# The European Extremely Large Telescope and its AO systems

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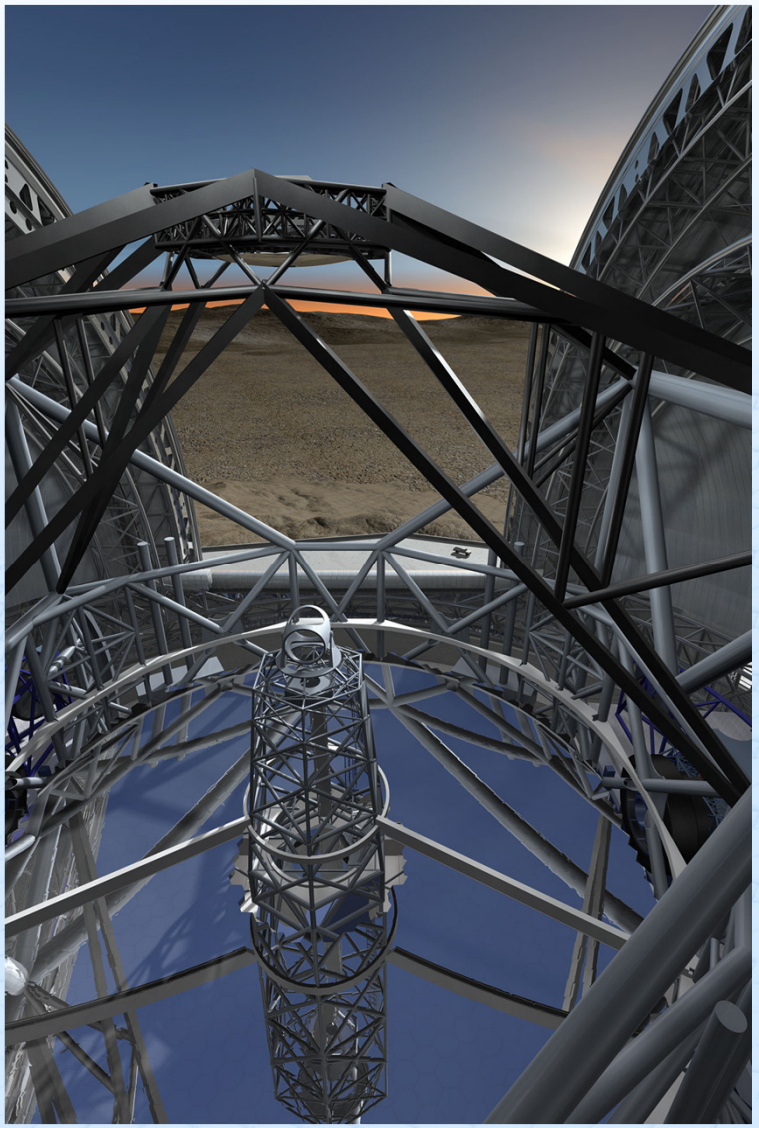
**based on slides kindly provided by ESO**
**Special thanks to N. Hubin and S. Ramsay**

# The E-ELT

- 40-m class telescope: largest optical-infrared telescope in the world.
- Segmented primary mirror.
- Active optics to maintain collimation and mirror figure.
- Adaptive optics assisted telescope.
- Diffraction limited performance.
- Wide field of view: 10 arcmin.
- Mid-latitude site (Armazones in Chile).
- Fast instrument changes.
- VLT level of efficiency in operations.



# The Science

- Contemporary science:

  Exoplanets: radial velocity detections, direct imaging, transit spectroscopy, proto-planetary disks

  Fundamental physics: GR in the strong field limit, variation of fundamental constants, expansion history of the Universe

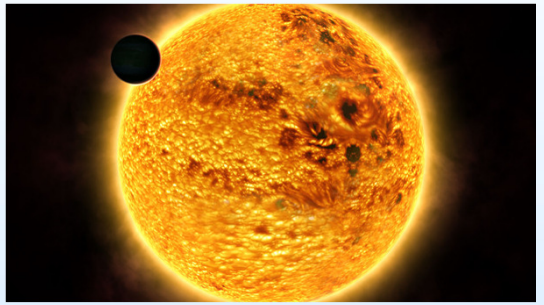
  Resolved stellar populations: beyond the Local Group

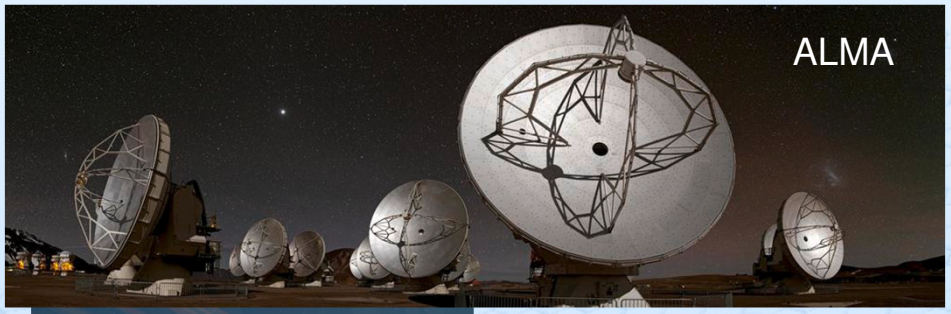
  The physics of high-redshift galaxies

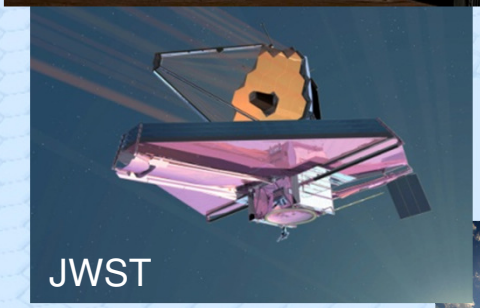
  …and much more!

- Synergies with other top facilities:
  ALMA
  JWST
  LSST and other survey telescopes
  SKA

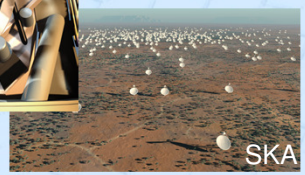
- Discovery potential:
  Opening new parameter space in terms of spatial resolution and sensitivity







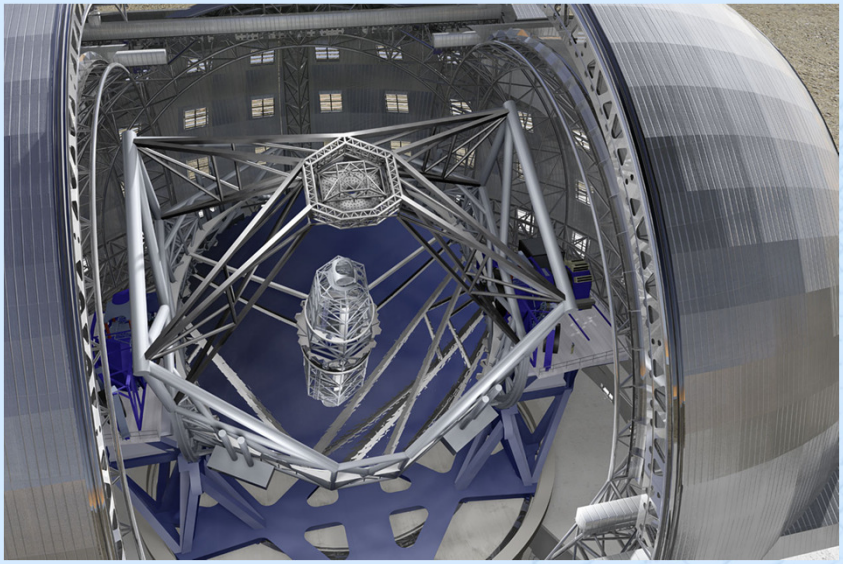


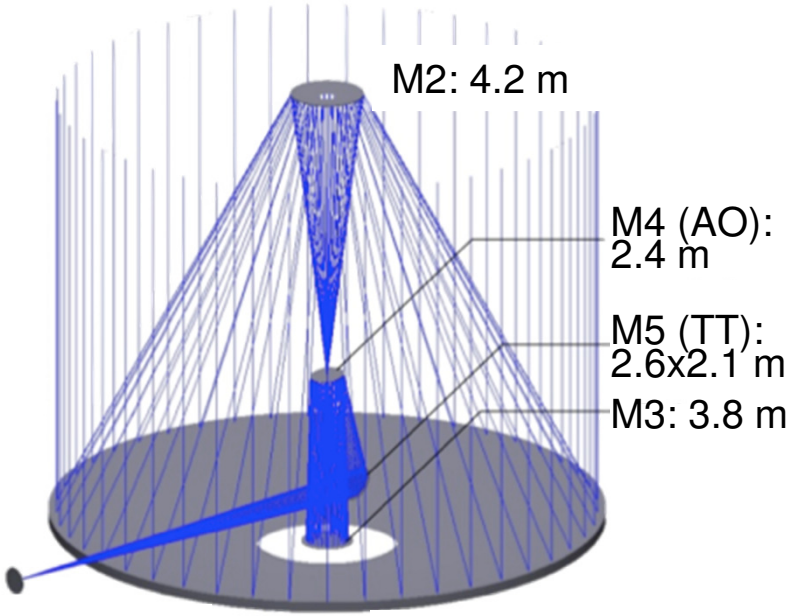
# The E-ELT Project

- Top priority of European ground-based astronomy (on Astronet and ESFRI lists).
- Cerro Armazones in Chile selected as the E-ELT site in April 2010.
- Detailed Design Phase completed in 2011. Construction Proposal published in Dec 2011.
- Instrument Roadmap (Nov 2011): 2 first-light instruments + plan for 1st generation.
- Project fully approved in Dec 2012.
- Construction started in 2013.
- Start of operations early next decade.
- Construction cost: 1083 M€ (including first-light instrumentation).

# The Telescope

- Nasmyth telescope with a segmented primary mirror.
- Novel 5 mirror design to include adaptive optics in the telescope.
- Classical 3mirror anastigmat + 2 flat fold mirrors (M4, M5).

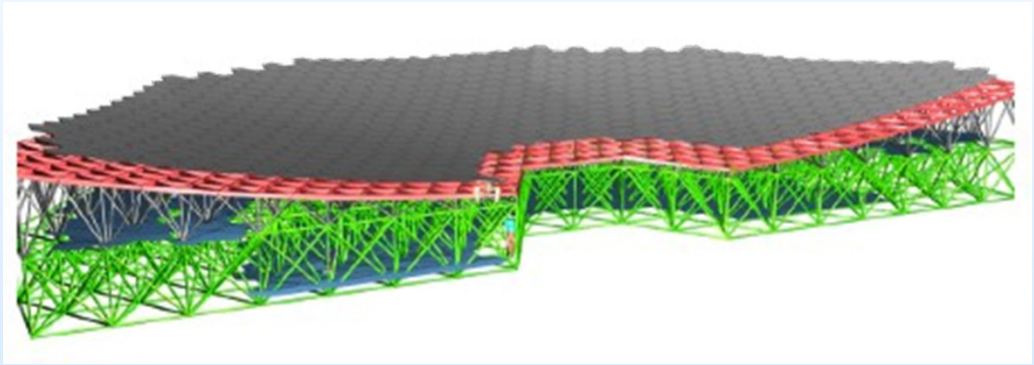


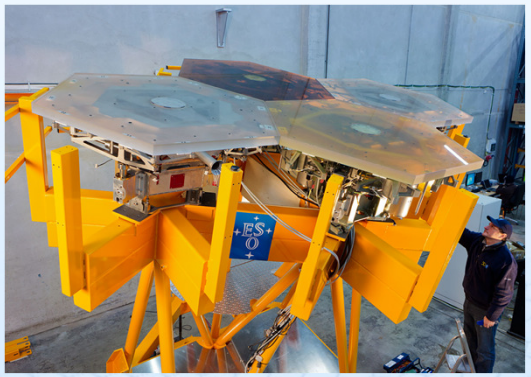


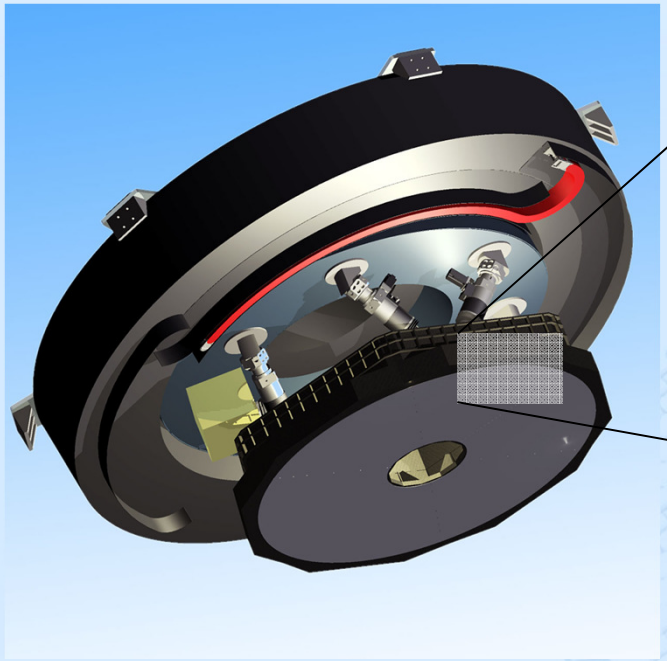

- Two instrument platforms nearly the size of tennis courts can host 3 instruments each + Coudé lab.
- Multiple laser guide stars, launched from the side.
- Nearly 3000 tonnes of moving structure.

# The Mirrors

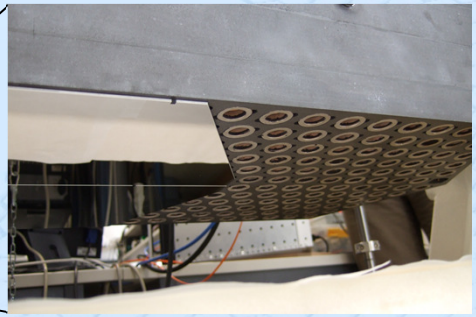
M1: 39.3 m, 798 hexagonal segments of 1.45 m tip-to-tip: 978 $m^2$ collecting area







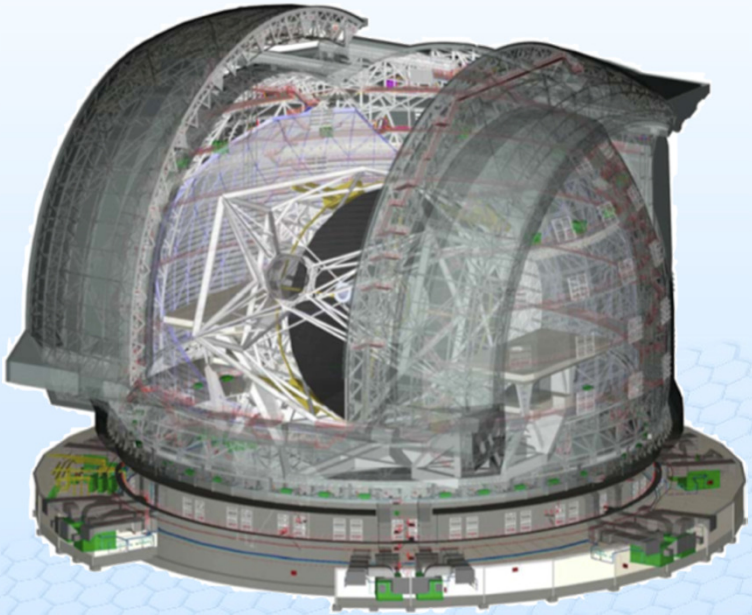
M4: 2.4 m, flat, adaptive
6000 to 8000 actuators

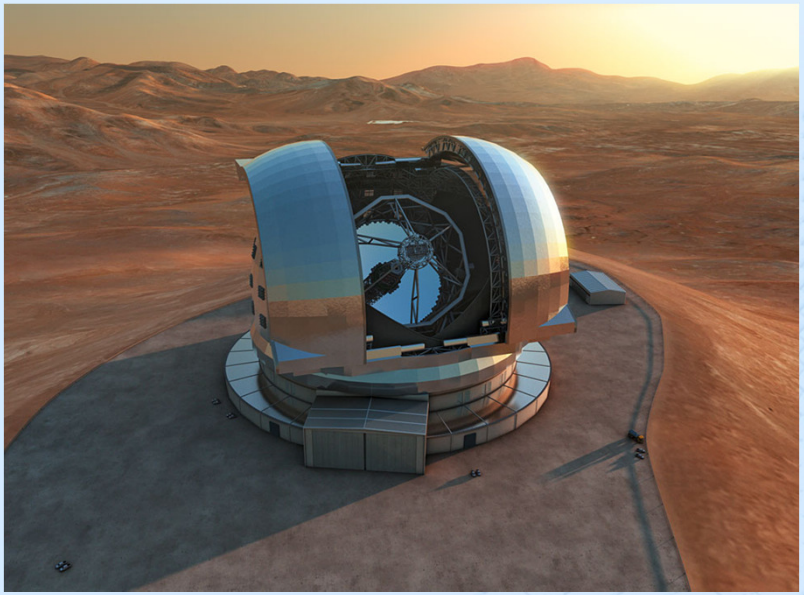


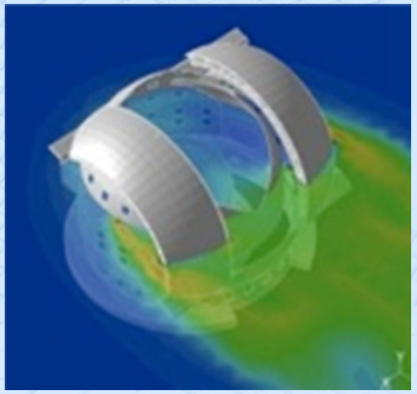
M5: 2.6 x 2.1 m, flat,
provides tip-tilt correction

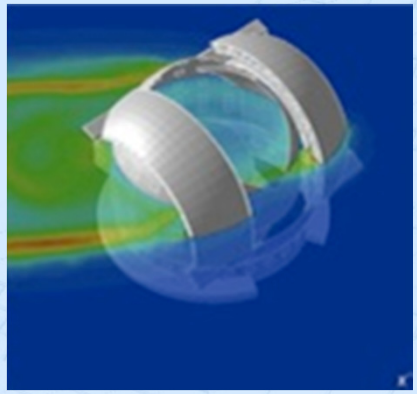
# The Dome

- Classical design.
- Diameter = 86 m, height = 74 m.
- ~3000 tonnes of steel.
- Fully air-conditioned and wind shielded.

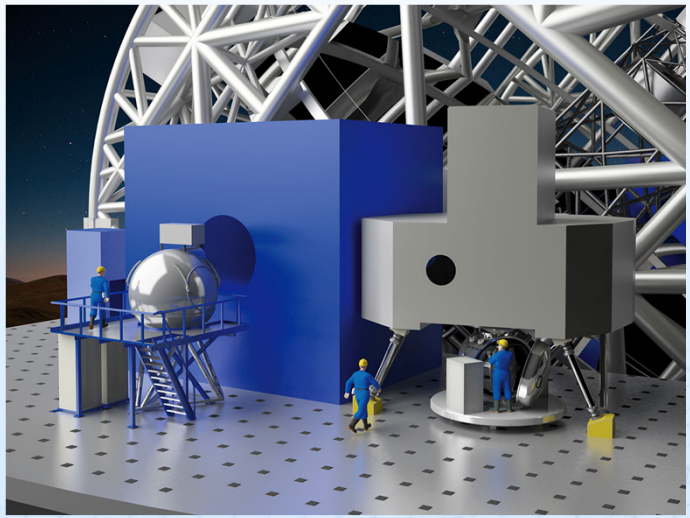








# The Instruments



- The telescope can host eight instruments.
- 2007 – 2010: eight instrument and two adaptive optics module concept studies were conducted by the community.

- Instrument Roadmap (2011):
  - Following recommendations by the E-ELT Science Working Group and ESO's Scientific Technical Committee two first-light instruments have been identified: a diffraction-limited near-infrared imager and a single-field near-infrared wide-band integral field spectrograph.
  - The next group (ELT-3, 4 and 5) has been broadly identified as covering the mid-infrared, as well as multi-object and high-resolution spectroscopy.
  - Planet camera and spectrograph on separate track.
  - Flexibility is maintained by including an as yet unspecified instrument.
  - All concept studies remain in the pool of possible instruments.

# Instrument Roadmap

| Year | ELT-IFU | ELT-CAM | ELT-MIR | ELT-4 (MOS or HIRES) | ELT-5 (MOS or HIRES | ELT-6 | ELT-PCS |
|---|---|---|---|---|---|---|---|
| 2012 | Decide science requirements, AO architecture. | | VISIR start on-sky | Develop science requirements for MOS/HIRES | | | Call for proposals for ETD |
| 2013 | | | TRL Review | Call for proposals for MOS/HIRES | | | |
| 2014 | | | | | | | |
| 2015 | | | | Selection ELT-MOS/HIRES | | Call for proposals | |
| 2016 | | | | | | | |
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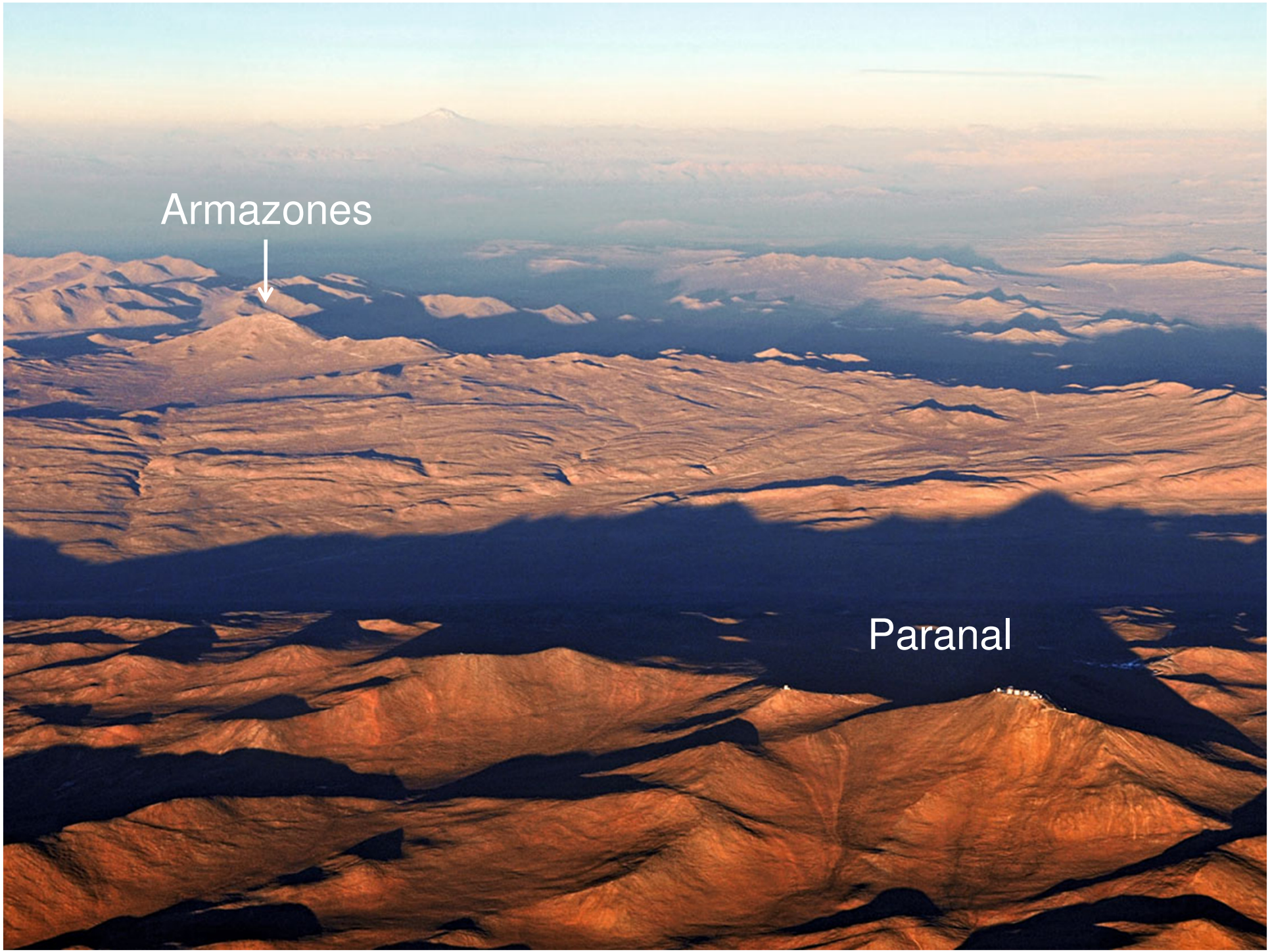
| 2019 | | | | | | Selection | TRL check |
| 2020 | | | | | | | TRL check |
| 2021 | | | | | | | TRL check |
| 2022 Tel technical first light | | | | | | | |
| | Pre-studies taking the form of phase A or delta-phase A work and/or ESO-funded Enabling Technology Development (ETD) | | | | | | |
| | Decision point | | | | | | |
| | Development of Technical Specifications, Statement of Work, Agreement, **Instrument Start.** | | | | | | |

# The Site

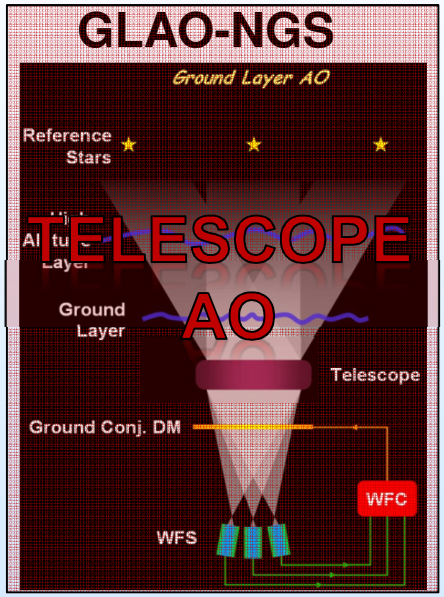
Following an extensive site testing campaign, involving several sites in Chile, Morocco, the Canary Islands, Argentina, Mexico, etc, ESO Council selected Cerro Armazones as the E-ELT site.

Selection criteria: impact on science, outstanding atmosphere, but also construction and operations logistics (roads, water, electricity, nearby cities, ...).

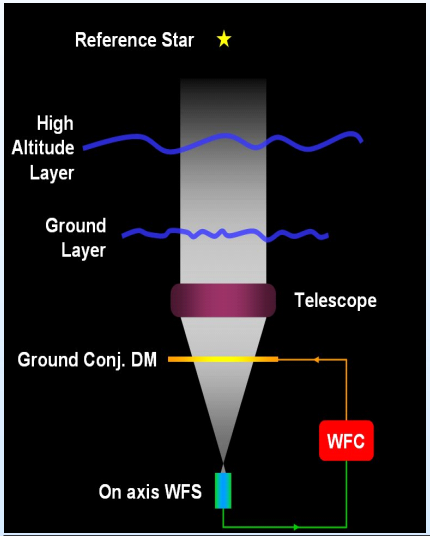

Armazones
Paranal

# Adaptive Optics Zoo


## GLAO-NGS




## SCAO & XAO: EPICS




Natural Guide Stars

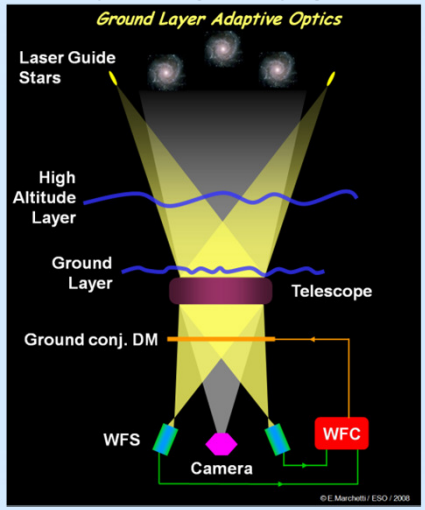
Laser Guide Stars

+

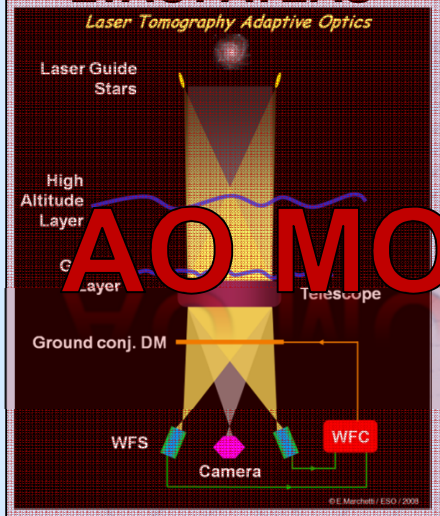
Tomography

TELESCOPE AO

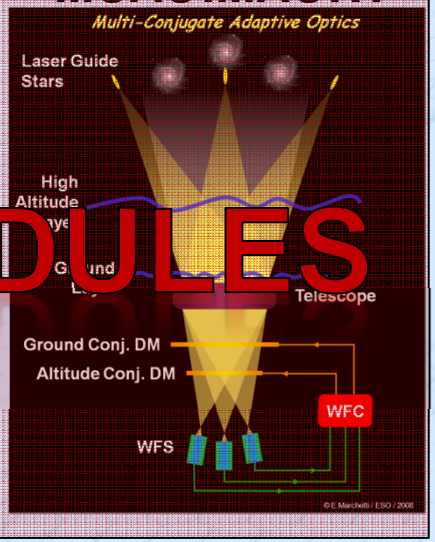
## GLAO-LGS



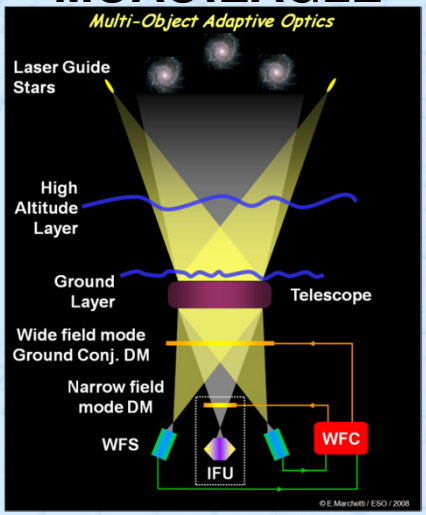

## LTAO: ATLAS




## MCAO:MAORY

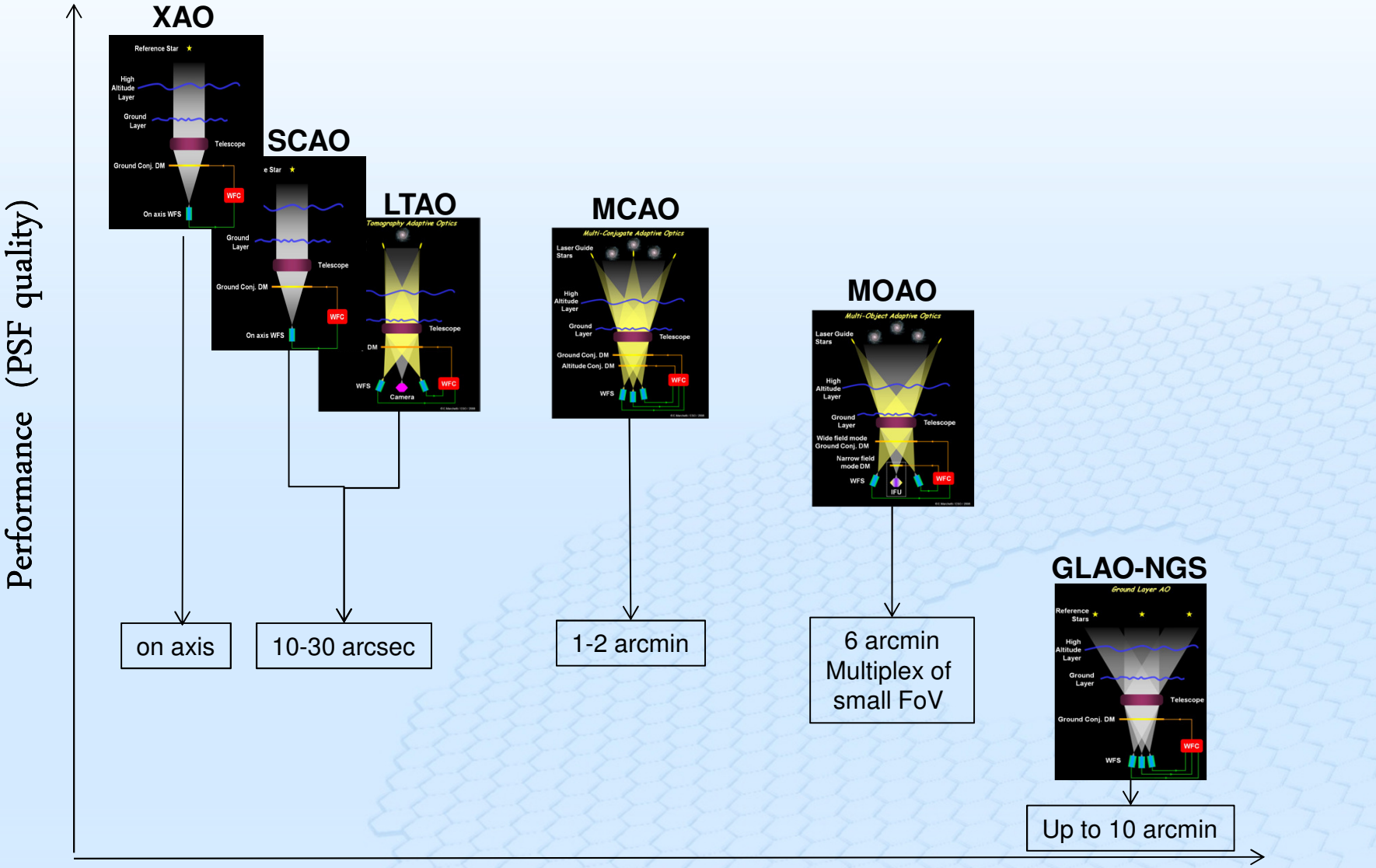



## MOAO:EAGLE

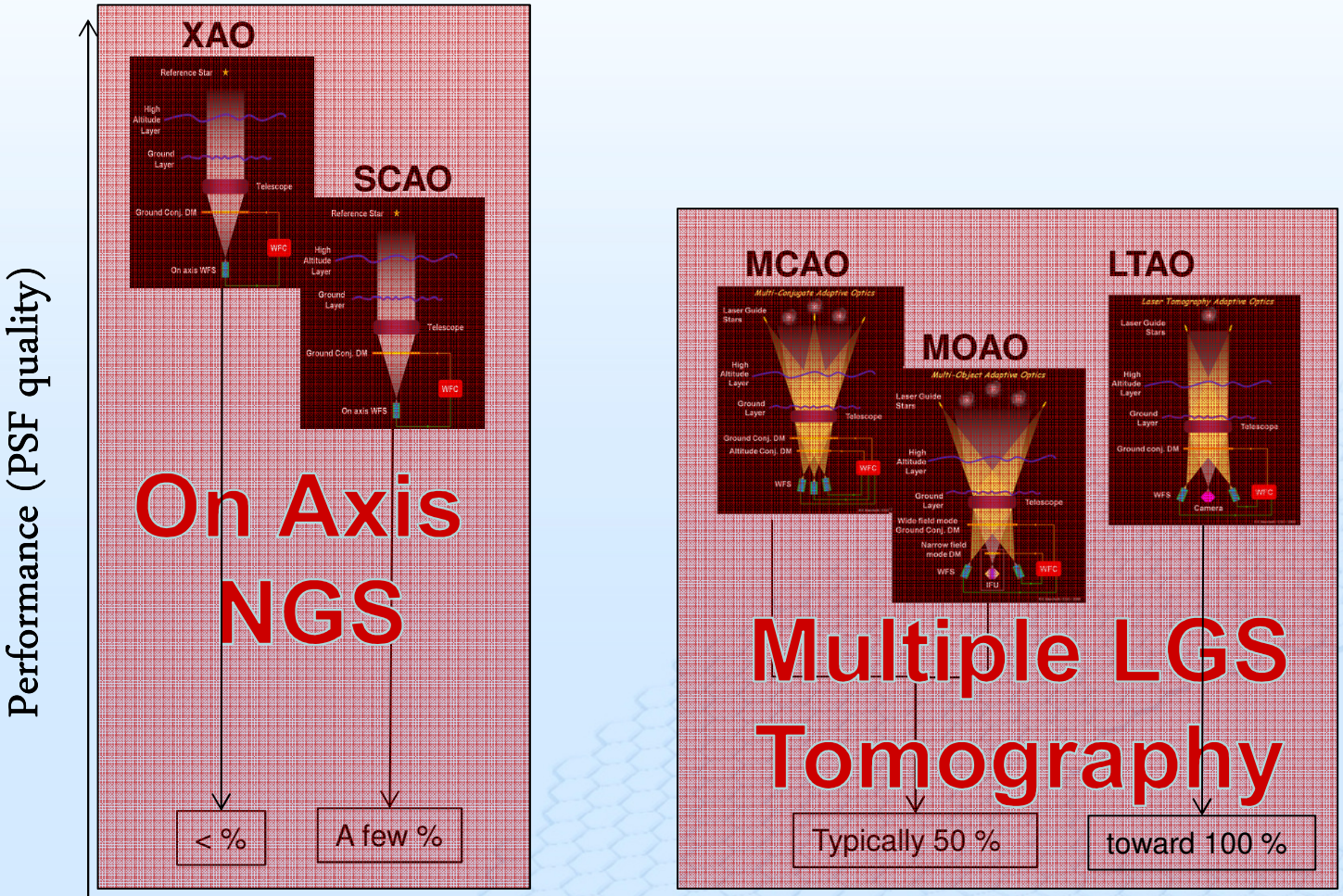



AO MODULES

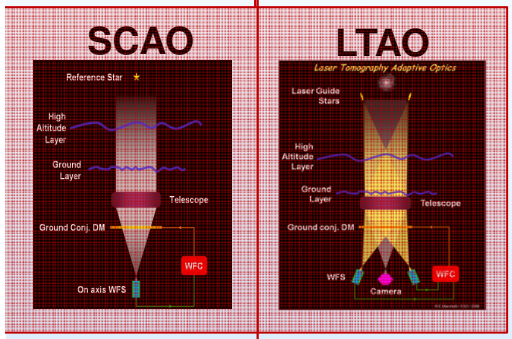
# AO systems:perf vs accessible FoV



# AO systems:perf vs sky coverage

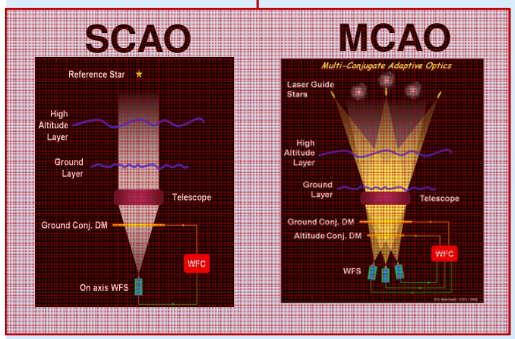


# Instrument Roadmap & AO













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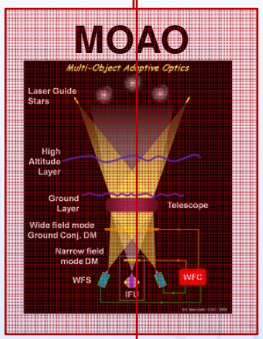
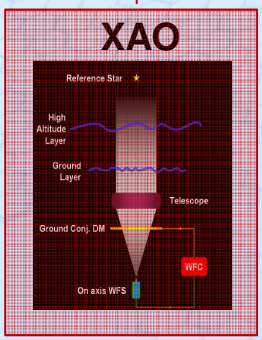


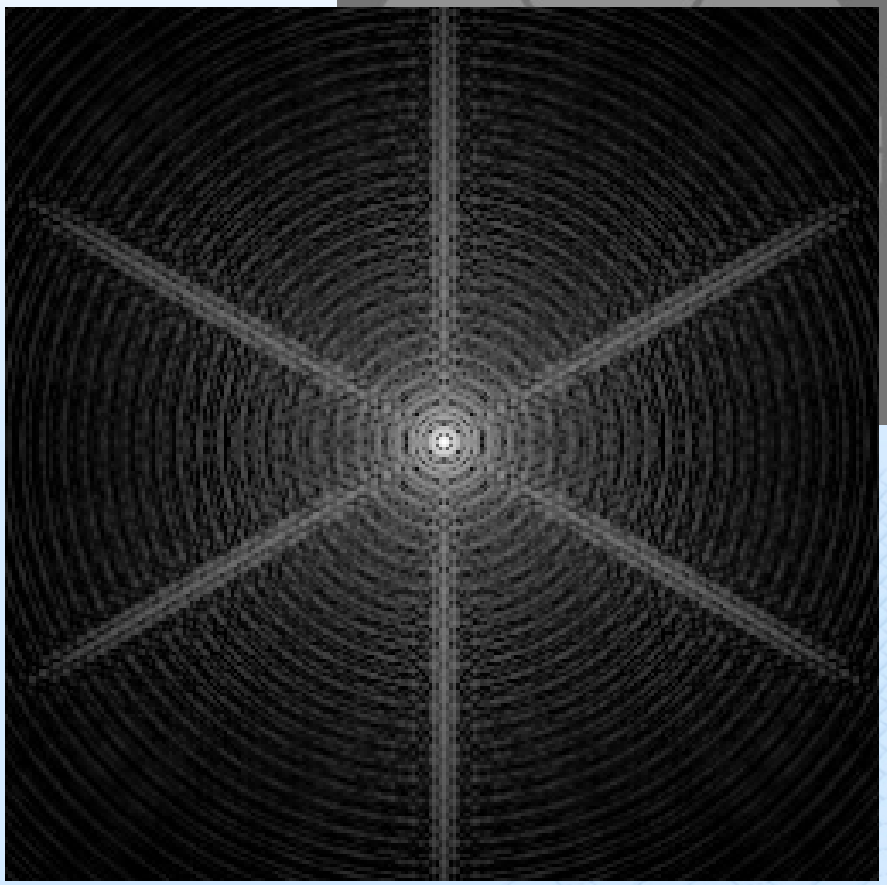



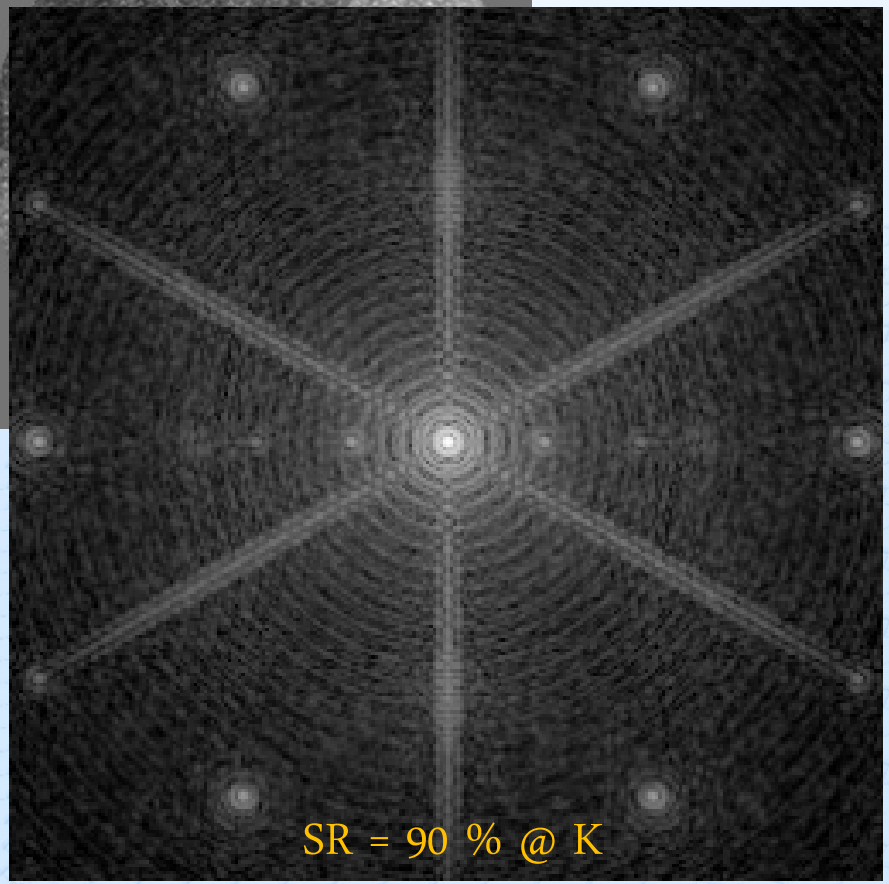
# Common key features for all AO systems

- Telescope residual defects after correction by M4
- Residual windshake
- Control of M4 / M5
- Pupil stabilisation
- Optical axis stabilisation
  - Coronagraphic imaging
  - Astrometry
- Overhead minimization : every second counts !
  - Should be smaller than a few minutes.

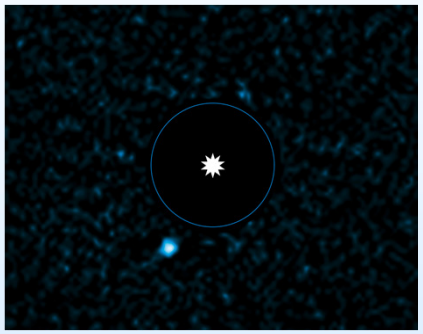
  =>Identification processes rather than on-sky calibration !

# Telescope residual defects

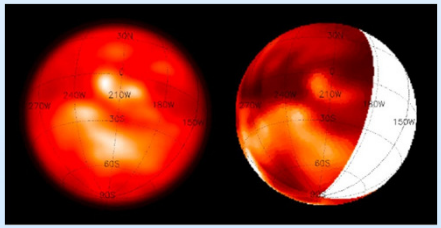


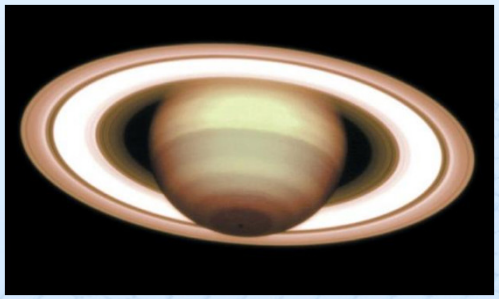


# SCAO : Why ?



- Best performance for bright objects
  - Exoplanet characterisation (SPHERE follow up)
  - Solar system observation



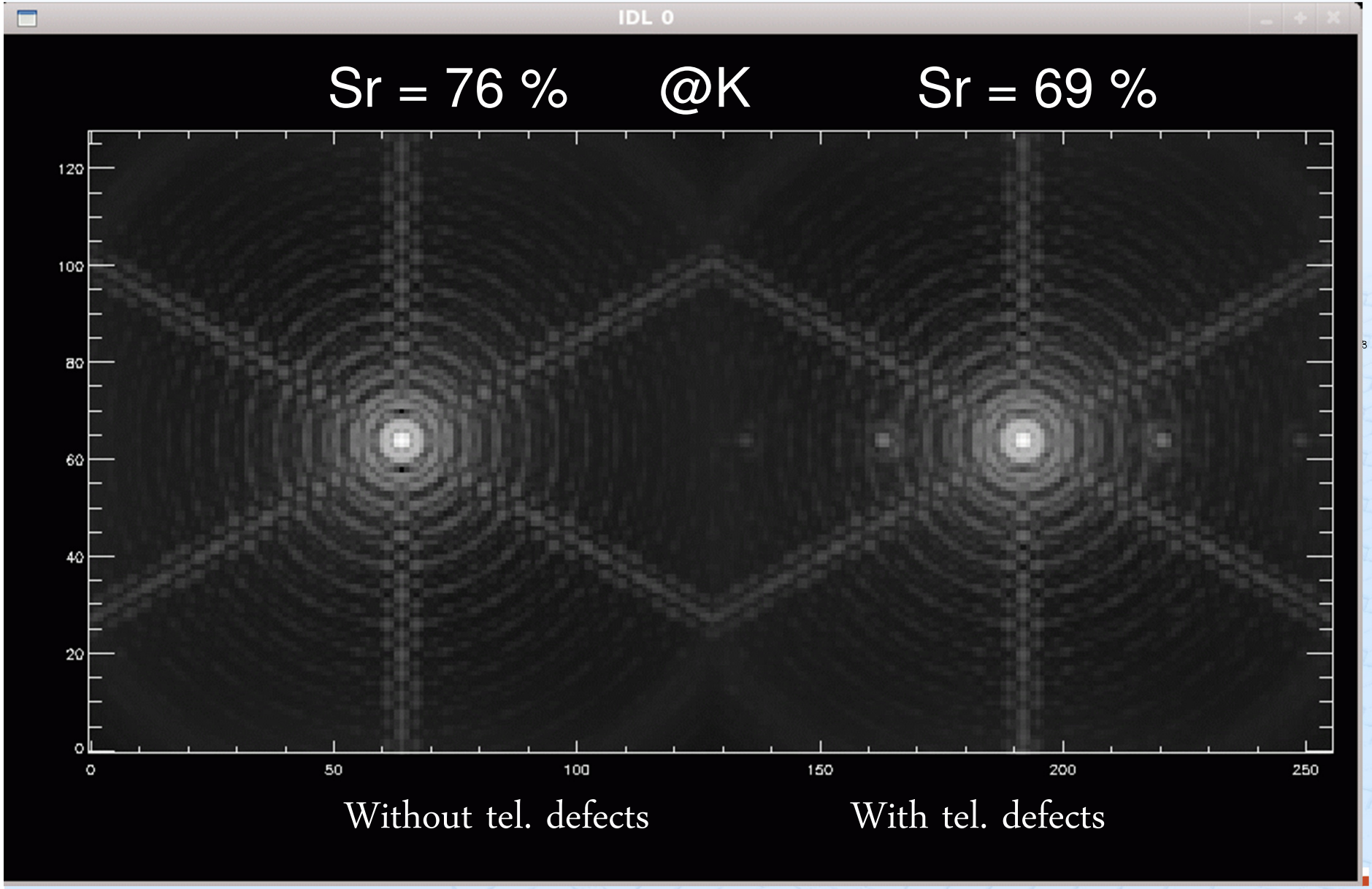


- First year(s) of operation – risk mitigation for LTAO & MCAO
  - observe as much objects as we can with a « very decent » image quality
  - acquire as much feedback as possible

  on the telescope before integrating complex AO system

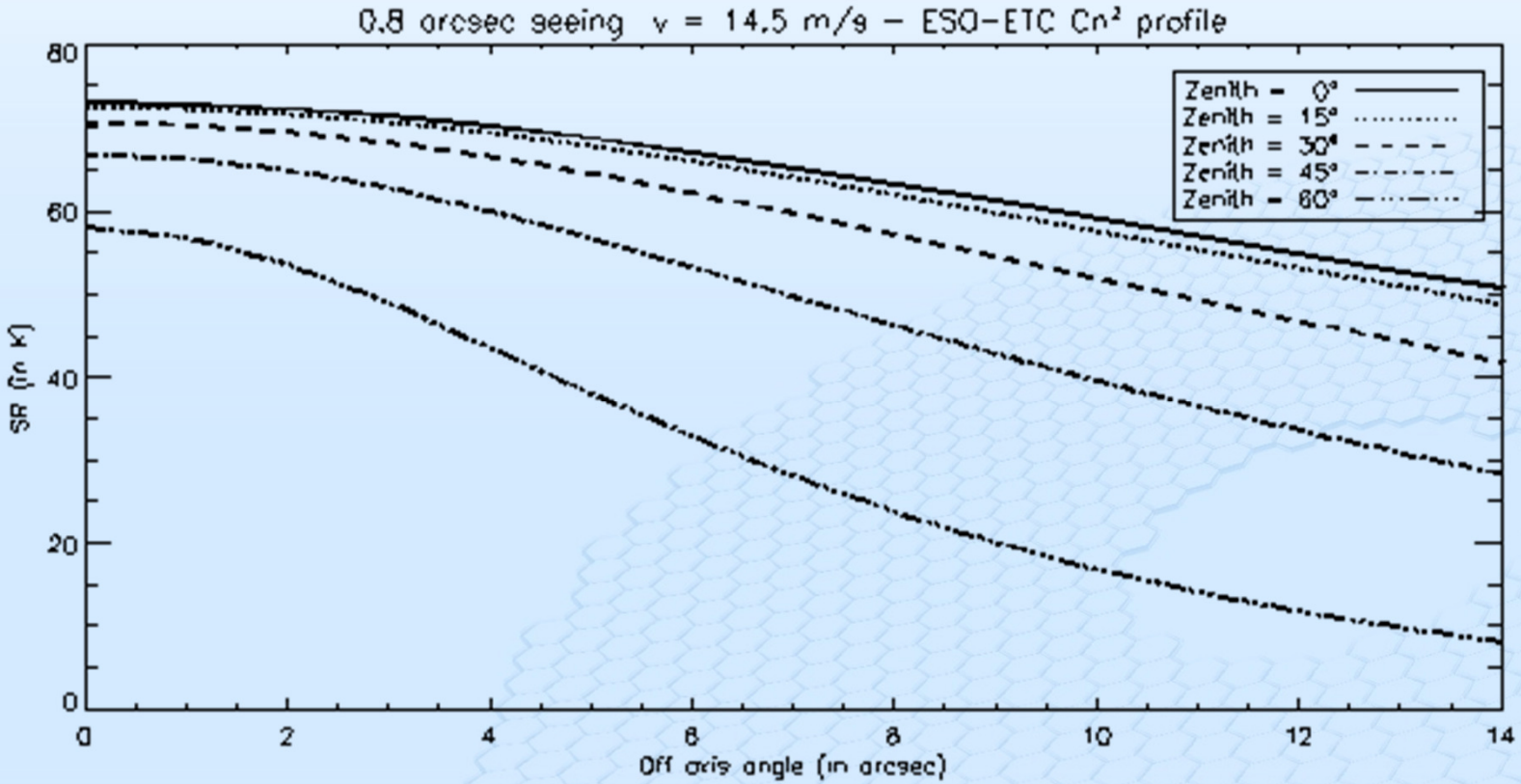
win-win strategy

# SCAO performance - on axis

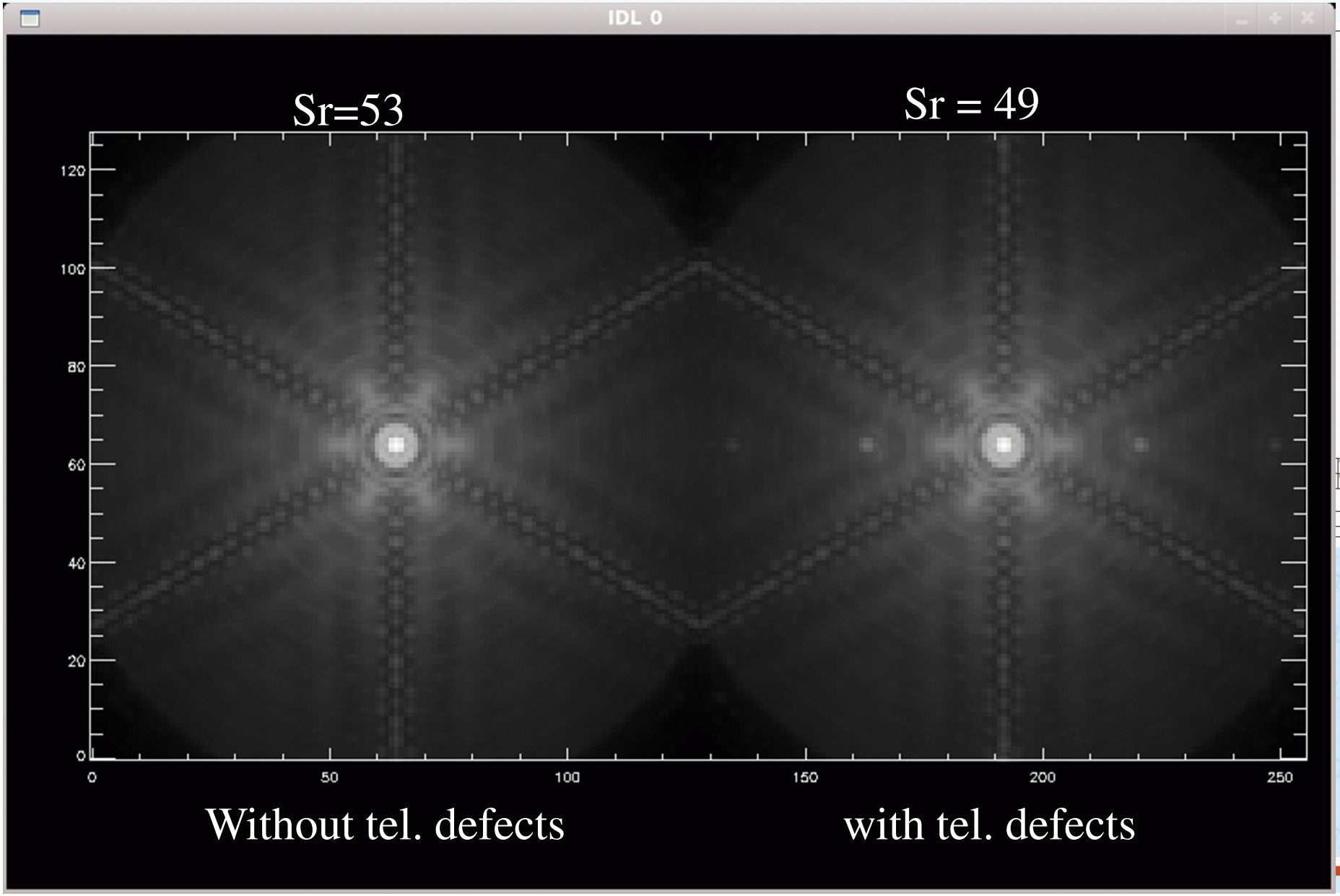


# SCAO performance - anisoplanatism

| Layer nb | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $C_n^2$ [%] | 33.5 | 22.3 | 11.2 | 9.0 | 8.0 | 5.2 | 4.5 | 3.4 | 1.9 | 1.1 |
| h [m] | 0 | 600 | 1200 | 2500 | 5000 | 9000 | 11500 | 12800 | 14500 | 18500 |



# LTAO : toward a 100 % sky coverage



# LTAO performance (from ALTAS PhaseA)

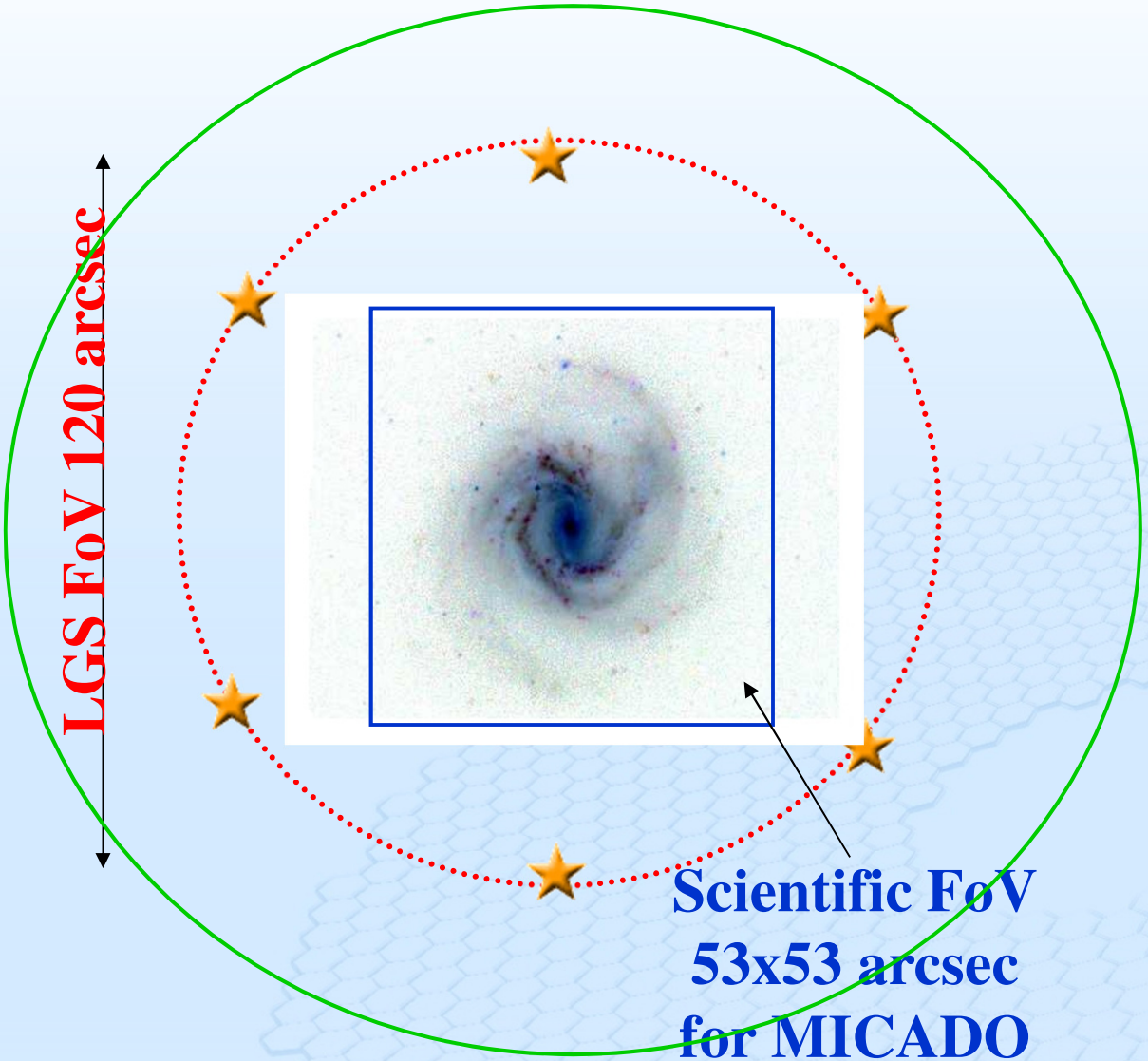
| NOMINAL CONDITION; Sseeing = 0.8; Zenith = 0°; θ0 = 2.08" | | | | | | | |
|---|---|---|---|---|---|---|---|
| **lambda (nm)** | **900** | **1250** | **1650** | **2200** | **3500** | **4800** | **10500** |
| **Ensquared Energy (%)** | | | | | | | |
| **Width 10 mas** | 10,3 | 21,1 | 26,1 | 26,4 | 17,8 | 13,7 | 3,9 |
| **Width 20 mas** | 15,1 | 32,1 | 42,5 | 48,5 | 45,6 | 37 | 14,3 |
| **Width 40 mas** | 18,2 | 37,8 | 53,6 | 63,8 | 62,8 | 61 | 35,1 |
| **Width 60 mas** | 22,4 | 40,5 | 56,3 | 67,8 | 75,9 | 69,1 | 54,2 |
| **Width 80 mas** | 23,2 | 42,4 | 58,2 | 70,2 | 79,8 | 80,1 | 63,8 |
| **Width 100 mas** | 25,6 | 44,8 | 59,5 | 71,7 | 81,3 | 84,6 | 67,5 |
| **Strehl Ratio (%)** | 5,5 | 18,8 | 35,3 | 52,7 | 75,6 | 90,5 | 96,9 |
| **FWHM (seeing limited) [mas]** | 646 | 609 | 586 | 546 | 483 | 442 | 357 |
| **FWHM (ATLAS) [mas]** | 8,2 | 9 | 10,1 | 12,1 | 17,6 | 23,7 | 49,1 |
| **FWHM (Diffraction) [mas]** | 4,4 | 6,1 | 8,1 | 10,8 | 17,2 | 23,6 | 49,6 |

| | |
|---|---|
| | HARMONI / SIMPLE |
| | METIS |
| | OPTIMOS / EAGLE like |

| ATLAS sky coverage | |
|---|---|
| **Perf** | **SC (pole)** |
| **52 % SR in K** | **92 %** |
| **40 % SR in K** | **96%** |
| **35 % SR in K** | **97%** |
| **13 % SR in K** | **100 %** |

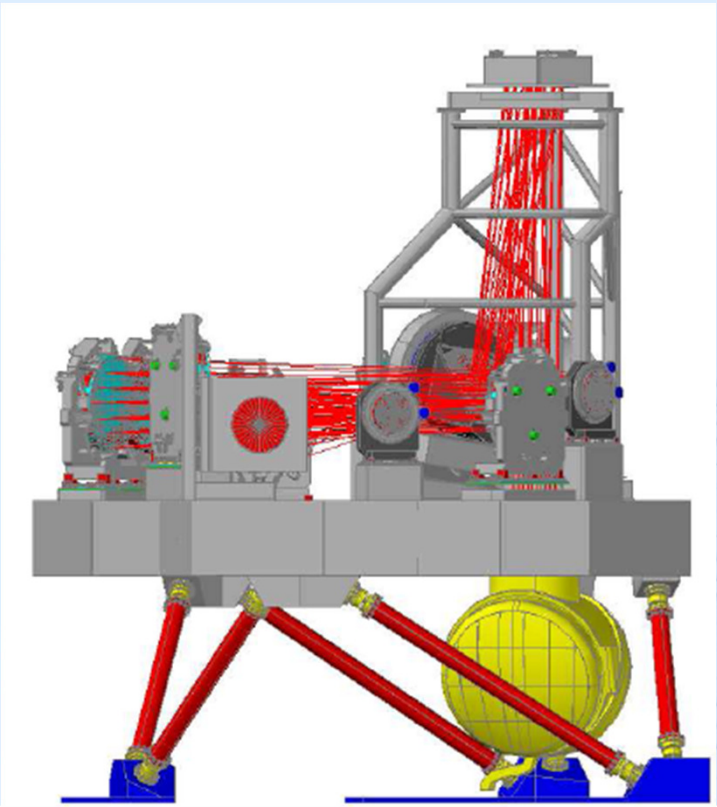
**Without telescope error budget to be updated for 39 m**

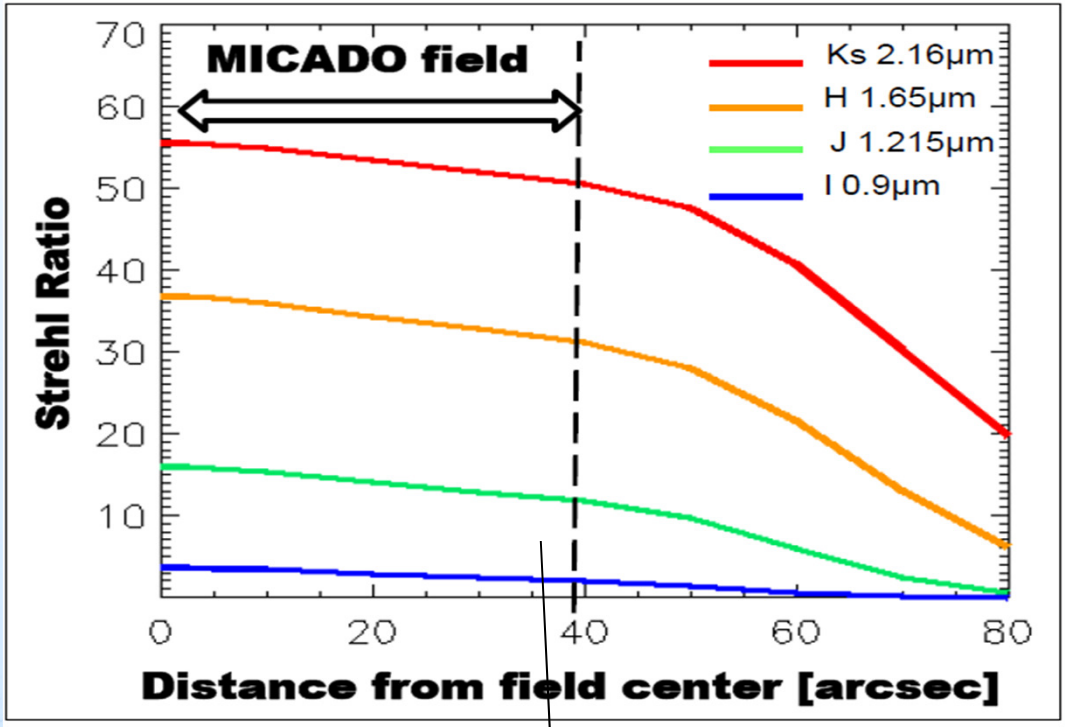
# MCAO FoV


LGS FoV 120 arcsec
NGS Search FoV 160 arcsec
Scientific FoV
53x53 arcsec
for MICADO

# MCAO

- 6 LGSs side launched
- 3 NGSs (IR WFSs)
- 0.6 μm < λ < 2.4 μm
- S.R. >50% in K over 2'
- Central 1' clear
- DM conjugated at 4km, 12.7km
- Two output ports






- Sky coverage Galactic Pole
- No telescope error budget included yet

| Minimum field-averaged Strehl Ratio (53"×53") | | | | % Sky |
|---|---|---|---|---|
| 2.16 μm Ks band | 1.65 μm H band | 1.215 μm J band | 0.9 μm I band | |
| 0.53 | 0.34 | 0.14 | 0.03 | **39%** |
| 0.51 | 0.32 | 0.13 | 0.03 | **50%** |
| 0.41 | 0.22 | 0.06 | <0.01 | **80%** |

# MOAO & XAO

15h05-15h20 **XAO**

ELT-PCS,
orateur : J.-L. Beuzit (IPAG)

14h00-14h20 **MOAO**

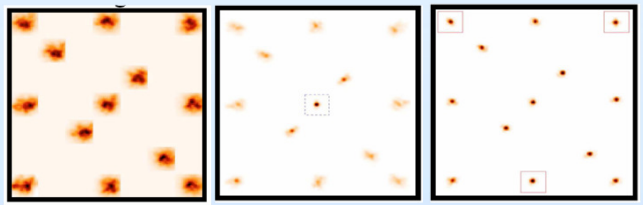
ELT-MOS (MOSAIC/DIORAMAS),
orateurs : F. Hammer (GEPI), O. Le Fèvre (LAM)

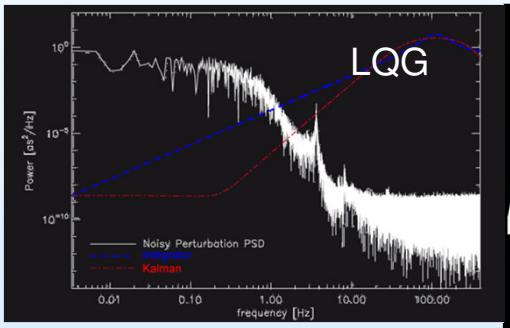
# Key issues (non-exhaustive list)

16h25-16h45

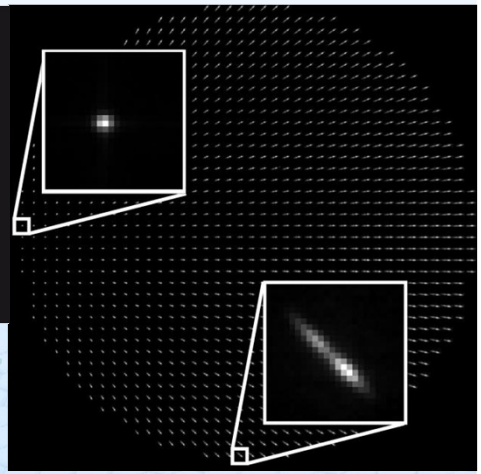
Optique adaptative pour l'E-ELT : état actuel et enjeux, orateur : M. Tallon (CRAL, ASHRA)

- **Concepts**
  - Multi LGS wavefront sensing
  - Tomography
  - Very faint NGS wavefront sensing
  - Vibrations and windshake

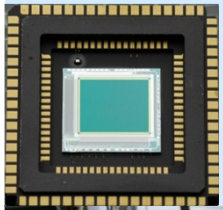


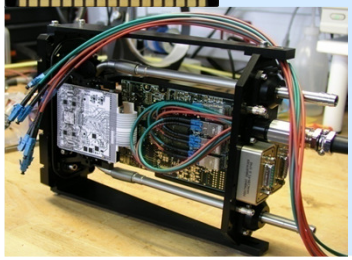


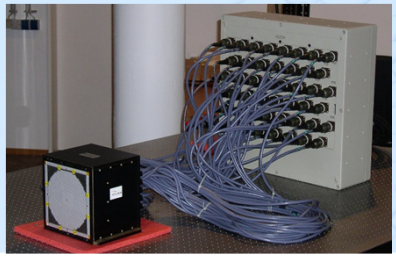


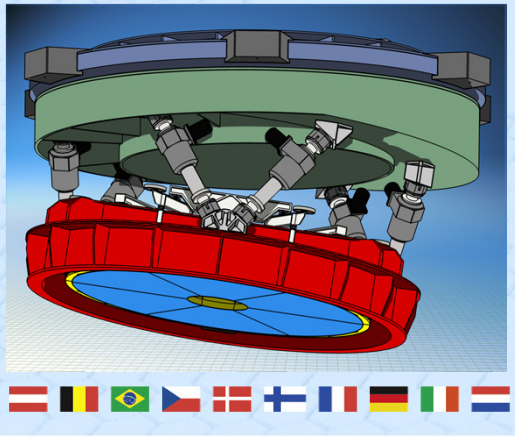


- **Techno**
  - Laser
  - Detector (VIS ans IR ) : large, fast and sensitive
  - RTC
  - Deformable mirror
    - Large DM → M4 (for all AO systems)
    - Medium DM → (MCAO)
    - Mini DM → (MOAO)
    - Micro-DM → (XAO)









First Light of the VLT Laser Guide Star

# Next steps

- Preliminary design of M4 unit
- Consolidation of MAORY Project plan for next phases
- Pursue technology development for MAORY
- Optical design trade-off incl. 39 m update
- Update Nasmyth platform configuration: telescope metrology-LTAO – HARMONI & METIS
- Update performance estimates/error budgets for the different AO capabilities
- Consolidate interfaces with instruments

# Conclusions

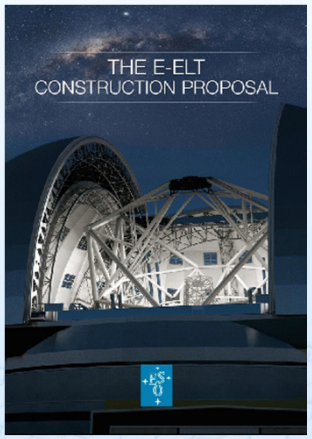
- An aggressive AO program is being developed for the VLT
- AO pathfinders for E-ELT are on-going @ VLT, WHT,…
- Major efforts & collaborations to bring key technologies to appropriate TRL
- Facilitating AO community effort to address remaining key AO fundamental issues (calibration, identification, control, tomography, LGS & NGS WFSing, simulation….)
- Preparing for construction of E-ELT AO capabilities
- Setting up Consortium for the AO instrumentation
- The main power of the E-ELT will reside in achieving, with the help of AO, a spatial resolution never achieved at optical/infrared wavelength to this depth before.


THANK YOU FOR YOUR
ATTENTION

# More information

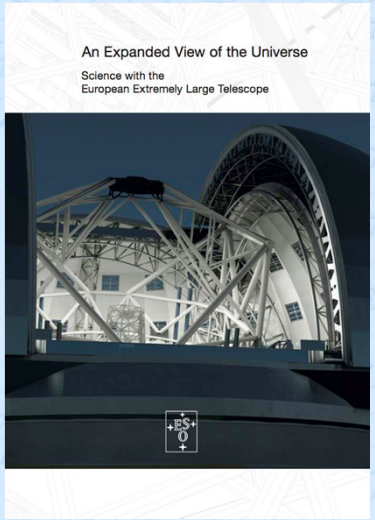
The science users web pages:
www.eso.org/sci/facilities/eelt

The E-ELT Construction Proposal:
www.eso.org/sci/facilities/eelt/docs/eelt_constrproposal.pdf




The E-ELT Science Case:
www.eso.org/sci/facilities/eelt/science/doc/eelt_sciencecase.pdf

The E-ELT Design Reference Mission:
www.eso.org/sci/facilities/eelt/science/doc/drm_report.pdf




The public web pages:
www.eso.org/public/telesinstr/eelt.html

Brochures, Posters, etc:
www.eso.org/public/products/brochures/

Gallery:
www.eso.org/public/images/archive/category/eelt/