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
- **In Phase B since Jan 2007**
  - Goal of Phase B: Proposal for construction by 2010
- **Schedule:**
  - Detailed design phase until end 2010
    - External reviews: Mid-term (May 2009), construction (Sep 2010)
  - Start of construction: 2011
  - First light: 2018
- **Cost**
  - Telescope + 1st gen instruments: ~ 950 million Euros
  - Operations (incl new instruments, overheads): ~ 50 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

- **Phase B extended to December 2010**
- **Mid-term review**
  - Passed 12-13 May 2009
- **All major telescope subsystems undergoing first or second 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 Committee**

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"***

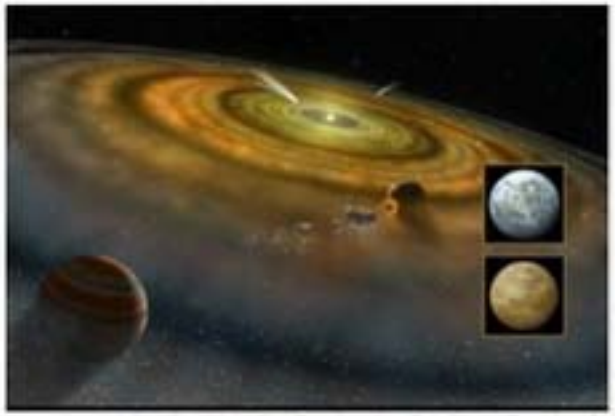
- Mid 00s: consolidation to E-ELT, TMT & GMT

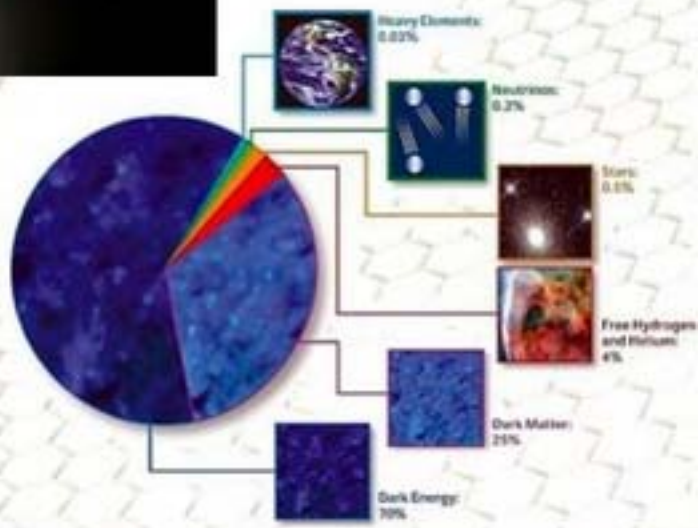
GUIDELINES

- **Affordable**
  - **Cost ~ VLT, ALMA**
- **Timely**
  - **JWST (2014) synergy, competitors**
  - **→ First science ~ 2018**
- **Acceptable risk**
  - **No essential items R&D on critical path**
  - ***Upgrade paths* where appropriate**

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





ELT SCIENCE CASE DEVELOPMENT IN EUROPE

Florence 2004

Web site

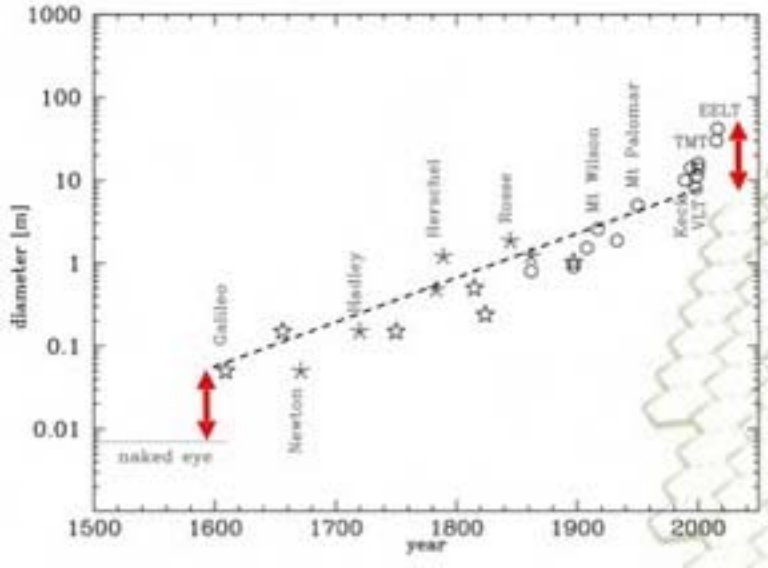
Marseilles 2003

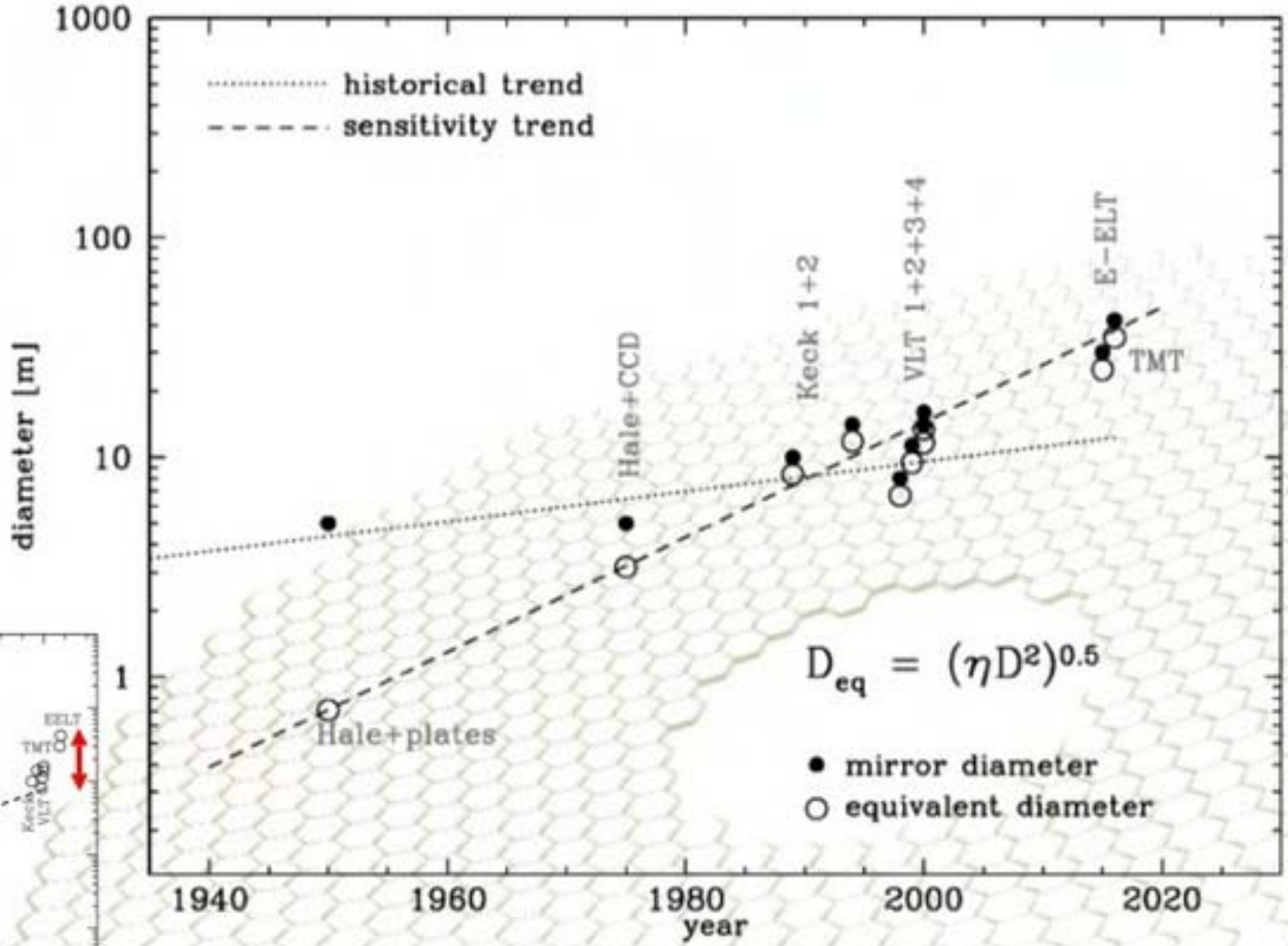
Science case documents

Marseilles 2006

Brief history of the telescope:
Why break a time honored tradition?
Detectors have improved more than diameters

We need to break the "factor-of-two increase in diameter" law





The Science Case: three pillars

- **Contemporary science:** *Today's clever ideas* ➠ *the DRM*
- **Synergy with other facilities:**


8-10m telescopes

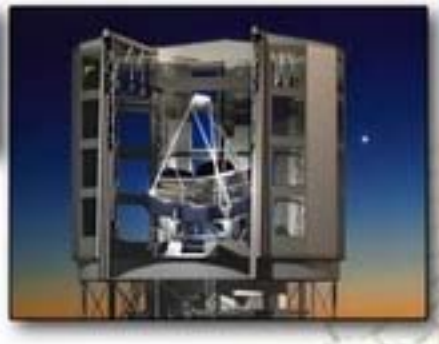

ALMA


JWST

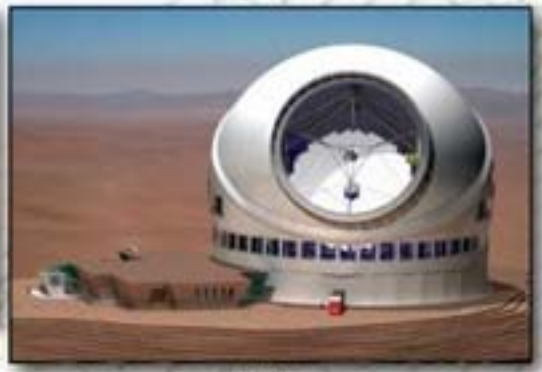
LSST


SKA

- **Discoveries:** *Opening parameter space* (*photon sensitivity, spatial resolution*)



VLT
~50 m²
1μm: 25 mas



GMT
~400 m²
9 mas

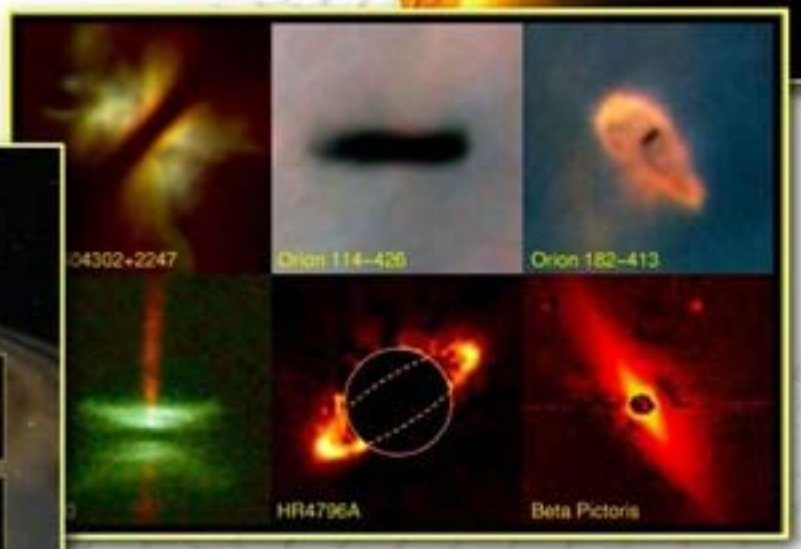
TMT
~600 m²
7 mas

(With thanks to Markus Kissler-Patig and Isobel Hook)

Key Contemporary Science (1)

Exo-planets / planet- and star-formation

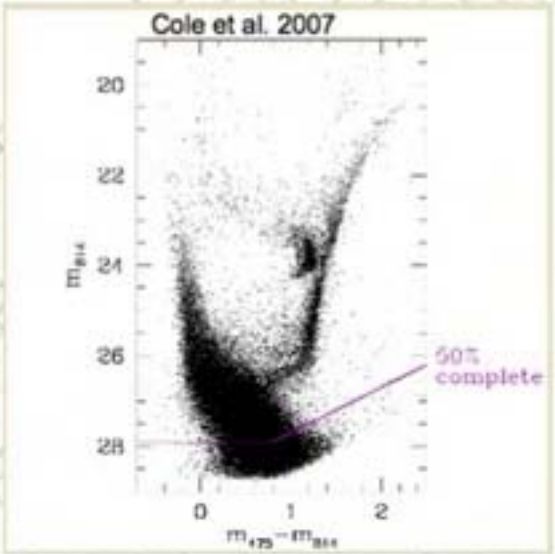
- Direct detections of rocky planets in habitable zones
- Characterisation of Exo-planet atmospheres
- Pre-biotic molecules

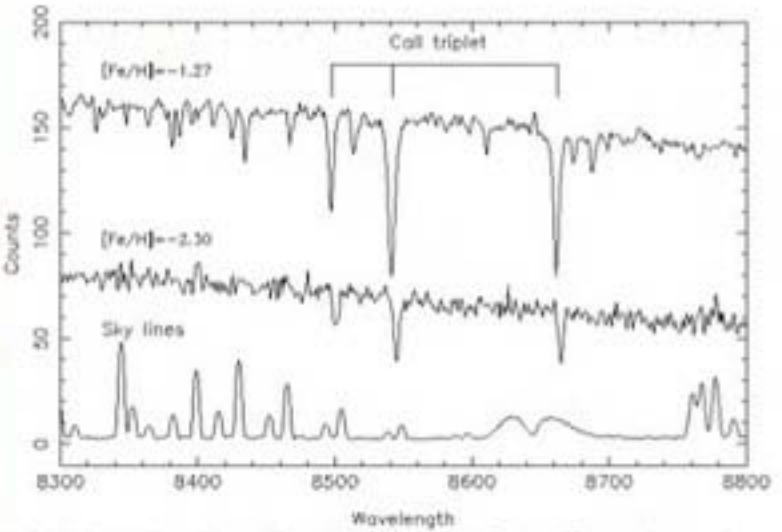


Key Contemporary Science (2)

Understanding the formation and evolution of galaxies

- Imaging and spectroscopy of resolved stellar populations in galaxies
- Black holes and AGN (Active Galactic Nuclei)

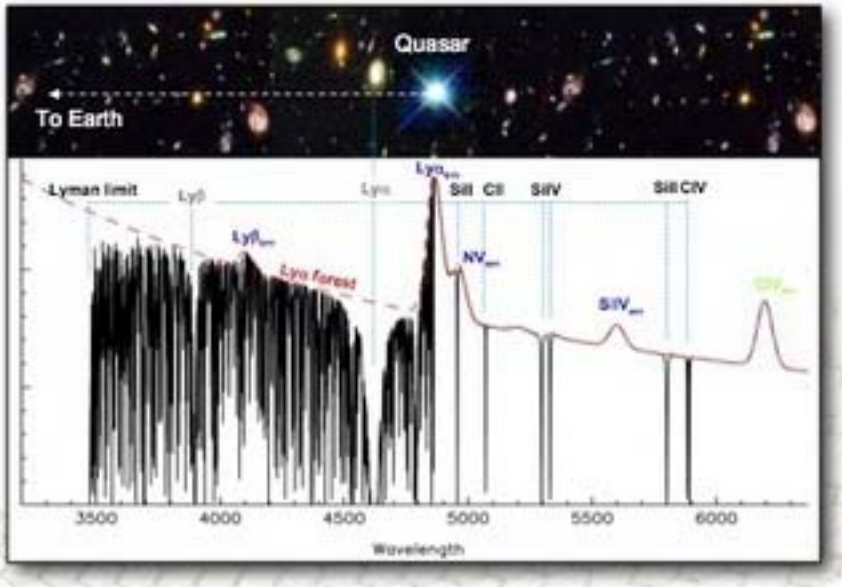


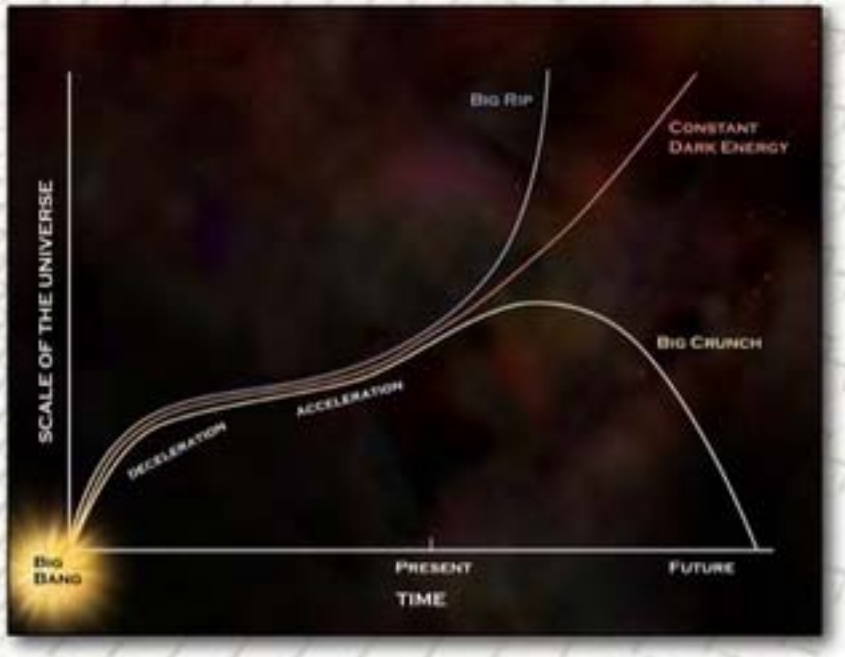


Key Contemporary Science (3)

Fundamental physics

- Variation of fundamental constants (α, μ)
- Direct measurement of the expansion of the universe
- Test of General relativity around black holes





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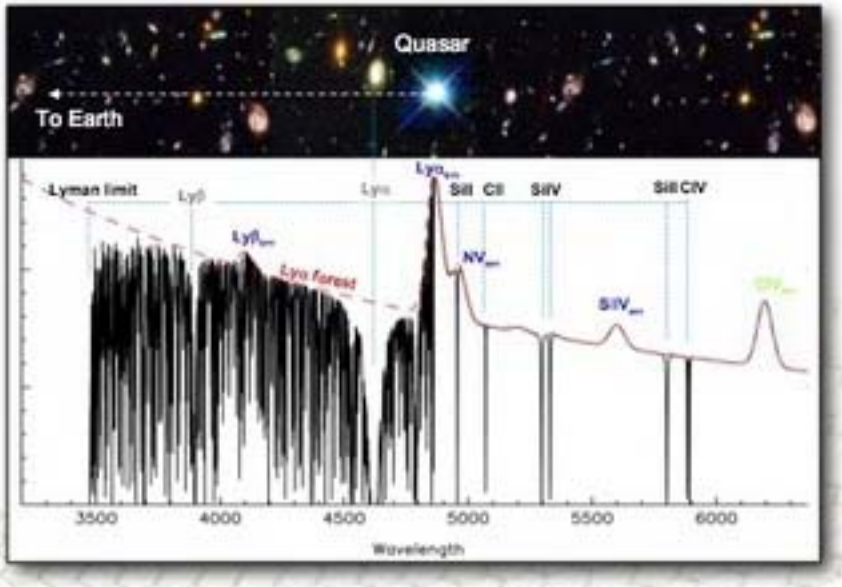
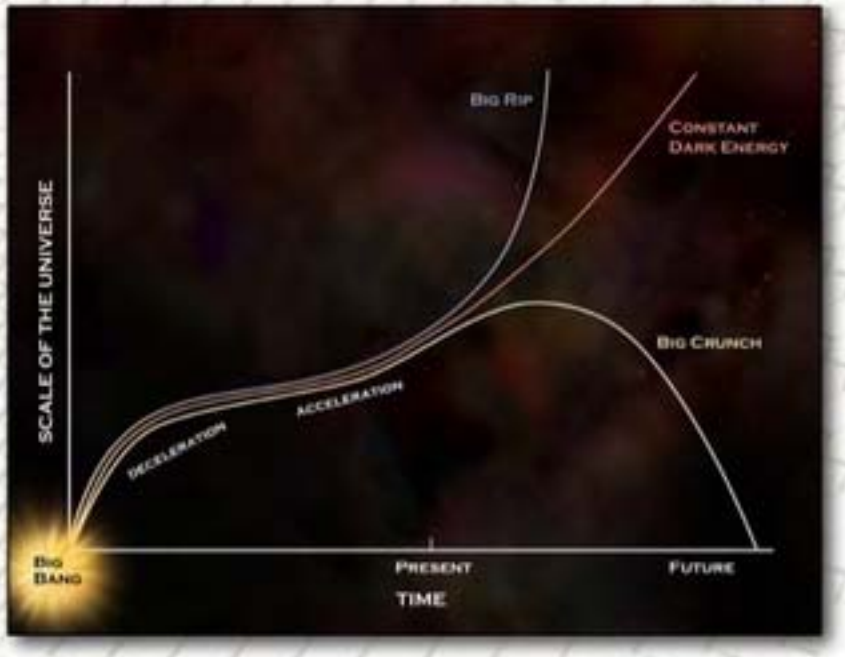
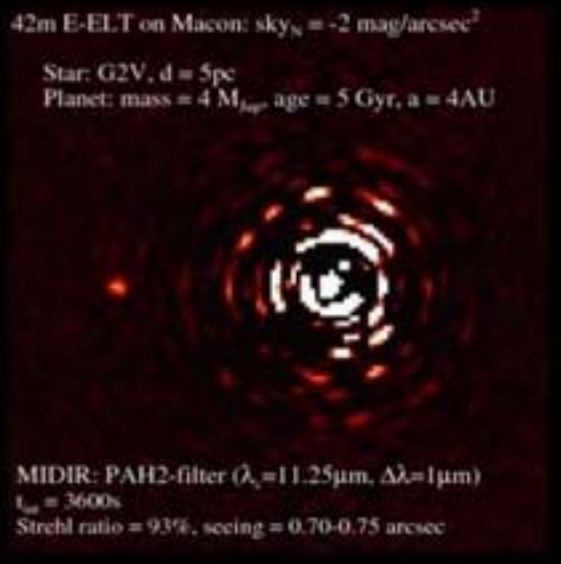


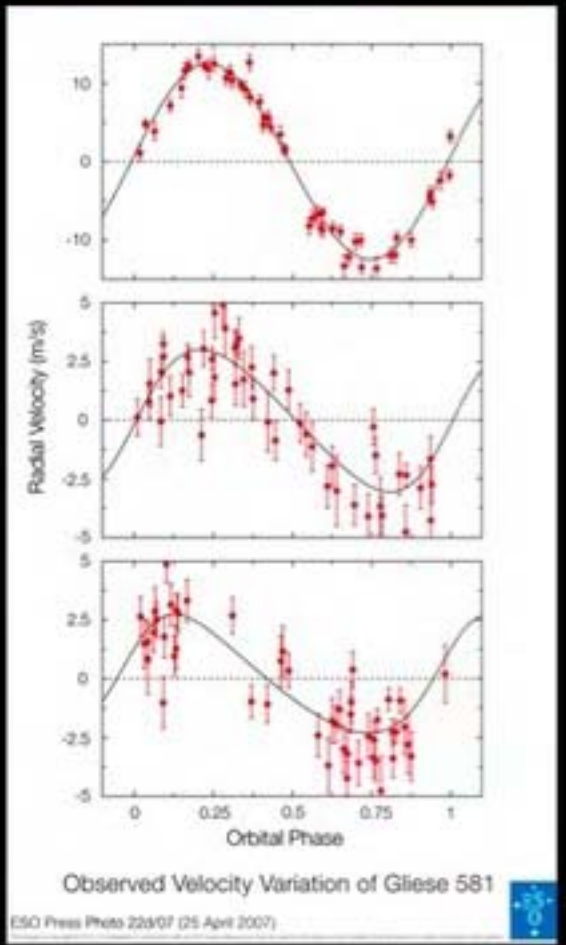


Exoplanets

Right: Simulation by the METIS team

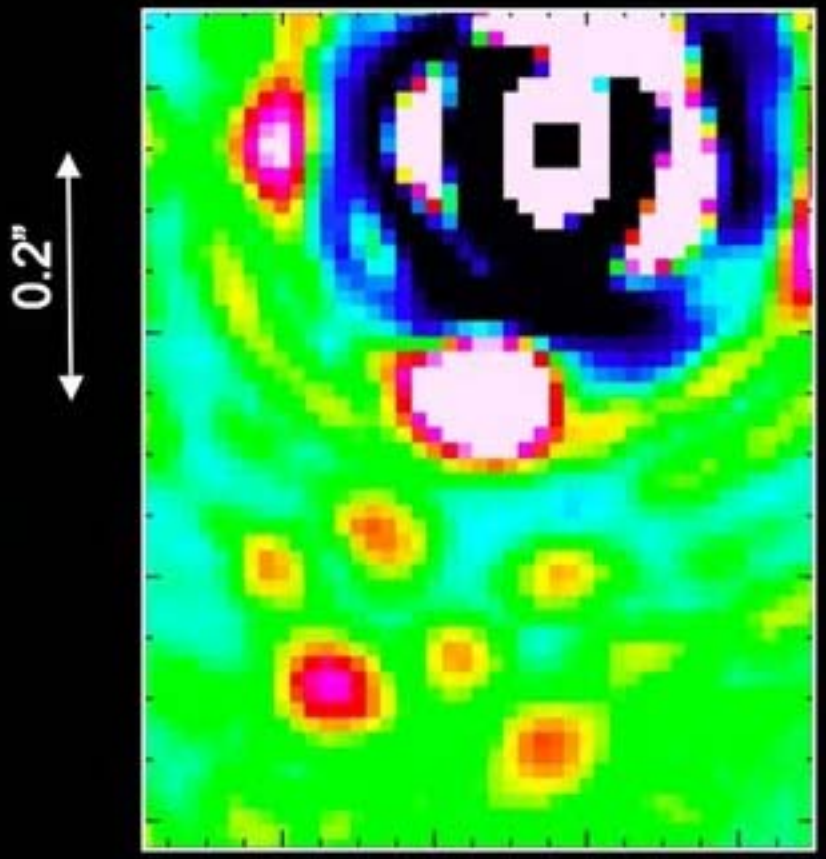


- How common are systems like ours?
- How do planetary systems form?
- Direct Detection
  - Spatial resolution with ExAO: ~ 10^9 contrast required for Earth-like planets
  - Mid-IR direct detection (contrast reduced but larger PSF)
- Radial velocity method (HARPS legacy)
  - Potential to reach lower-mass planets
  - ELT provides required collecting area
  - cm/s precision required for Earth-like planets
- Atmospheres
  - High resolution NIR spectroscopy of transiting planets

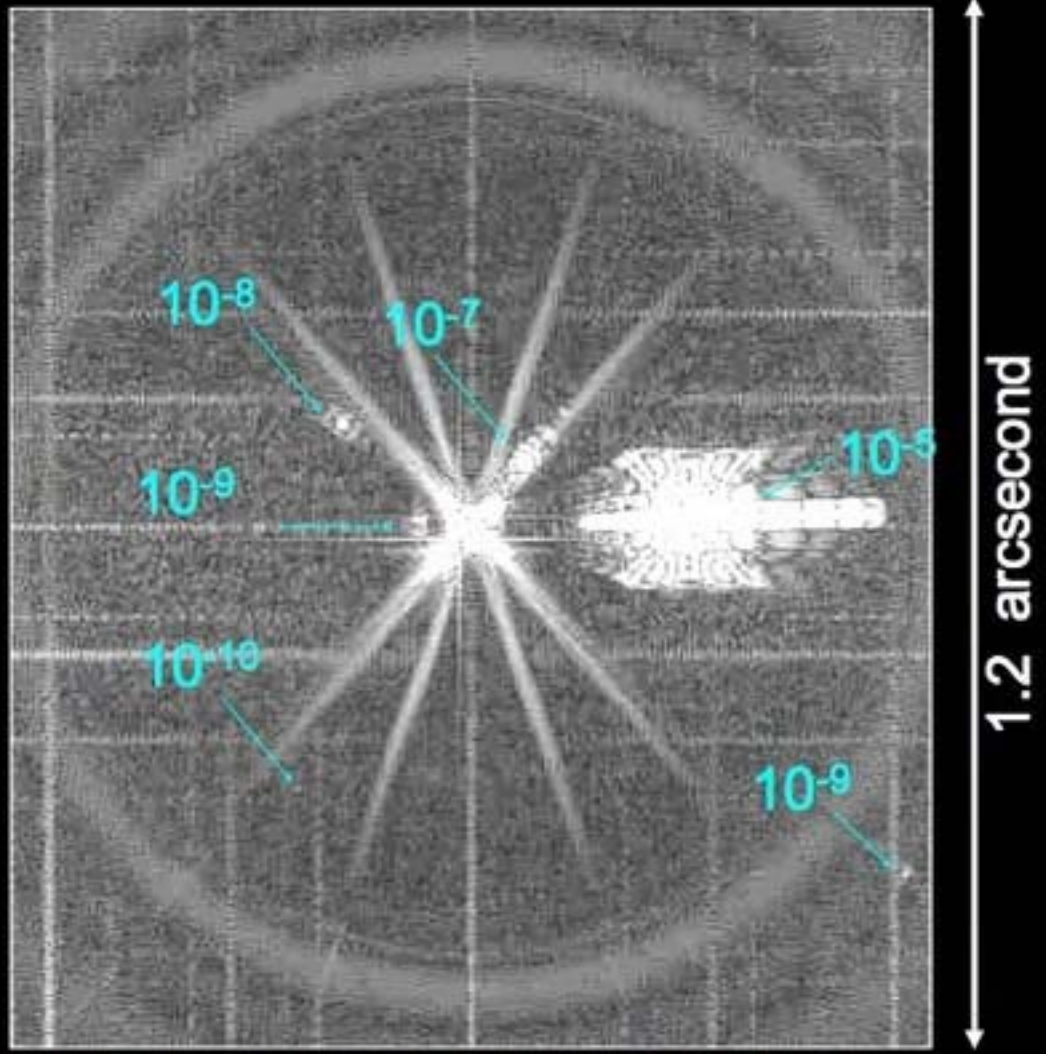


Direct detection of a “Super Earth”

- Simulations including systematic effects (e.g. speckles)



Speckle subtraction technique
AB Dor, VLT/ SINFONI (Thatte et al 2007)



Simulated image courtesy of **EPICS** team.
10 hours, J band - PRELIMINARY

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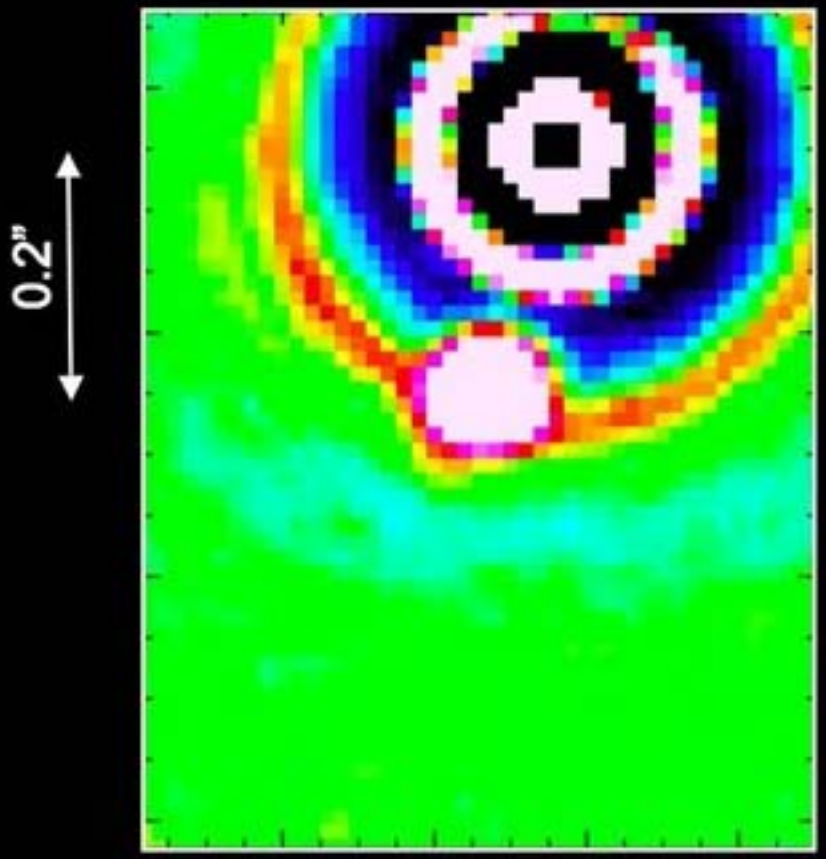

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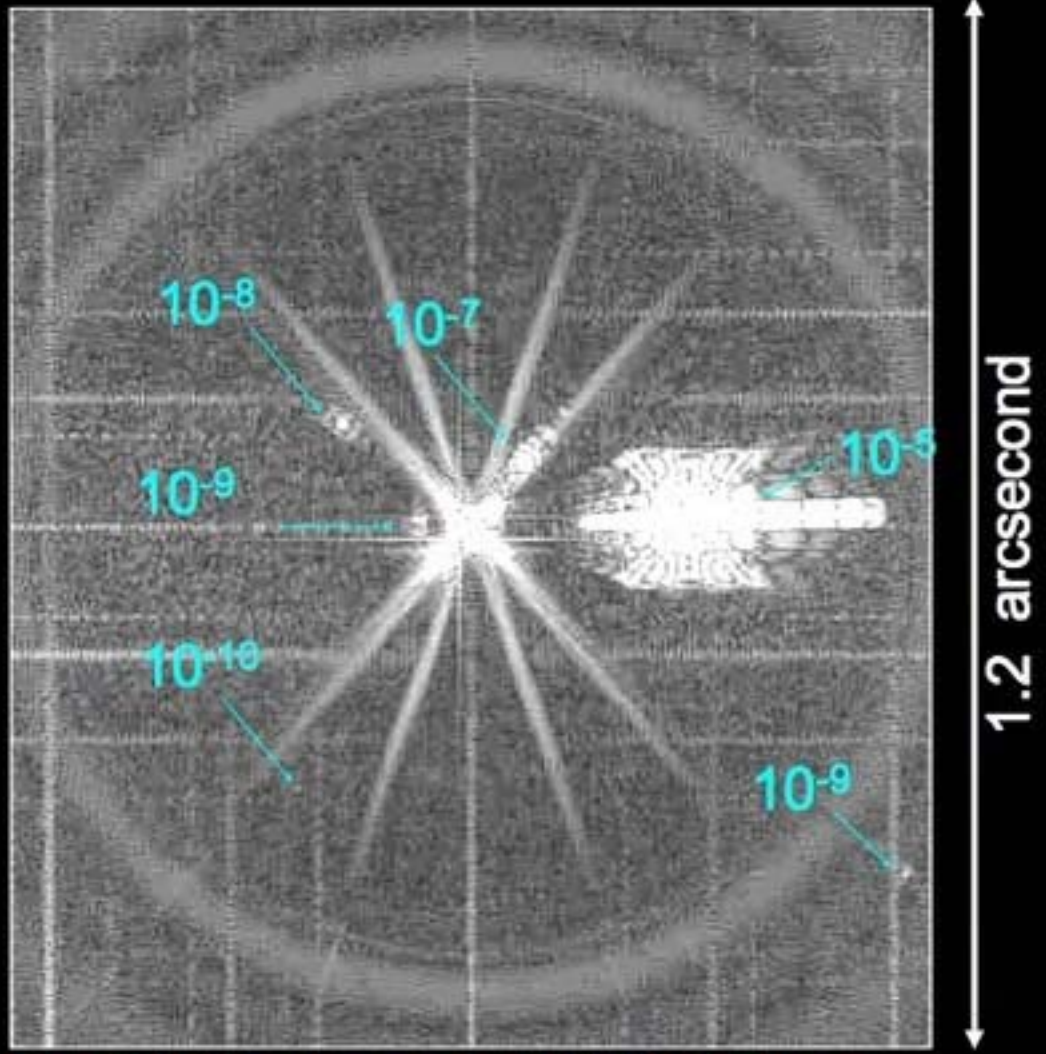
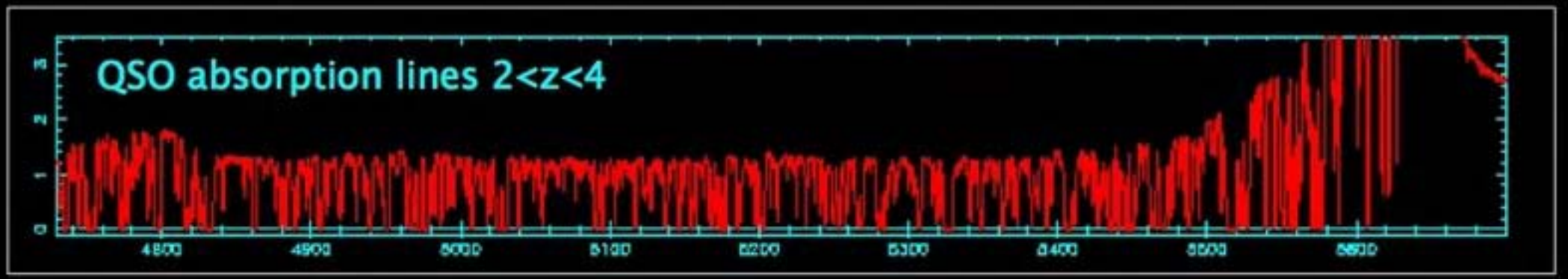


Simulated image courtesy of **EPICS** team.
10 hours, J band - PRELIMINARY

Watching the Universe accelerate in real time

- What is the Dark Energy?
- E-ELT can measure acceleration **directly**, in real time
- Fundamentally different probe (dynamical vs geometrical)
- Weak signal: ~ cm/s/yr. Requires:
- ELT (collecting area)
- 20 year monitoring campaign
- Ultra-high stability, high-resolution spectrograph (CODEX)



J. Liske et al., MNRAS, 2008 and Final DRM report

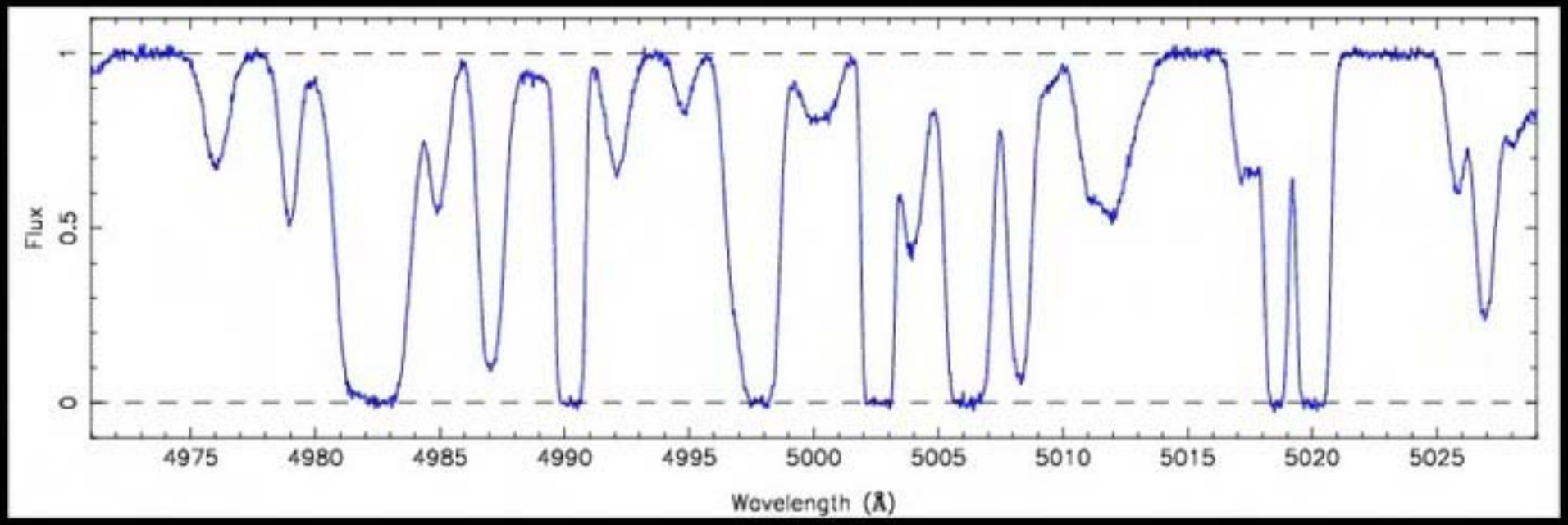
Cosmic Dynamics Experiment

$$\dot{z} = \frac{dz}{dt} = (1+z)\,H_0 - H(t_e)$$

Measuring the redshift drift requires:

- Many photons, high resolution, extremely stable spectrograph
- ~20 yr long spectroscopic monitoring campaign

Best place to observe the redshift drift: the Lyman-α forest.



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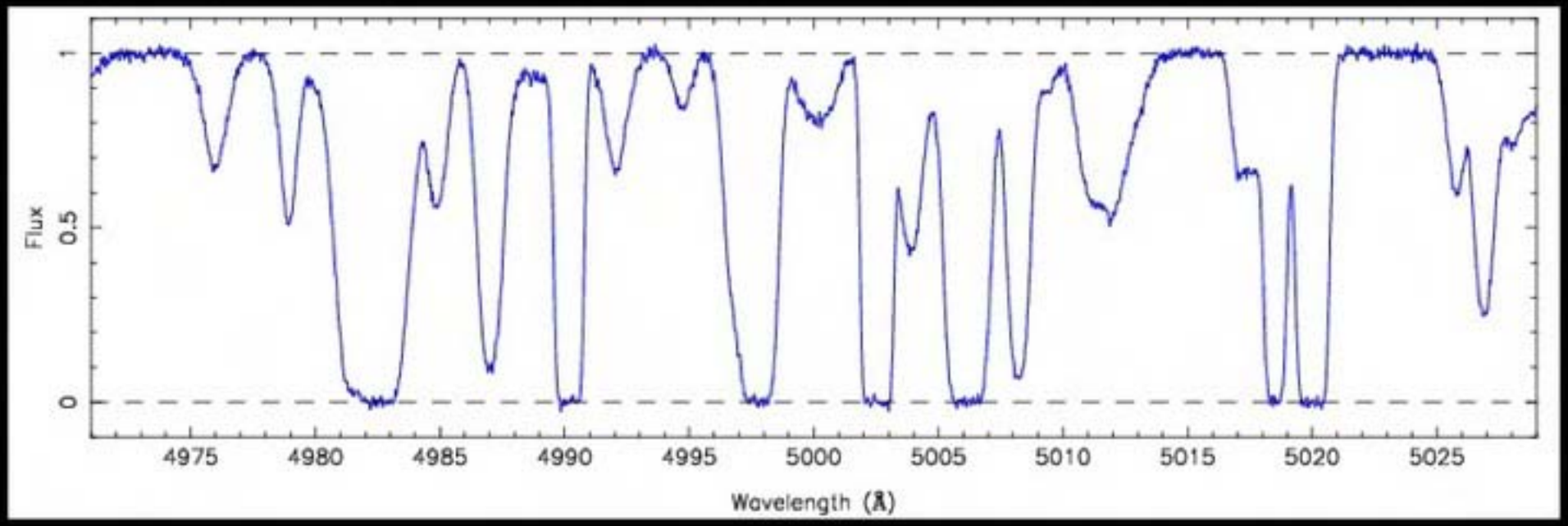

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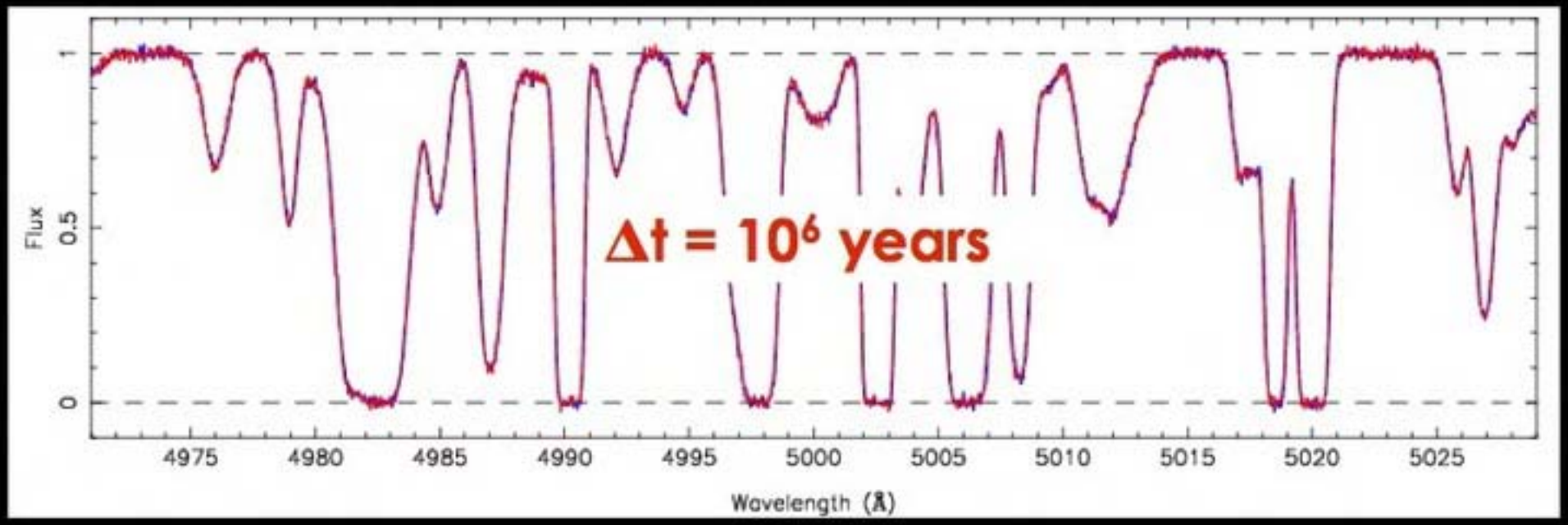
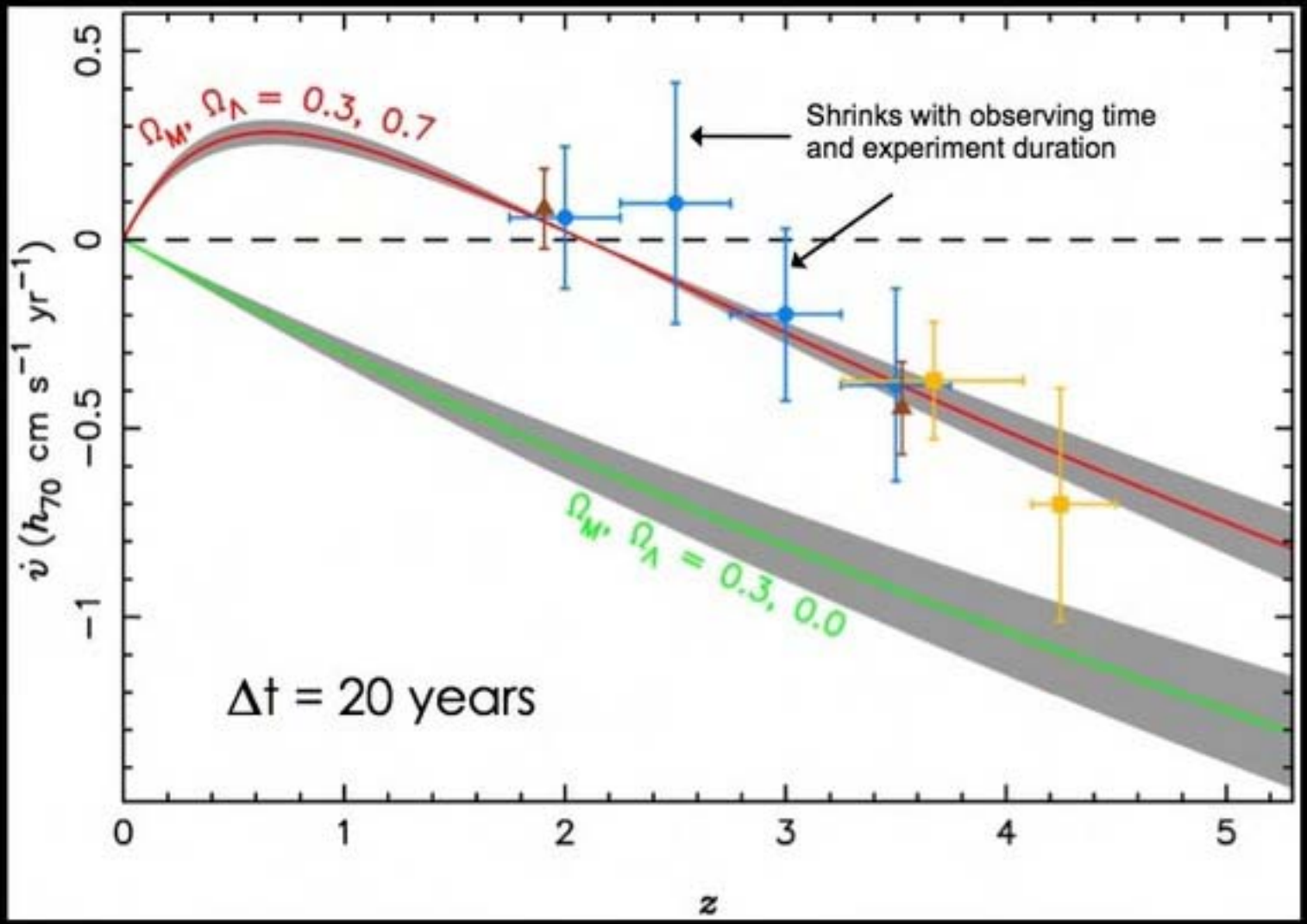


Cosmic Dynamics Experiment

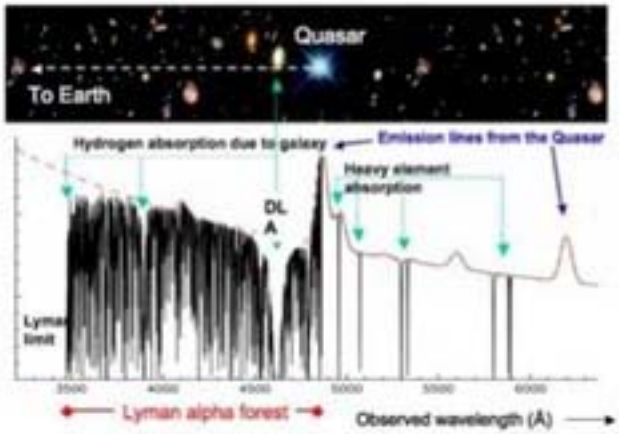
Simulations:

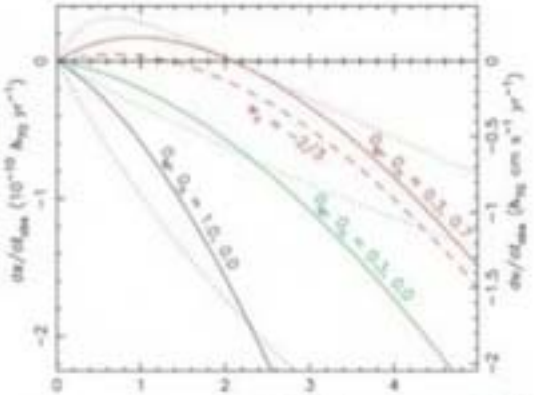
4000 hours over 20 years will deliver any *one* of these sets of points.

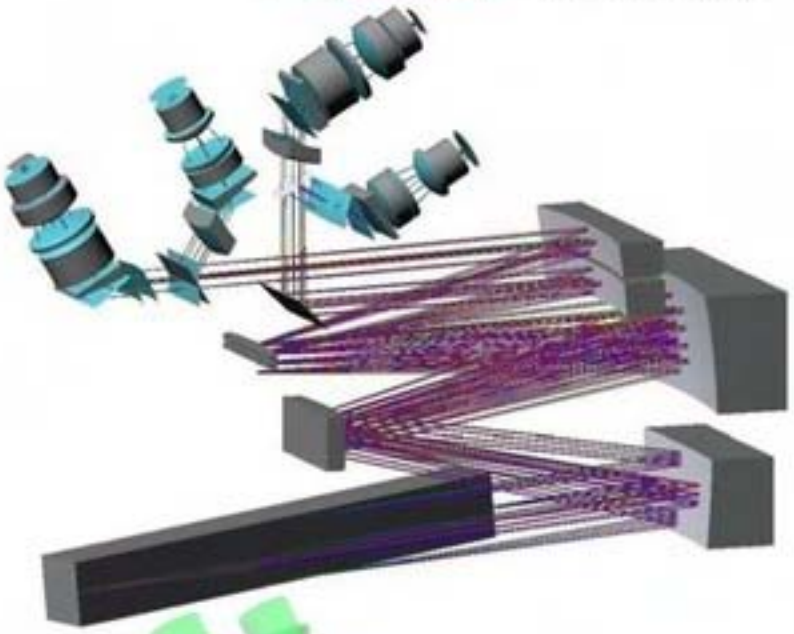
Different sets correspond to different target selection strategies.

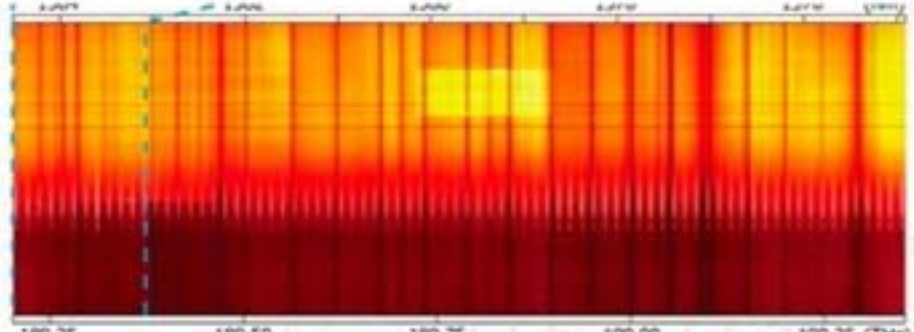


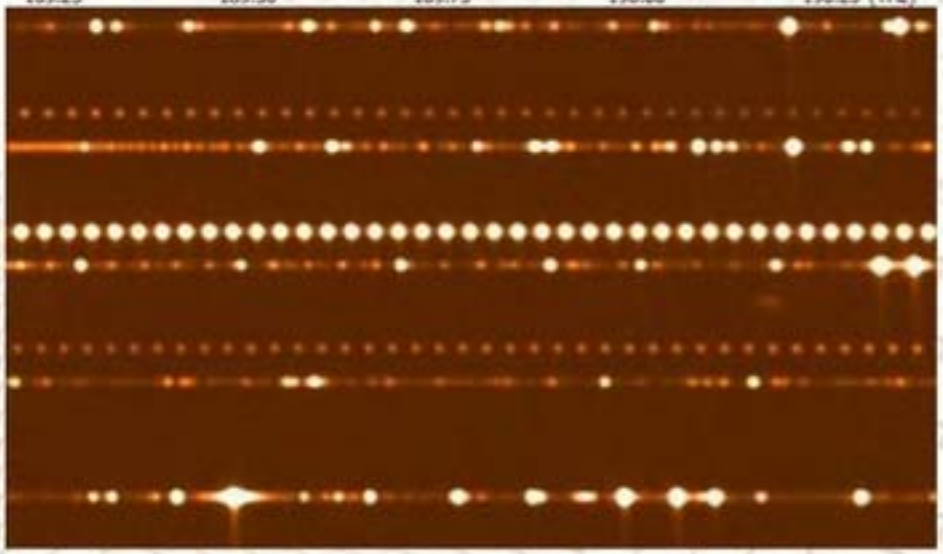
CODEX

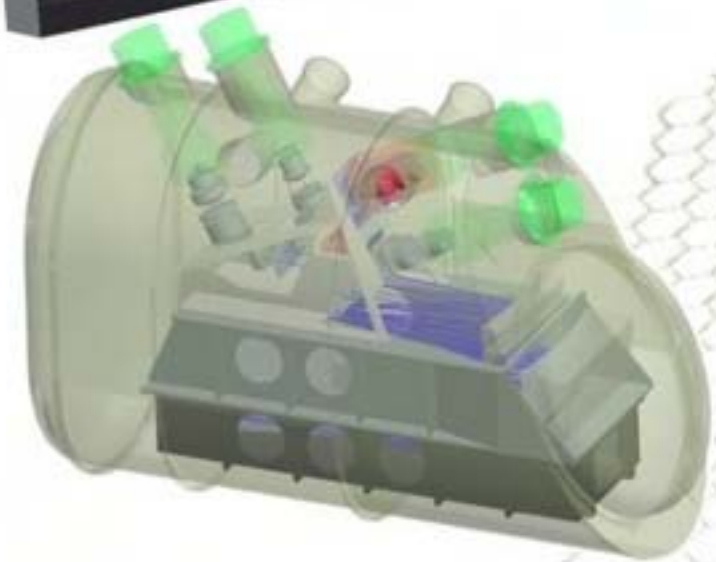




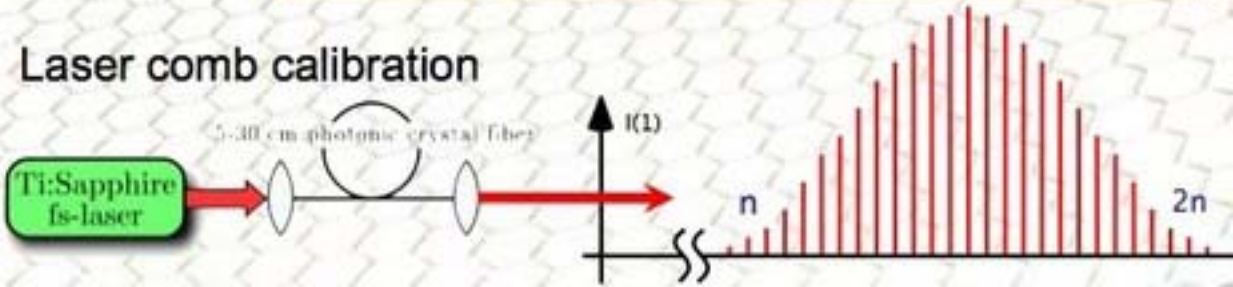




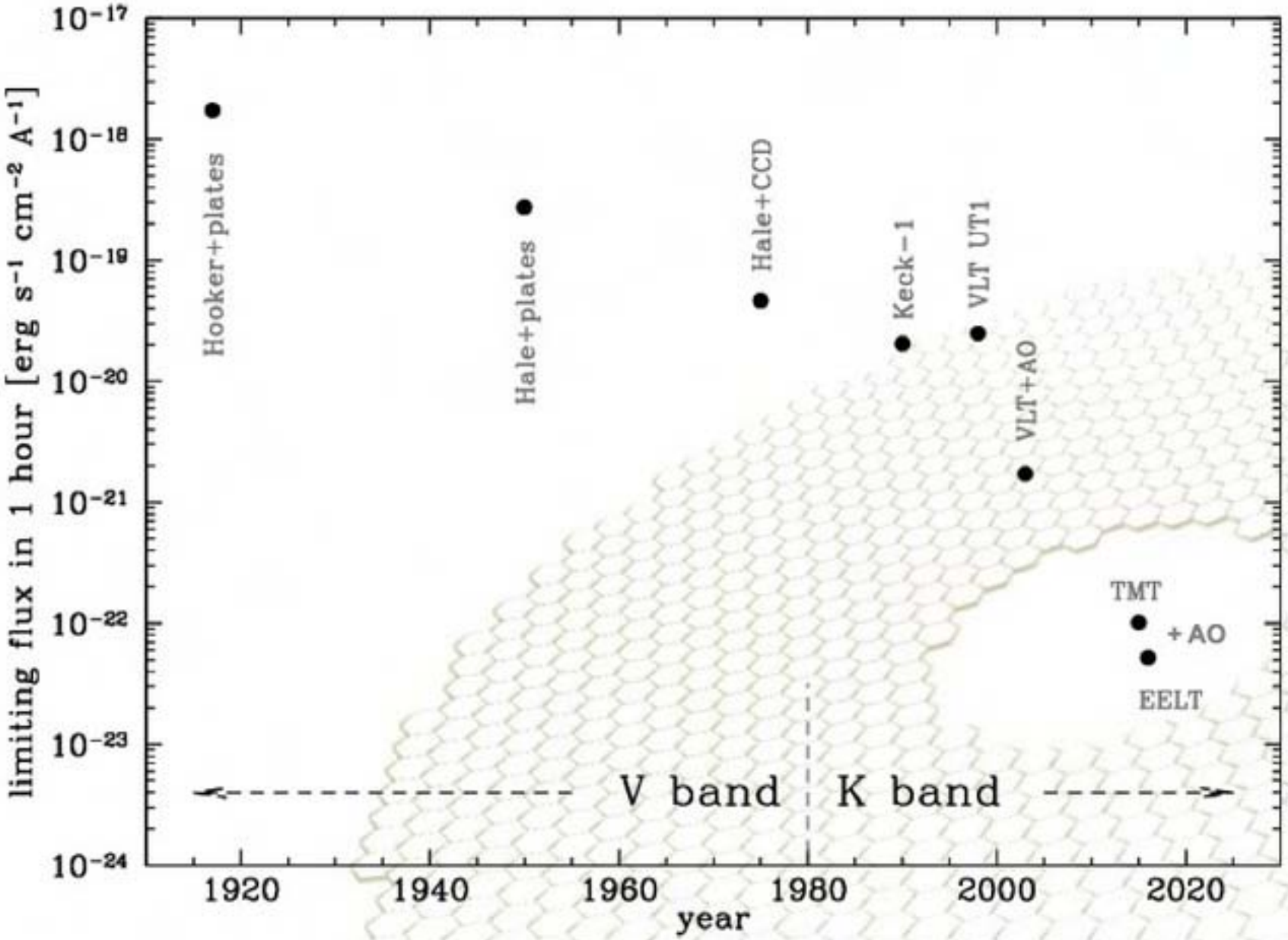




Laser comb calibration

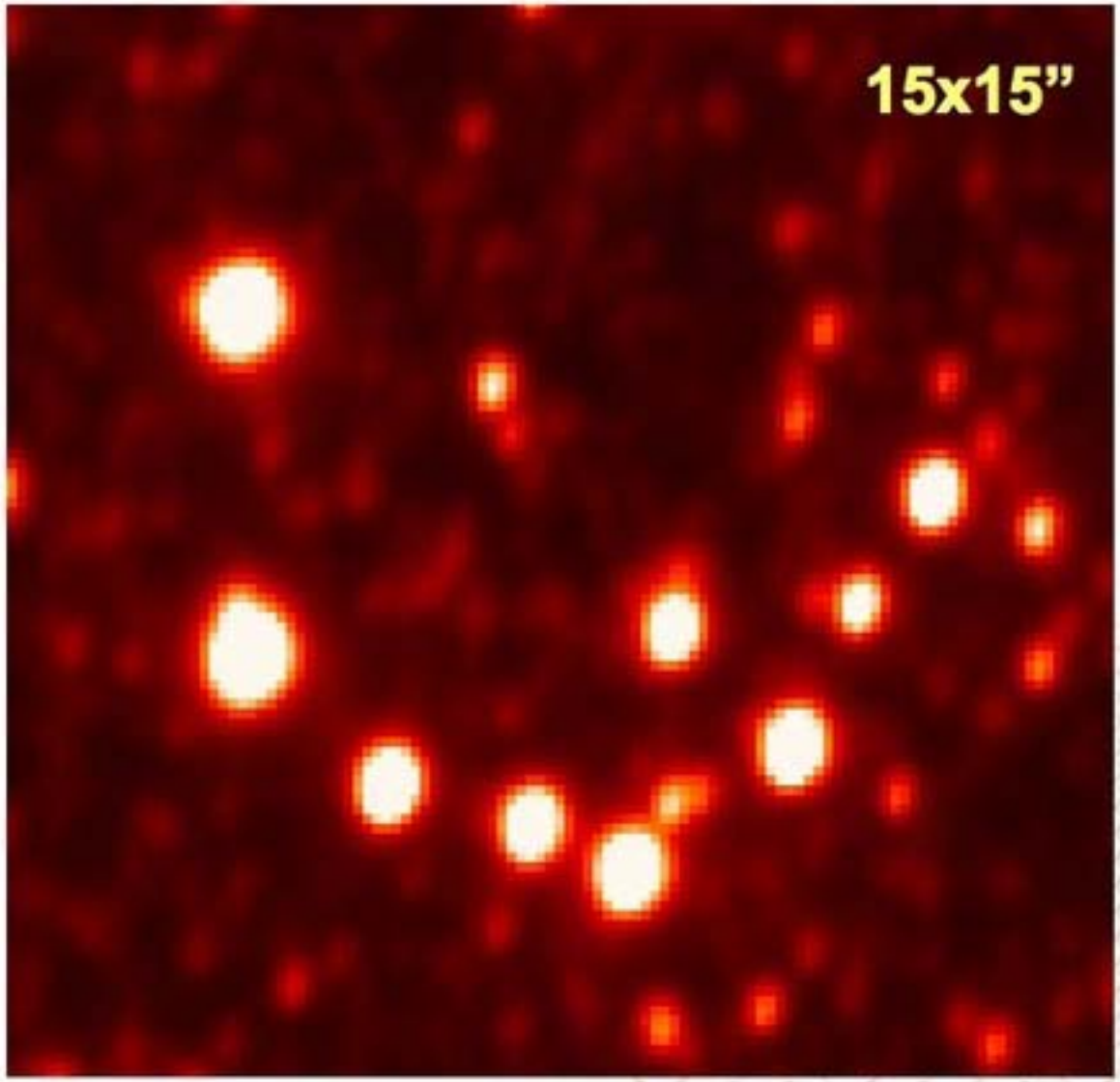


SCIENCE → REQUIREMENTS: 1. SENSITIVITY



2. High spatial resolution

AN AO MILESTONE: MAD



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

ISAAC seeing: ~ 0.5"

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

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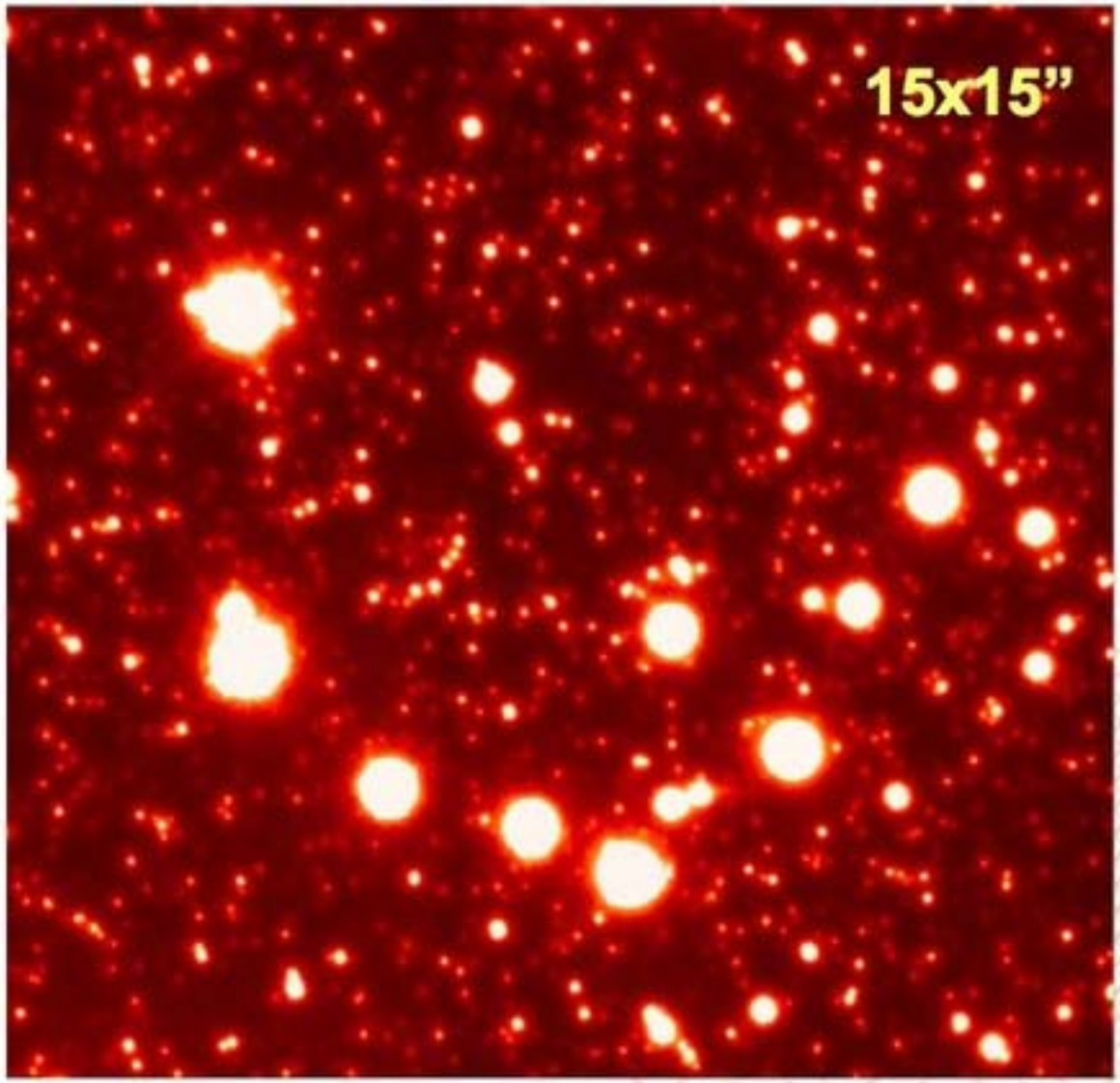

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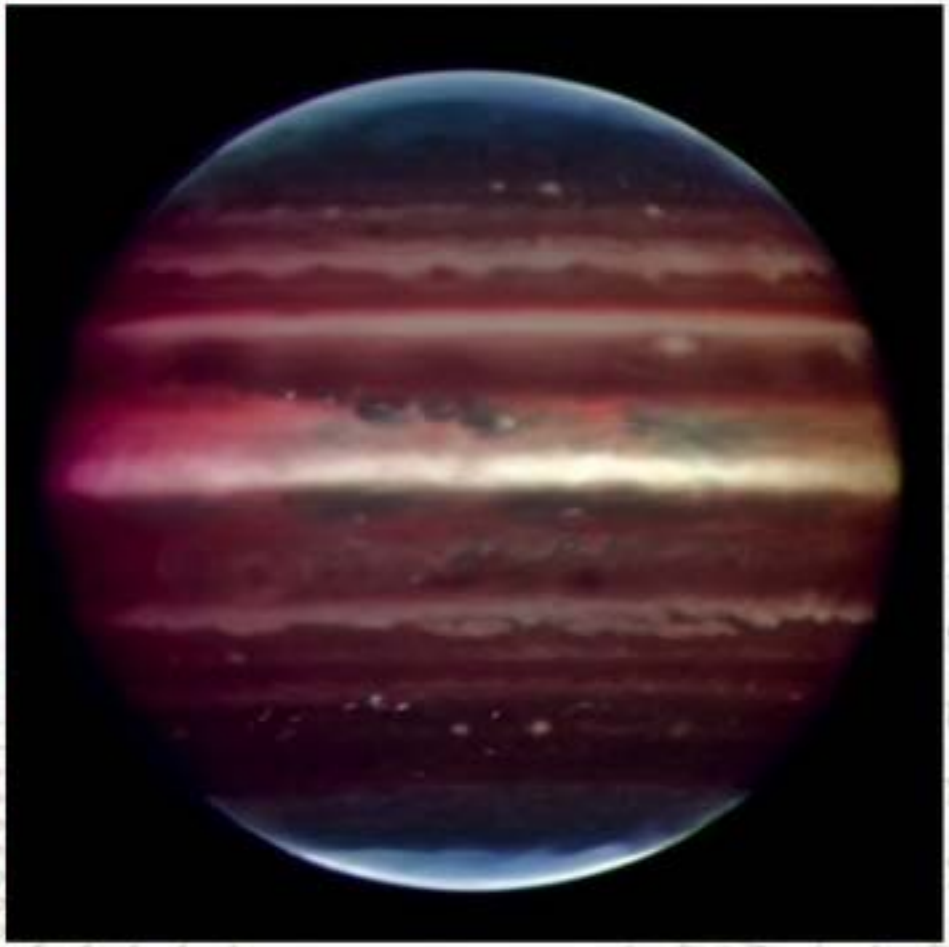

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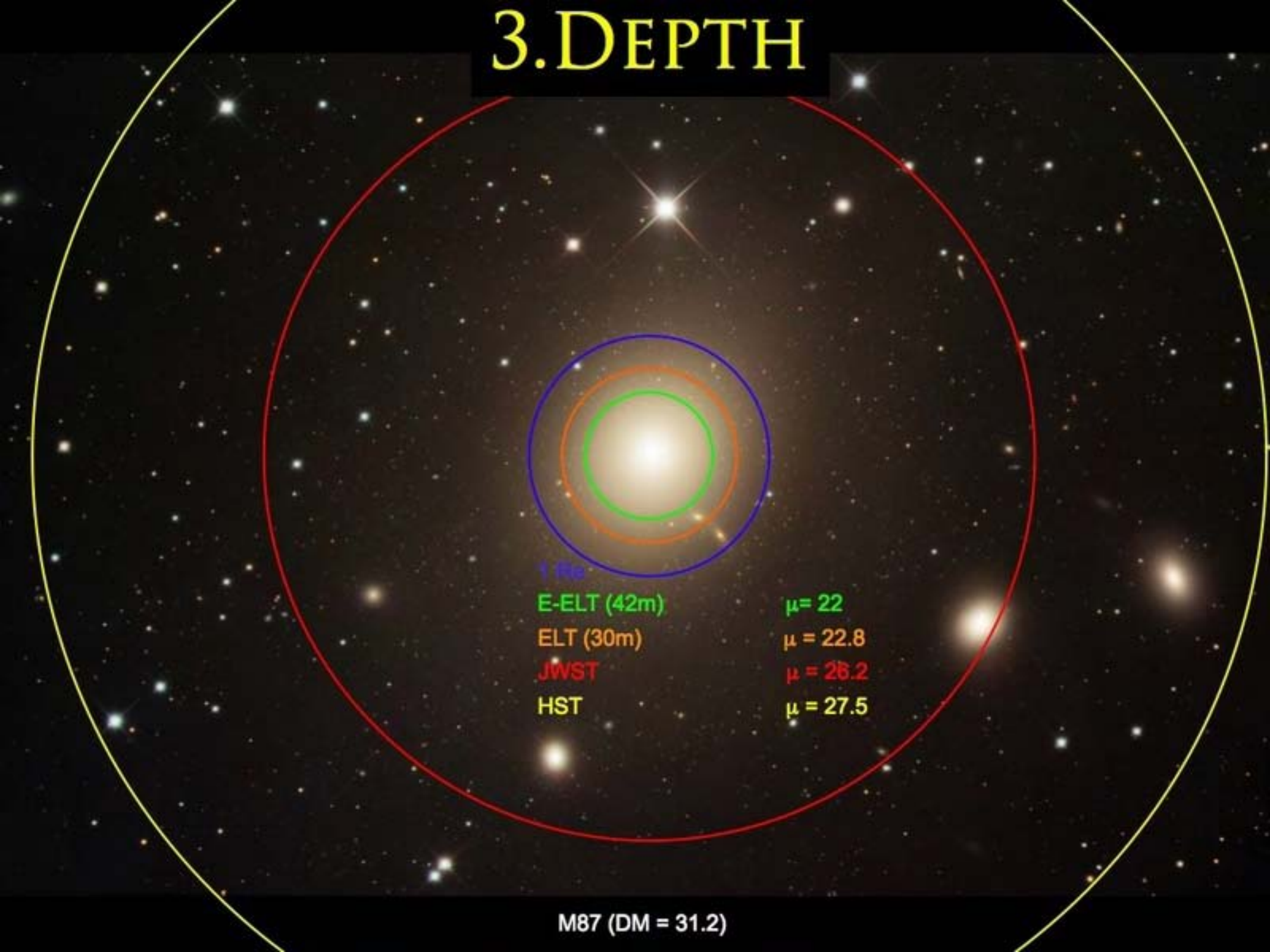
90 mas resolution (300 km at Jupiter)

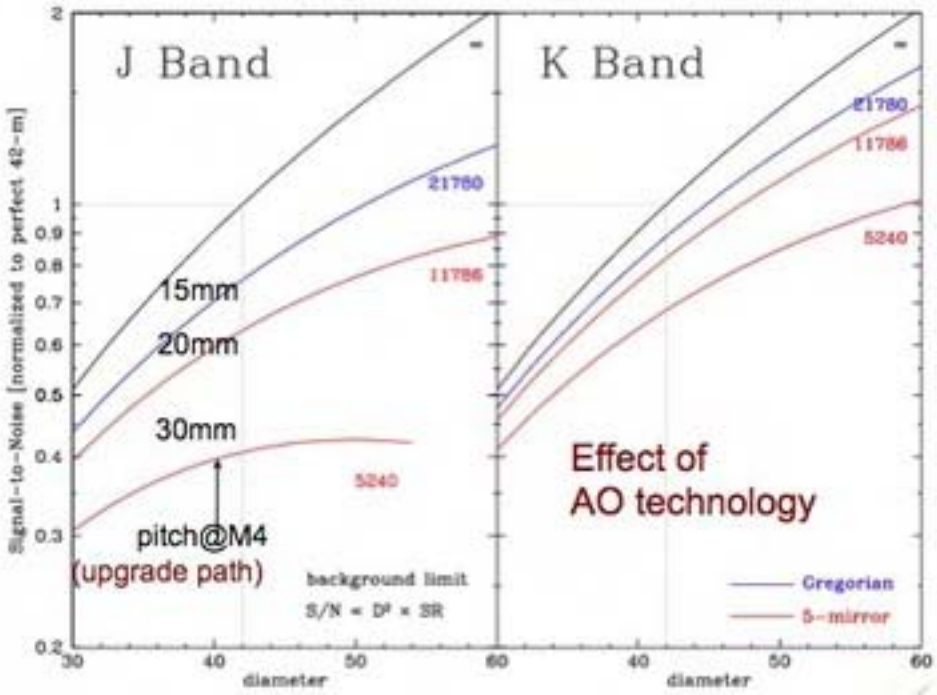
3. Depth

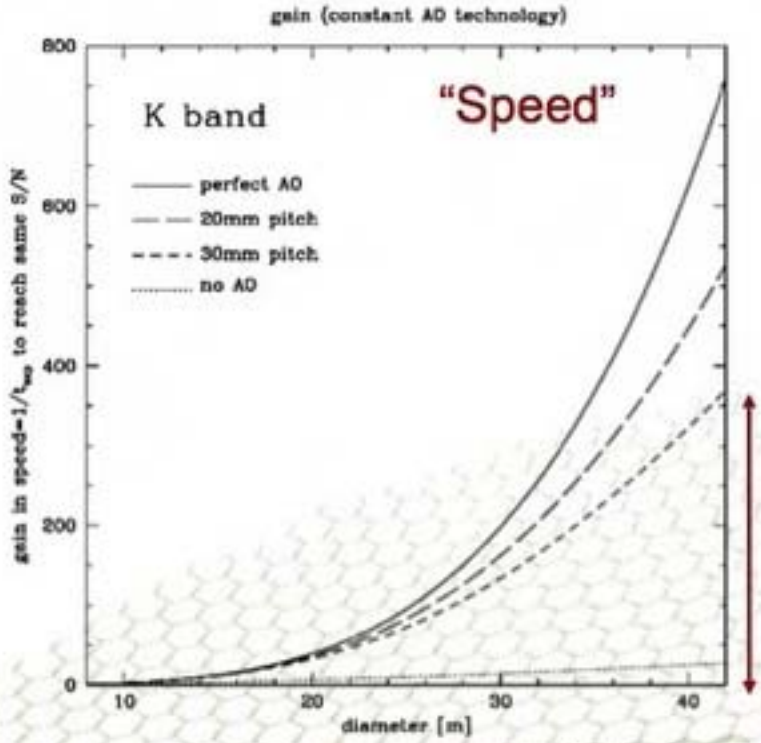


E-ELT Top Level Requirements

- **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)

SUMMARY: POWERFUL PERFORMANCE





≈ 1 year
of VLT obs
in 1 night

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

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

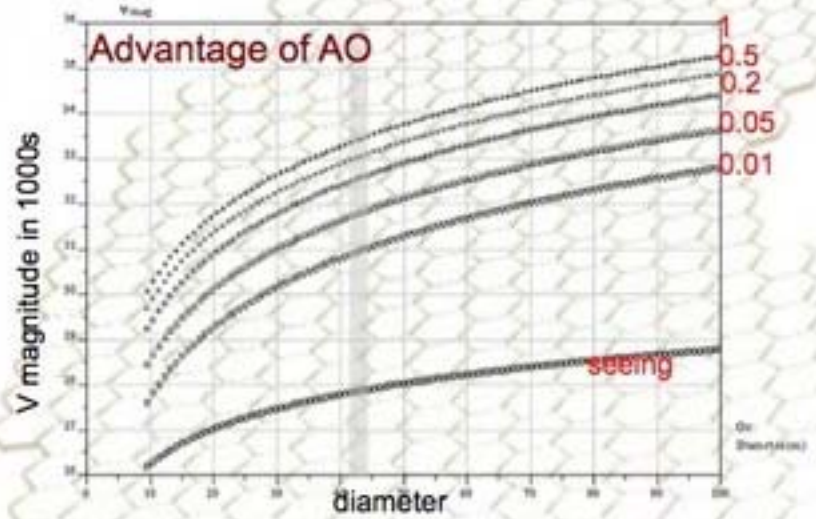
Bgd: $B = sky \times pix^2 \propto D^2 \times D^{-2} \equiv B_0$

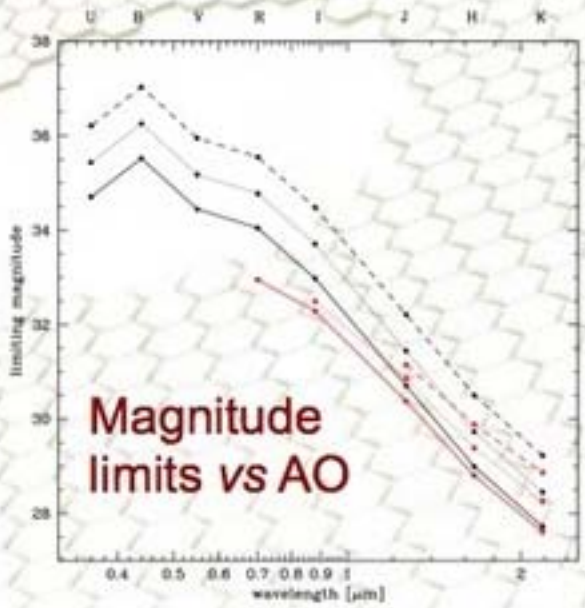
For faint sources:

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

For exo-planets:

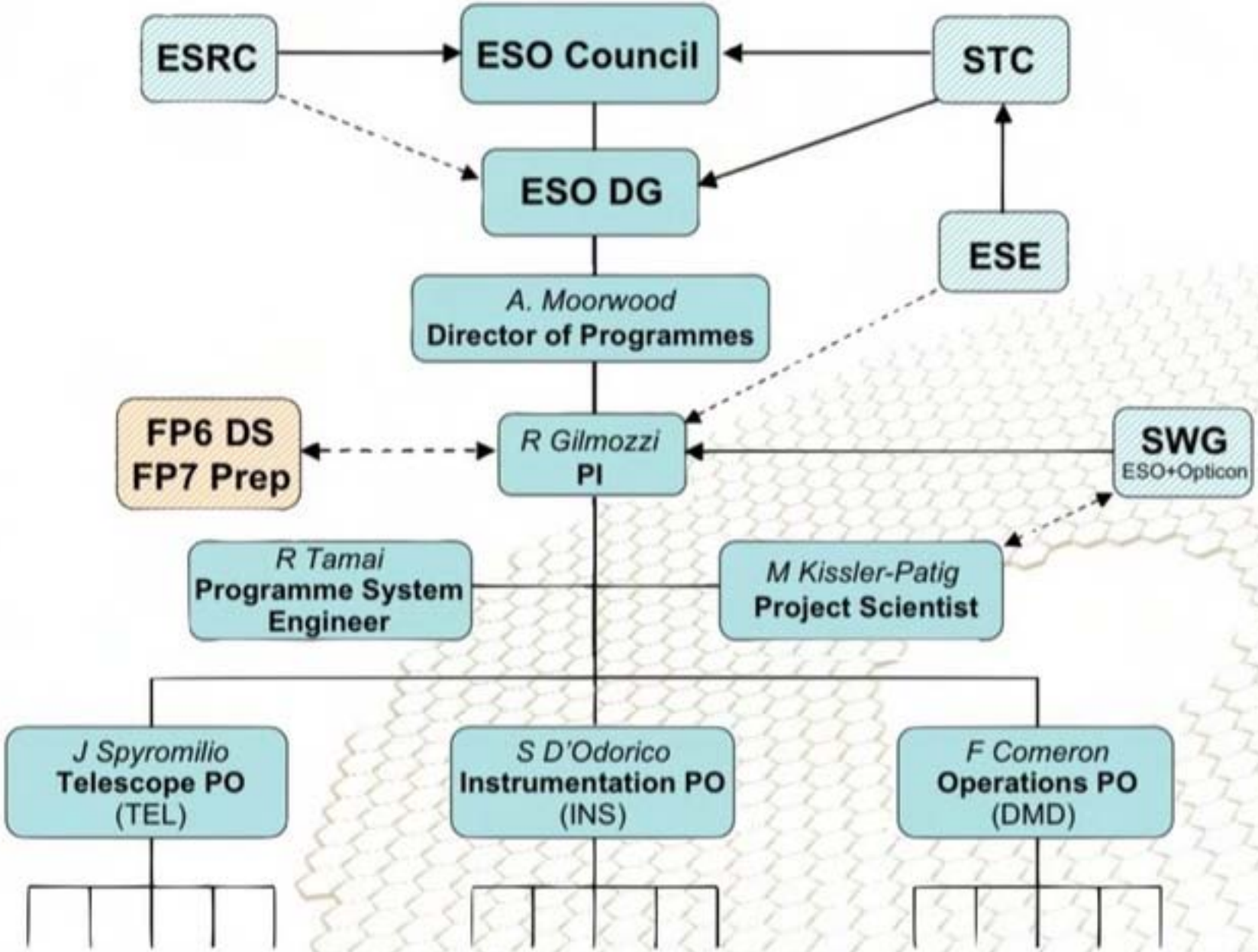
$S/N \approx F/\sqrt{B_\star} \propto \mathbf{D^2 \times SR^2/(1-SR)}$

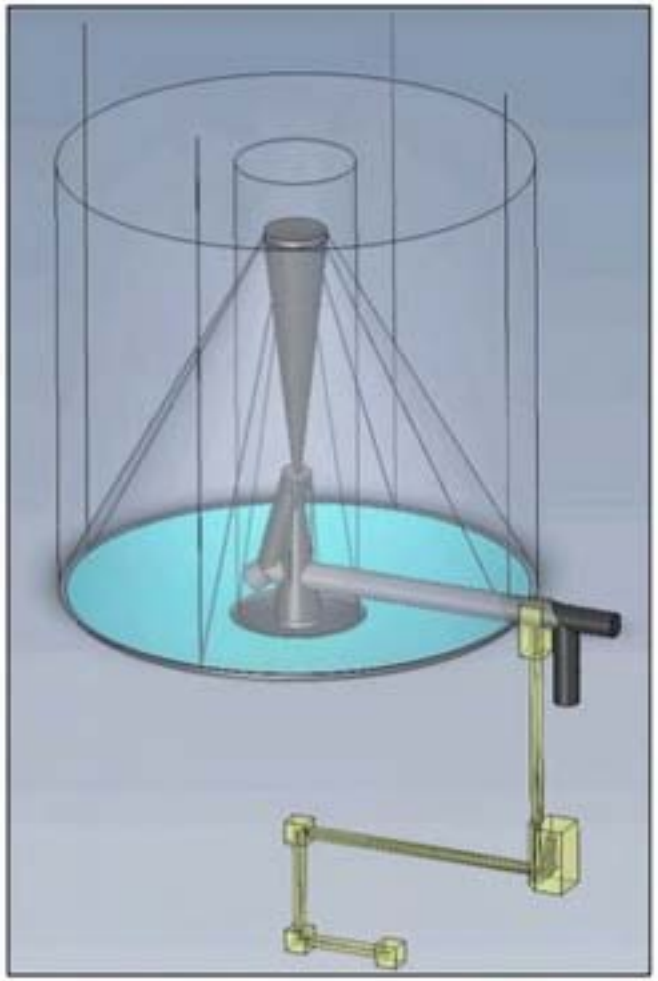


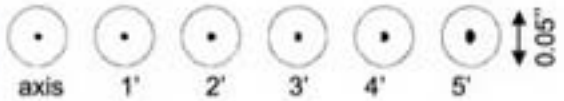


Project Status

PROGRAMME ORGANIZATION



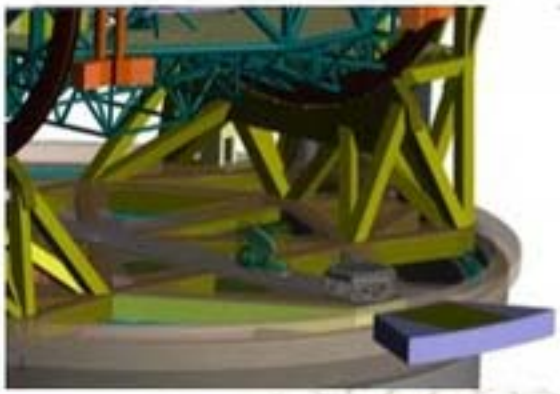


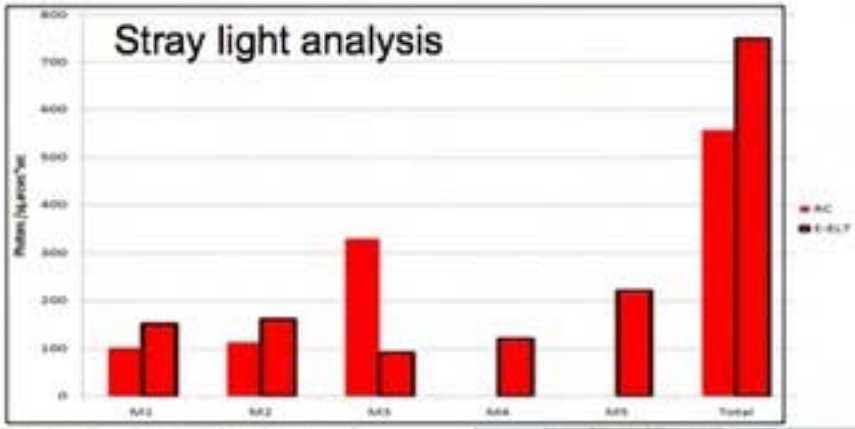


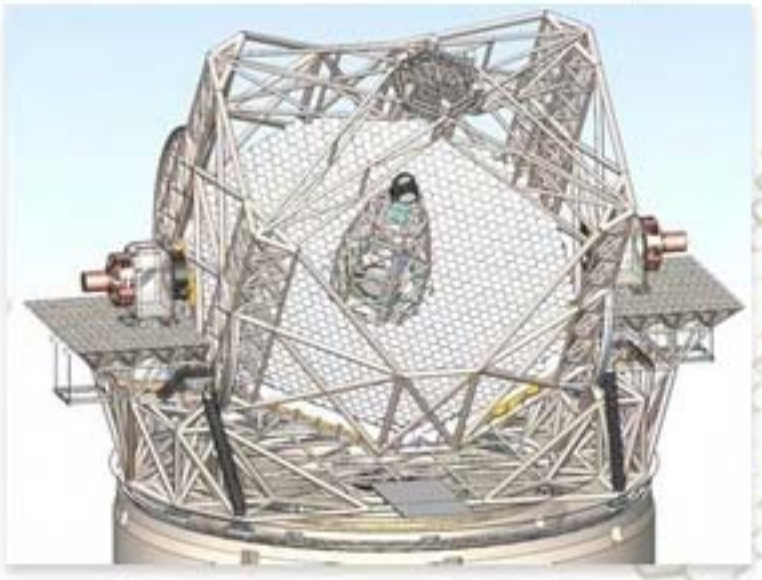
TELESCOPE

Optical design

- novel 5 mirror concept (3 mirror anastigmat + 2 flats)
- diffraction limited over full 10′ FoV
- flat, almost telecentric FoV
- “zoom” capability (Nasmyth, gravity invariant, coudé foci)
- laser “friendly” (very low aberrations even at zenith)



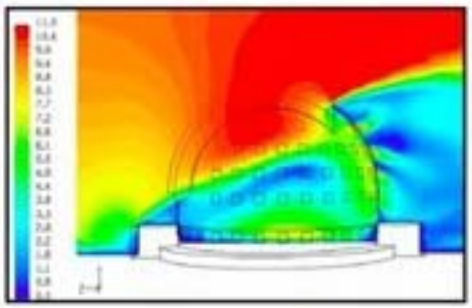


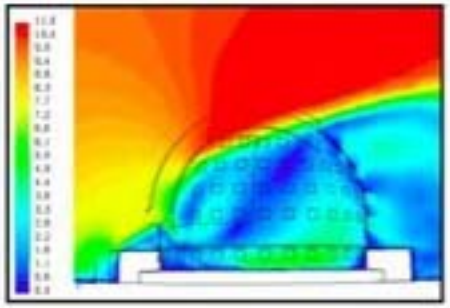


Telescope mount

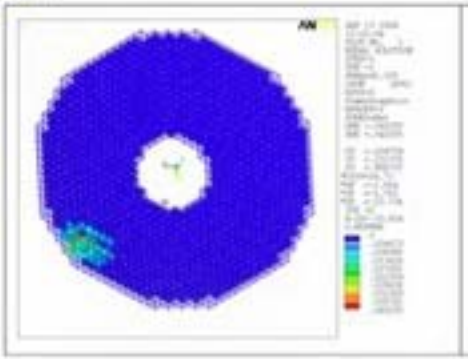
- Two cradle solution
- **Two industrial contracts concluded**
- **FEED ongoing**
- Confirm cost and schedule
- Excellent stiffness (≥3Hz)

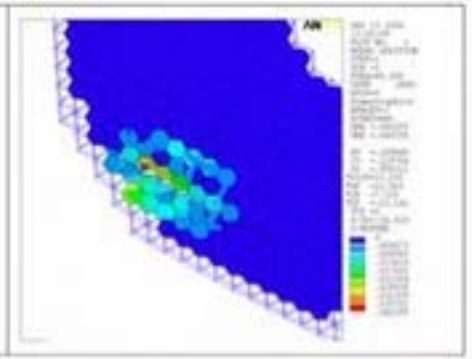
Control System

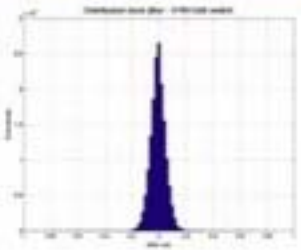


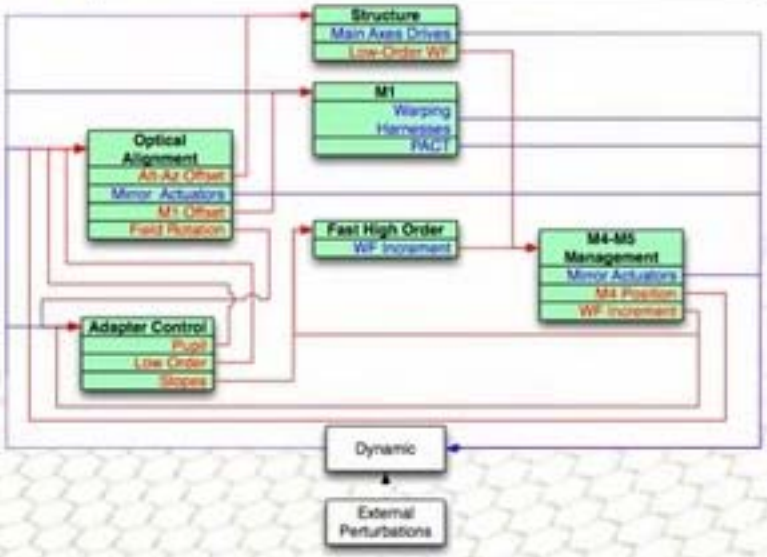


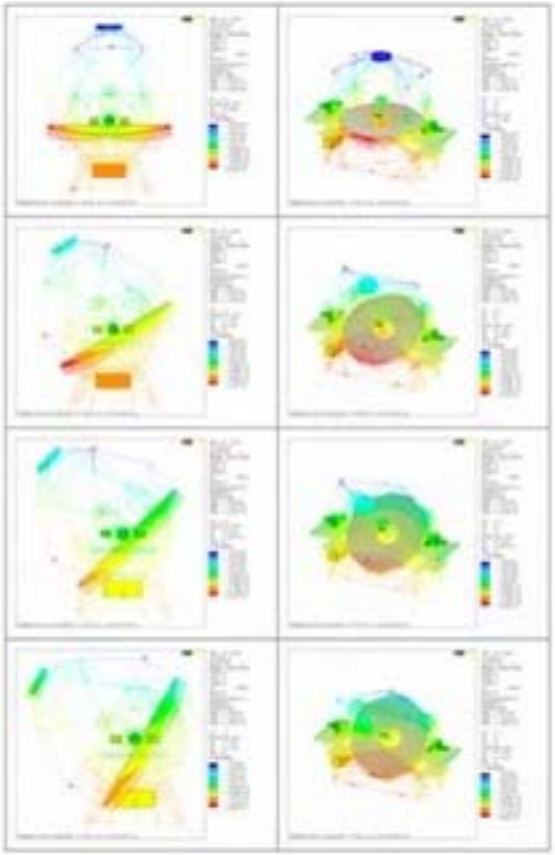
- Technology identified
- Error budget defined
- Testing at VLT, GTC

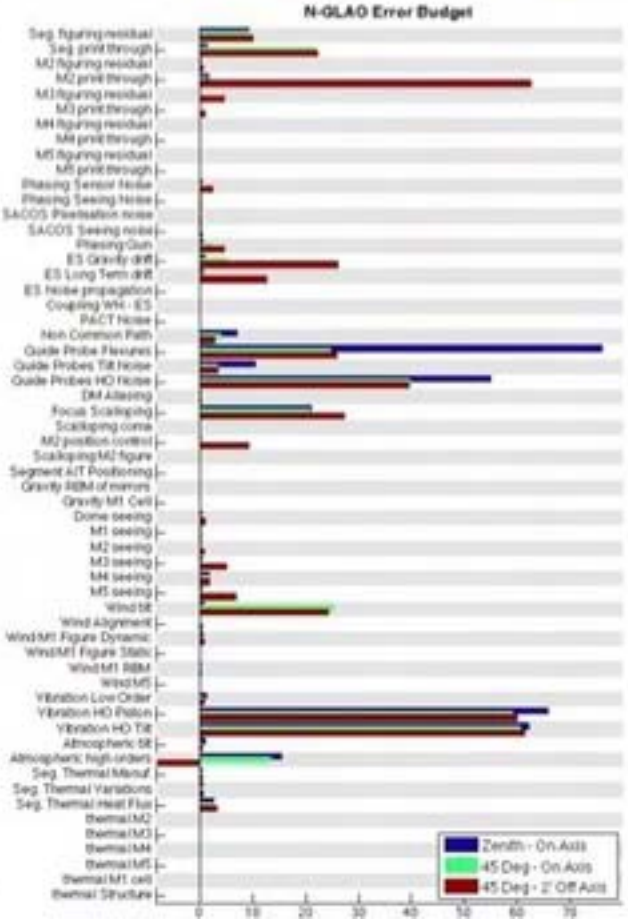






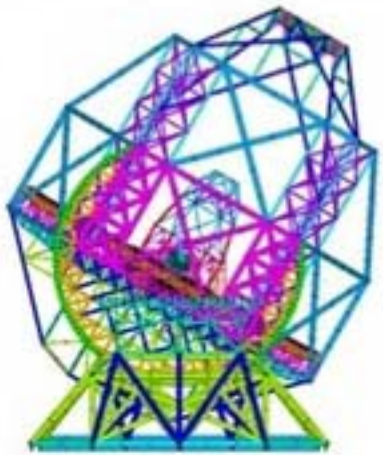


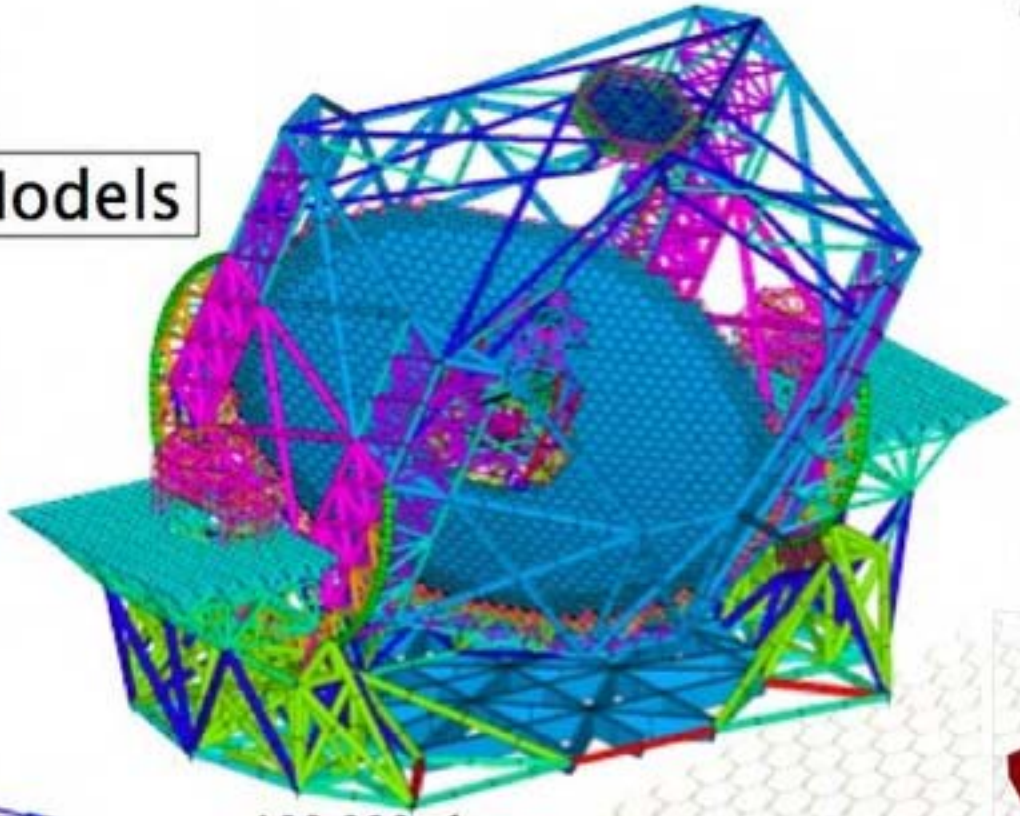




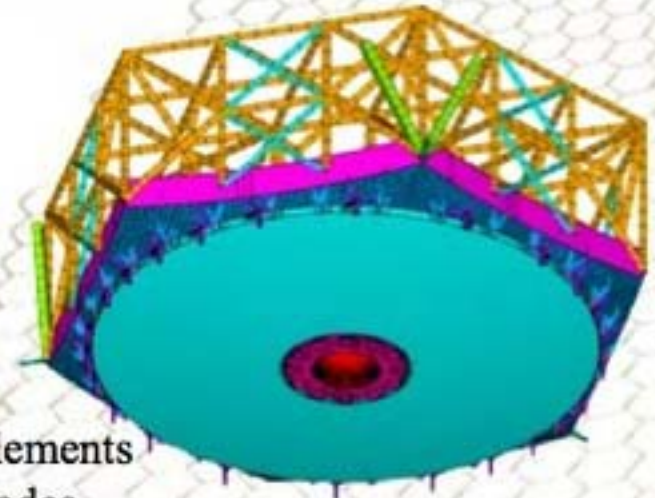
ANALYSIS

Global FE Models

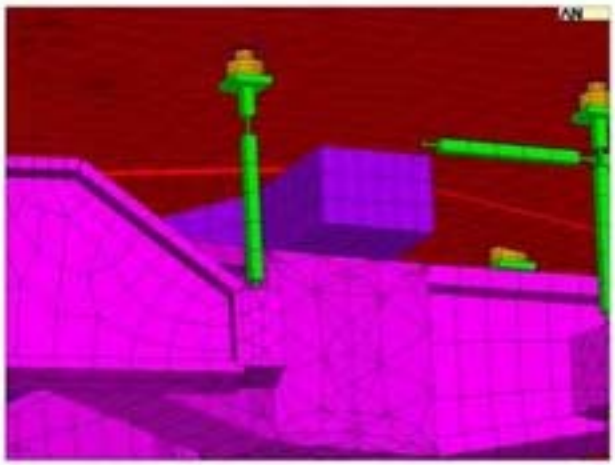


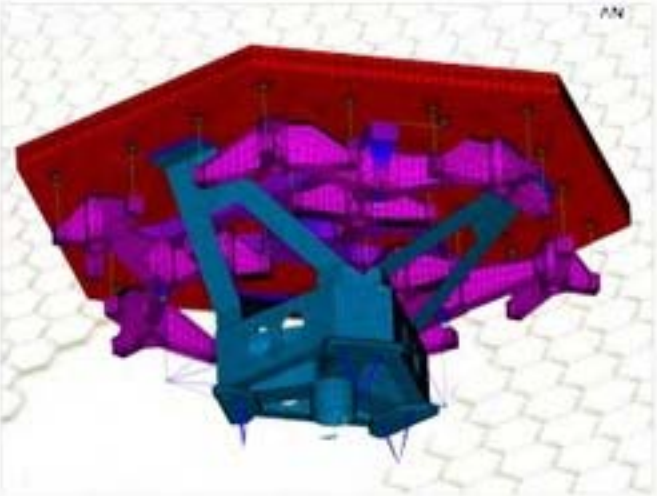


100,000 elements
36,000 nodes



M2 Unit
250,000 elements
240,000 nodes

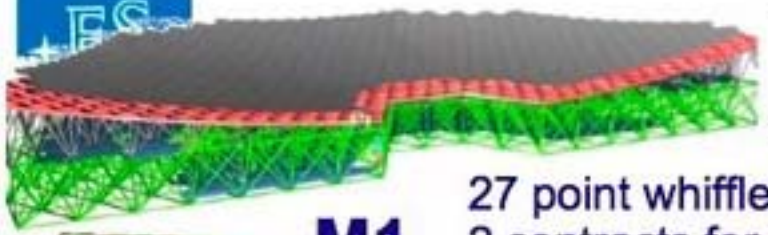




M1 Segment Support
155,000 elements
389,000 nodes

Subsystems and local FE Models

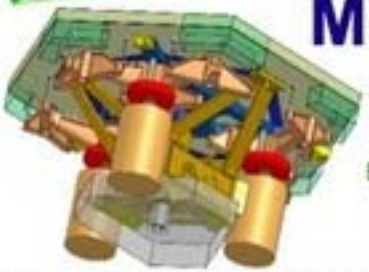
THE MIRRORS

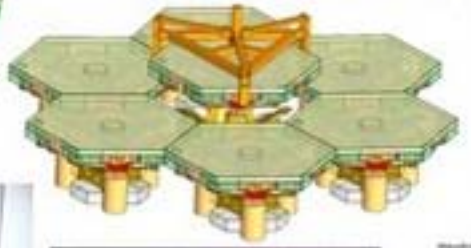


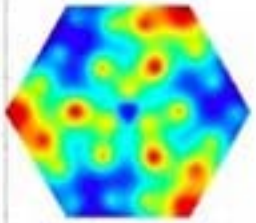
1148 segments:
984 mirror +
1 spare/family

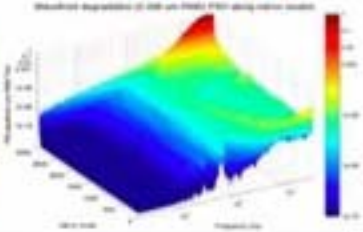
M1

27 point whiffle tree
2 contracts for **7 prototypes** +
M1 cell B1 contract ongoing

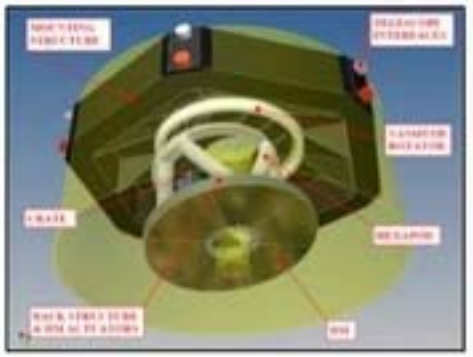


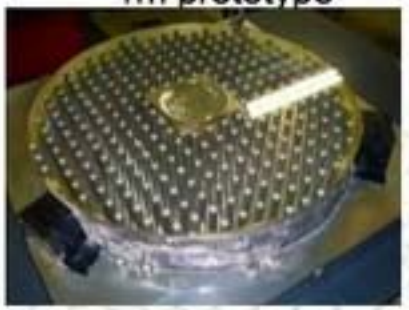






1m prototype



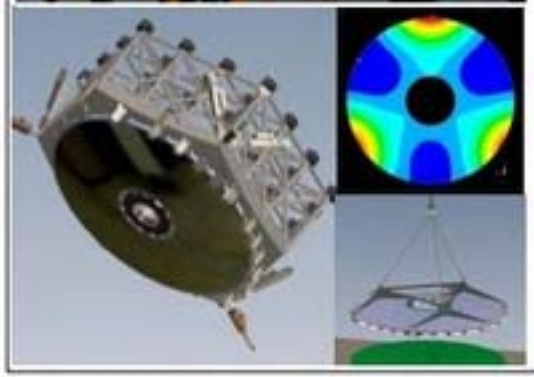


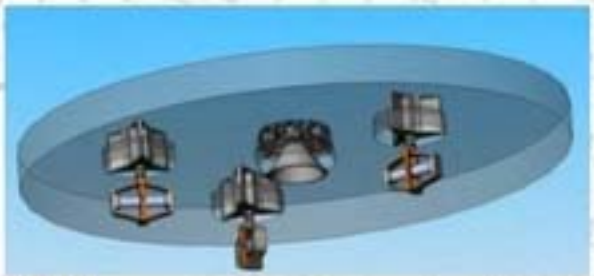
M4

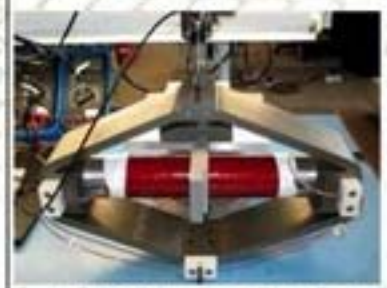
Two industrial studies
will deliver working
prototypes

M2

M2 cell contract ongoing
M2 mirror offers received
M2 Unit FEED tendered





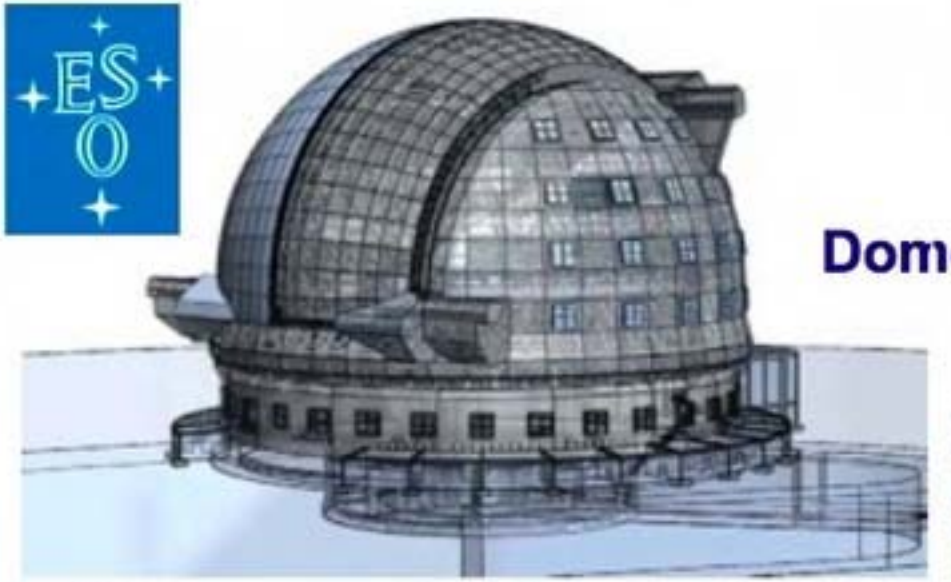


prototype actuator

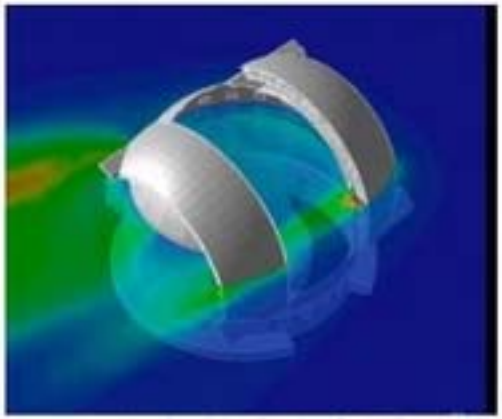
M5

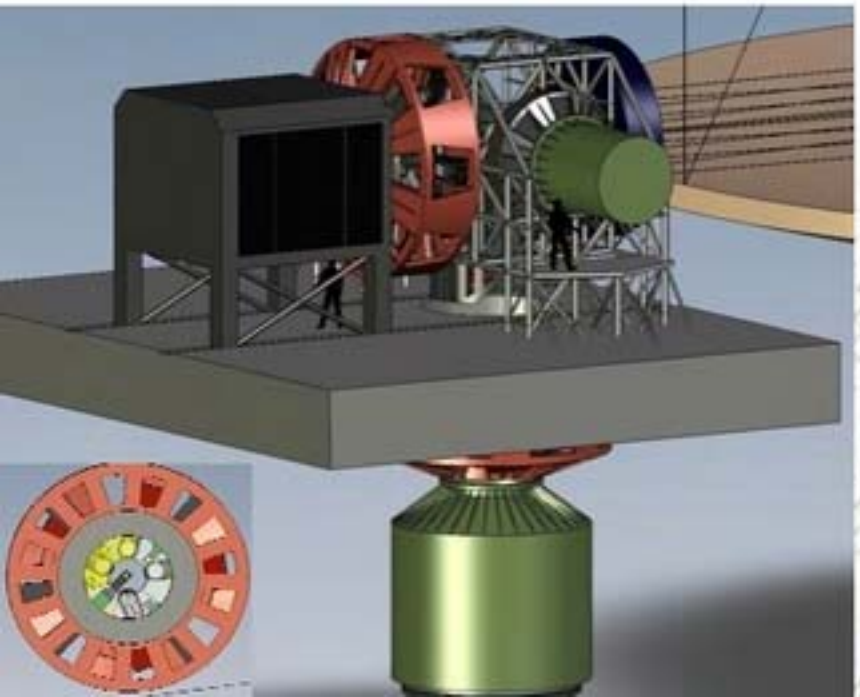
Deliverable of industrial
electromechanical study:
scale 1 prototype
4 mirror studies
"heavy" option considered

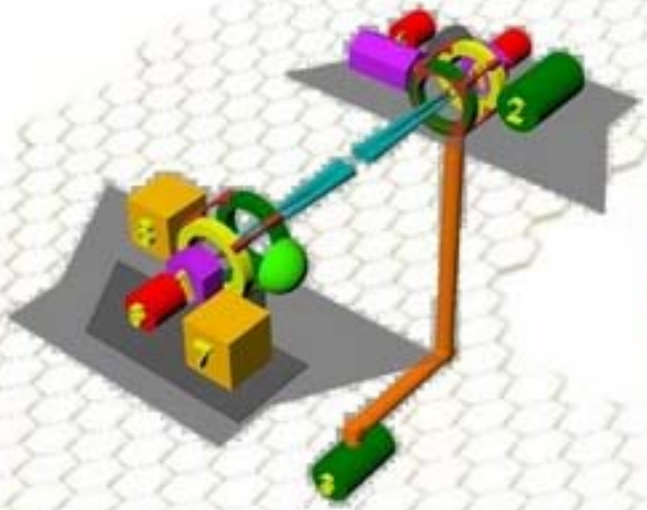
Dome, adapter



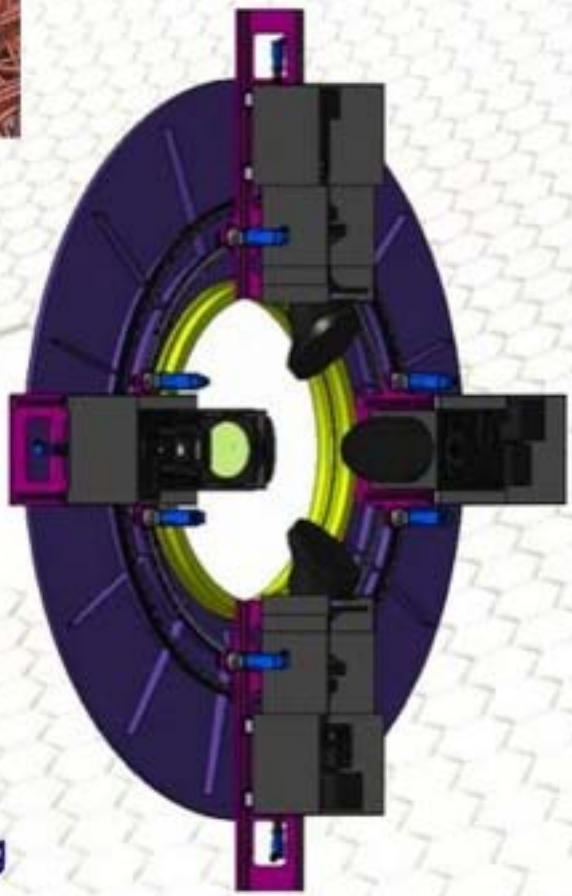
Dome Two preliminary design contracts concluded
FEED ongoing







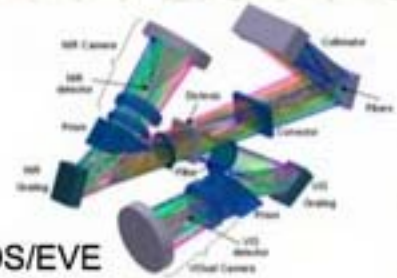
Adapter rotator
LGSs and NGSs WFSs
in a single unit. Contract ongoing

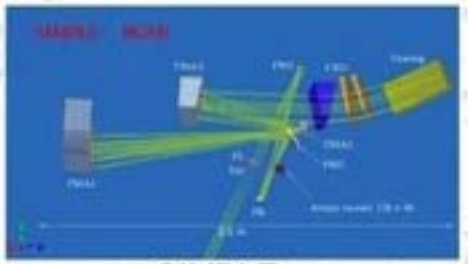


INSTRUMENTATION PHASE A STUDIES

Possible instruments location

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 AO 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)





Science detector requirements as of end of phase 1

	Pixels	Detector type	Comments
OPTIMOS	4x [2x (4kx12k)] 4 channels a 2 arms	1/2 CCDs, 1/2 HgCdTe 15 µm pixels	DIORAMAS concept fast camera profits from concave detectors
CODEX	4kx4k blue + 6kx6k red	CCDs (blue/red sensitive) 15 µm pixels	fast camera profits from concave detectors
EPICS	5x (4kx4k) + x	HgCdTe + CCD	+ detectors for the Extreme AO system
MICADO	16kx16k + 4kx4k	HgCdTe (<0.8-2.5 µm)	if 4kx4k, then 4-edge butting desired
HARMONI	8x (4kx4k)	HgCdTe 15 µm pixels	
SIMPLE	6kx2k or 12kx4k	HgCdTe 15 µm pixels	
EAGLE	10x (4kx4k)	HgCdTe 15 µm pixels	+ detectors for AO system
METIS	4x (2kx2k) + 5x (1kx1k)	HgCdTe 18 µm pixels Aquarius 30 µm pixels	NIR and mid-IR
ATLAS	6x (1kx1k) LGS + 1x (256x256) NGS	CCDs HgCdTe	used for LGS and NGS wavefront sensing
MAORY	6x (1kx1k) LGS + 3x (256x256) NGS	CCDs HgCdTe	used for LGS and NGS wavefront sensing

(Markus Kissler-Patig)

Conclusions

- **The E-ELT is in the detailed design phase**
- **The Phase B is proceeding well**
  - On time and in budget.
  - Passed its midterm review.
- **Consolidation with industry:**
  - Mitigation of cost and schedule uncertainties.
  - 90% of telescope subsystems are in the industrial study pipeline.
  - Final costing based largely on *firm fixed price offers* for construction.
- **Financing**
  - 1/3 of construction budget in ESO's projections < 2020 (all < 2035)
  - Options to find the other 2/3 being discussed by ESO's Council
  - Operations budget is included in long term projections
- **If approved, construction will take seven years**
  - First light possible in 2018