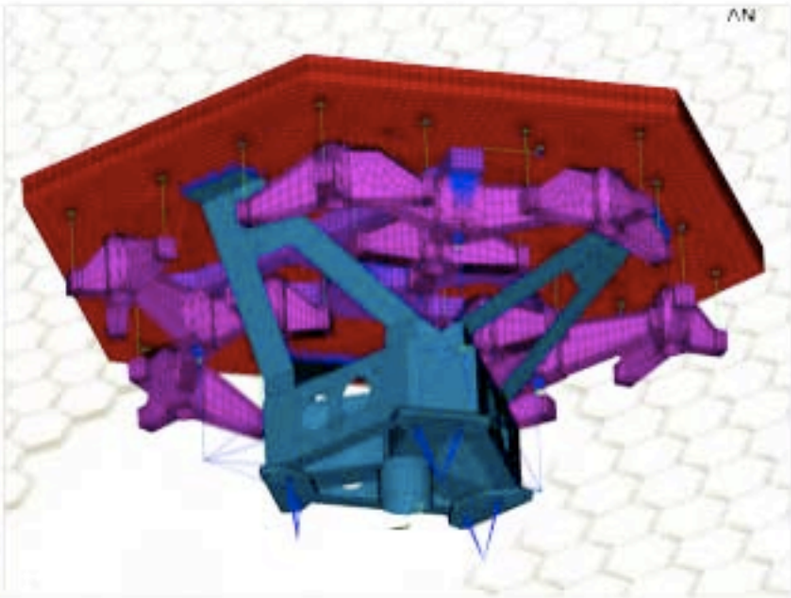
100,000 elements
36,000 nodes





M2 Unit
250,000 elements
240,000 nodes

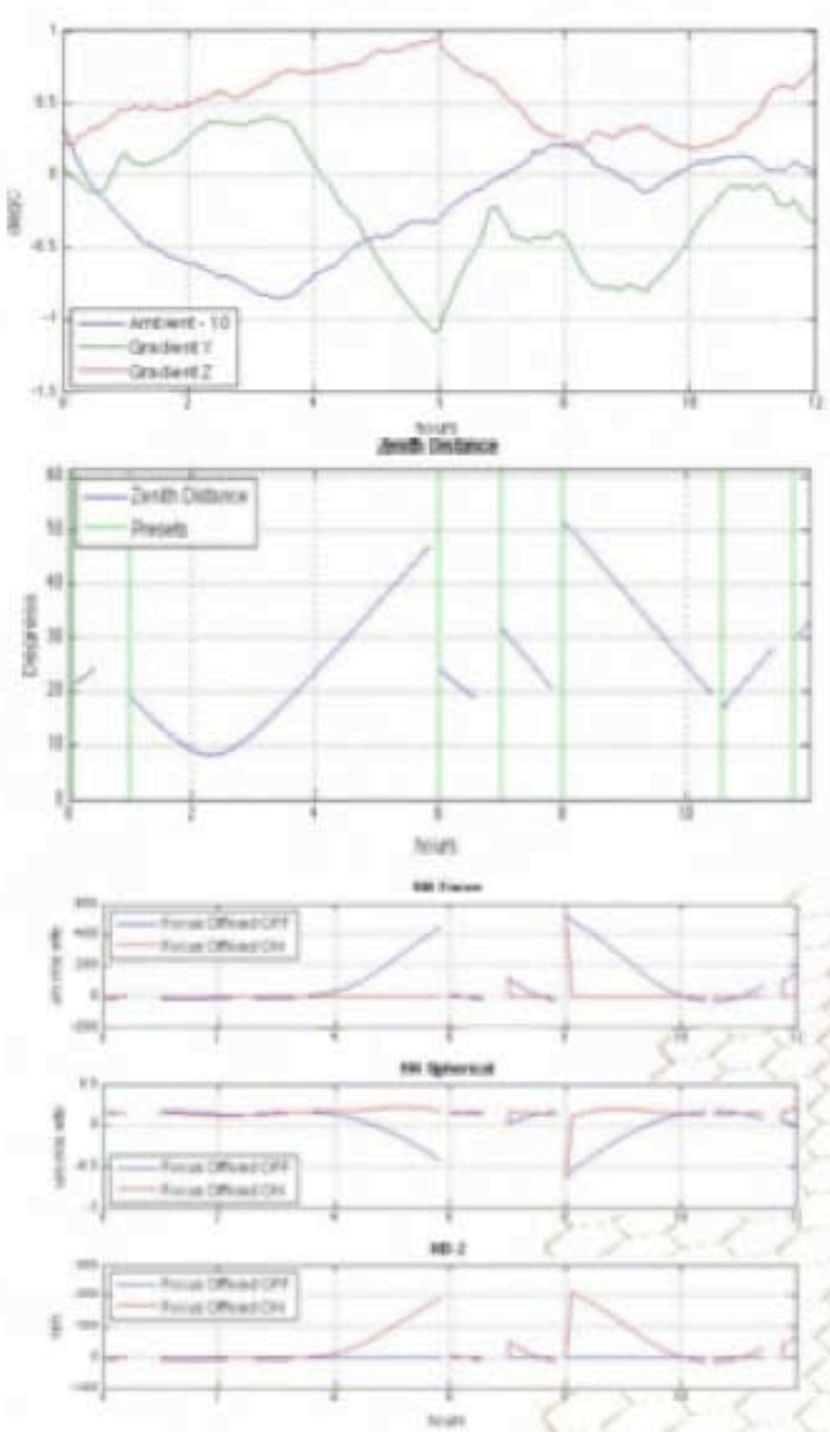




M1 Segment Support
155,000 elements
389,000 nodes

Subsystems and local FE Models

Alignment control scenario



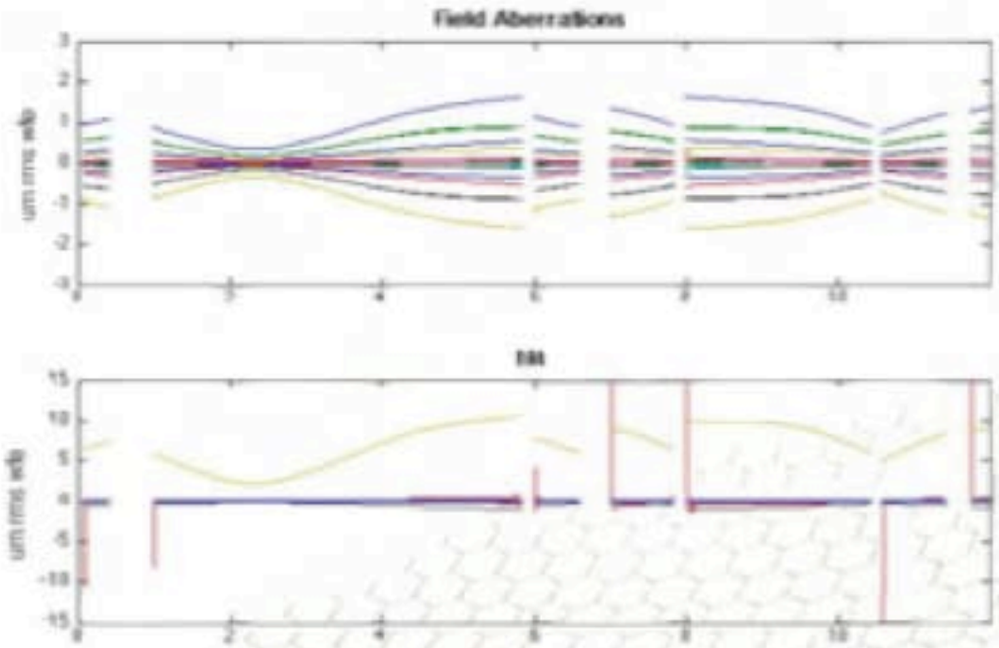


Figure 3: Field Aberrations and M4 load: M2 Alignment OFF

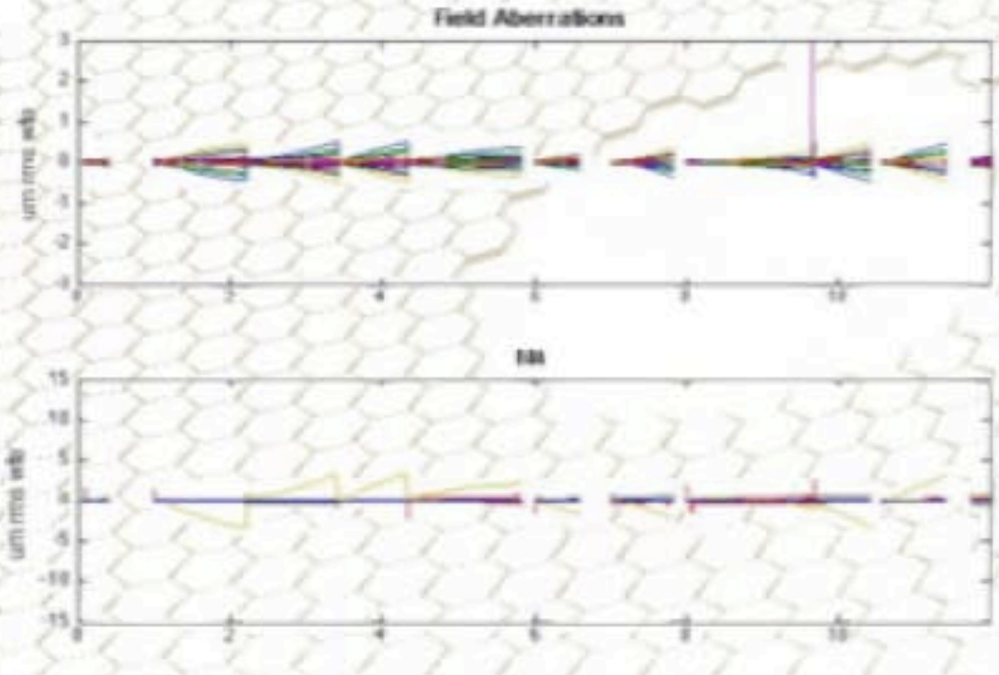
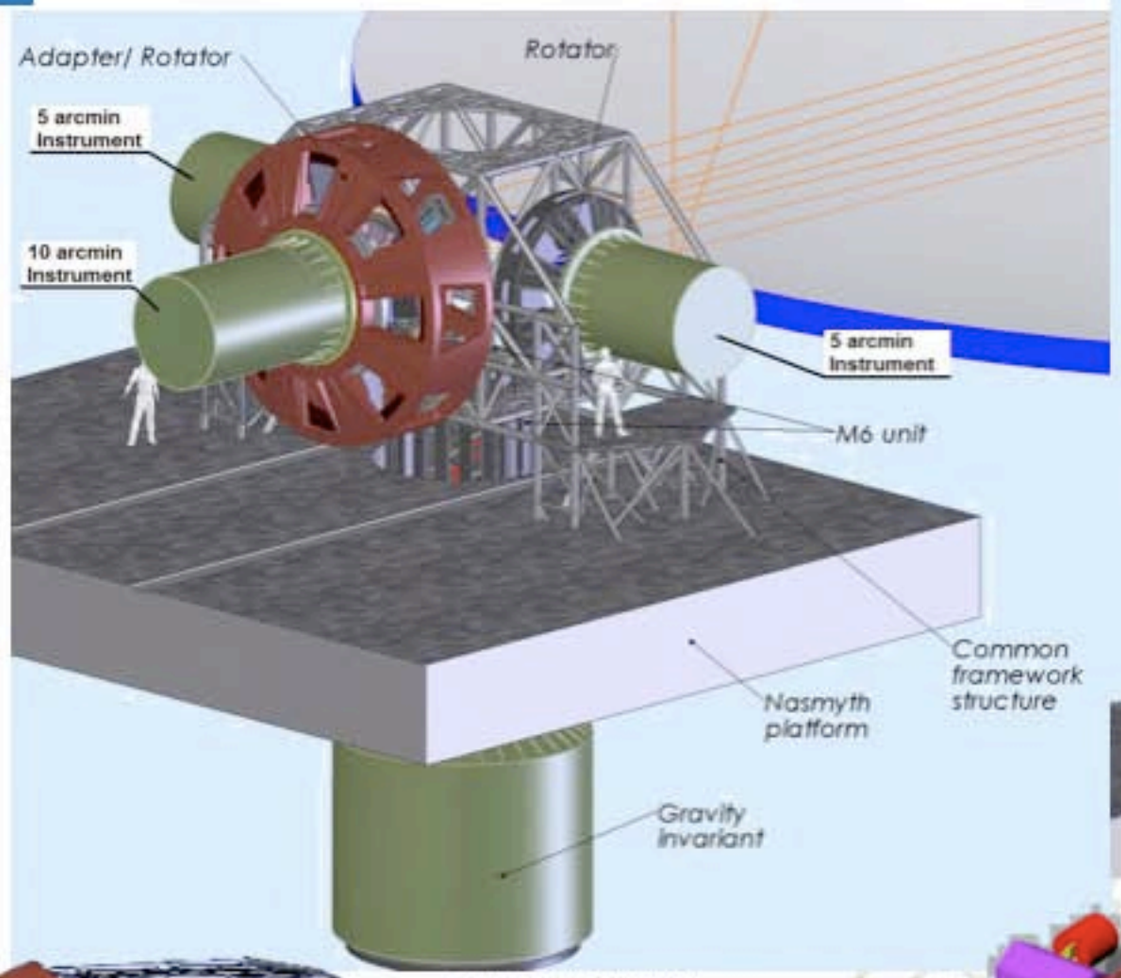
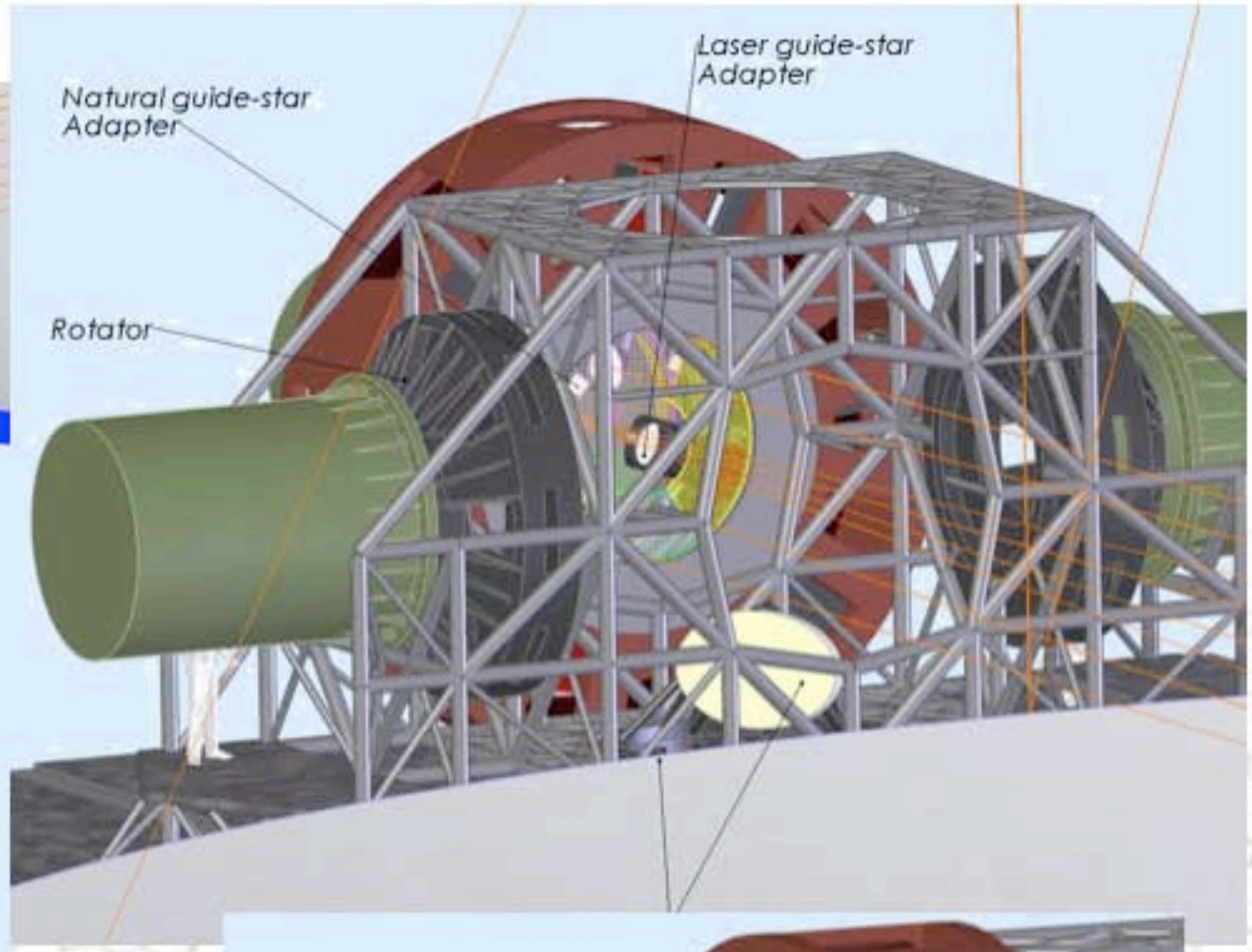
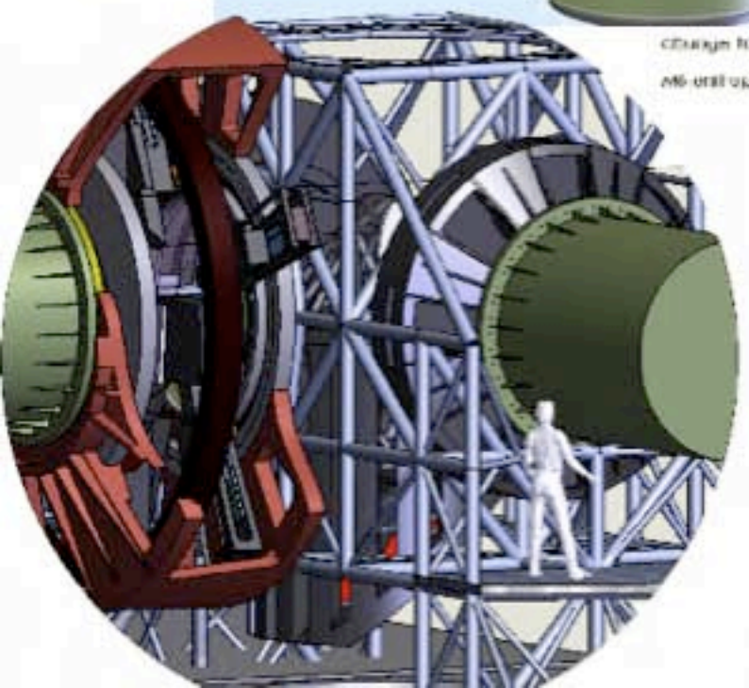


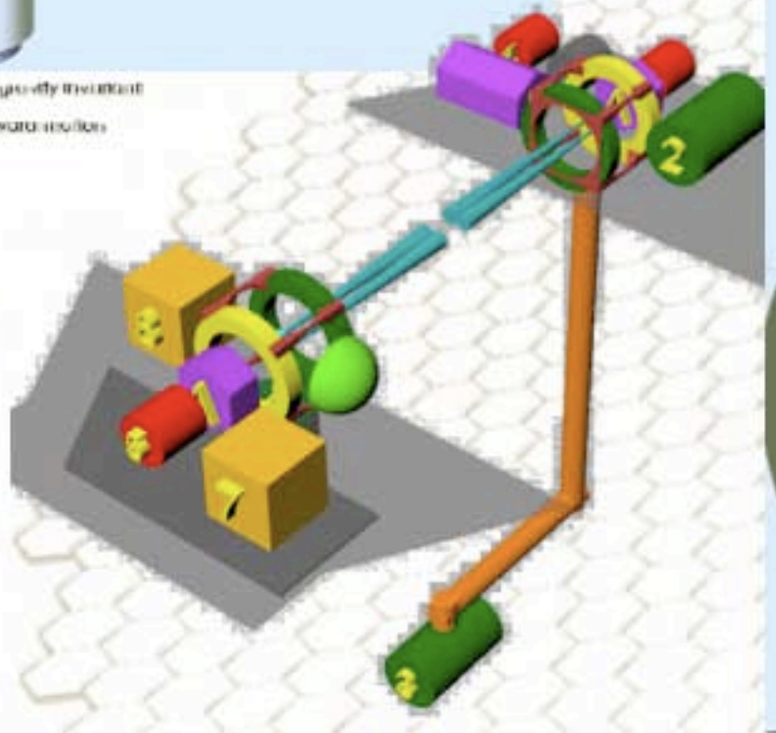
Figure 4: Field Aberrations and M4 load: M2 Alignment ON

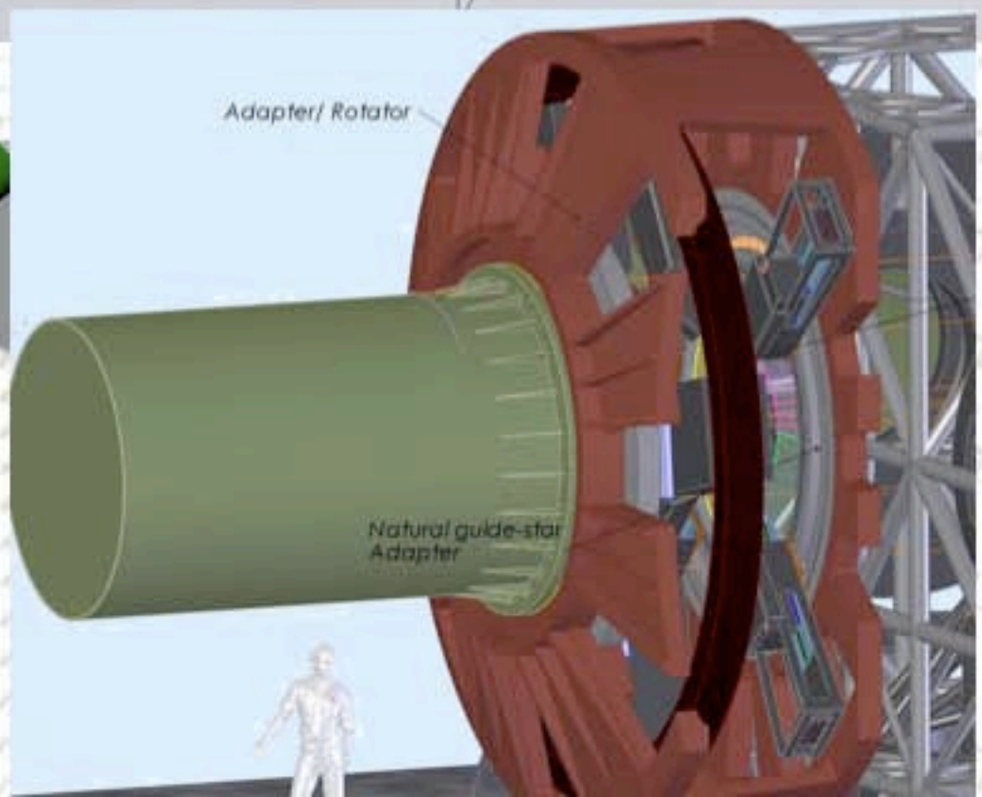
Pre Focal Stations







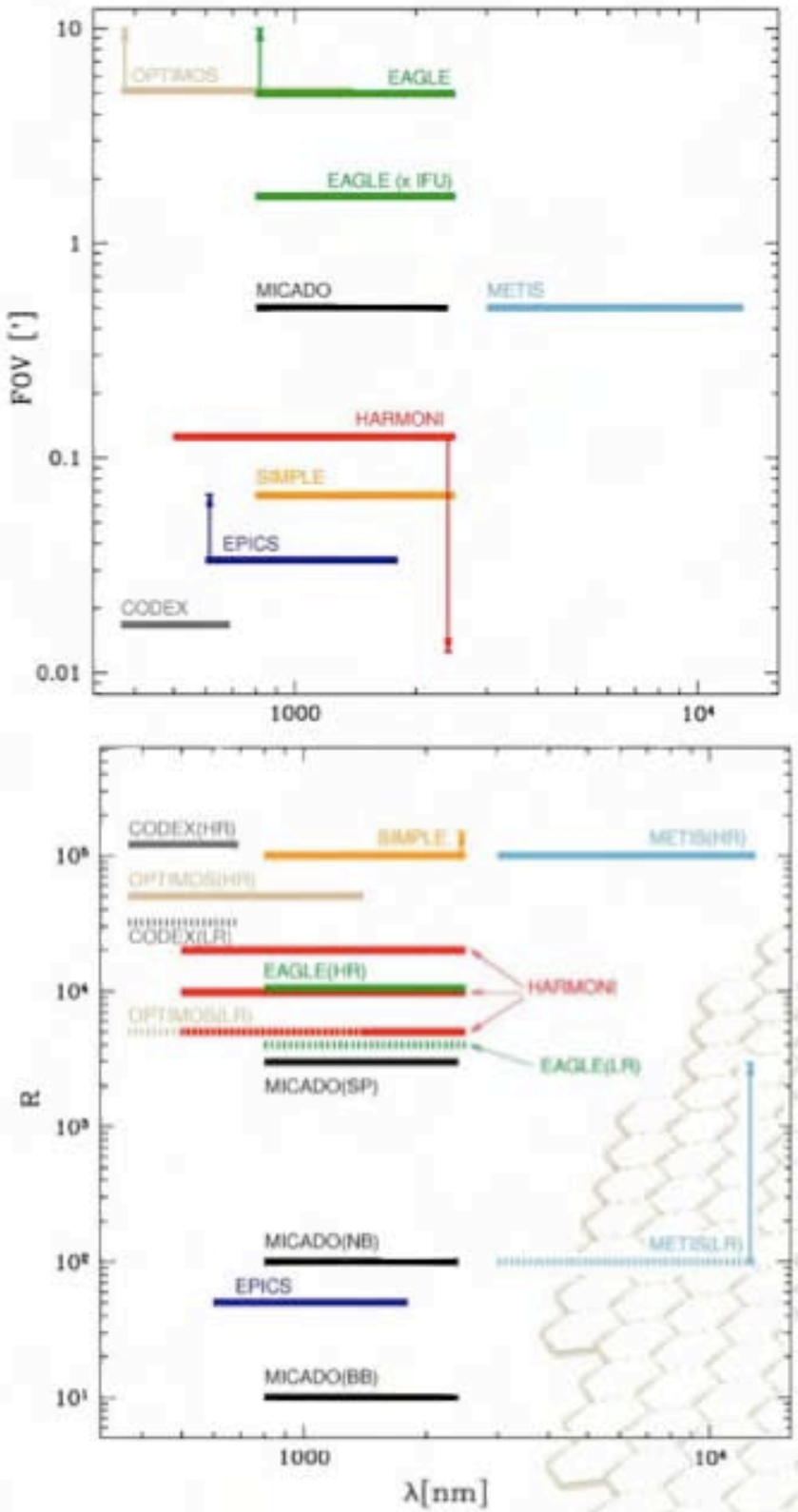


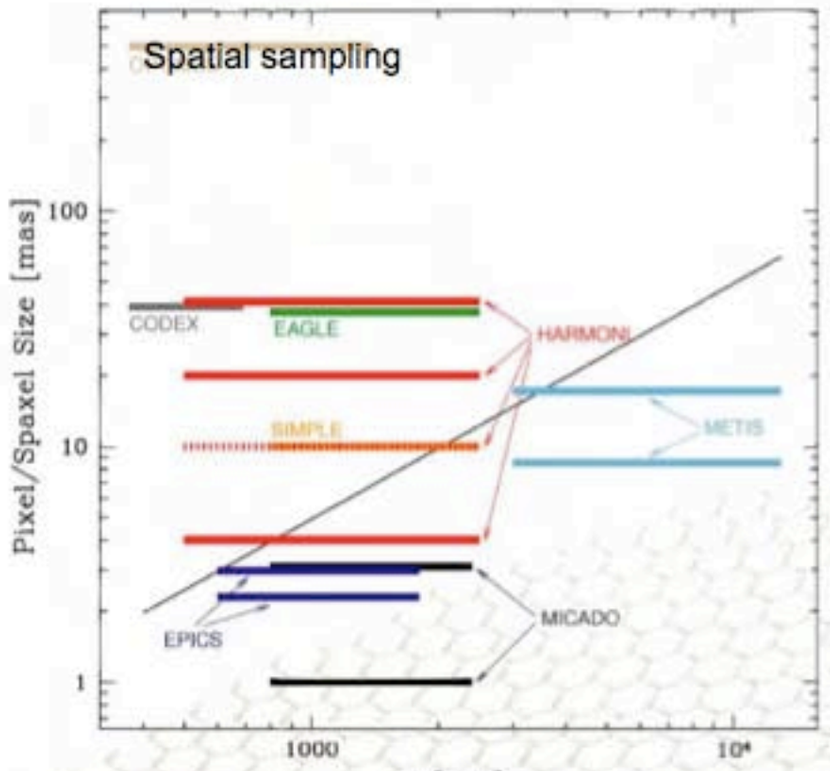


INSTRUMENTATION: PHASE A STUDIES

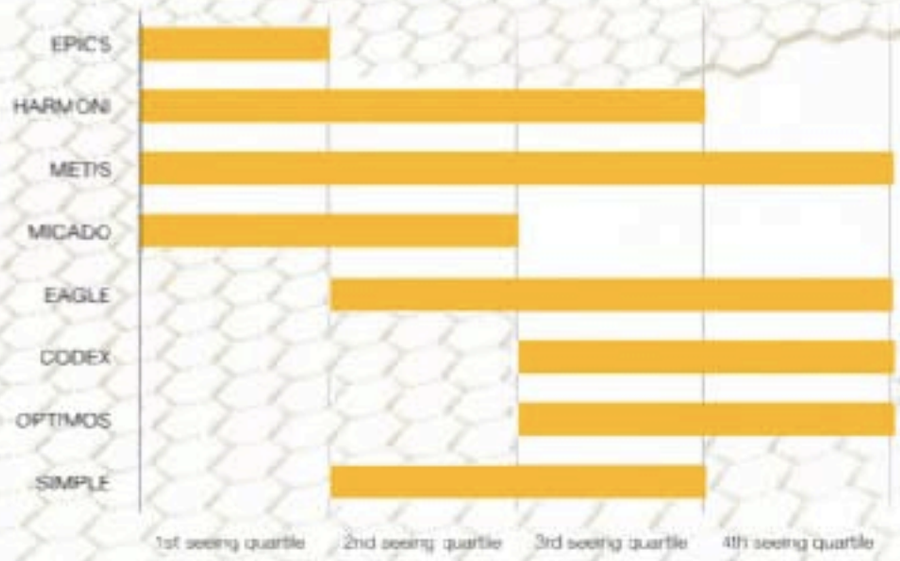
ACRONYM (P.I.)	INSTRUMENT TYPE
EAGLE (J.G. Cuby)	Wide Field, Multi IFU NIR Spectrograph with MOAO
EPICS (M. Kasper)	Planet Imager and Spectrograph with XAO
MICADO (R. Genzel)	Diffraction-limited NIR Camera- AO assisted
HARMONI (N. Thatte)	Single Field, Wide Band Spectrograph - AO assisted
CODEX (L.Pasquini)	High Spectral Resolution, High Stability Visual Spectrograph
METIS (B. Brandl)	Mid Infrared Imager & Spectrograph –AO assisted
OPTIMOS (F.Hammer,-O.LeFevre)	Wide Field , Visual, MOS (fibre or slit-based)- AO assisted?
SIMPLE (L. Origlia)	High Spectral Resolution NIR Spectrograph –AO assisted
	POST –FOCAL ADAPTIVE OPTICS MODULES
MAORY (E. Diolaiti)	Multi Conjugate AO module (high Strehl, field up to 2')
ATLAS (T. Fusco)	Laser Tomography AO Module (high Strehl, narrow field)

Parameter space





Seeing conditions

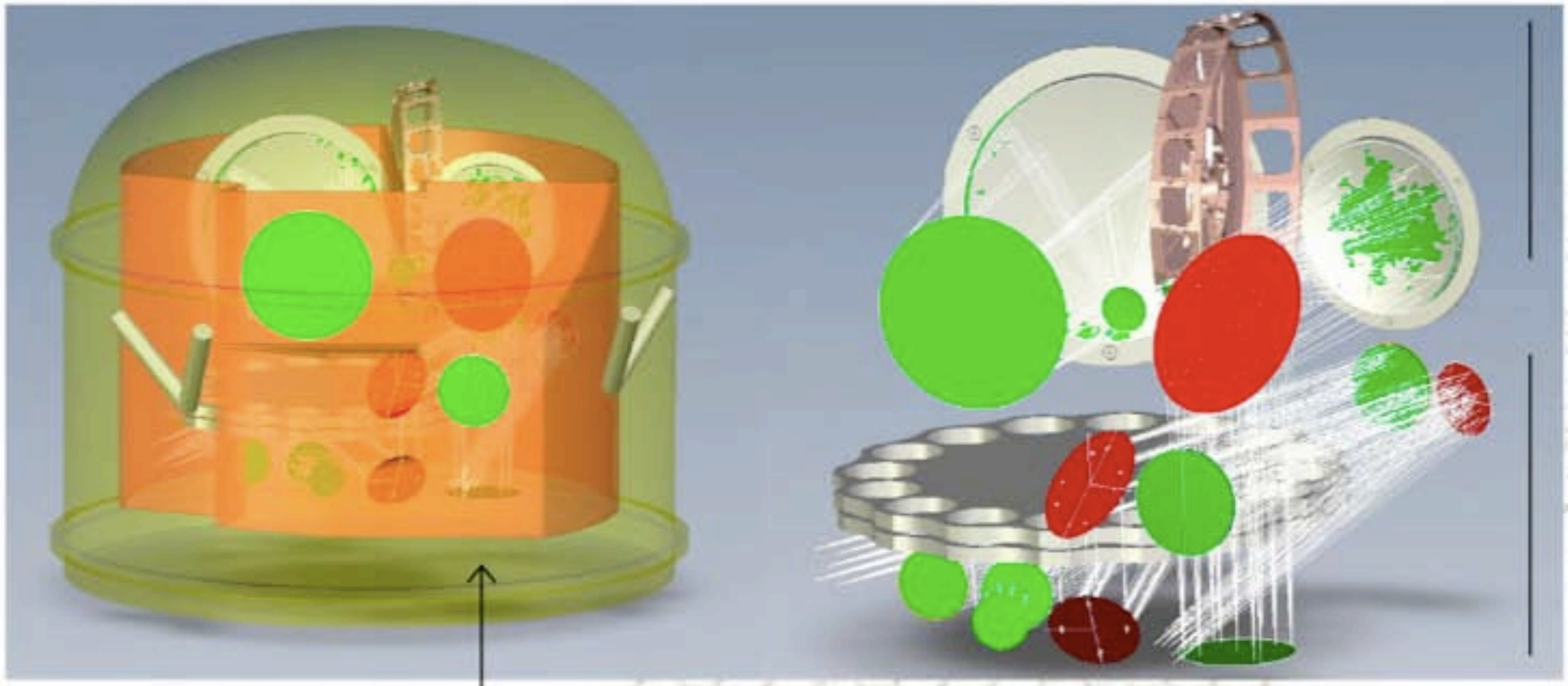


The current suite of instruments nicely covers the various seeing conditions. A plan for sequential implementation of the instruments at the E-ELT should take into account that at a given time all seeing quartiles can be used by the present instruments.

MICADO

Concept for MICADO and its cryostat, approximately 2m across

Concept for MICADO optics



modified Offner relay for high throughput with a single large filter wheel

'Christmas Tree' Arm with 2 large filter wheels and exchangeable fold optics

instrument rotates about this axis, and mounts to the MCAO system MAORY

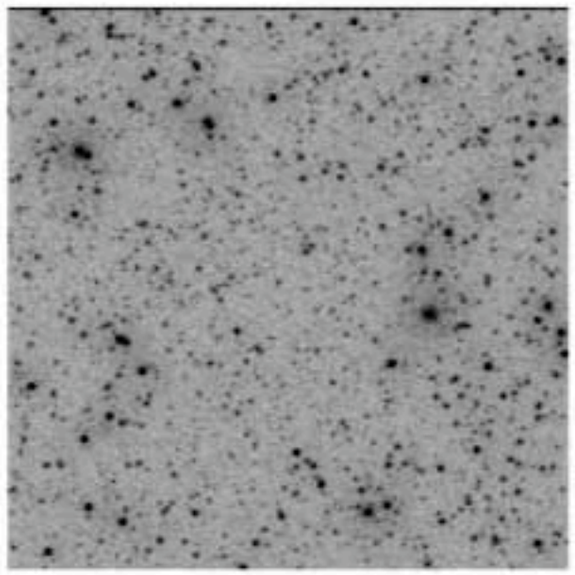
entrance window

MICADO

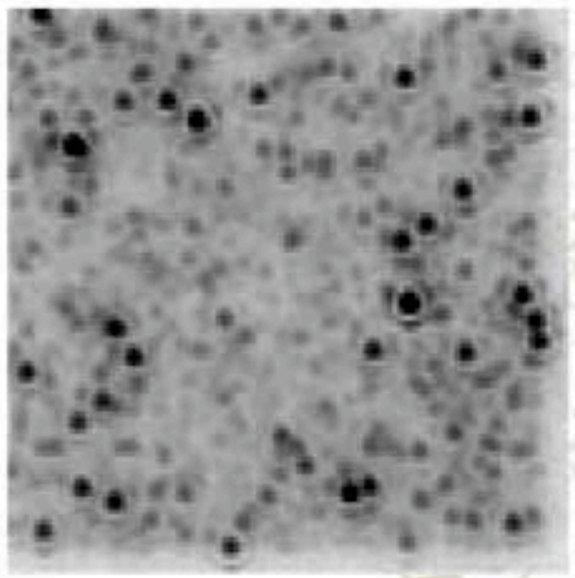
Crowded Field Photometry: MICADO vs JWST

Resolution gives an effective sensitivity gain – cf. 3mag for MAD vs ISAAC

5-hr K-band simulated exposure



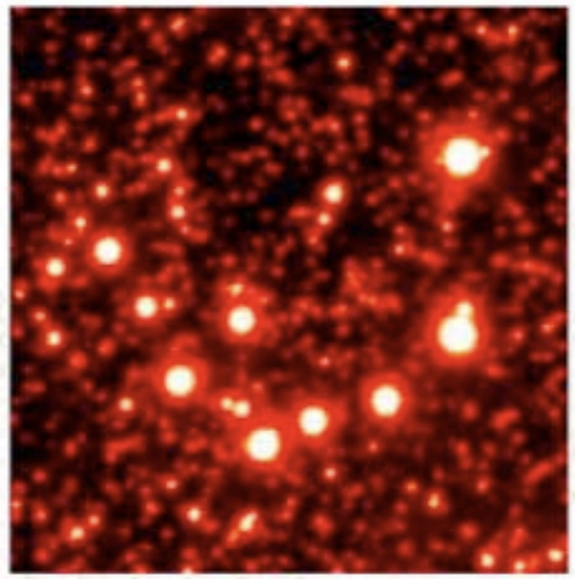
MICADO



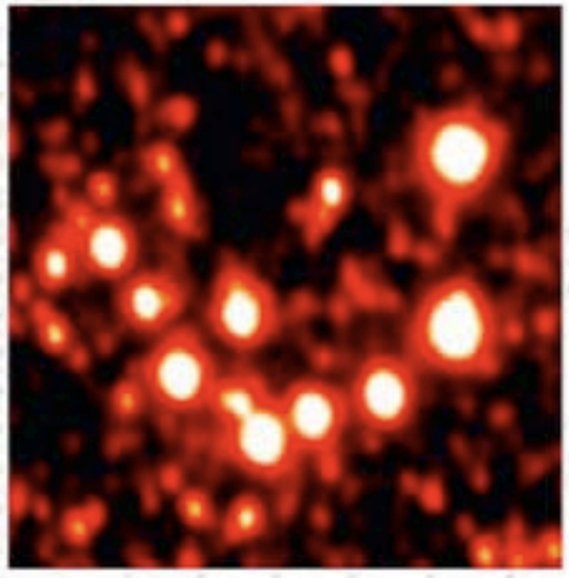
JWST

Omega-Cen

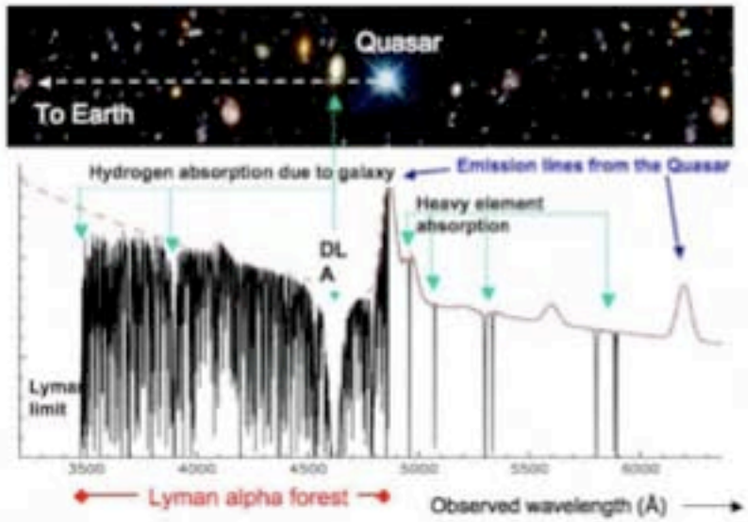
MAD

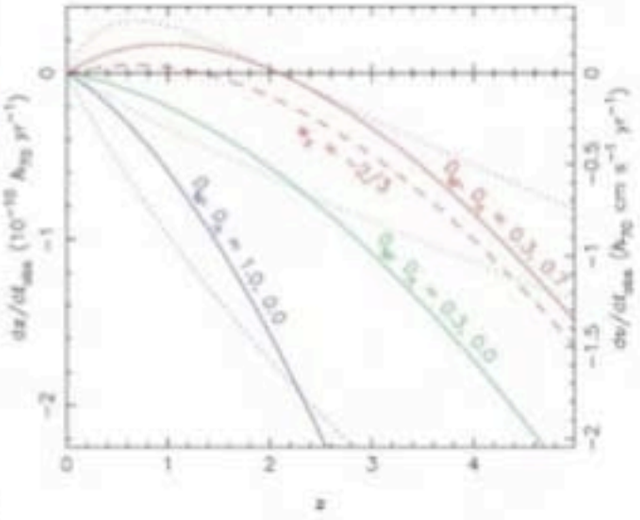


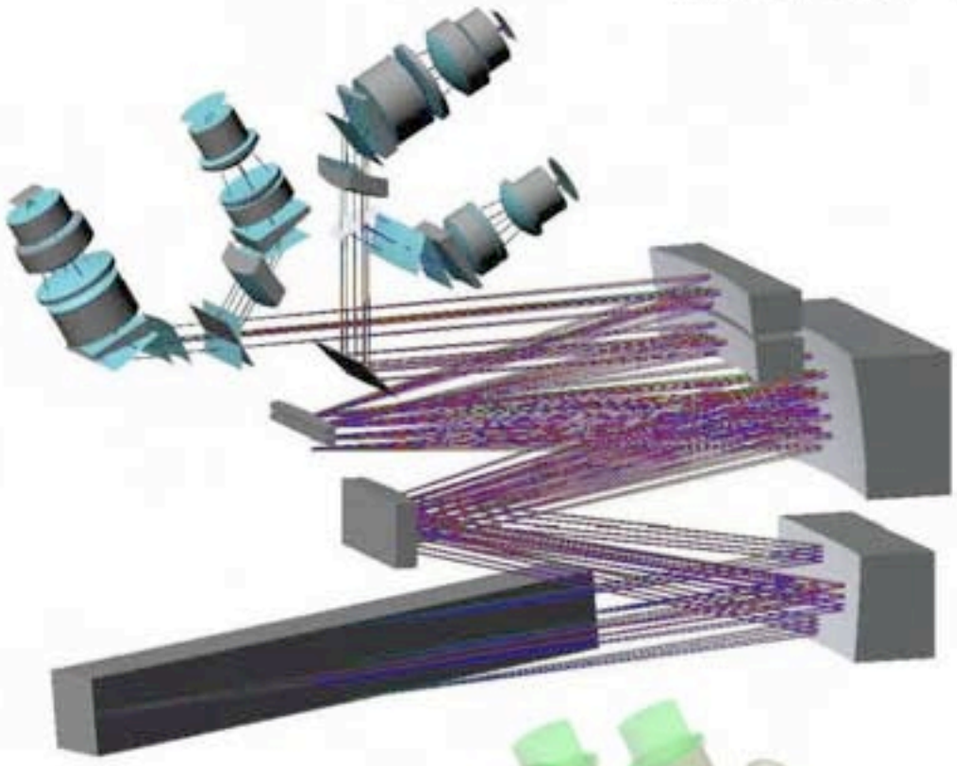
ISAAC

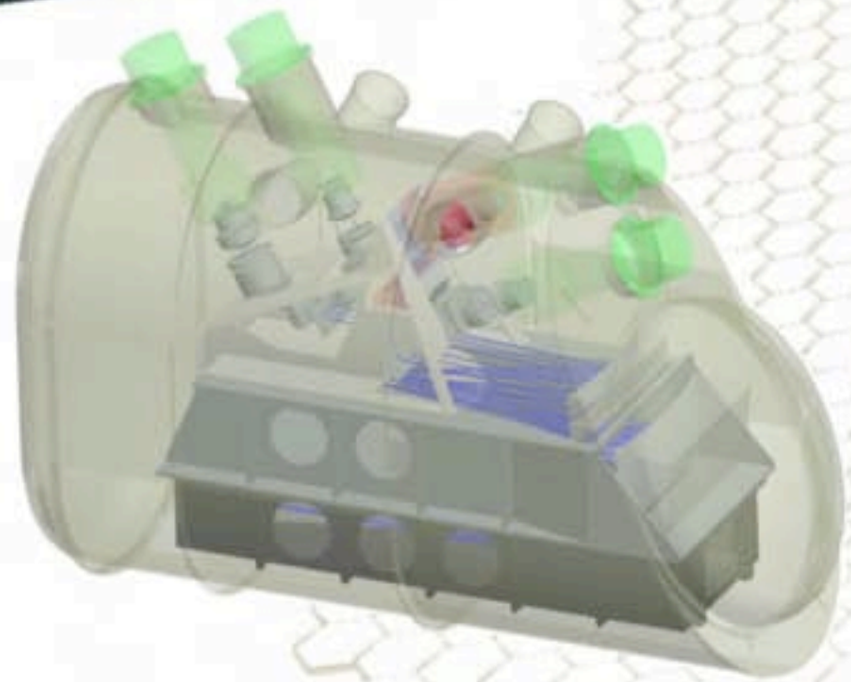


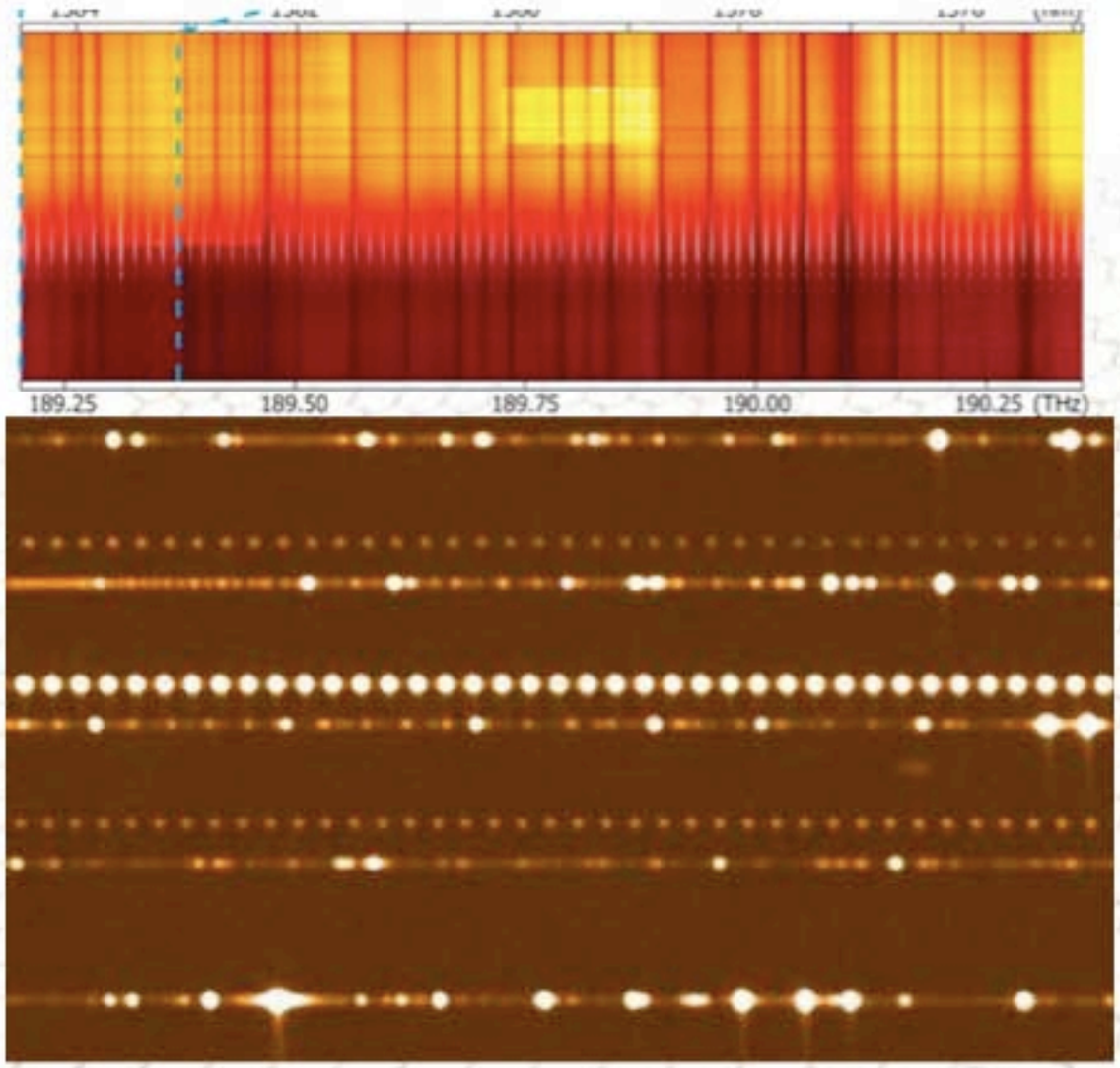
CODEX



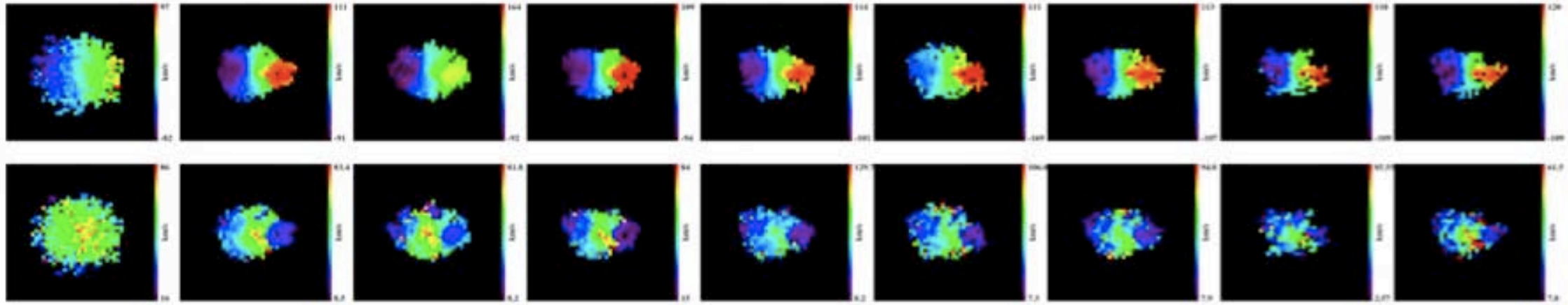


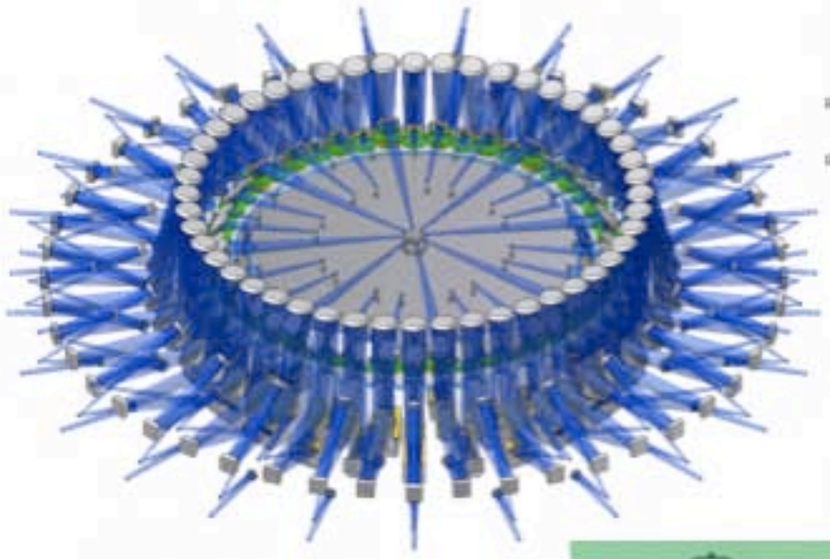


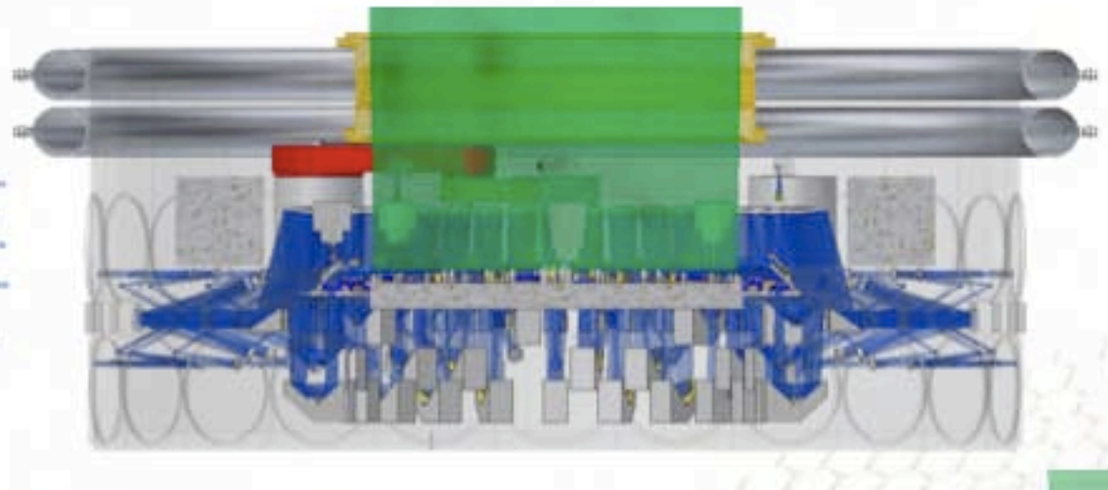




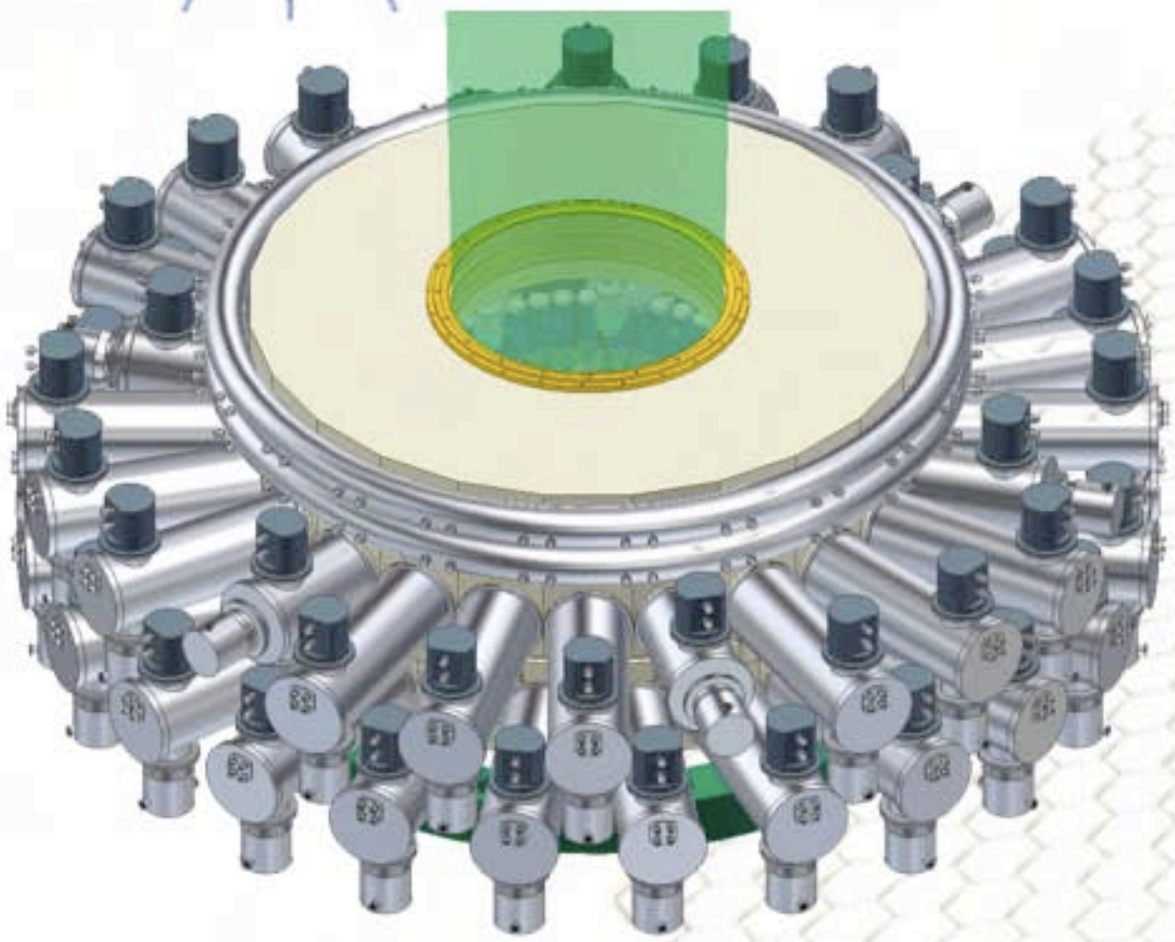
Laser comb calibration

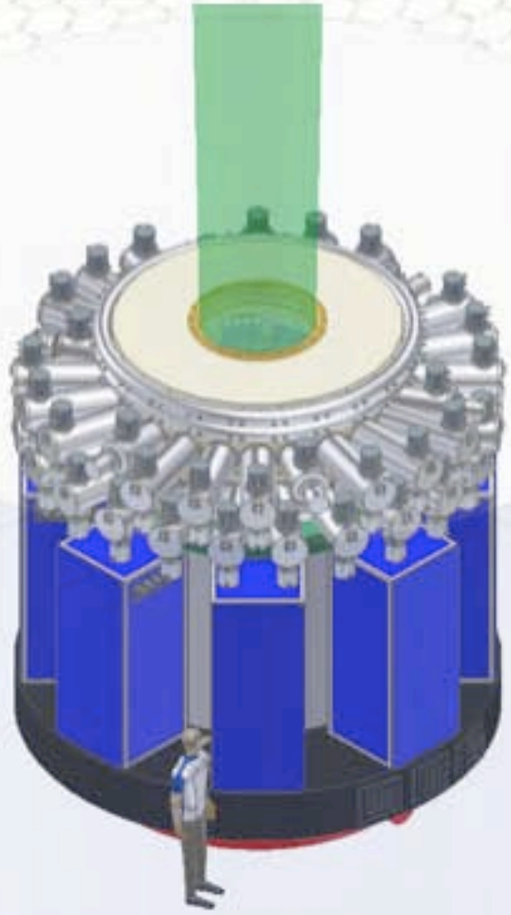






EAGLE

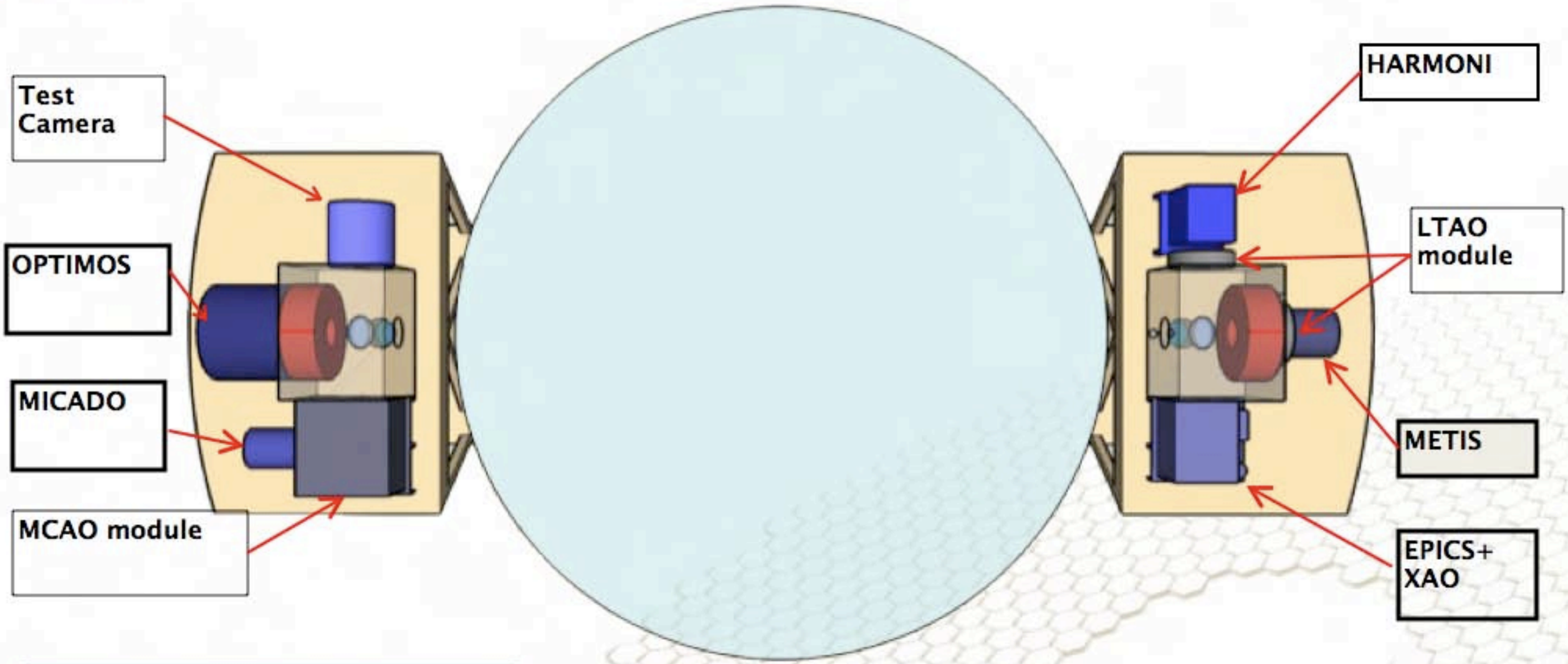


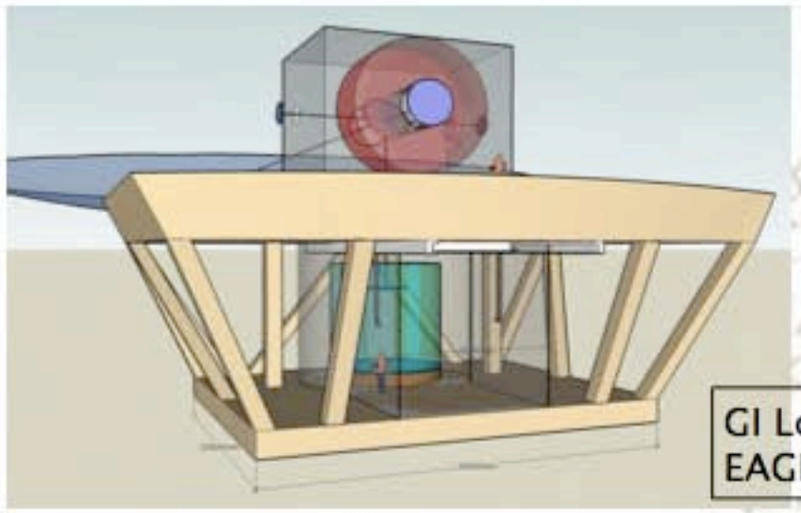


Instrument Phase A Milestones

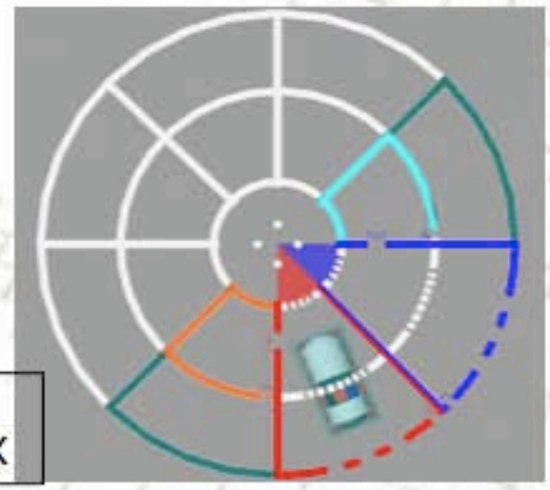
Study	ESO Responsible	K.O. meeting	End Phase I Review	Delivery Final Report	Study Review TBC
EAGLE	Ramsay	27/09/2007	07/07/08	September 2009	October 2009
EPICS	Kasper	24/10/07	24/09/08	January 2010	February 2010
MICADO	Kissler-Patig	20/02/08	11-12/12/08	October 2009	November 2009
HARMONI	Vernet	01/04/08	11/02/2009	November 2009	December 2009
METIS	Siebenmorgen	07/05/08	26/01/09	November 2009	December 2009
CODEX	Pasquini	16/09/08	02/2009	November 2009	December 2009
OPTIMOS	Ramsay	10/2008	06/2009	December 2009	January 2010
SIMPLE	Käufl	10/2008	04/2009	December 2009	January 2010
MAORY	Marchetti	09/11/07	24/10/08	December 2009	January 2010
ATLAS	Paufique	19/09/08	04/09	December 2009	January 2010

POSSIBLE INSTRUMENT DISTRIBUTION





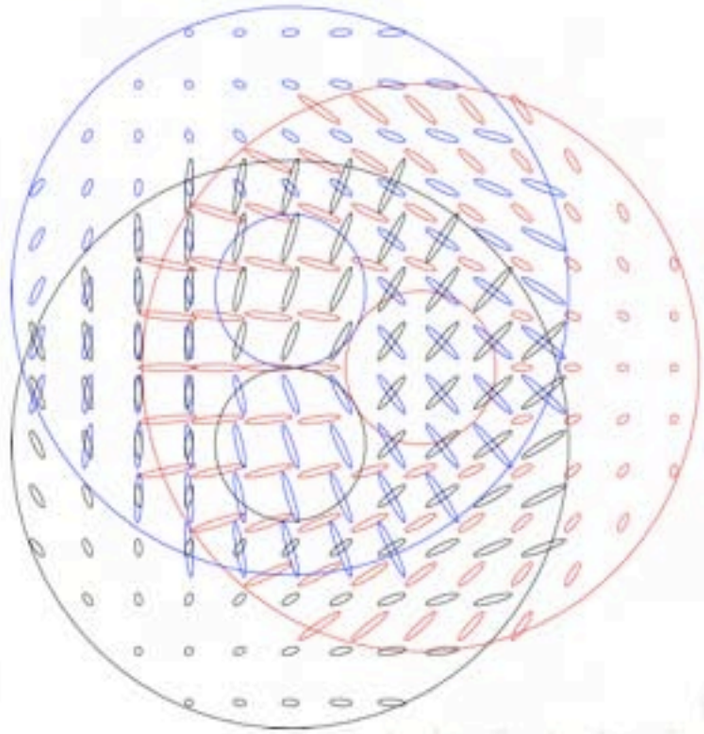
GI Location envisaged
EAGLE and SIMPLE

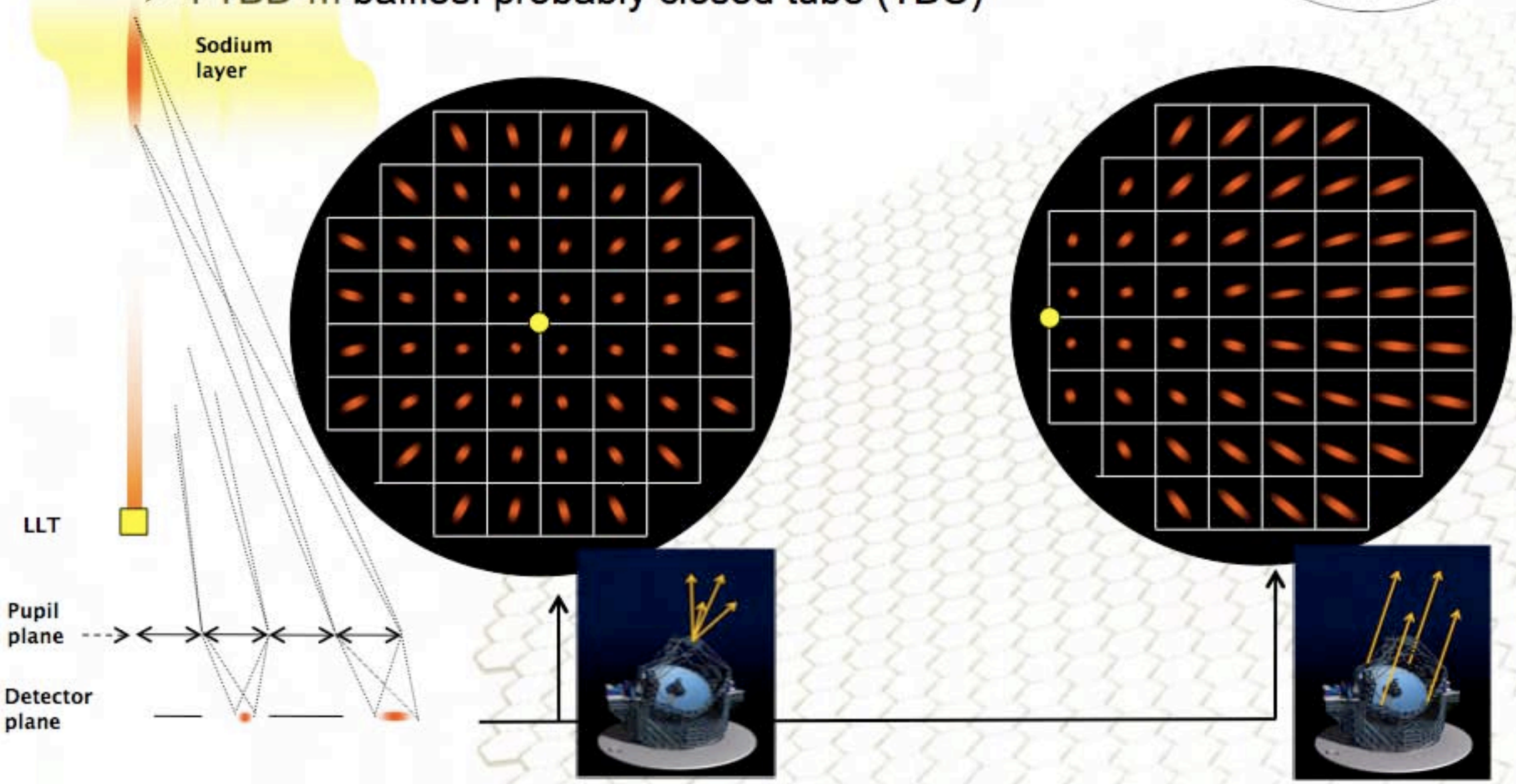


Coudè Location
envisaged for CODEX

LASERS

- 4 laser stations consisting of:
  - 6 laser units of ~25 W ; 4 required for telescope GLAO
  - 4 Launch telescopes of 40cm (30 cm useful aperture)
  - 4 beam relay units beam steering, field selector and beam diagnostic tools compatible with 2 laser beams
  - 4 TBD-m baffles: probably closed tube (TBC)

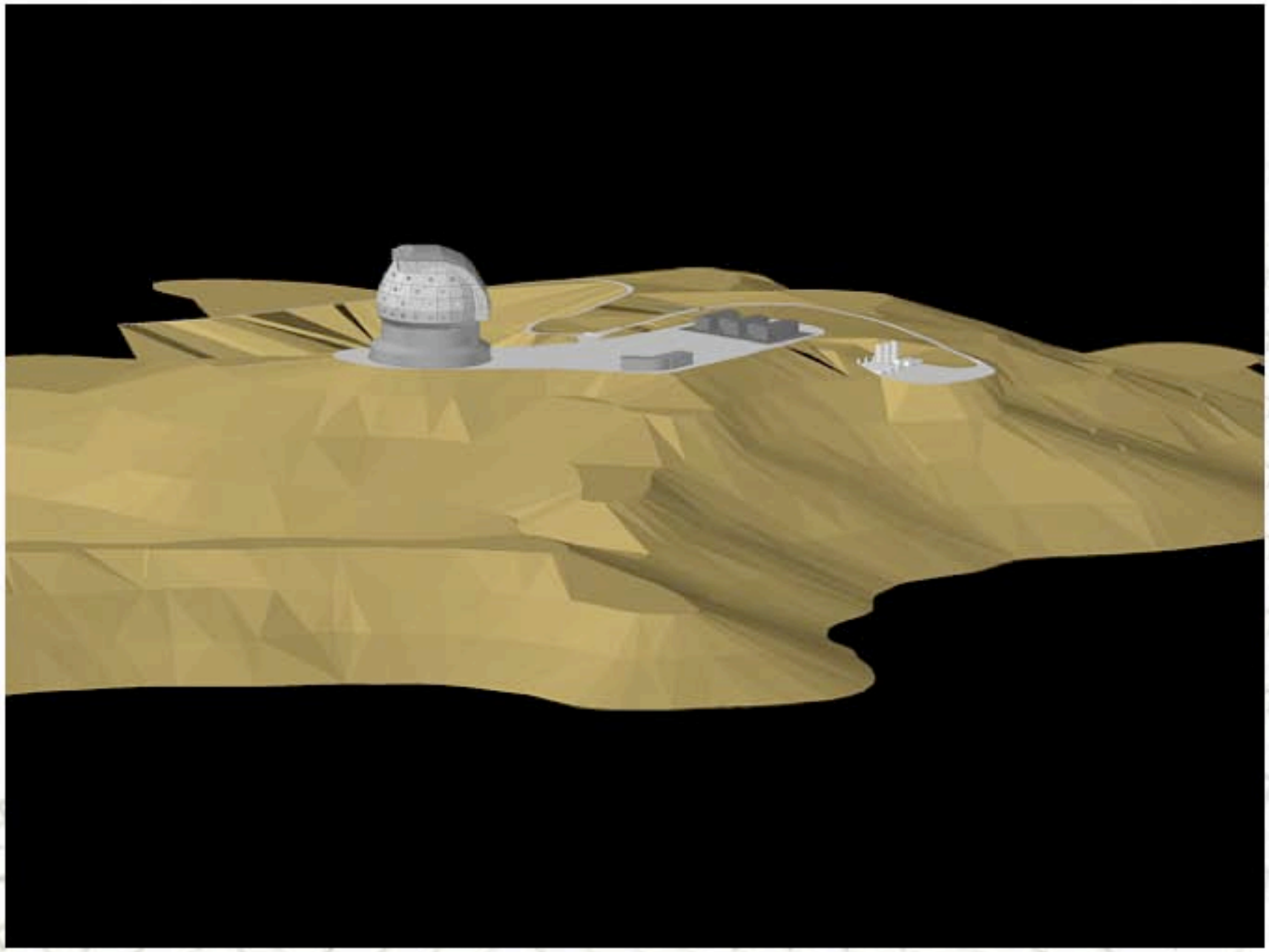




INFRASTRUCTURE

The infrastructure plan includes:

- 10 km of paved road
- 10 MWatts of local generated power
- Wind turbines
- Water capacity of 500 cubic metres
- Telecommunications in and out of the site
- Accommodation for 100 staff
- Control building and laboratories separated from the dome.
- Temporary accommodation during construction.



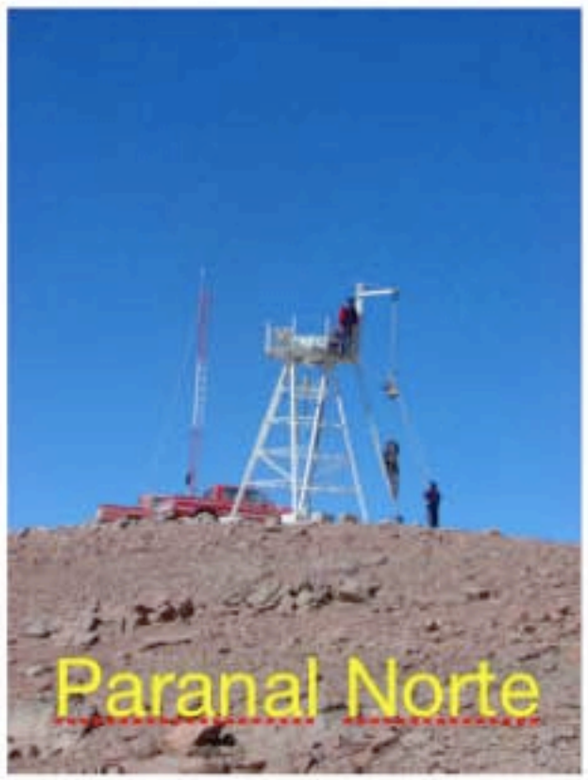
Operations

- Science operations modes further developed
  - Service Mode (fully flexible scheduling, without real-time interaction by the user); **[baseline per DRM]**
  - Remote Mode (highly flexible scheduling giving the remotely located user the possibility of interacting with the observatory in real time);
  - Visitor Mode (non-flexible time allocation with the presence of the observer at the facility).
- Developed manpower requirements for observatory
  - based on identified operational and maintenance tasks
- Requirements on telescope (from TLRs), instruments, and operations (SciOps + daily engineering and maintenance activities), and their interfaces, have been consolidated.

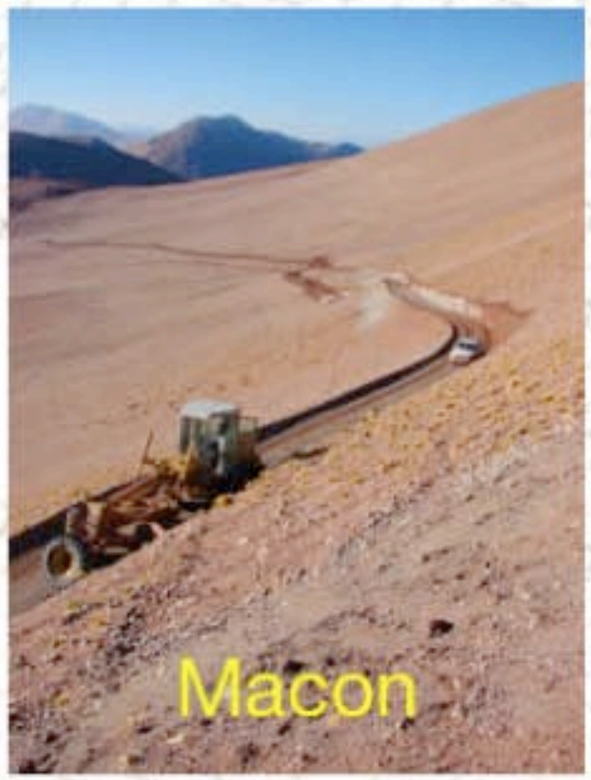
Site characterization

SSAC nominated

Selection by end 2009



Site characterization
on-going for 5 sites



Status of phase B contracts

- **Preliminary design dome (done)**
  - Delta study doors (done)
  - Wind tunnel (done), detailed CFD (in the pipeline)
- **Preliminary design mount (done)**
  - Delta study interfaces (almost done)
- **Preliminary design primary mirror cell (done)**
  - SOW and TecSpec for prototype units & actuators & edge sensors
- **Preliminary design M2 cell (underway)**
- **Preliminary design M3 cell (underway)**
- **Preliminary design PFS (underway)**
- **Prototype M1 segments (underway)**
  - Two different technologies, 7 segments each
- **Preliminary design/prototypes M4 (2x, underway)**
- **FEED studies (underway)**
  - 2x mainstructure, 2x dome

Conclusions

- **The E-ELT is in the detailed design phase**
- **The Phase B is proceeding well**
  - On time and in budget
- **Consolidation with industry:**
  - Mitigation of cost and schedule uncertainties.
  - Subsystem costs from industry within global BRD envelope.
  - Construction timescales for subsystems compatible with global project schedule.
  - 90% of telescope subsystems are already in the industrial study pipeline.
  - Final costing based largely on firm fixed price offers for construction.
- **If approved, construction will take seven years**
  - First light possible in 2018