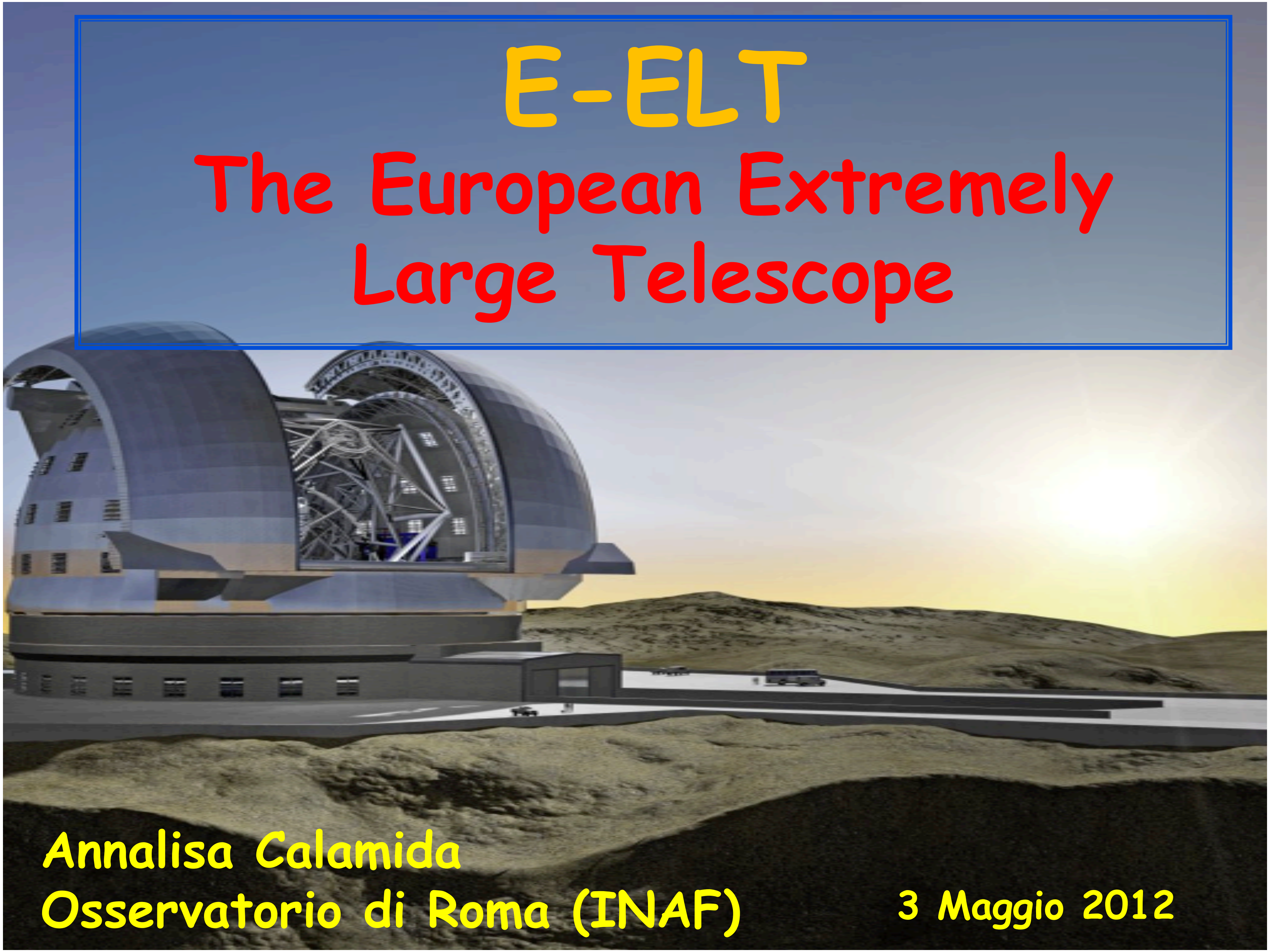
E-ELT

The European Extremely Large Telescope



Annalisa Calamida
Osservatorio di Roma (INAF)

3 Maggio 2012

ESO: the European Southern Observatory

- ESO is the European Organisation for Astronomical Research in the Southern Hemisphere
- It was created in **1962**
- ESO headquarters are in Germany, in Garching, near **Munich**
- ESO currently operates **telescopes at three different sites in Chile**

ESO observatory sites in Chile

- Paranal (2600 m)
- La Silla (2400 m)
- Chajnantor (5000 m)

ESO Declaration **1954**

ESO Convention **1962**

3.6-m Telescope 1976

NTT 1989

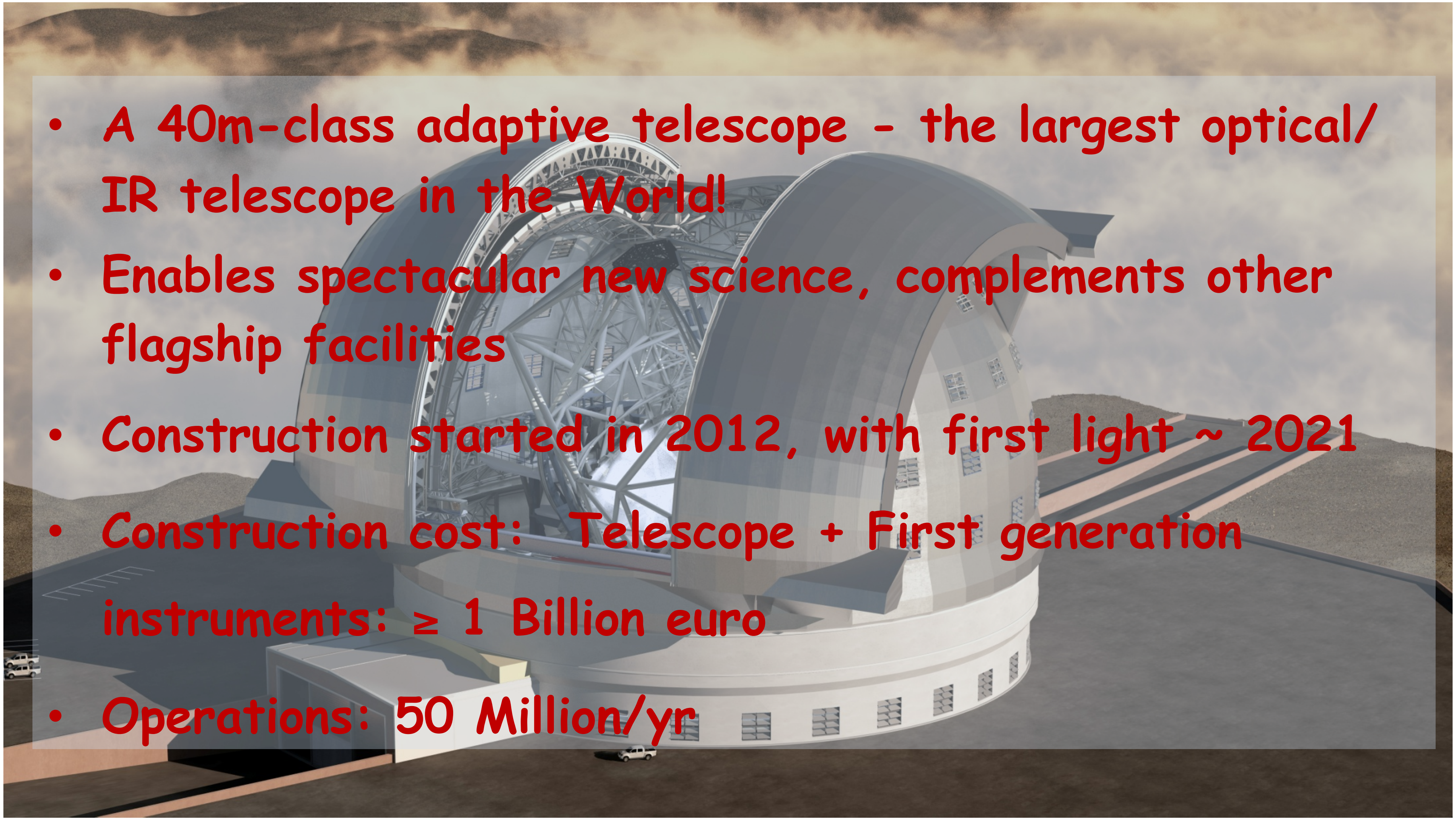
VLT 1998

ALMA
E-ELT
present

CERN

Today: 15 member states

E-ELT



- A 40m-class adaptive telescope - the largest optical/ IR telescope in the World!
- Enables spectacular new science, complements other flagship facilities
- Construction started in 2012, with first light ~ 2021
- Construction cost: Telescope + First generation instruments: ≥ 1 Billion euro
- Operations: 50 Million/yr

Other International ELT projects

TMT

30m telescope

U. California, Caltech, Canada (+ Japan + China)

Construction proposal complete

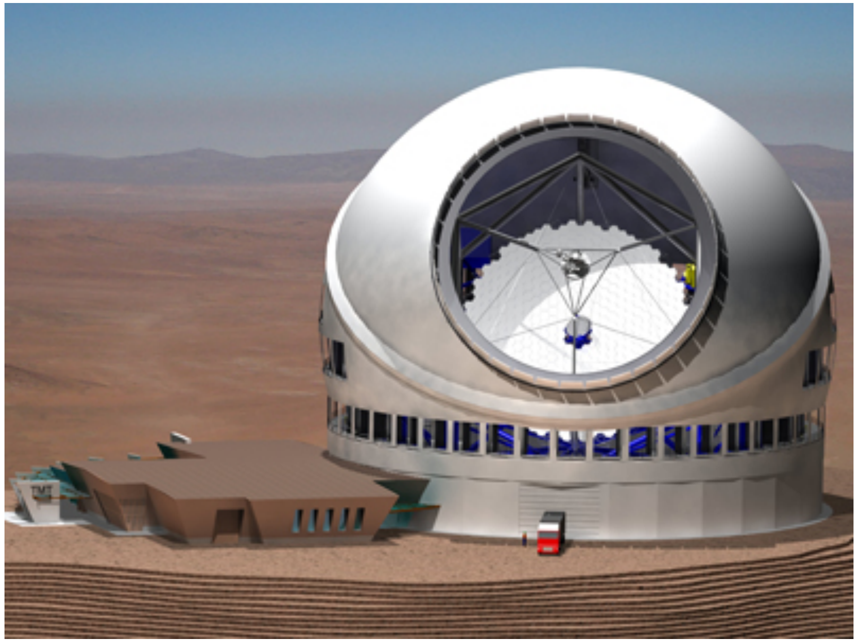
First light ~ 2020

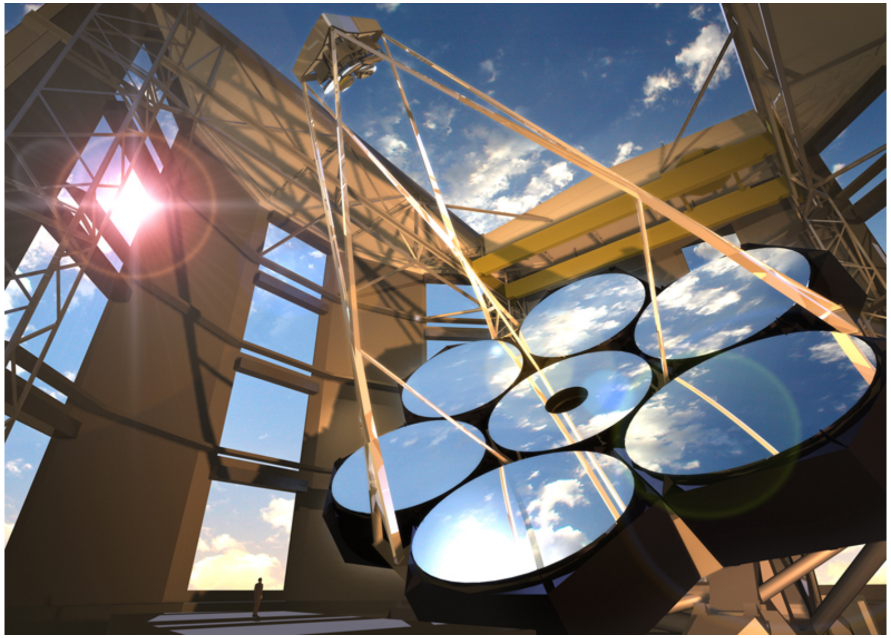
GMT

24m (7x 8m segments)

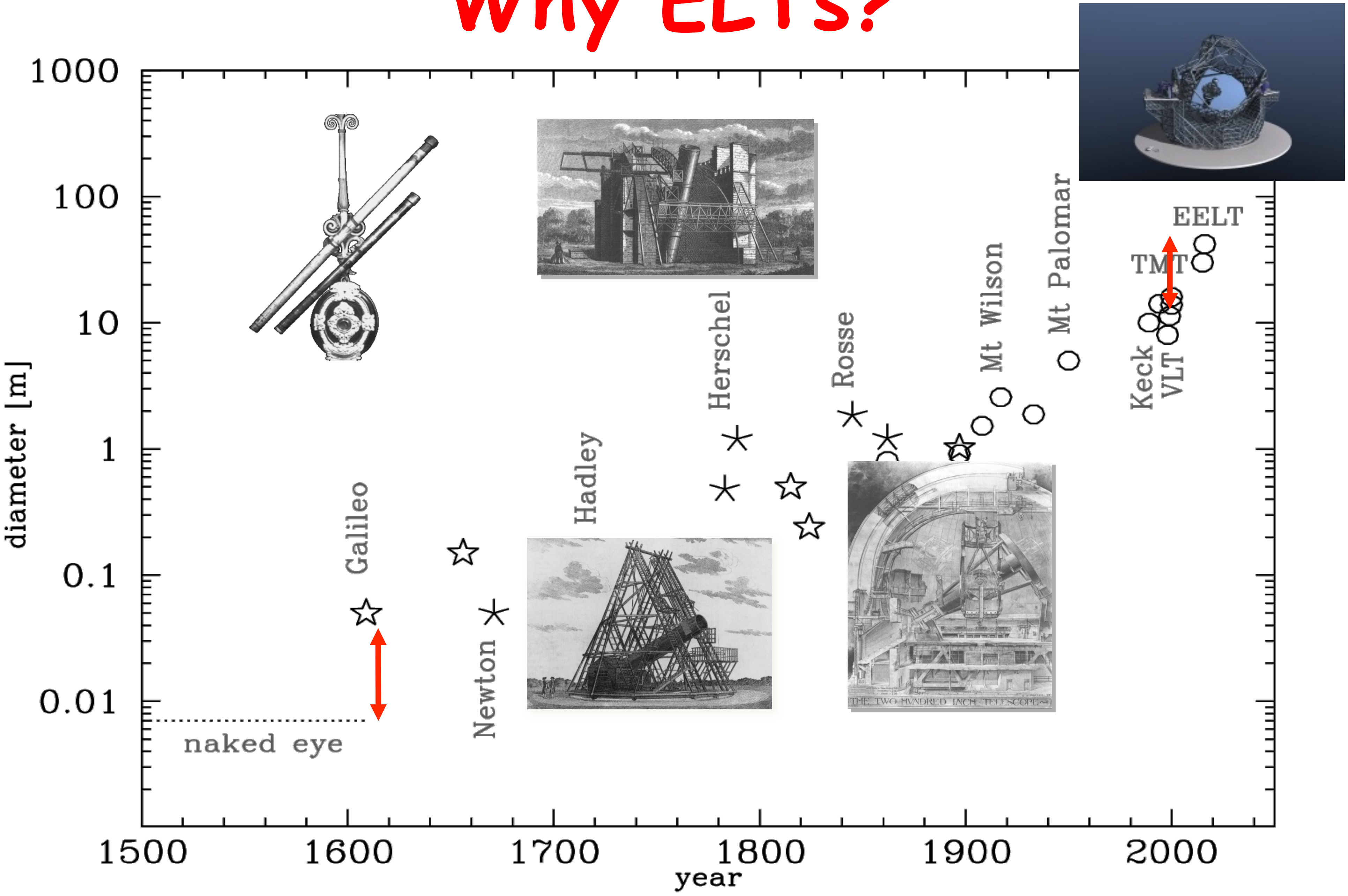
Collaboration of private US universities, Australia (ANU + AAL) + Korea

First light ~ 2020





Why ELTs?


1000
100
10
1
0.1
0.01
diameter [m]
1500
1600
1700
1800
1900
2000
year
naked eye
Galileo
Newton
Hadley
Herschel
Rosse
Mt Wilson
Mt Palomar
Keck
VLT
TMT
EELT
THE TWO HVNDRED INCH TELESCOPE

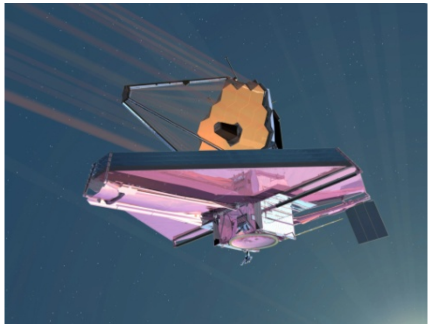
Why ELTs?

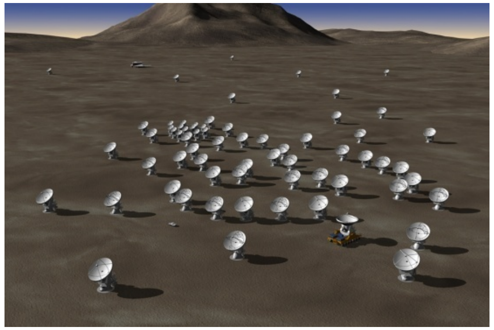
✓ We need sensitivity ($\propto D^2$) and **resolution ($\propto \lambda/D$)**

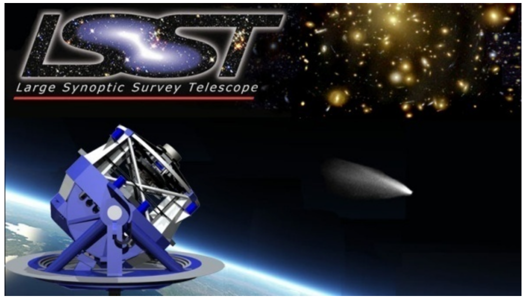
✓ We need to combine observations at different wavelengths

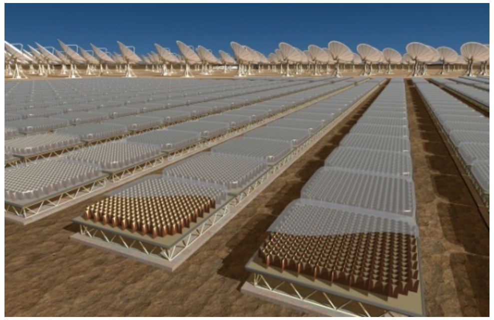
Synergies with Large Facilities

- ✓ JWST
- ✓ ALMA
- ✓ IXO, Far-IR mission
- ✓ SKA / SKA Pathfinders
- ✓ LSST
- ✓ GAIA
- ✓ ...

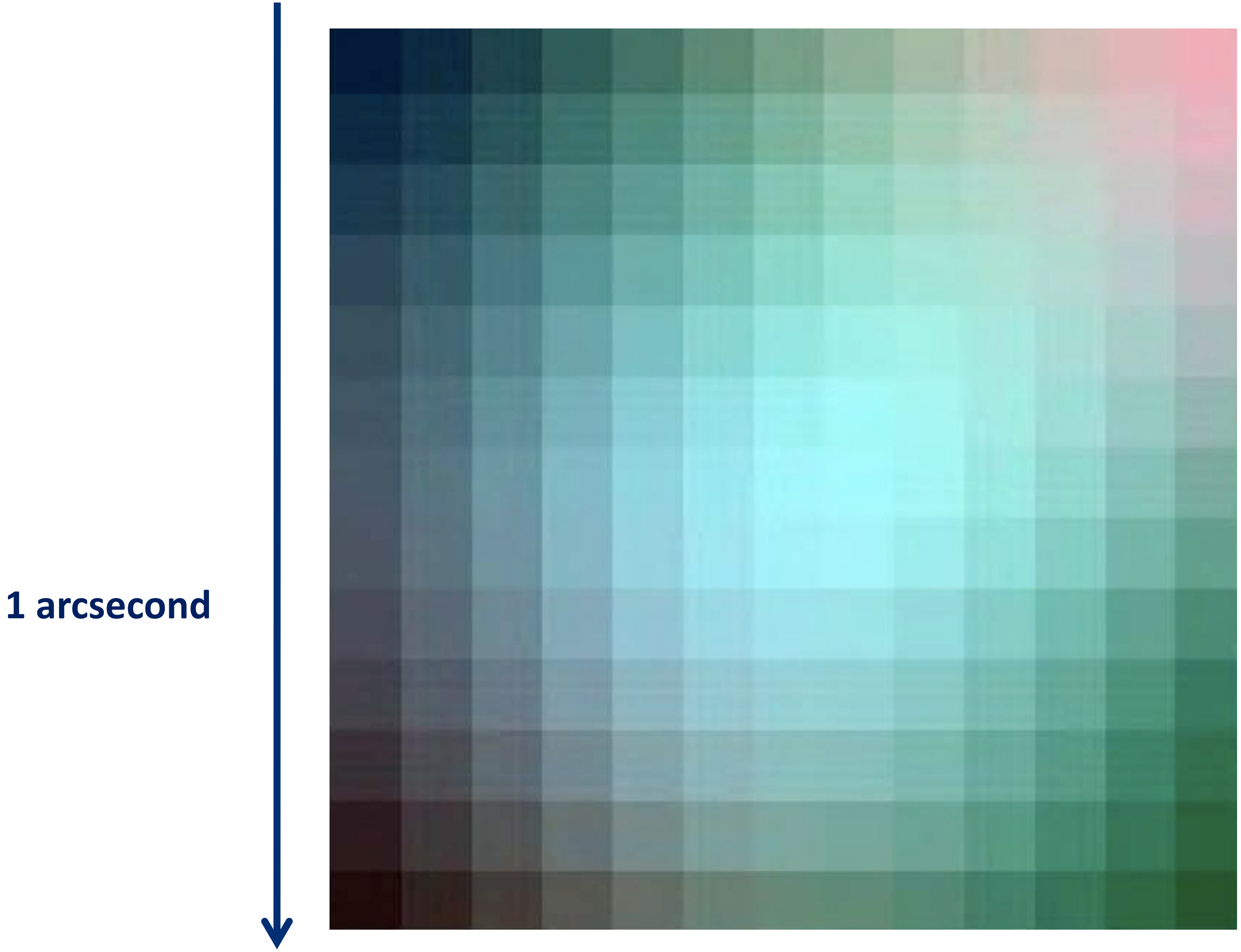








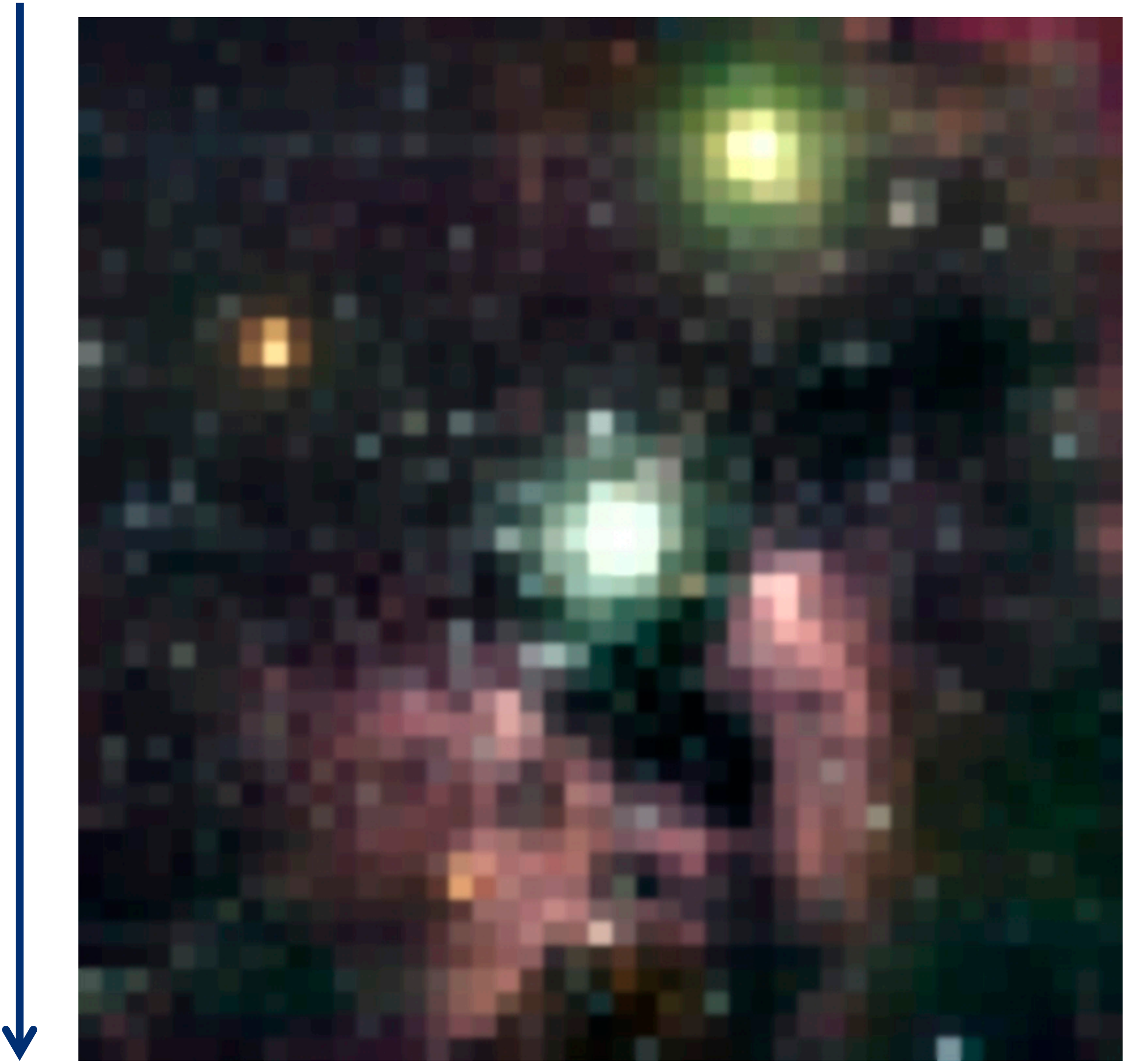
High spatial resolution



High spatial resolution

Hubble
Space
telescope

1 arcsecond



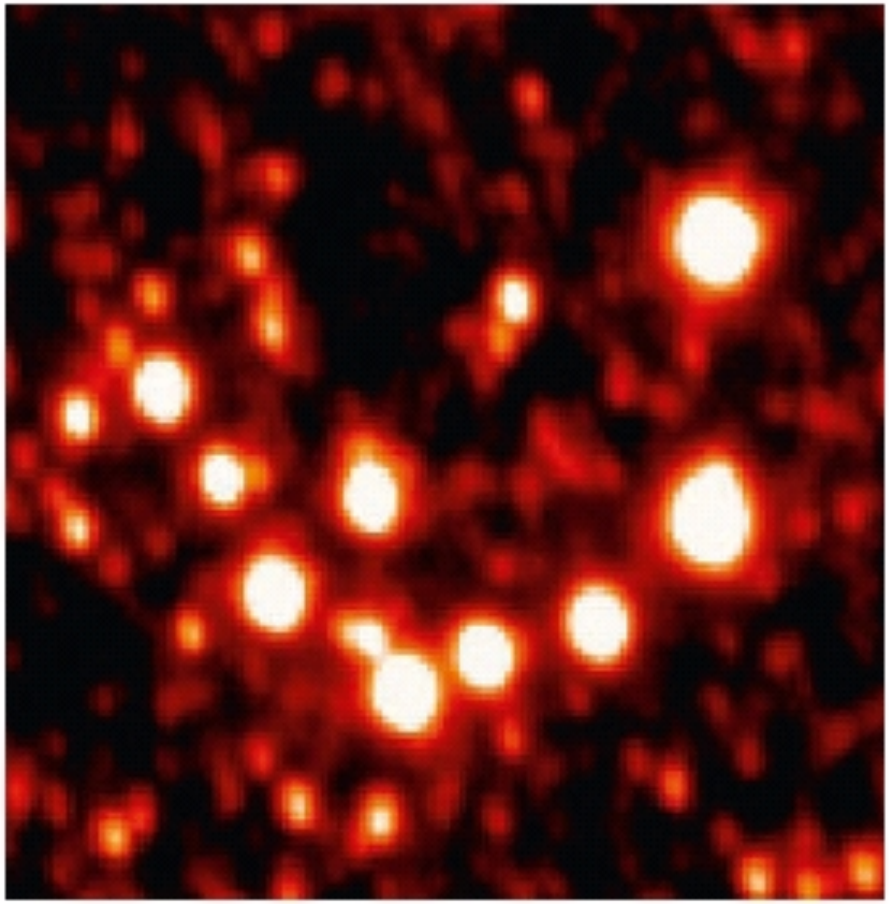
High spatial resolution

VLT + adaptive optics

High spatial resolution

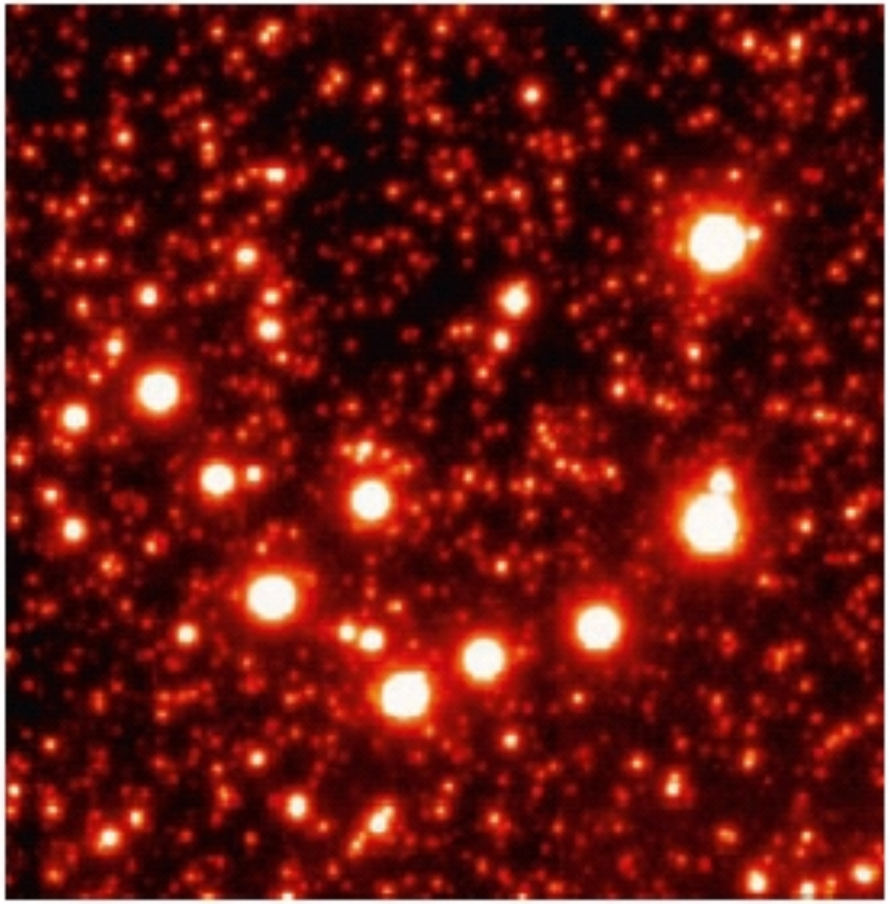
1 arcsecond

E-ELT with adaptive optics!



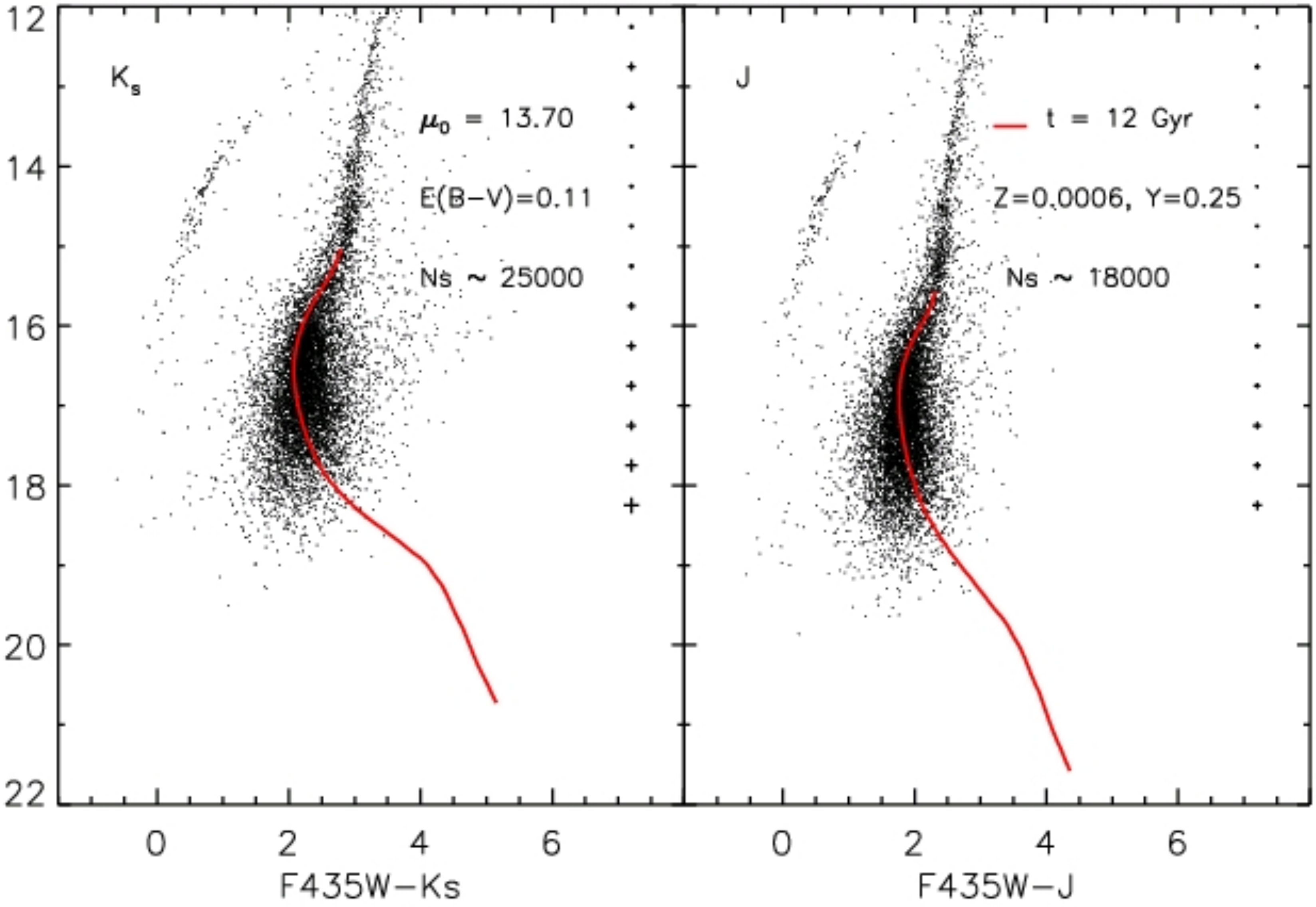
ISAAC e VLT:

Seeing ~ 0.6″



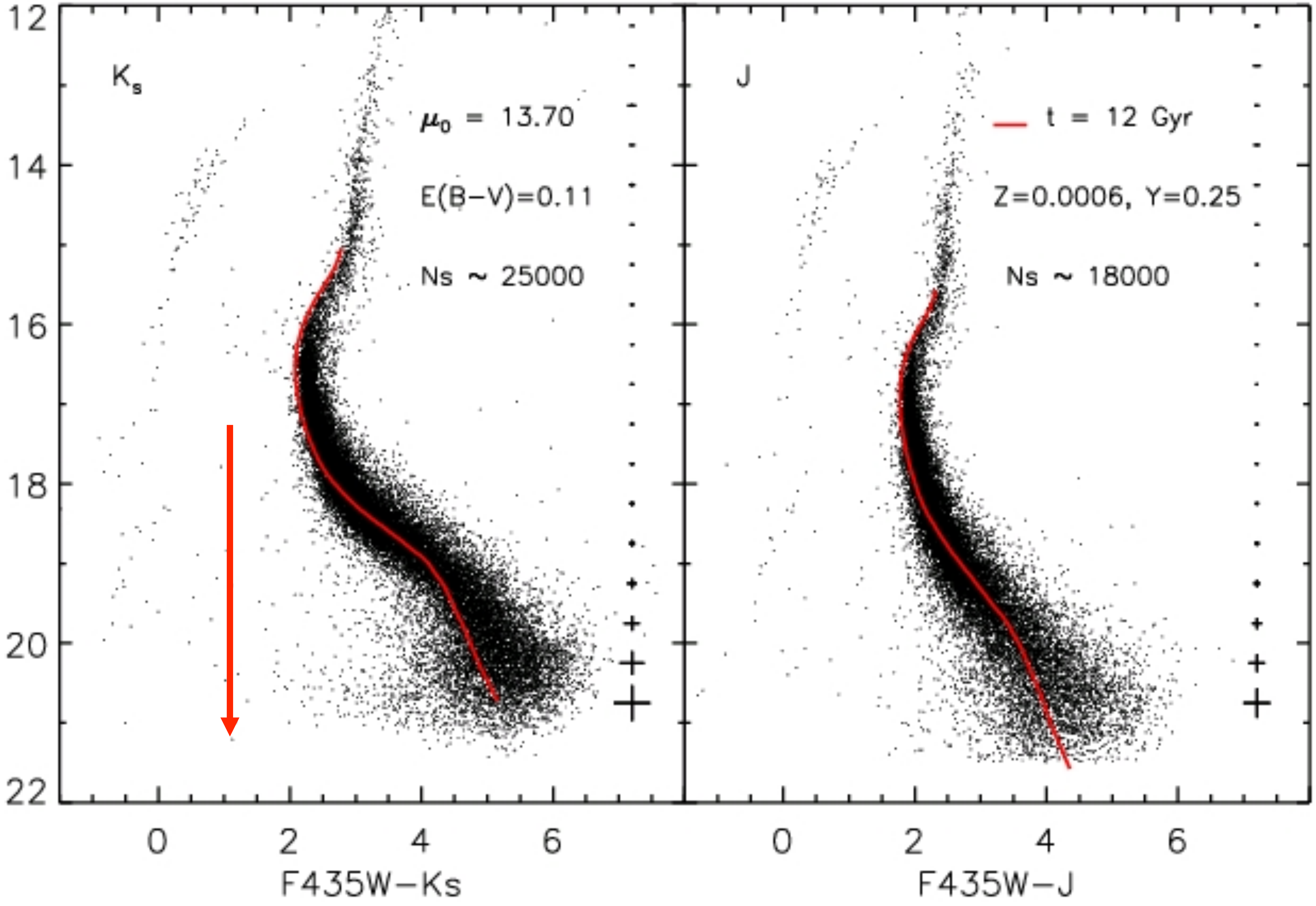
MAD e VLT

Seeing ≤ 0.1″



12
14
16
18
20
22
0
2
4
6
F435W−Ks
F435W−J
K_s
J
μ_0 = 13.70
E(B−V)=0.11
Ns ~ 25000
t = 12 Gyr
Z=0.0006, Y=0.25
Ns ~ 18000

ISAAC@VLT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12
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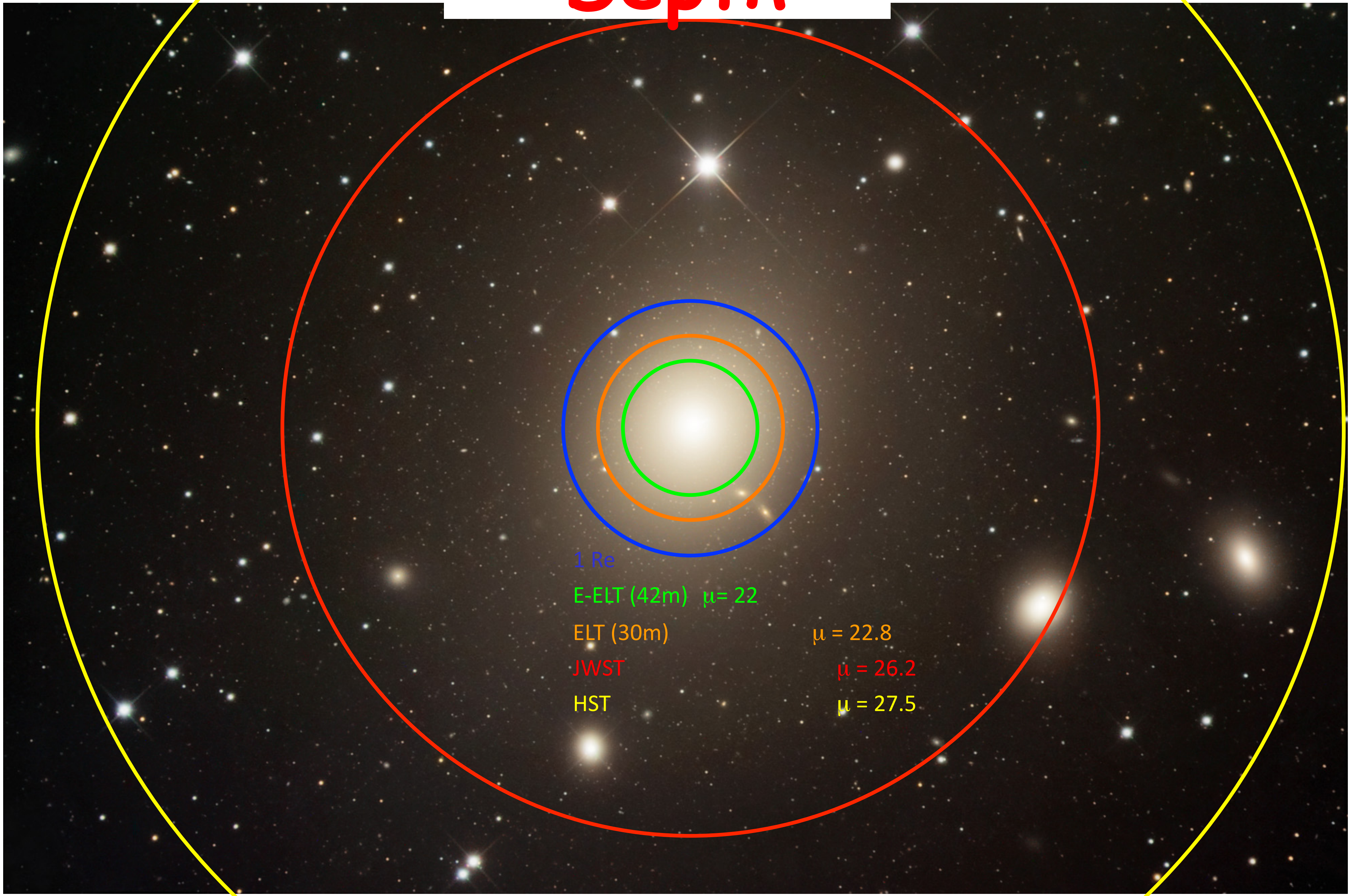
F435W−Ks
F435W−J

MAD@VLT

Depth



Credits: J. Liske

E-ELT Point source sensitivity - imaging

Band	λ/D (mas)	E-ELT - LTAO (5 mas pixels)	E-ELT GLAO (50 mas pixels)
V	2.7	27.5	29.0
R	3.1	28.5	29.0
I	3.9	29.5	28.5
J	6.1	28.5	26.0
H	8.1	28.0	25.0
K	10.6	27.5	24.5

› 5σ in 1hr, Vega magnitudes rounded to nearest 0.5 mag.

Calculated with E-ELT exposure time calculator

The European ELT

- Base ~ 80 m
- Height ~ 60 m
- Dome ~ 100 m

E-ELT Top Level Requirements

- D = 39m, Area ~ 1000 m^2

– Alt-Azimuth mount, fully steerable (0-360,0-90). Operational for zd = 0 – 70

- *Adaptive Telescope*

– Ground Layer Adaptive Optics correction (GLAO, for FoV ≥ 5 arcmin, for 80% of the observing time)

  - better than 2x FWHM improvement for median seeing conditions

– Post-focal corrections: *SCAO, MCAO, LTAO, ExAO, ...*

- Science field of view:

– 10 arcmin. Diffraction limited by design

- Wavelenght range: 0.3 – 24 μm (ultraviolet – mid infrared)

E-ELT Top Level Requirements

- Transmission at Nasmyth focus:

– > 50% at >0.35 µm, > 60 % at > 0.4 µm, > 70% at 0.7 µm, > 80% at > 1 µm

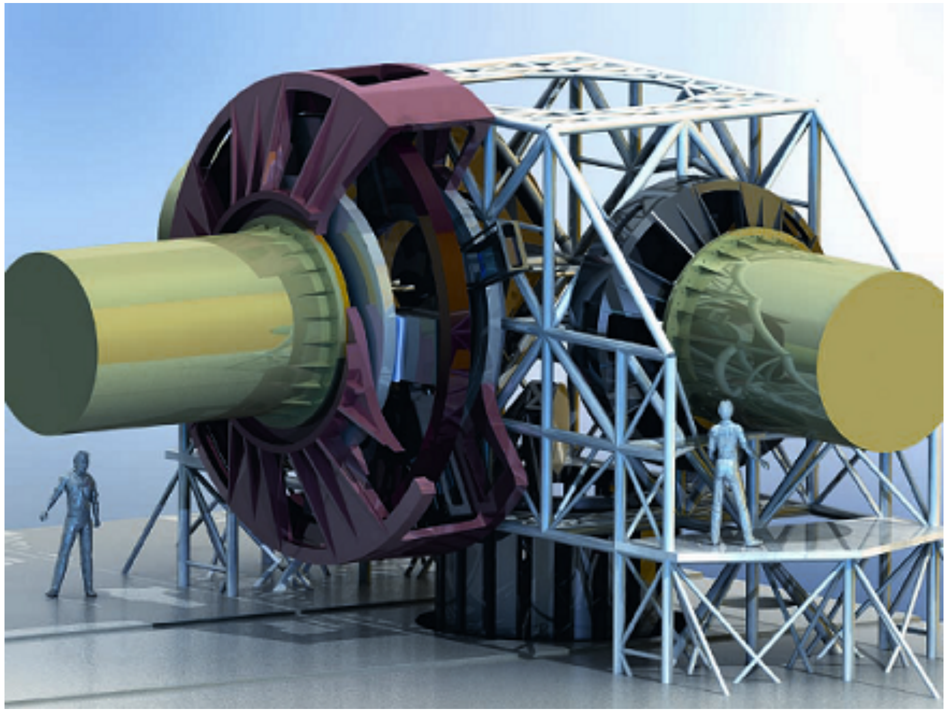
Total transmission: T = (1 mirror reflectivity = R) R^5

- Focal Stations:

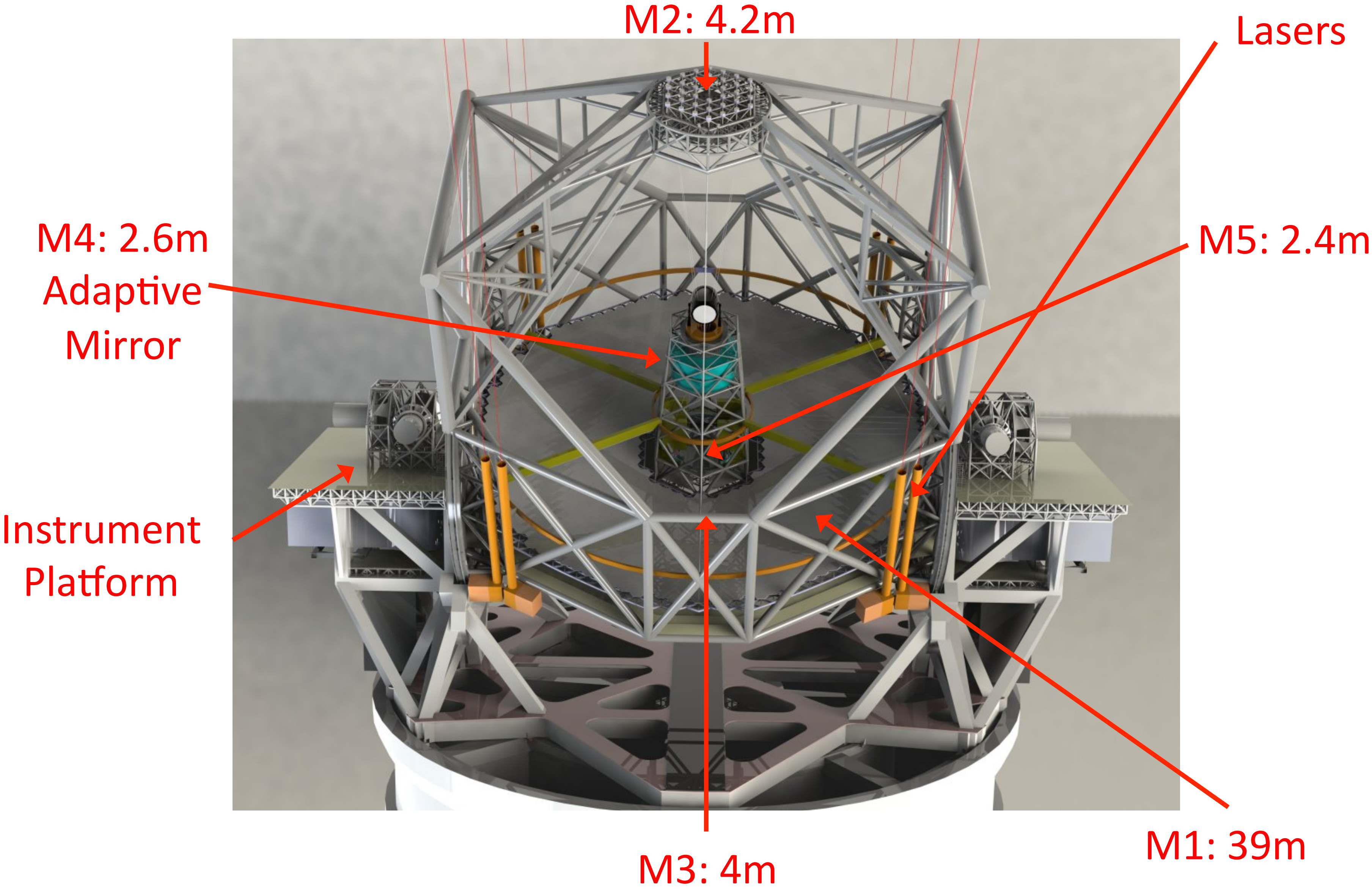
– Two Nasmyth foci

– At least one Coudé

– Fixed Instrumentation (fast switching: < 10 min same focus, < 20 otherwise)

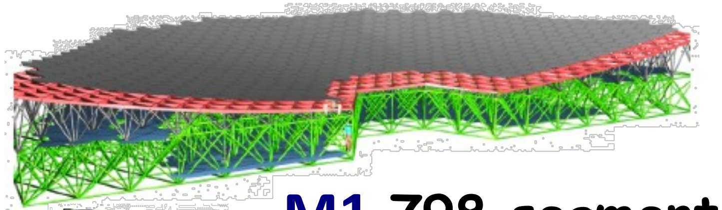


E-ELT Basic Reference Design

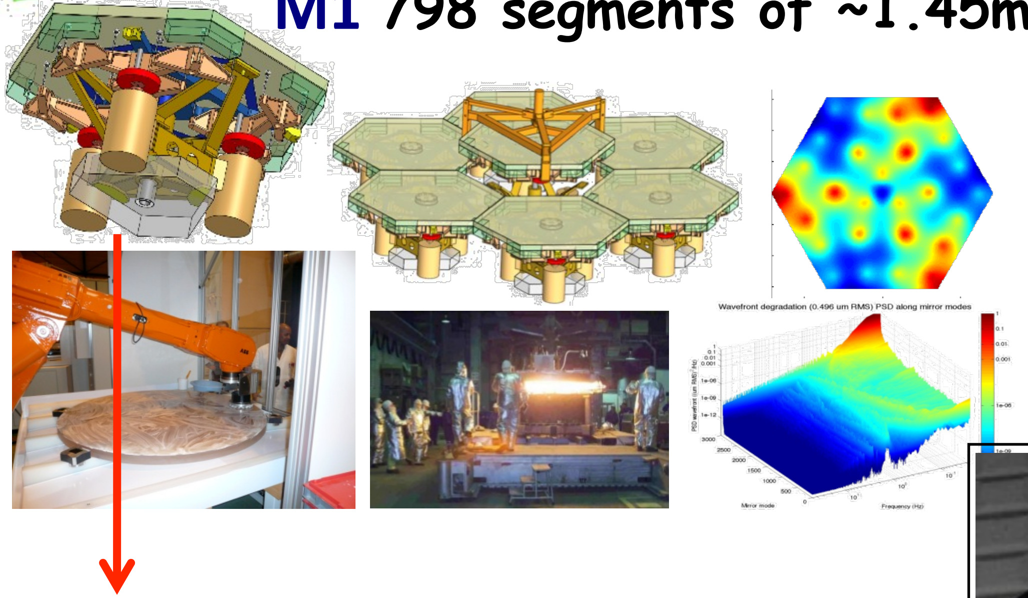


Credits: I. Hook

Mirrors



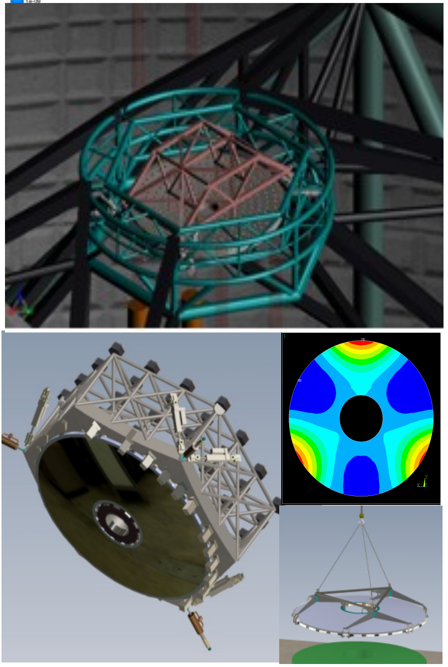
M1 798 segments of ~1.45m!!



Glass mirrors coated with Aluminium or Silver/ Aluminium-> different reflectivity

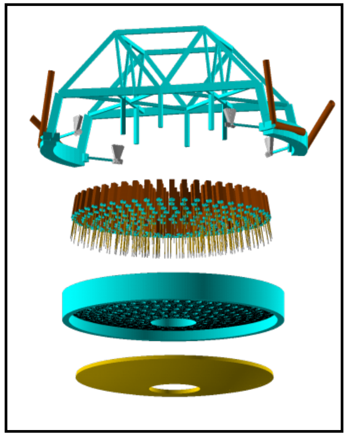
Support of M1 segments

Earthquakes!!



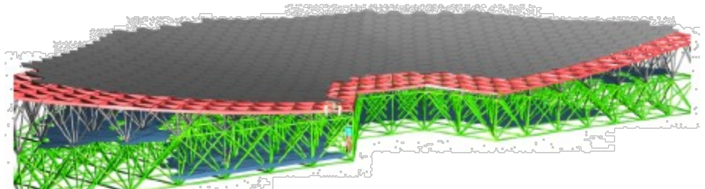
M2: 4.2m/100mm

M3: 4m

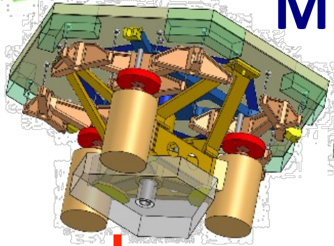


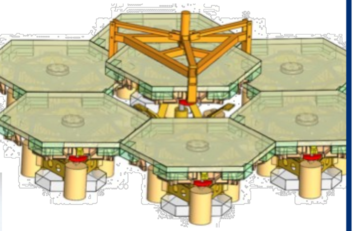
Credit:s R. Gilmozzi

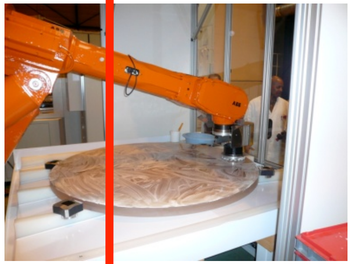
Mirrors

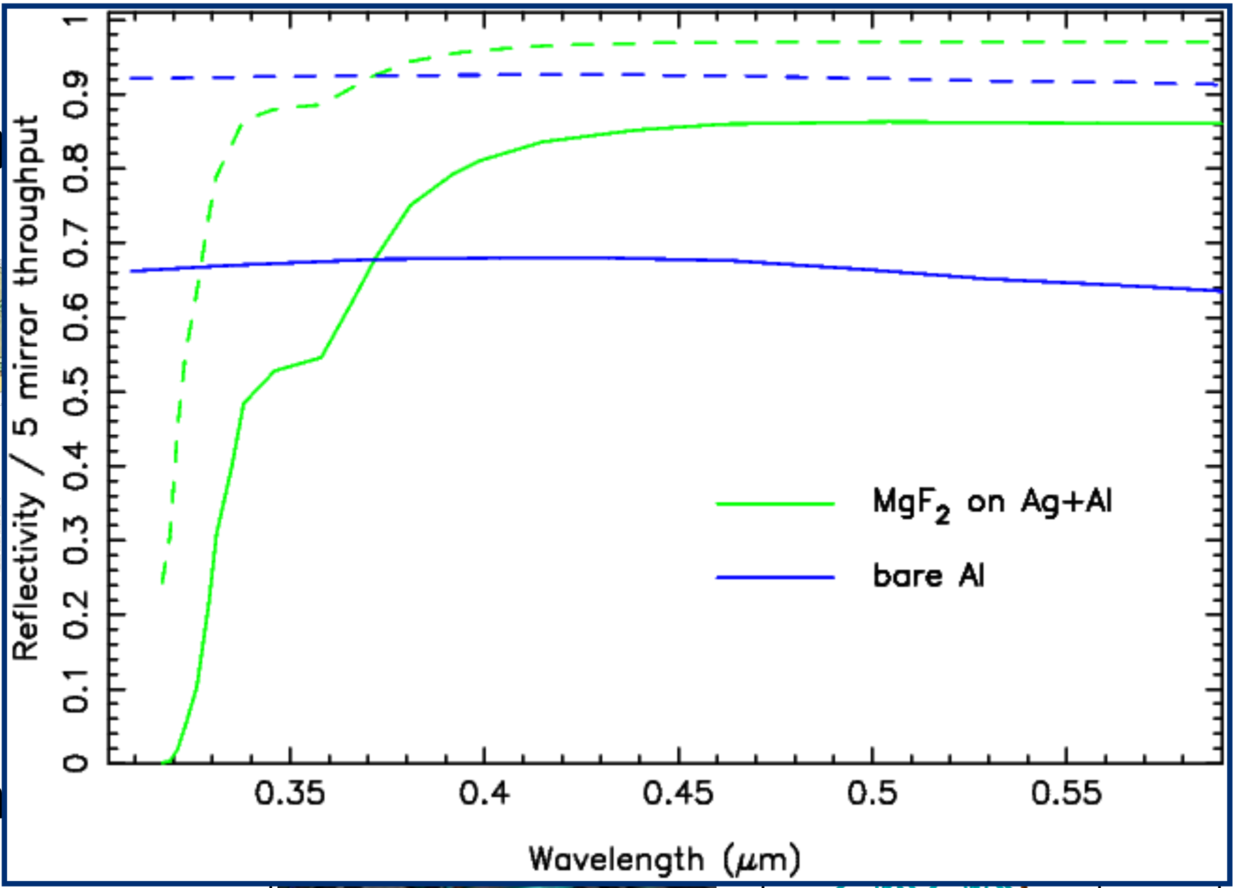


M1 798 segment

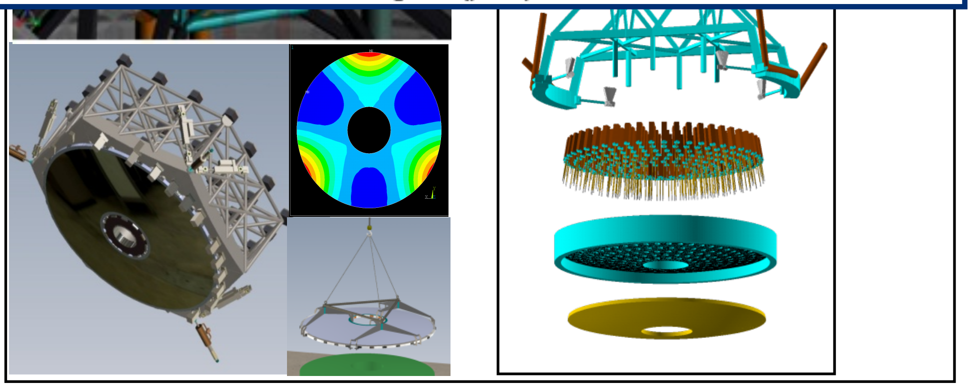








Support of M1 segmen



Earthquakes!!

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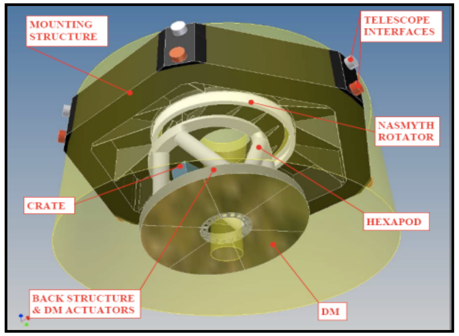
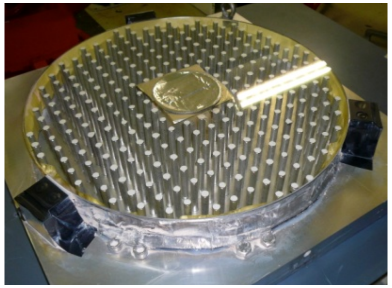
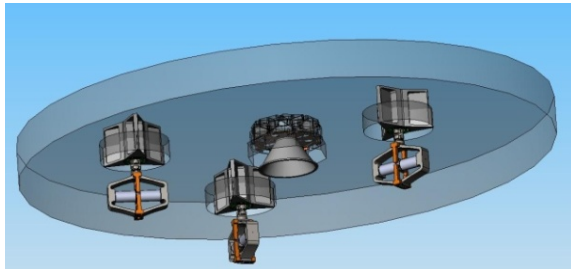
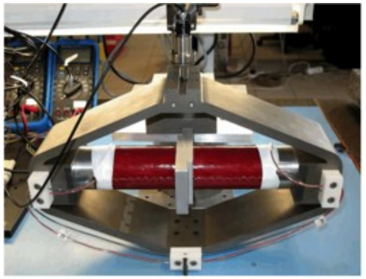


Adaptive Optics IN the telescope!!
(Ground Layer Adaptive Optics)



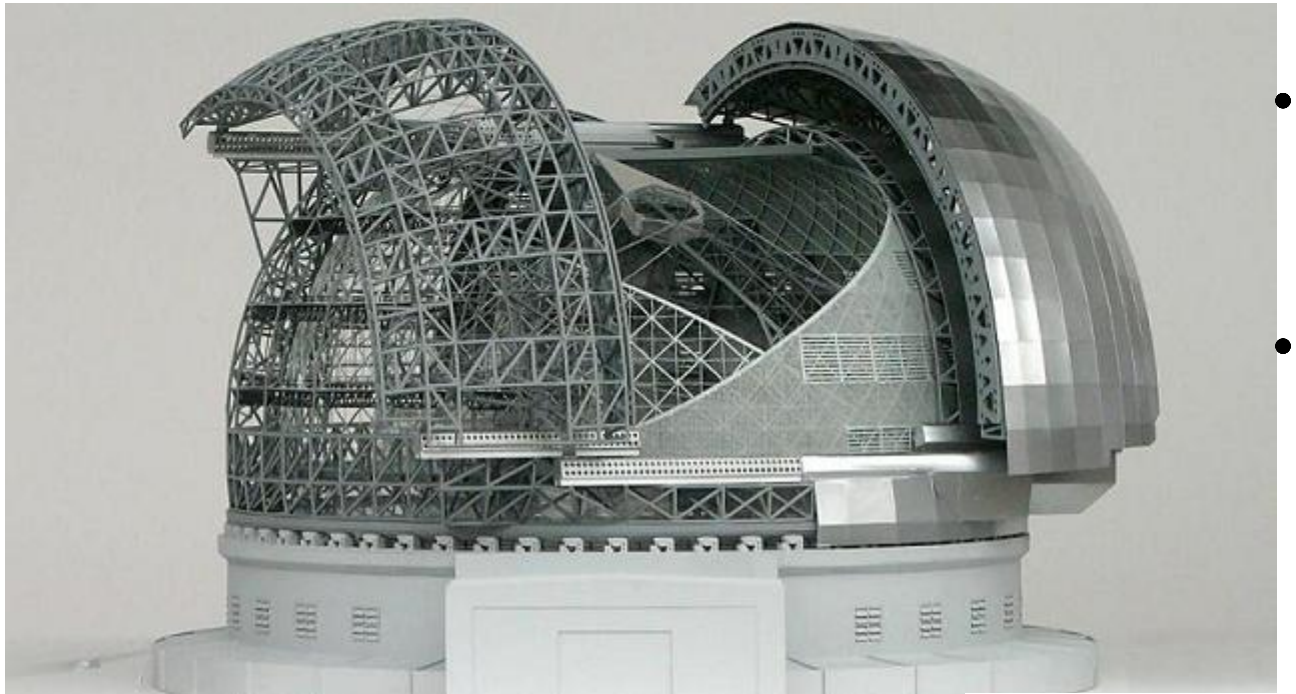
M4, 2.6m, adaptive with 6000-8000 actuators



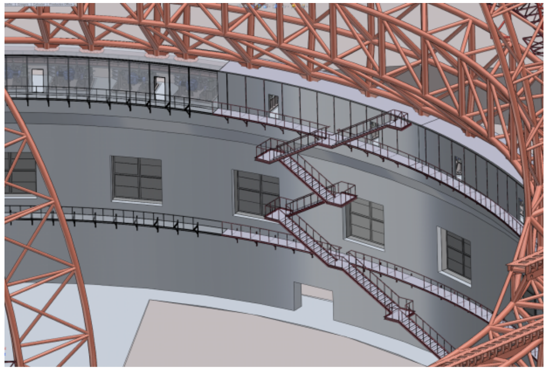


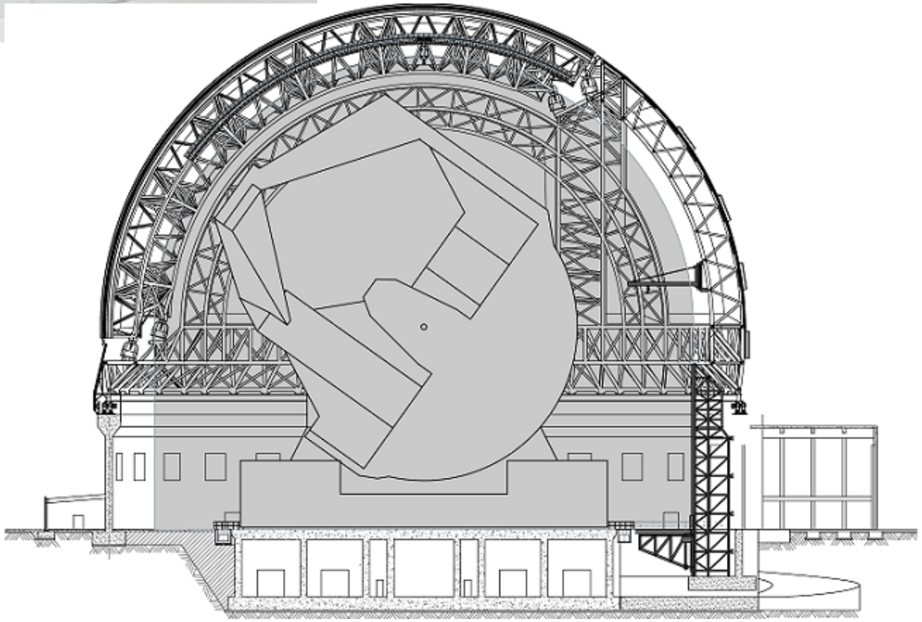
M5 :2.4m, flat, tip-tilt

The dome

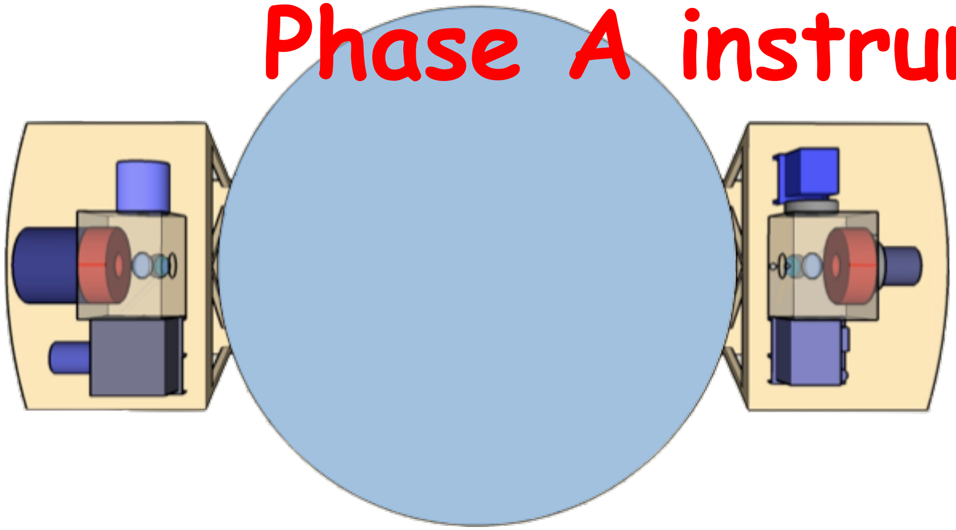


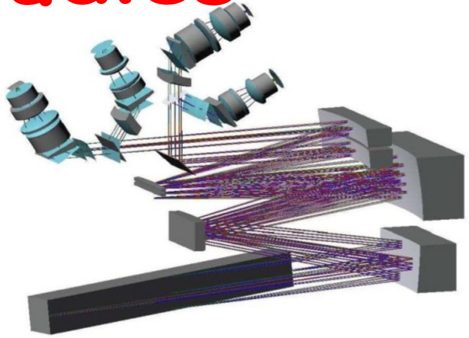
- About 3500 tons of steel!
- Equipped with air-conditioning and shielded from wind





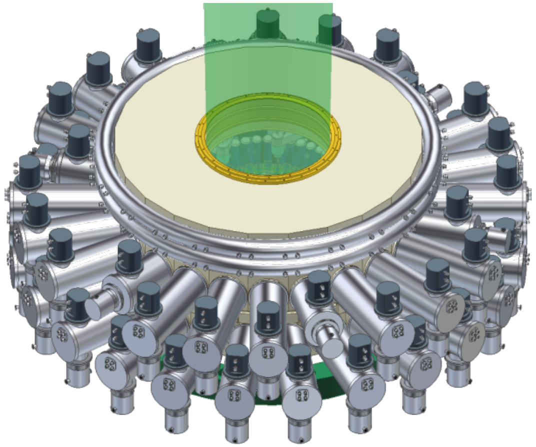
Phase A instrument studies



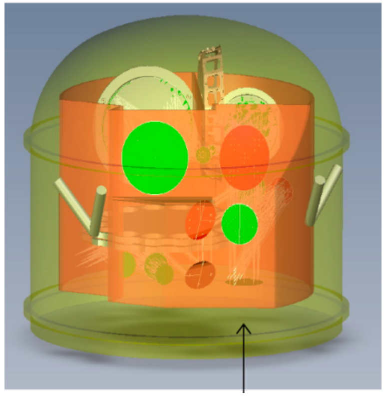


CODEX

EAGLE



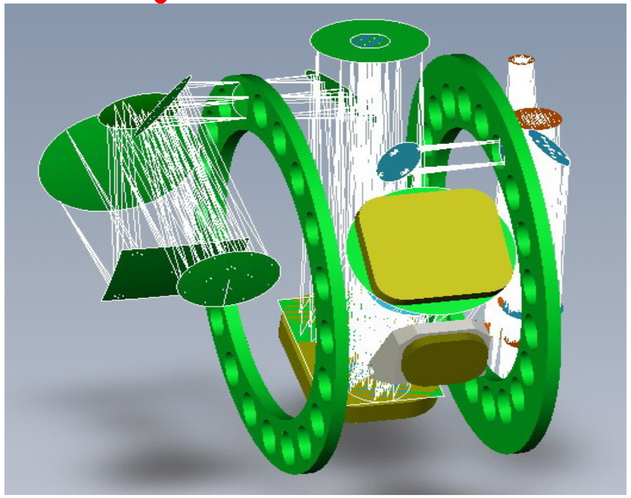
Acronym	Type of istruments
EAGLE	Near-Infrared (NIR) wide field spectrograph with Adaptive Optics (MOAO)
EPICS	Camera for imaging and spectroscopy of extra-solar planets with extreme adaptive optic (ExAO)
MICADO	Diffraction limit NIR Camera with AO
HARMONI	Wide field NIR spectrograph with AO
CODEX	High-resolution, high stability visual spectrograph
METIS	Mid-IR Camera & Spectrograph with AO
OPTIMOS	High-resolution wide filed visual spectrograph
SIMPLE	High-resolution NIR spectrograph with AO

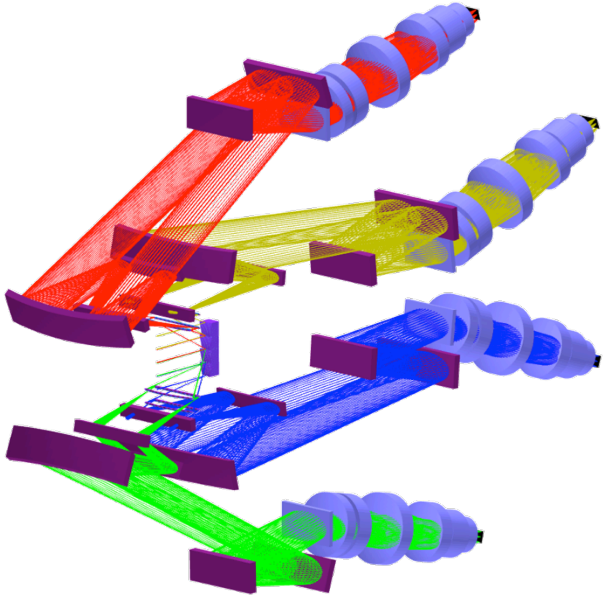


MICADO

E-ELT instrumentation plan

- **Two instruments** selected for first light:
  - **ELT-CAM** : Diffraction-limited NIR camera
  - **ELT-IFU** : wideband IFU spectrograph
  - Both with associated AO system(s)
- Specifications subject to change
- Other instruments remain in pool
- Construction proposal includes budget for 4-5 instruments





Credits: I. Hook

Tested telescope sites

Commission: **site selection advisory commette (SSAC)**


Vizcachas


Tolanchar


Macon

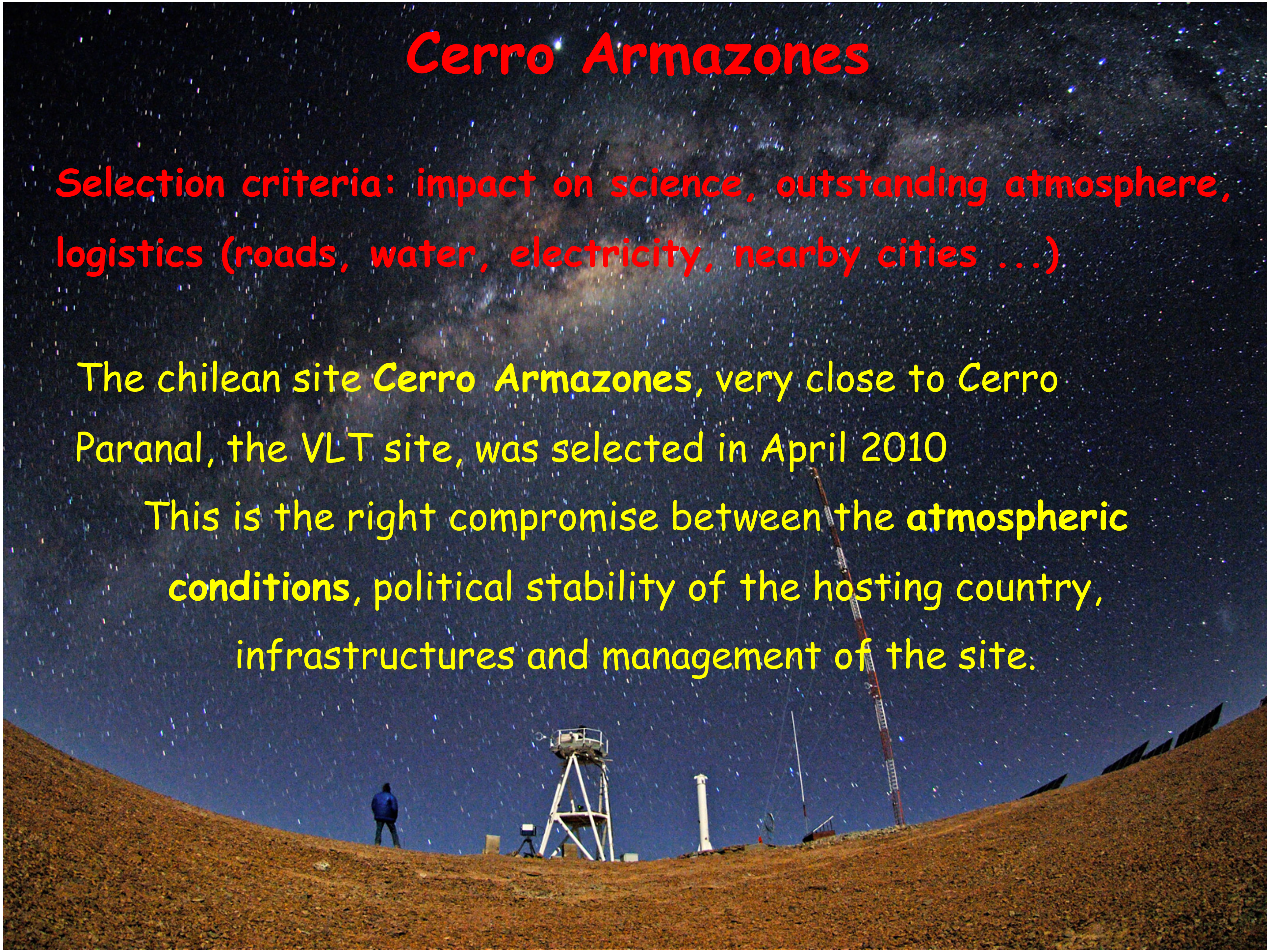

Paranal Norte

Site selected in April 2010


Marocco


Canarie

Cerro Armazones



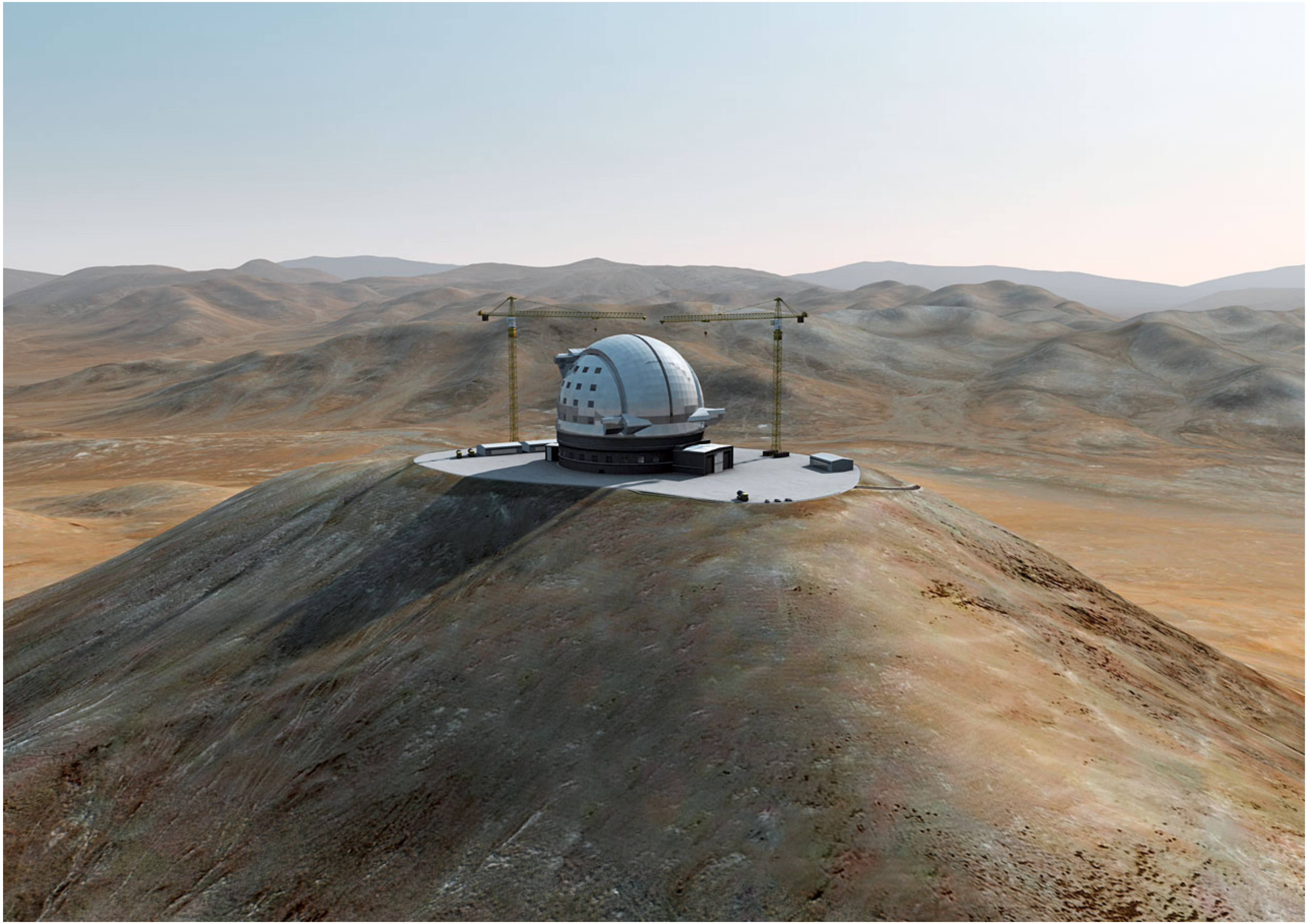
Selection criteria: impact on science, outstanding atmosphere, logistics (roads, water, electricity, nearby cities ...)

The chilean site **Cerro Armazones**, very close to Cerro Paranal, the VLT site, was selected in April 2010

This is the right compromise between the **atmospheric conditions**, political stability of the hosting country, infrastructures and management of the site.


Cerro Armazones
-24.58ºN -70.18ºW
3064 m
Cerro Paranal
-24.6ºN -70.4ºW
2600 m
©2009 Goog


Cerro Armazones
Cerro Paranal



Operations

- **Service mode** (fully flexible time allocation -> is expected to take most observing time at E-ELT)

- **Visitor mode** (non-flexible time allocation -> contact between community and observatory, complex strategies, visitor instruments…)

- **Remote mode (user available at short notice, having access to suitable computing and communications infrastructures. Real-time interaction and flexible schedule)**

E-ELT Science

The **Science Case** resides on **three pillars**:

- **Contemporary science cases:**

  European Astronomy Community via:
  - Design Reference Mission (**DRM**)
  - Design Reference Science Plan (**DRSP**)

  Instrument teams

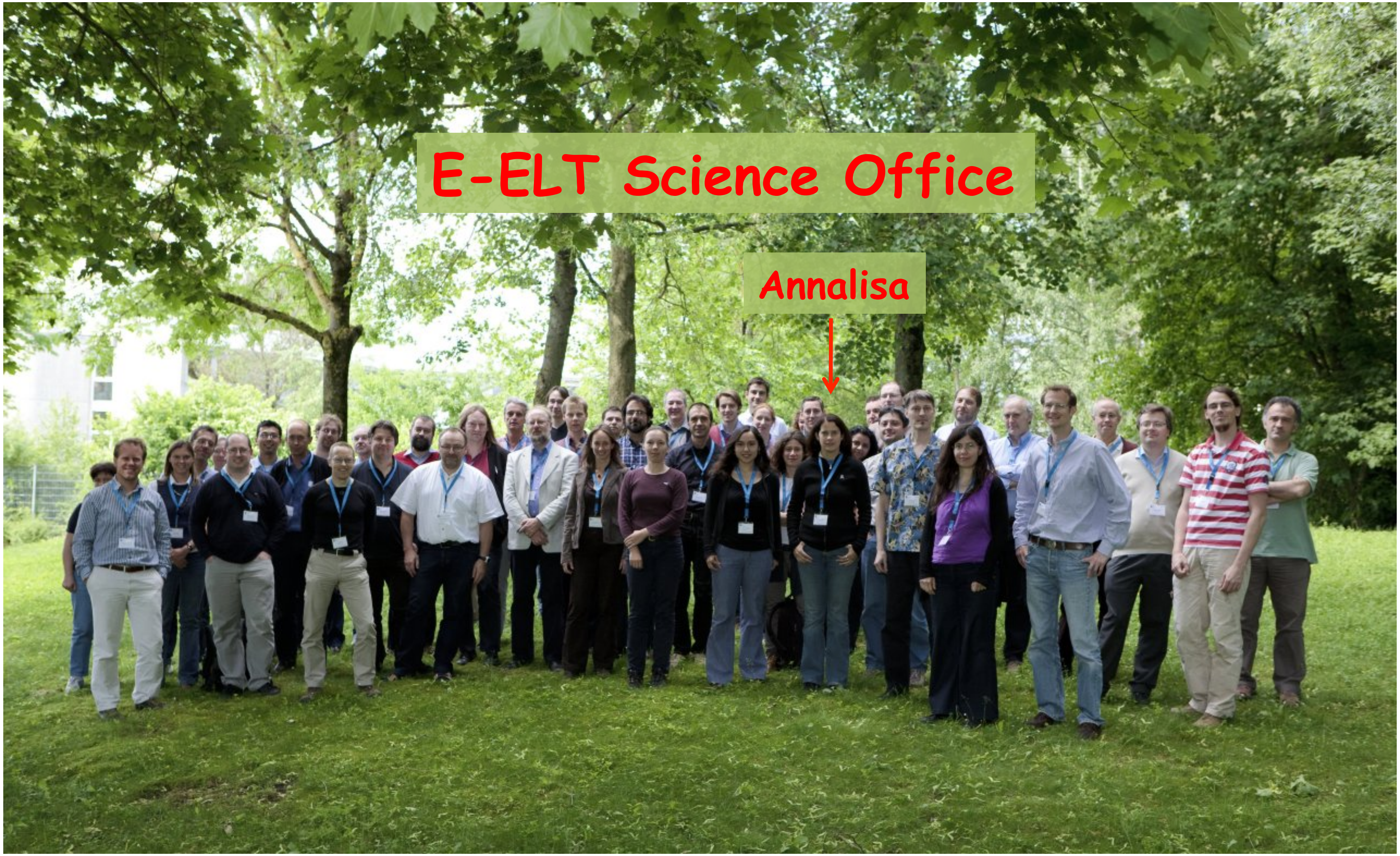
- **Synergy with other facilities**

  8m-class telescopes, interferometry, ALMA, JWST, LSST, IXO, SKA…

- **Discovery potential**

  A new unique parameter space (sensitivity, resolution) be prepared for the unexpected…

➡Design Reference Mission



E-ELT Science Working Group

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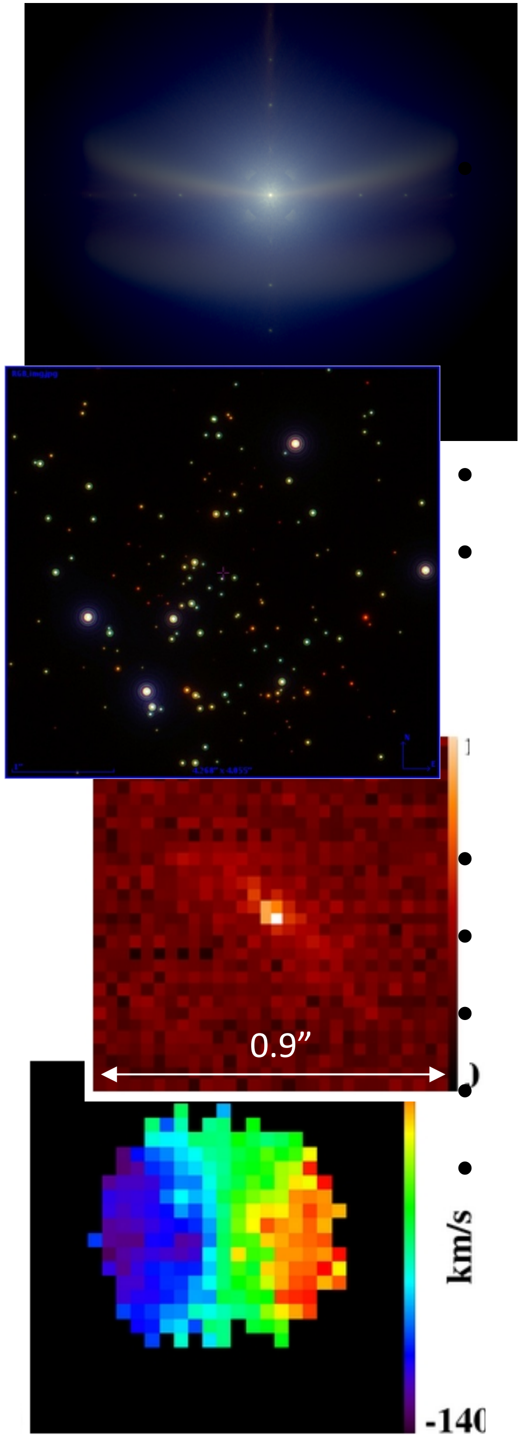
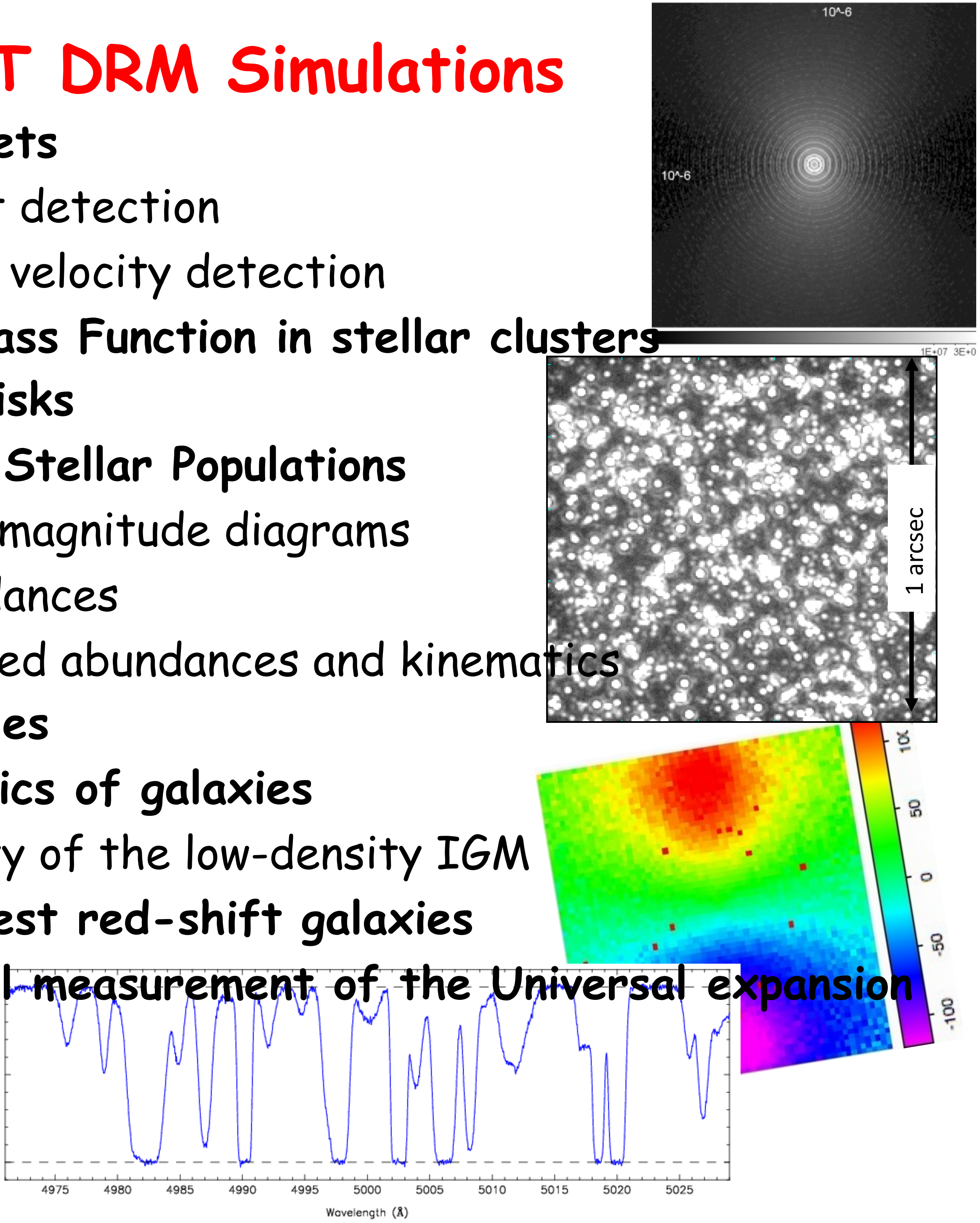
Aybuke Küpcü Yoldas
Daniela Villegas

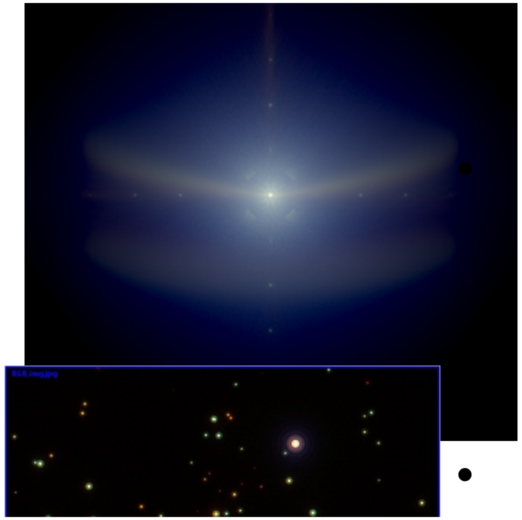
Lise Christensen
Sune Toft
Mathieu Puech

E-ELT DRM Simulations

- **Exo-planets**
  - Direct detection
  - Radial velocity detection
- **Initial Mass Function in stellar clusters**
- **Stellar disks**
- **Resolved Stellar Populations**
  - Color-magnitude diagrams
  - Abundances
  - Detailed abundances and kinematics
- **Black Holes**
- **The physics of galaxies**
- Metallicity of the low-density IGM
- **The highest red-shift galaxies**
- **Dynamical measurement of the Universal expansion**







E-ELT DRM Simulations

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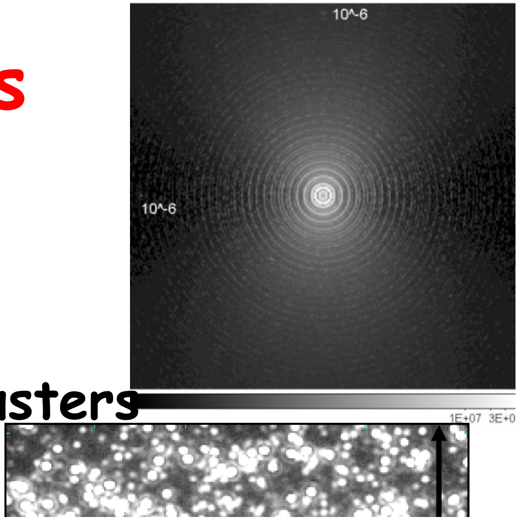
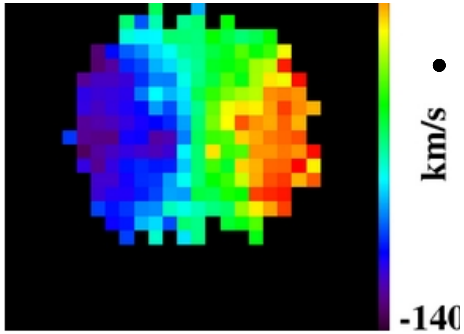
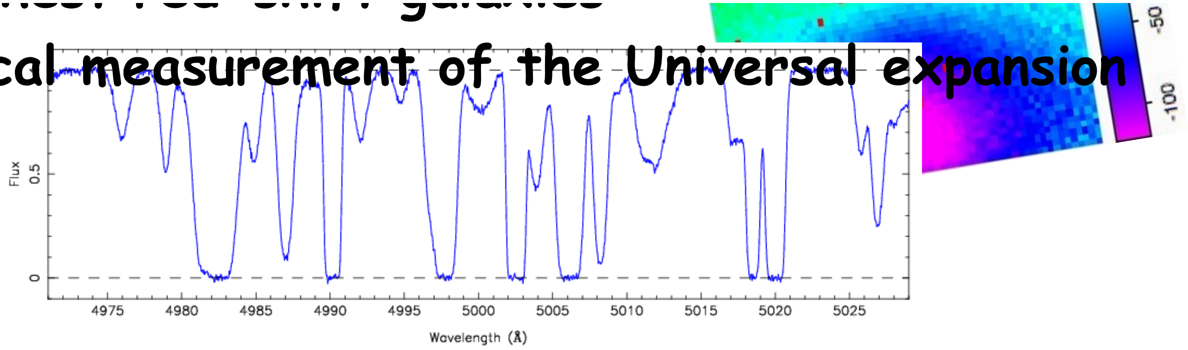


http://www.eso.org/sci/facilities/eelt/science/drm/drm_report.pdf



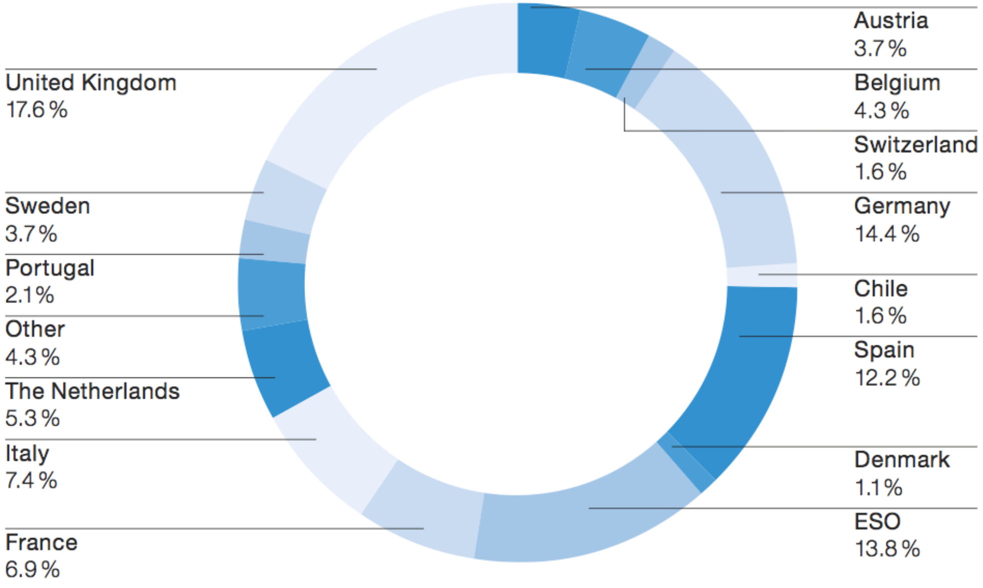
The highest red shift galaxies

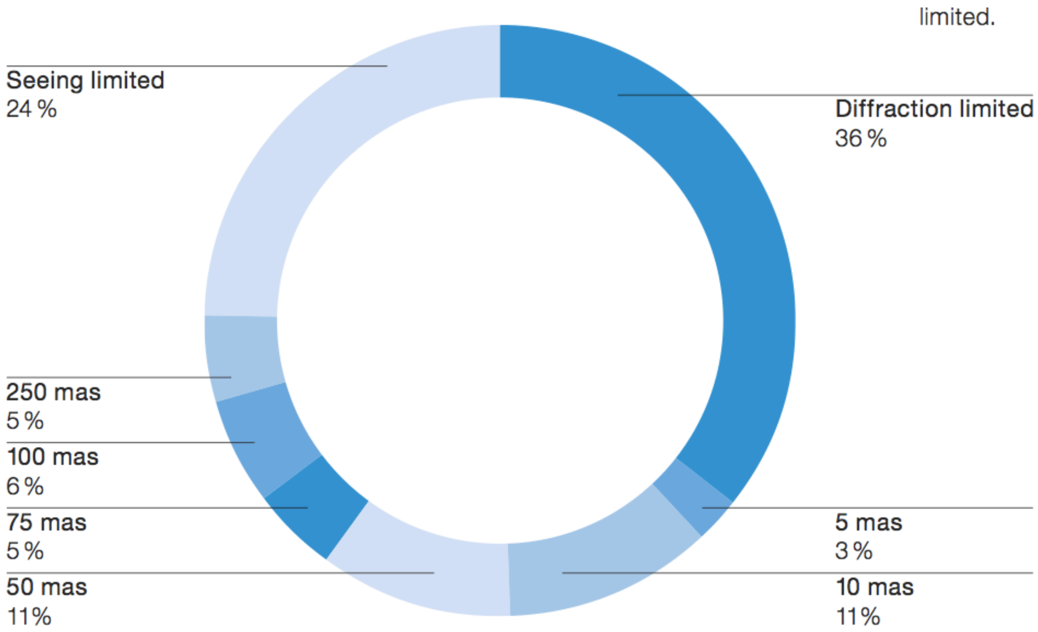
- Dynamical measurement of the Universal expansion



Design Reference Science Plan

- Input provided by the community via web form
  - science cases & requirements
  - broader science input than DRM
  - provides further input to design choices
    - Instrumentation
    - Operations modes
- Closed 5th June 2009
- 188 responses, report in **ESO messenger**





Design Reference Science Plan

- Input provided by the community via web form
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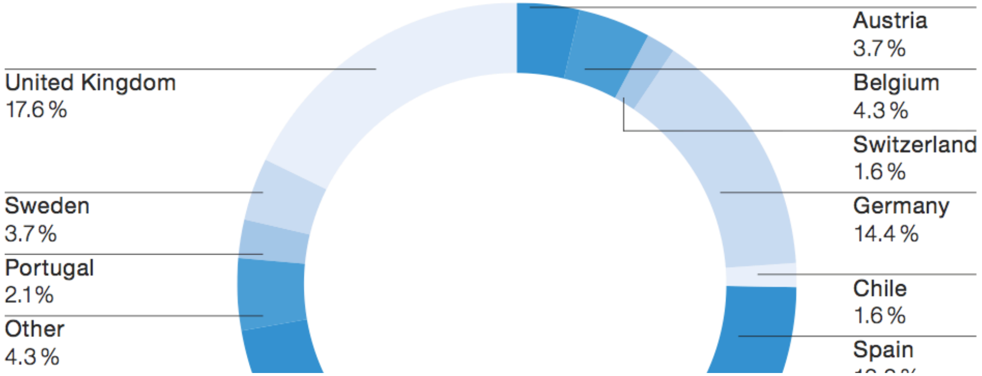
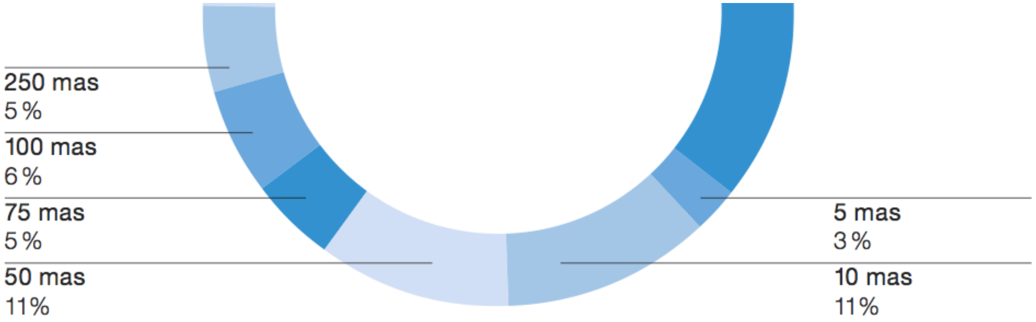


http://www.eso.org/sci/facilities/eelt/science/drsp/doc.html

- Closed 5th June 2009
- 188 responses, report in **ESO messenger**



Extra-solar planets

✓ When E-ELT will have first light **(2021)** many other extra-solar planets will be discovered (some of them being earth-like)

✓Most interesting selected and observed with E-ELT

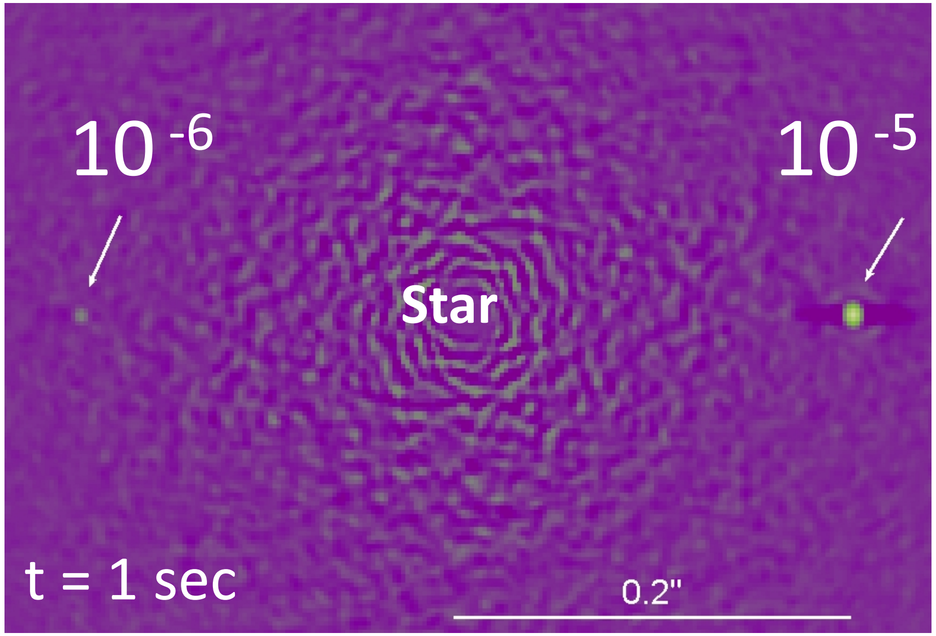
➢ **High-contrast images** with NIR **ExAO** (planet/star -> 10^{-8}, 10^{-9}) -> **direct detection**

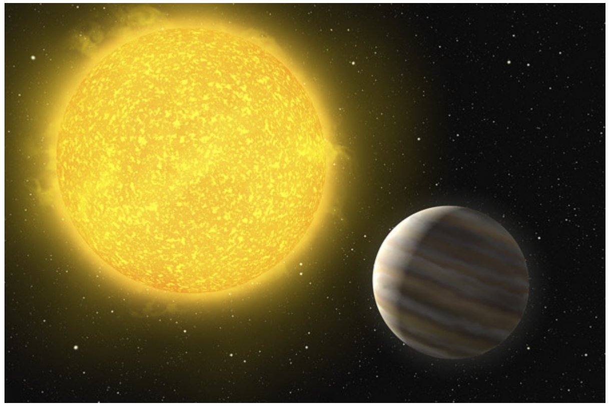
➢ **High resolution NIR spectroscopy** of transiting planets (atmospheric composition)

➢ Detection (**radial velocities**) of earth-like planets

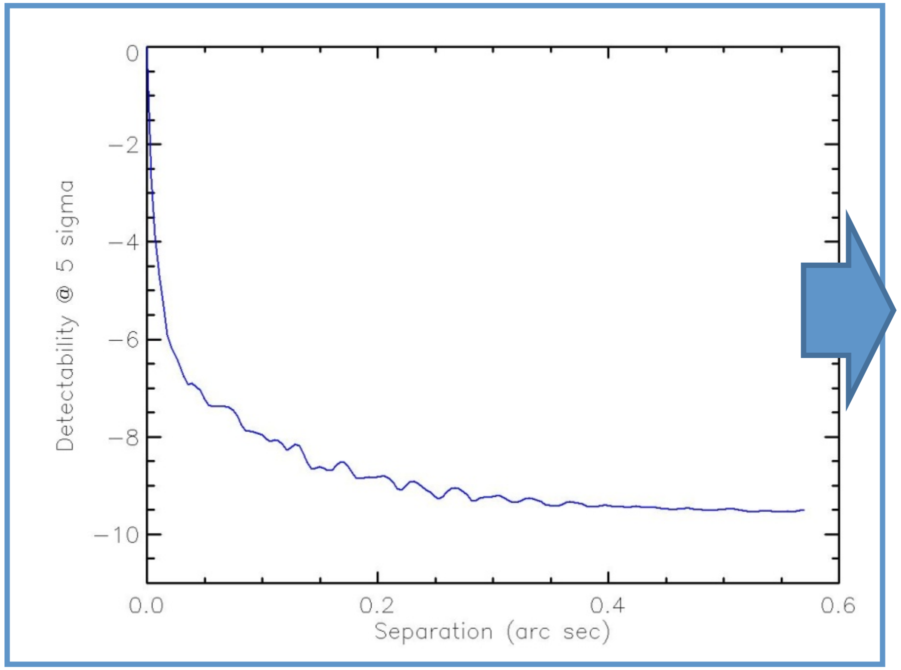
Simulations

Credit: S. Gladysz

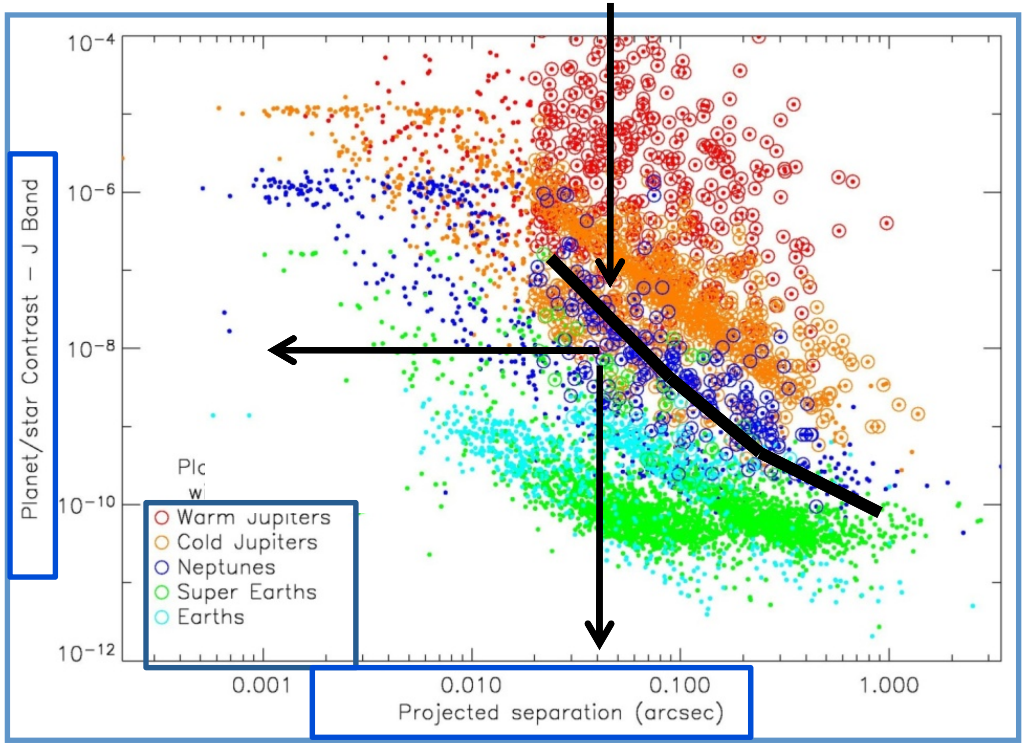




After 10 h of observations with ELT:



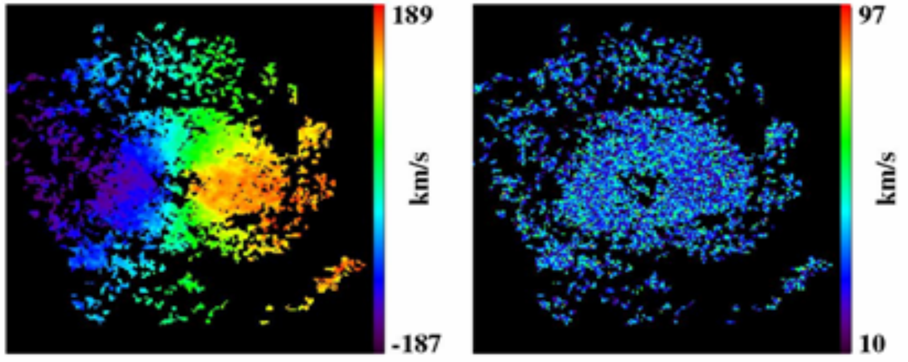
Contrast curve



Galaxy formation

- ➢ How were galaxies billions of years ago?
- ➢ How did they form?

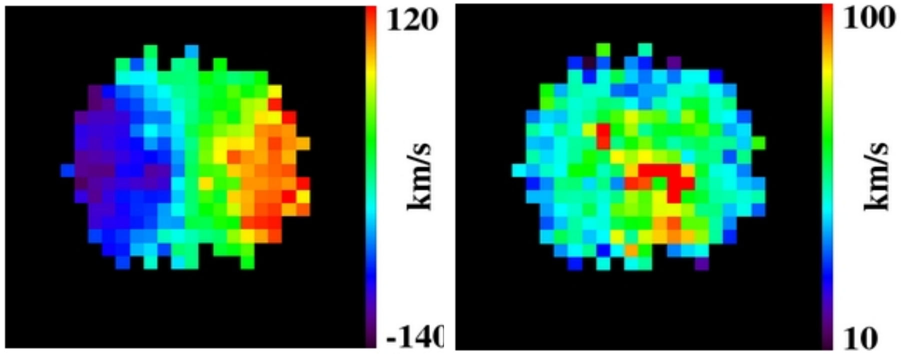
Spectroscopic observations: direct kinematics of first stars and gas in the most distant galaxies



Mergers or ordered rotation?

Distinguish via velocity maps

z ~ 4 (1.4 bn yrs)



Rotating disk simulations (M. Puech)

M83

Stellar populations

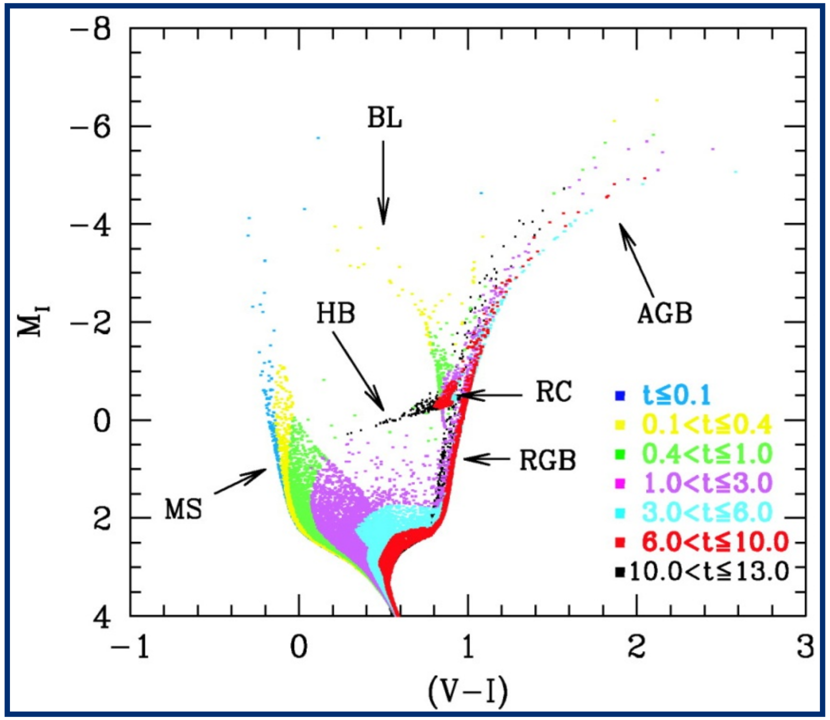
Chemical composition and age

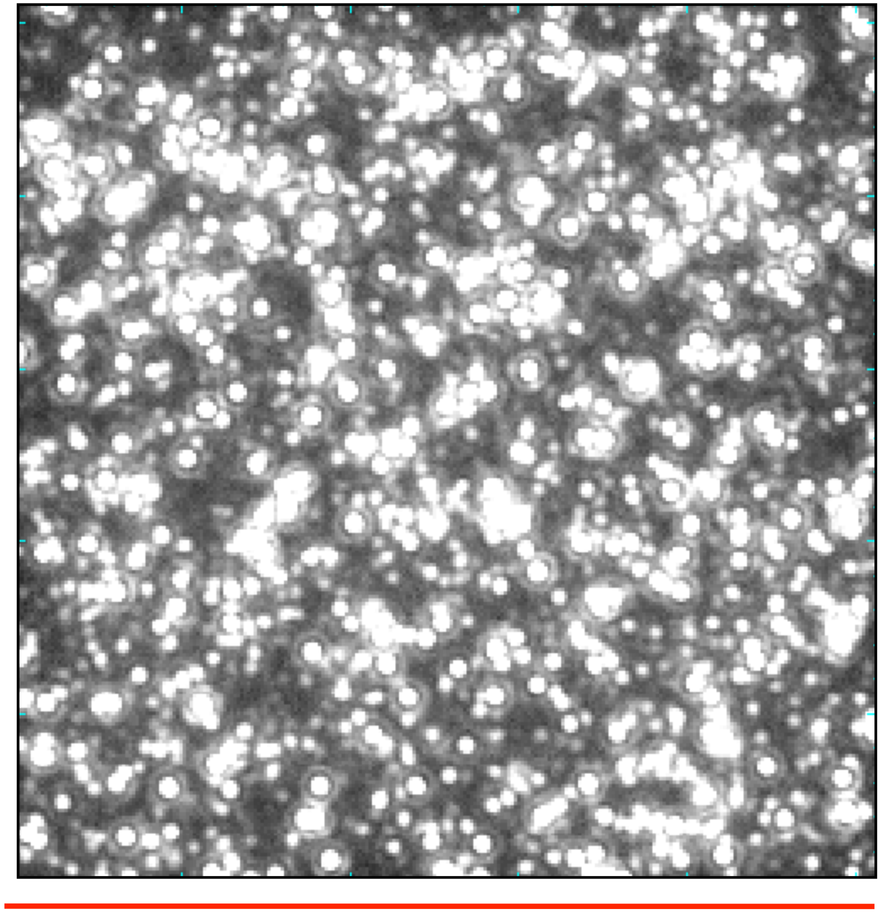
of stars in distant galaxies

(up to the Virgo cluster,

~ 17 Mpc)

-> History of galaxy





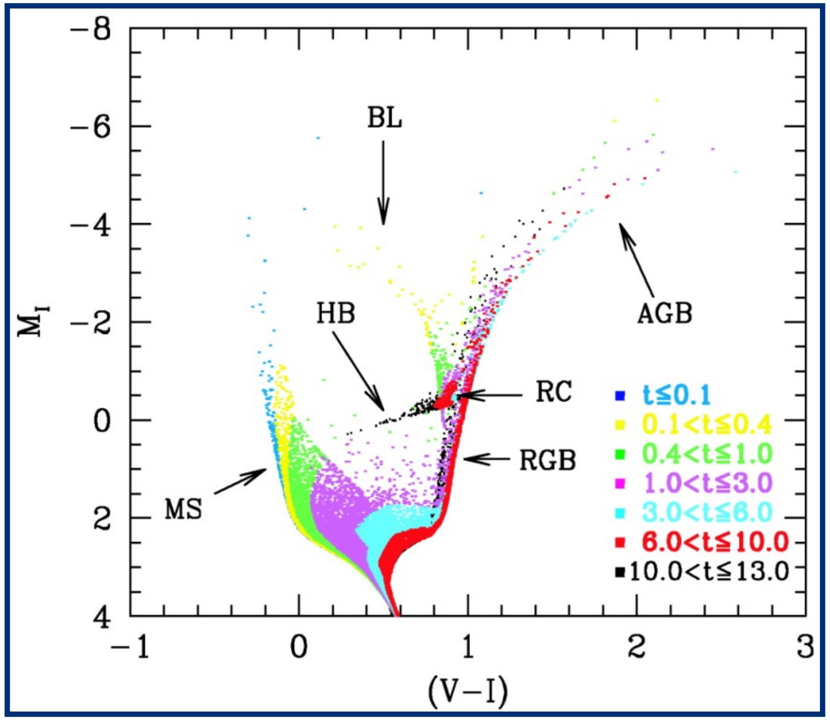
1 arcsecond

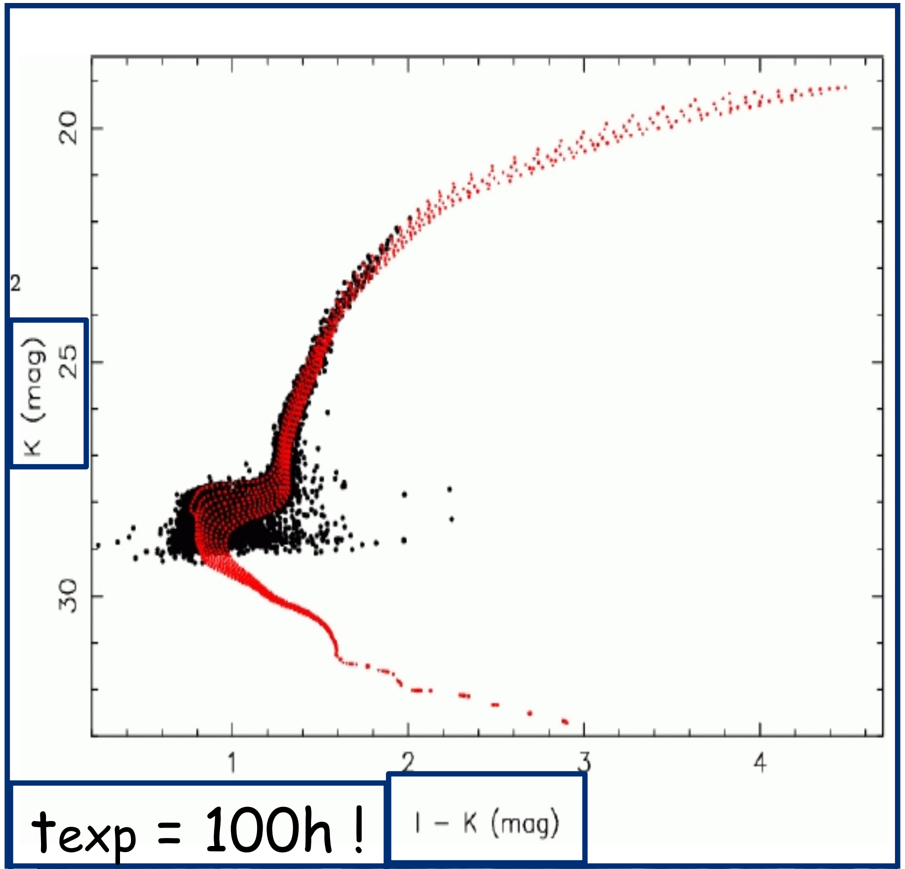
Simulations by J. Liske

Stellar populations

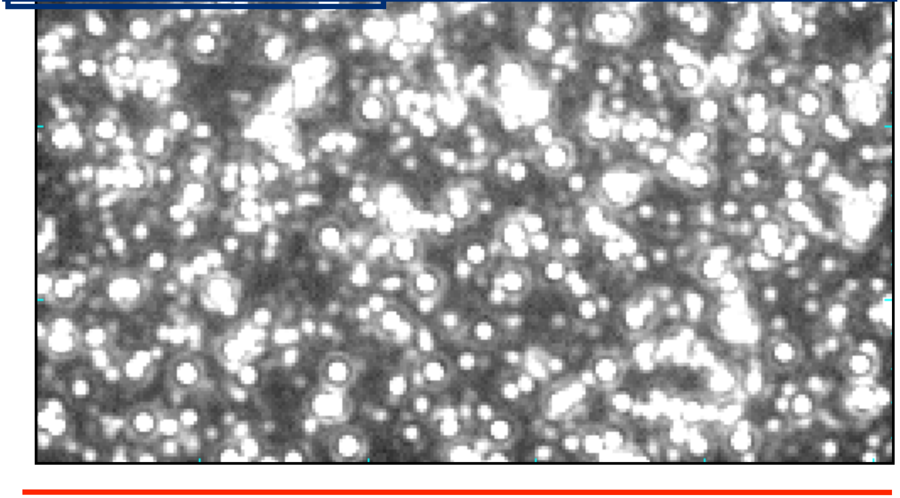
Chemical composition and age of stars in distant galaxies (up to the Virgo cluster, ~ 17 Mpc)

-> History of galaxy





texp = 100h !



1 arcsecond

Simulations by J. Liske

Photometry

✓**Cen A (4Mpc):** horizontal branch (HB) with an accuracy of 0.05 mag down to 0.3 effective radii (Re)

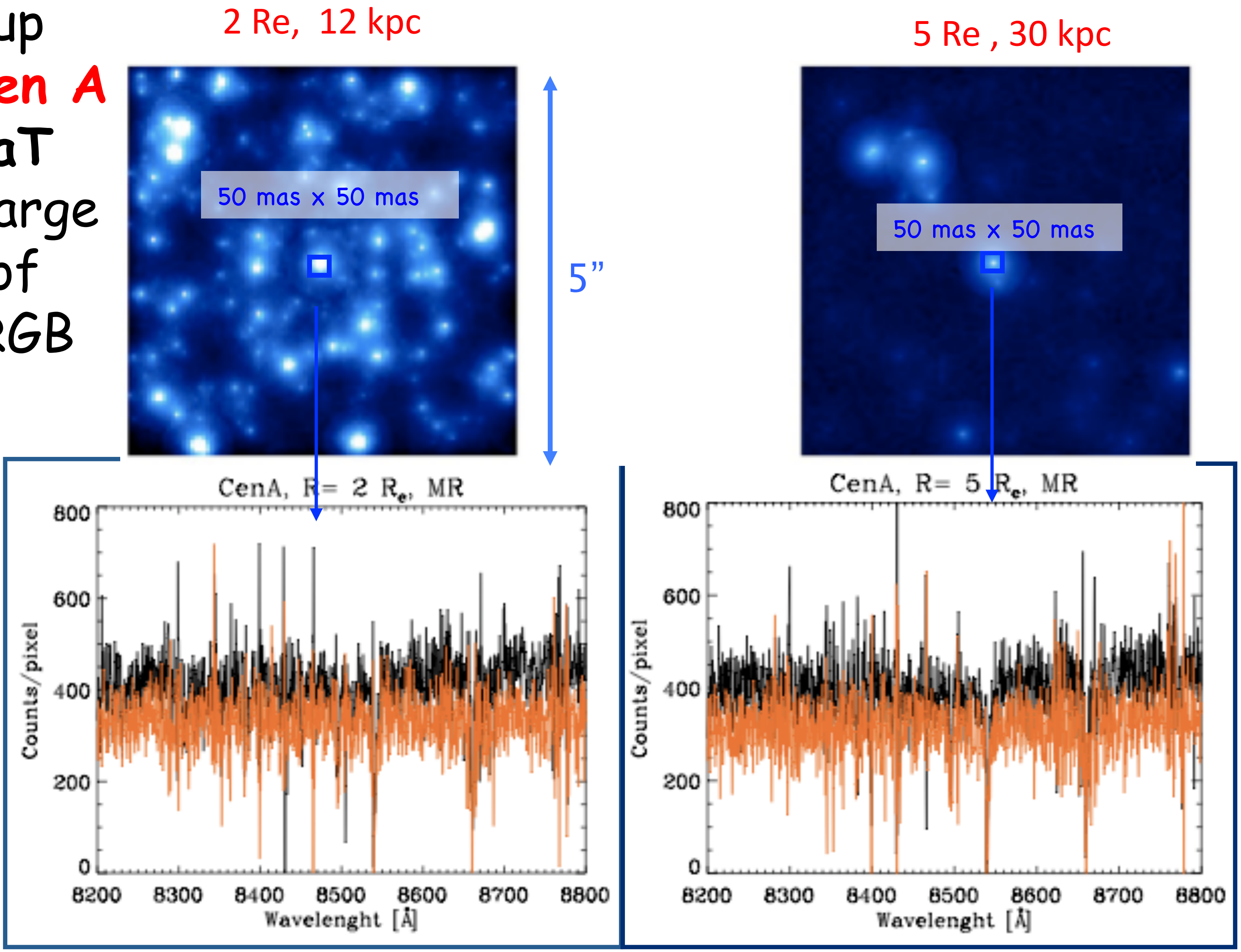
✓**M87 (Virgo):** tip of the red giant branch (RGB) with 0.05 mag accuracy down to 0.5 Re

Medium-resolution spectroscopy of red-giants

Local Group dwarf and **Cen A (4Mpc)**: **CaT** surveys of large numbers of individual RGB stars

Simulations by G. Battaglia

M87 (Virgo): borderline (crowding in the inner regions, and low S/N)



Targets: MR RGB at tip (black) and 0.5 mag below tip (orange) (**I = 24.4 mag**)

Assumes LTAO, 5h exposure time, Paranal-like, Ag/Al coating

Black holes

E-ELT will allow us to test the Theory of General Relativity measuring **positions (50/100 μas) and velocities (1 km/s) of stars orbiting the MW central black hole up to 0.01 pc (~ 100 Rs) where v ~ 0.1c**

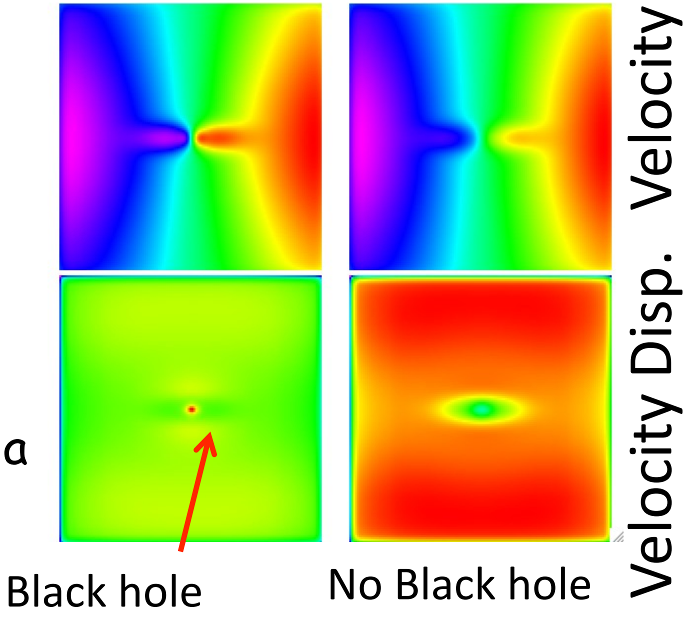
10^9M BHs up to 100Mpc

10^6M BHs up to Virgo distance

Only a few black holes have accurate mass measurements

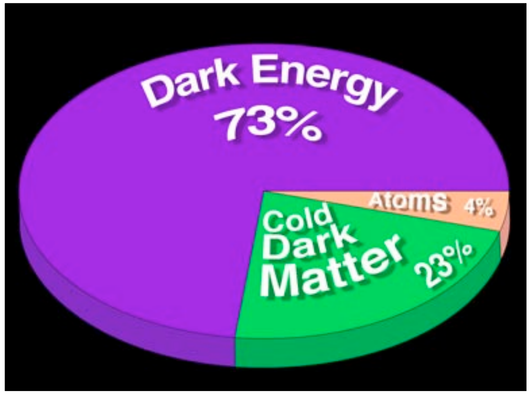
- How common are they?
- Why do their masses relate to that of the host galaxy bulges?

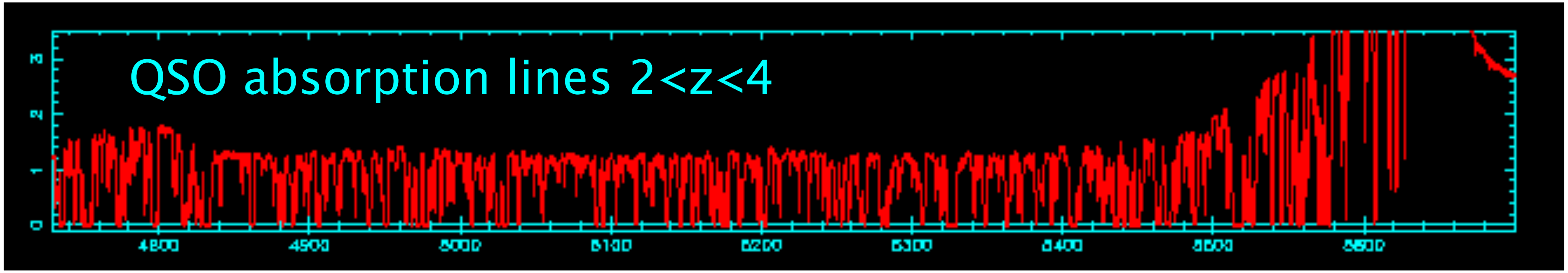
Simulations of gas rotating around a black hole (A. Küpcü Yoldaş)



Watching the Universe accelerate in real time

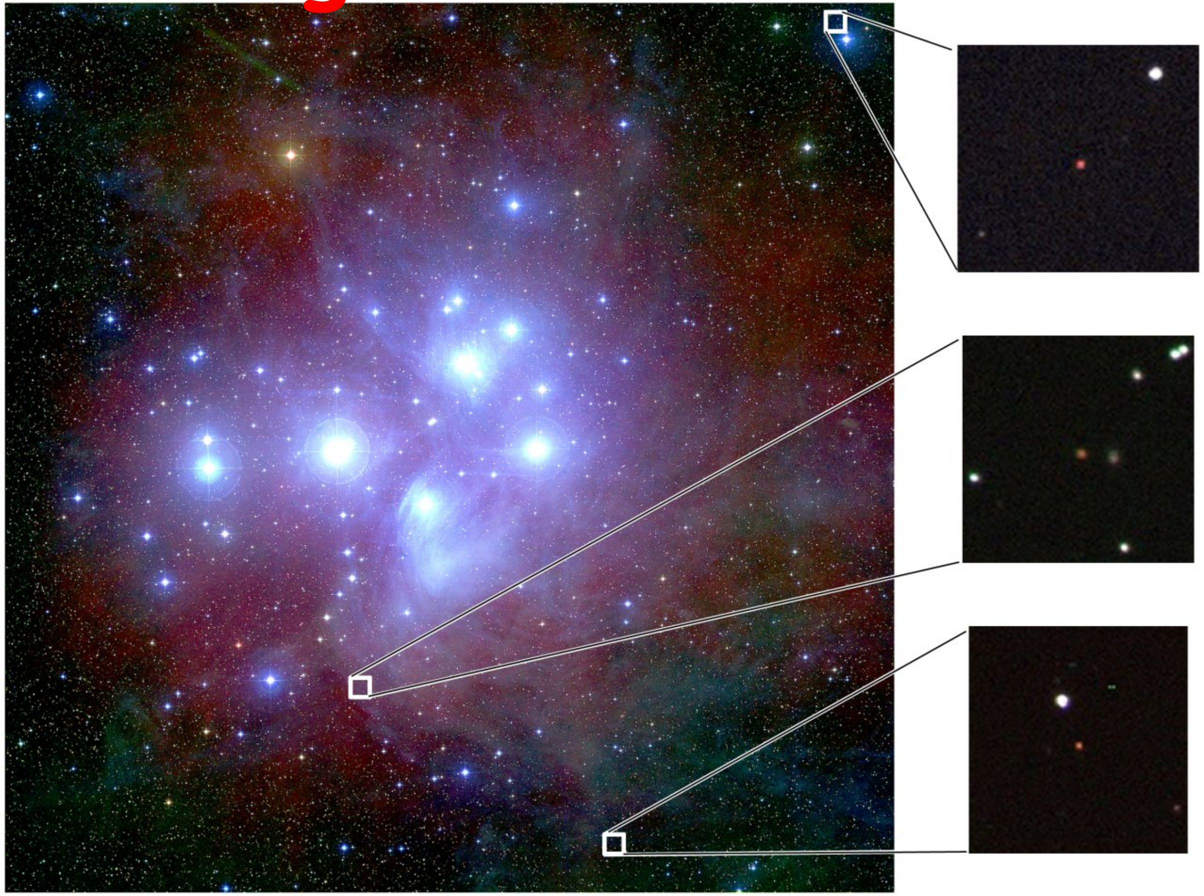
- What is the Dark Energy?
- **E-ELT will measure the acceleration directly, in real time**
- **Weak signal: ~ 1 cm/s/yr.** Requires:
- E-ELT (collecting area)
- **20 year monitoring** campaign
- **Ultra-high stability, high-resolution spectrograph** (e.g. CODEX)



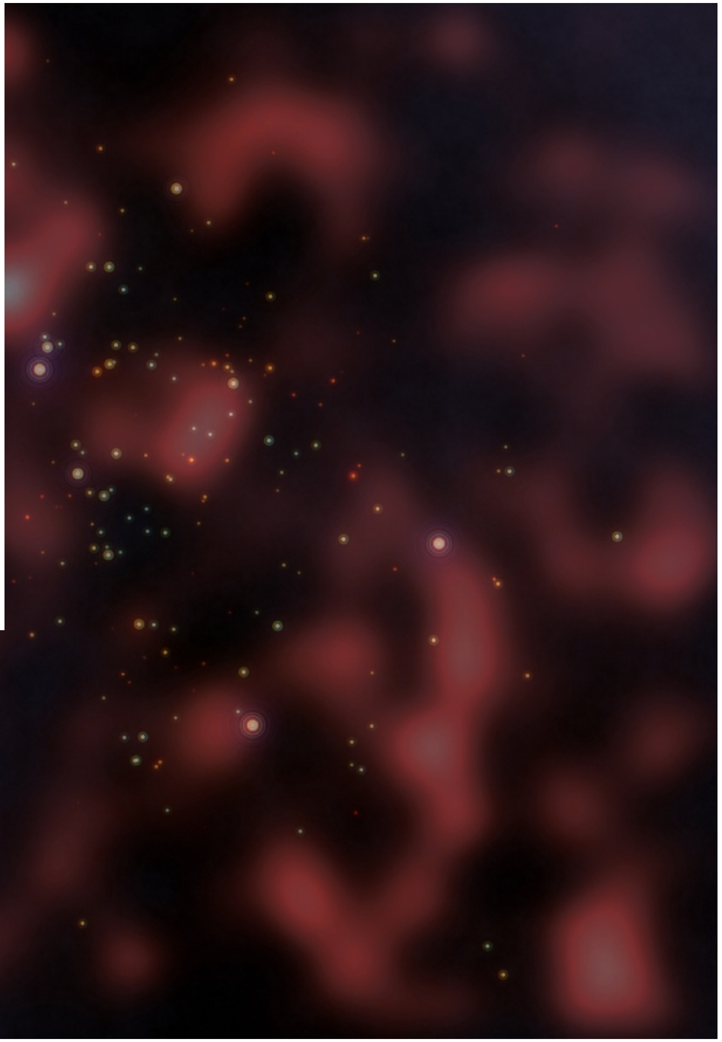


Young stellar clusters

A. Calamida & F. Comeron

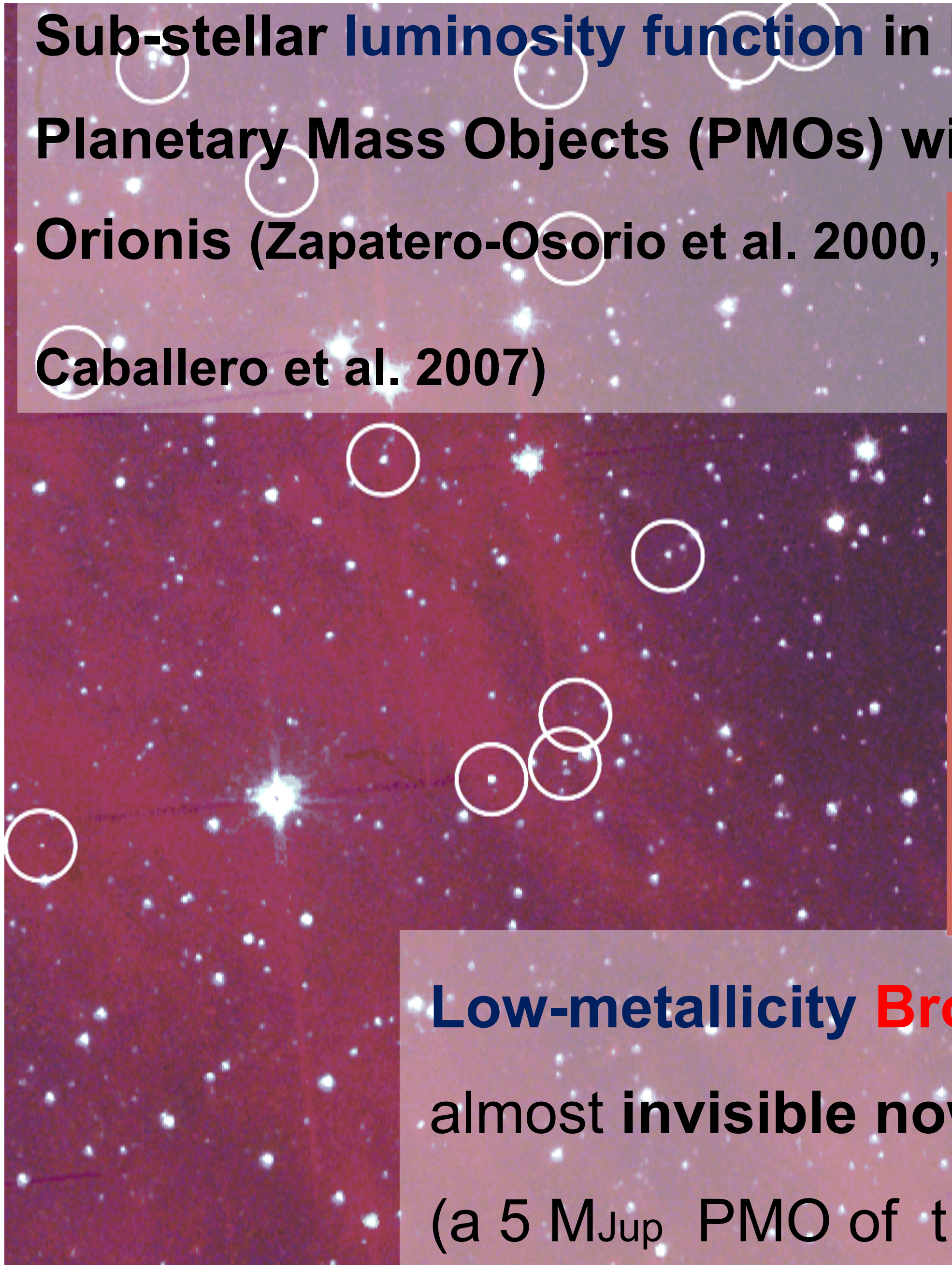


Giant planets or brown dwarfs?



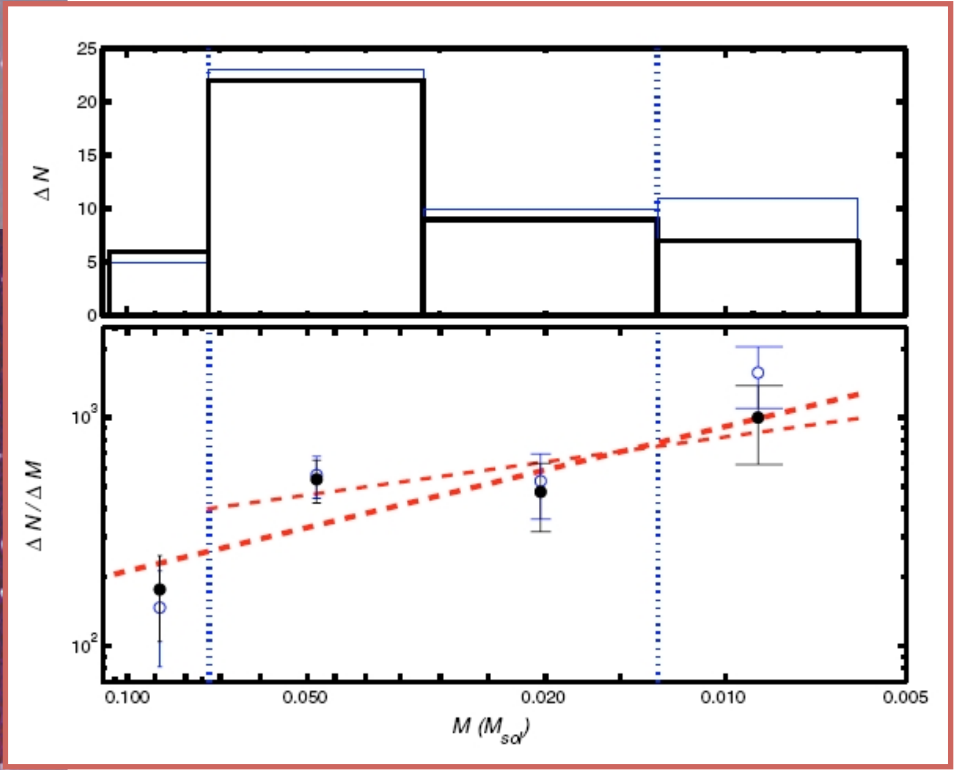
- How did brown dwarfs (BDs) form?
- Which are their characteristics?

Star forming regions in LMC



Sub-stellar luminosity function in MW (~ solar-metallicity):

Planetary Mass Objects (PMOs) with $M \lesssim 13\ M_{Jup}$ detected in σ Orionis (Zapatero-Osorio et al. 2000, Caballero et al. 2007)



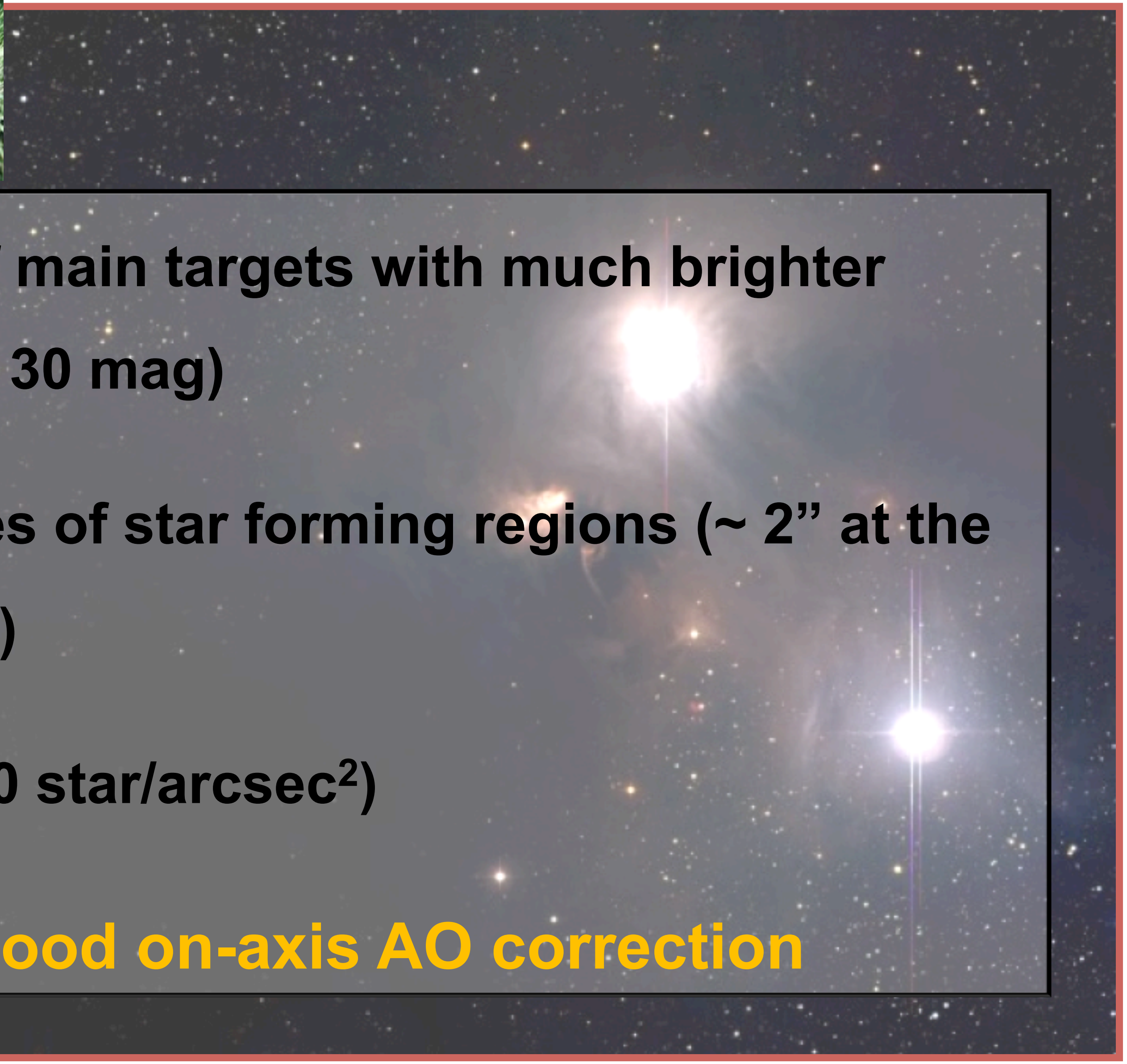
Low-metallicity Brown Dwarfs (BDs) and PMOs are almost **invisible now in MW but accessible in LMC**

(a 5 M_{Jup} PMO of t = 1 Myr → K ~ 28 mag)

Measurement goals

- Evolution of low-mass cut-off of IMF with metallicity
- What do low-mass, low metallicity BDs look like?
- How does the opacity limit depends on metallicity?

Challenges



- coexistence of main targets with much brighter stars (18 < K ≤ 30 mag)

- very small sizes of star forming regions (~ 2” at the distance of LMC)

- crowding (~ 20 star/arcsec^2)

Need good on-axis AO correction

Images

LTAO simulated PSFs (DRM technical database):

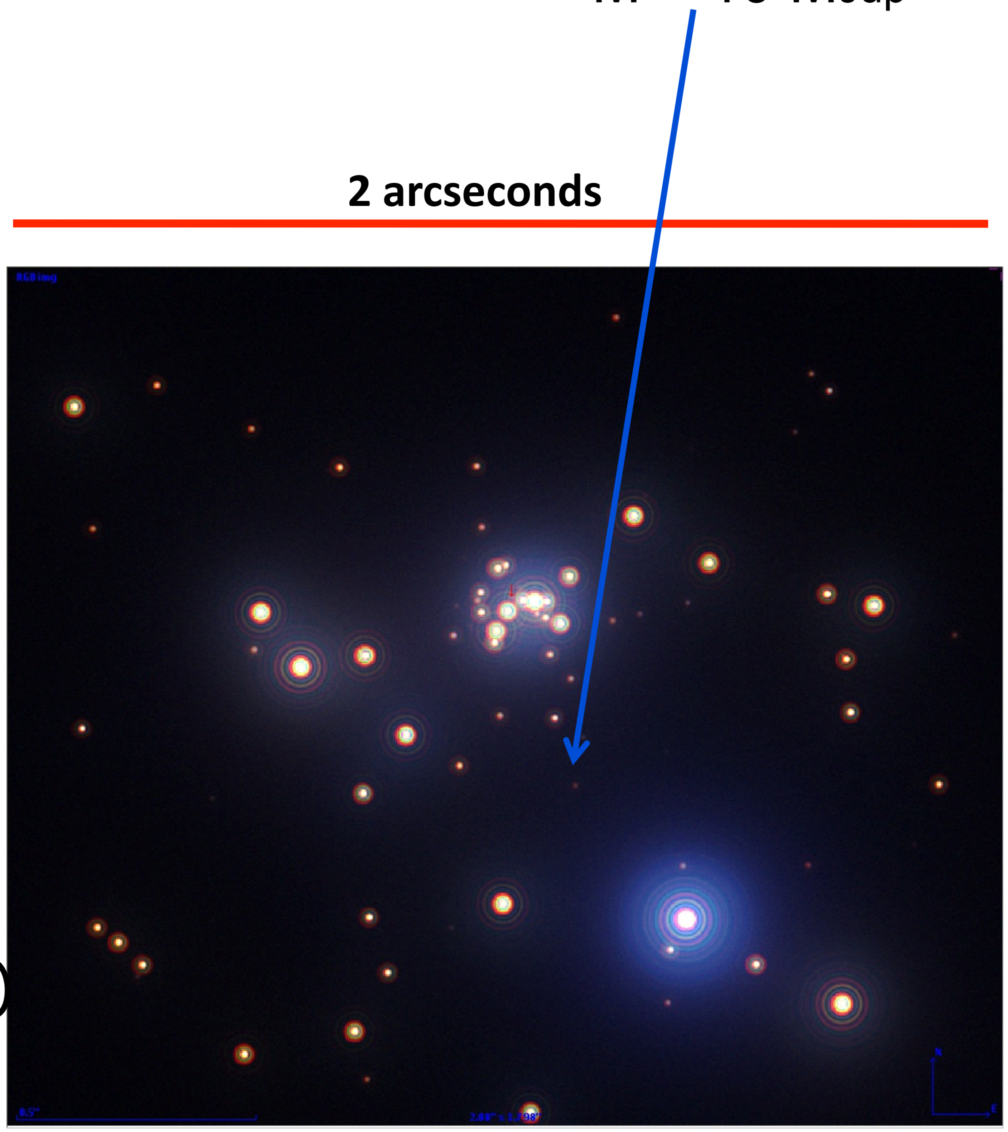
D = 42m, 6 LGS, seeing = 0.8″ at 0.5 μm, zd = 0 , 30, 60

K, H, J-band

t_{exp} (tot) = 60 h

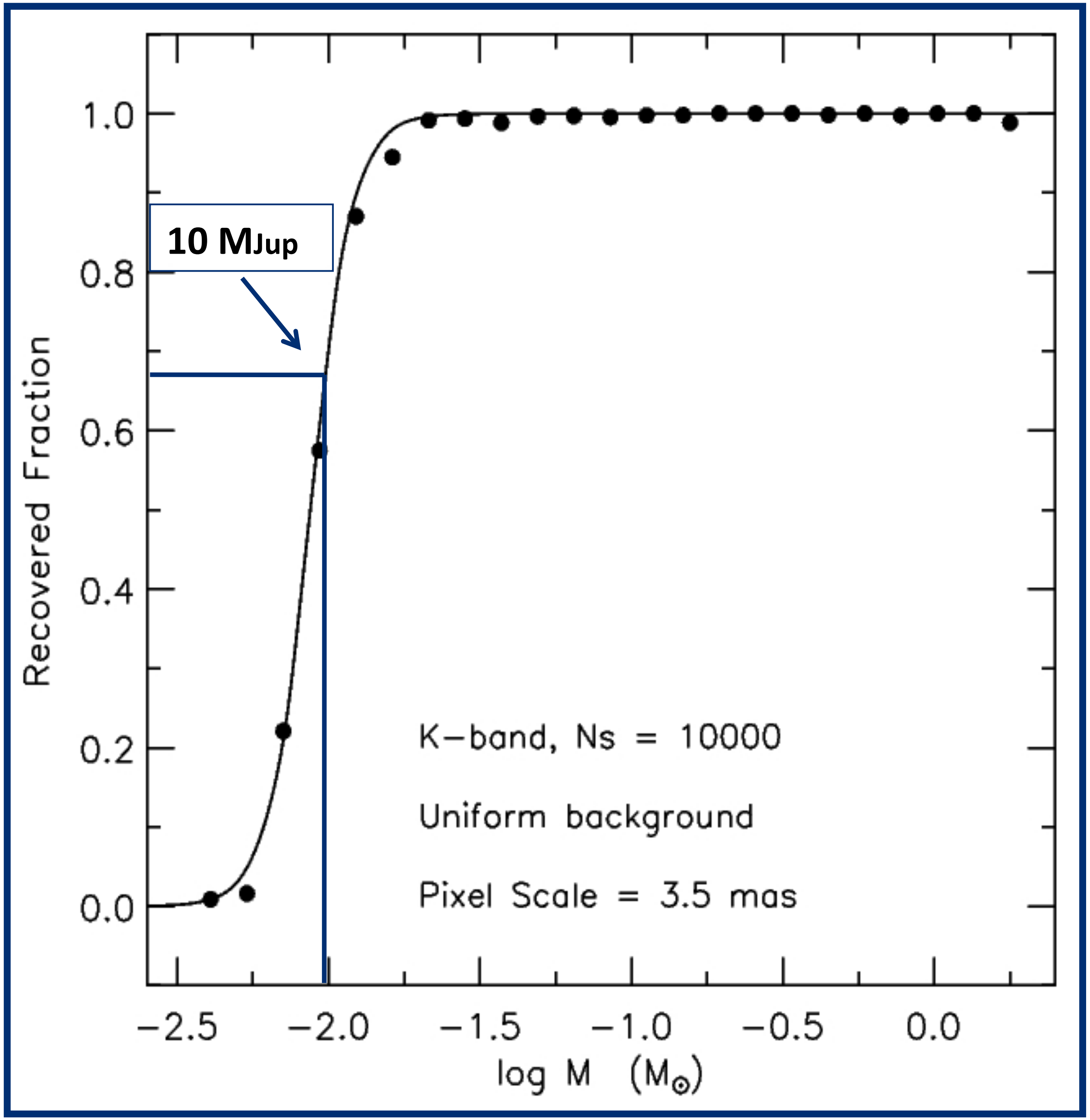
Sky = 13 (K), 14 (H), 16 (J) mag/ arcsec^2

Pixel scale = 3.5 (K), 2.6 (H), 2 (J) mas



Completeness

E-ELT will allow us to observe giant-planet-mass objects with **M<10 MJup** in young star clusters at d ~ **50 Kpc**



We reach J, K ~ 29-28.5 mag (~17-24 M_{Jup}, 90% completeness) and 29.5 mag (~ 9-16 M_{Jup}, 50% completeness) with 5 ≤ S/N ≤ 10 in T_{tot} = 60h+overheads

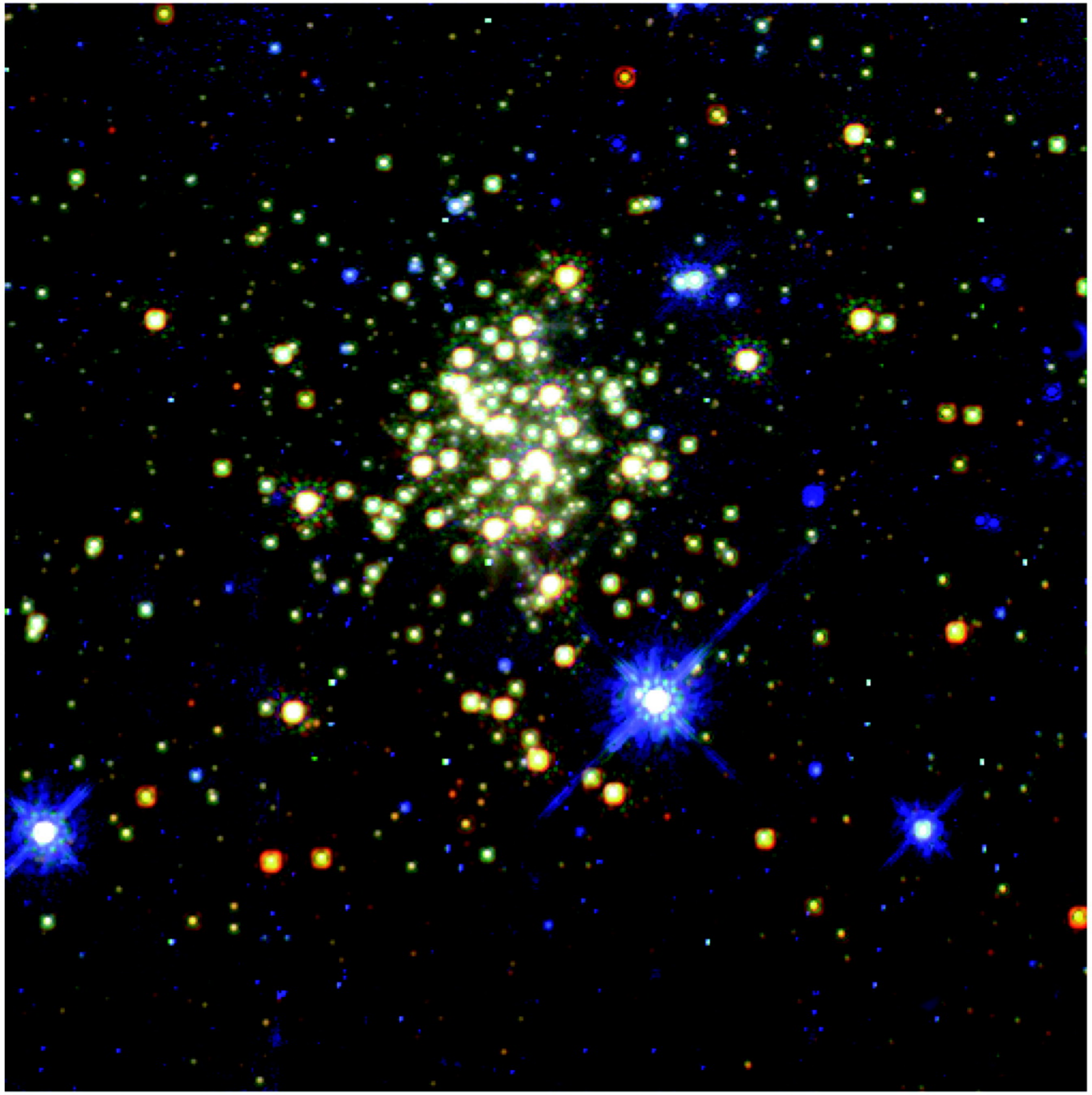
With E-ELT we will observe:

- Nearly complete sample of young BDs above the deuterium-burning limit (M~13 M_{Jup}) in LMC and possibly in other stellar systems (up to d~50 Kpc)
- PMOs (M ≤ 10 M_{Jup}) in the LMC in favorable conditions

See Calamida et al. (2011), arXiv1109.6235 (Magellanic Clouds Newsletter # 113)

The centres of dense young clusters

A. Calamida & H. Zinneker



✓ What did these clusters look like when they were still deeply **embedded in their proto-cluster parent cloud?**

Challenges

- We need to penetrate **100-200 mag** ($N_{H2} = 3 \cdot 10^{23}$ cm^{-2}) of **visual extinction!!!**

K-band: $A_K = 0.11 \cdot A_V$

Even better: $A_L = 0.06 \cdot A_V$ & $A_M = 0.02 \cdot A_V$

- We need to resolve **crowded fields** (compact clusters)

=> diffraction limit in K-band is 10 mas for D = 42 m

Some measurement goals

- ✓ **number density of massive stars** to investigate if collisions are likely

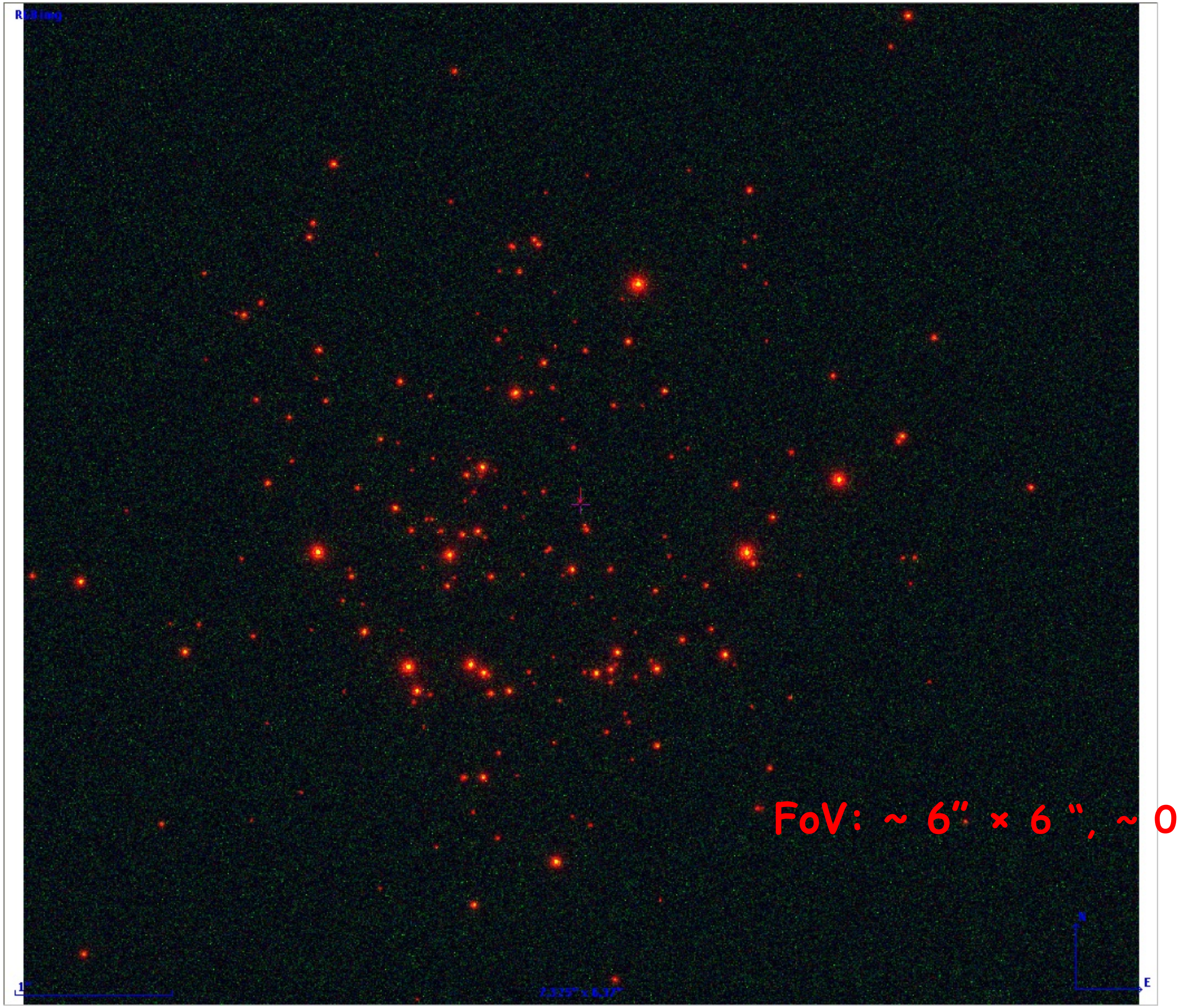
- ✓ **mass segregation: high mass stars in centre.** Is this the case from the very beginning?

Simulations

1) **Uniform reddening** distribution: **A_V = 50, 100, 150, 200 mag**
2) **Gaussian reddening** distribution: peak of **A_V = 150 mag**, and FWHM = 6″
3) **Clumpy reddening** distribution: **clumps with scale of 0.25″** and peaks of 50 A_V on top of a uniform extinction of 50 or **150 A_V**

- K, L, M-band **LTAO PSFs**
- Pixel scales: **3.5 mas (K), 5.6 mas (L), 7.7 mas (M)**
- **Sky brightness** (mag/arcsec^2): 13 (K), 5.3 (L) and 1.3 (M)
- **FoV = ~ 6″ × 6″** (0.2pc × 0.2pc at distances ~ 7 Kpc)

Uniform reddening distribution: Av = 200 mag



Faintest star:

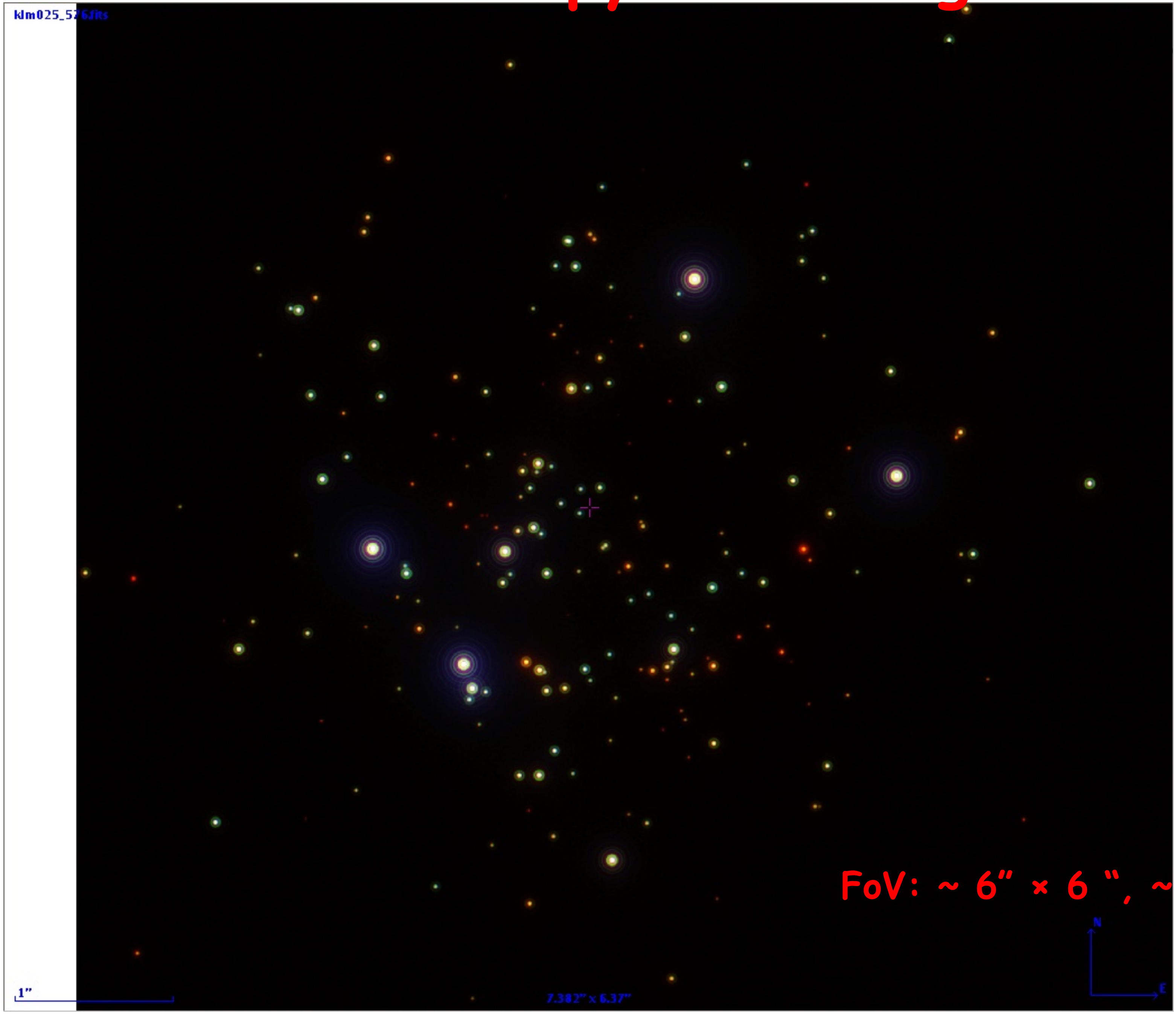
K ~ 38 mag

L ~ 27 mag

M ~ 18 mag

FoV: ~ 6" × 6 ", ~ 0.2pc at ~ 7 kpc

Clumpy reddening



- Faintest star:

  K ~ 38 mag

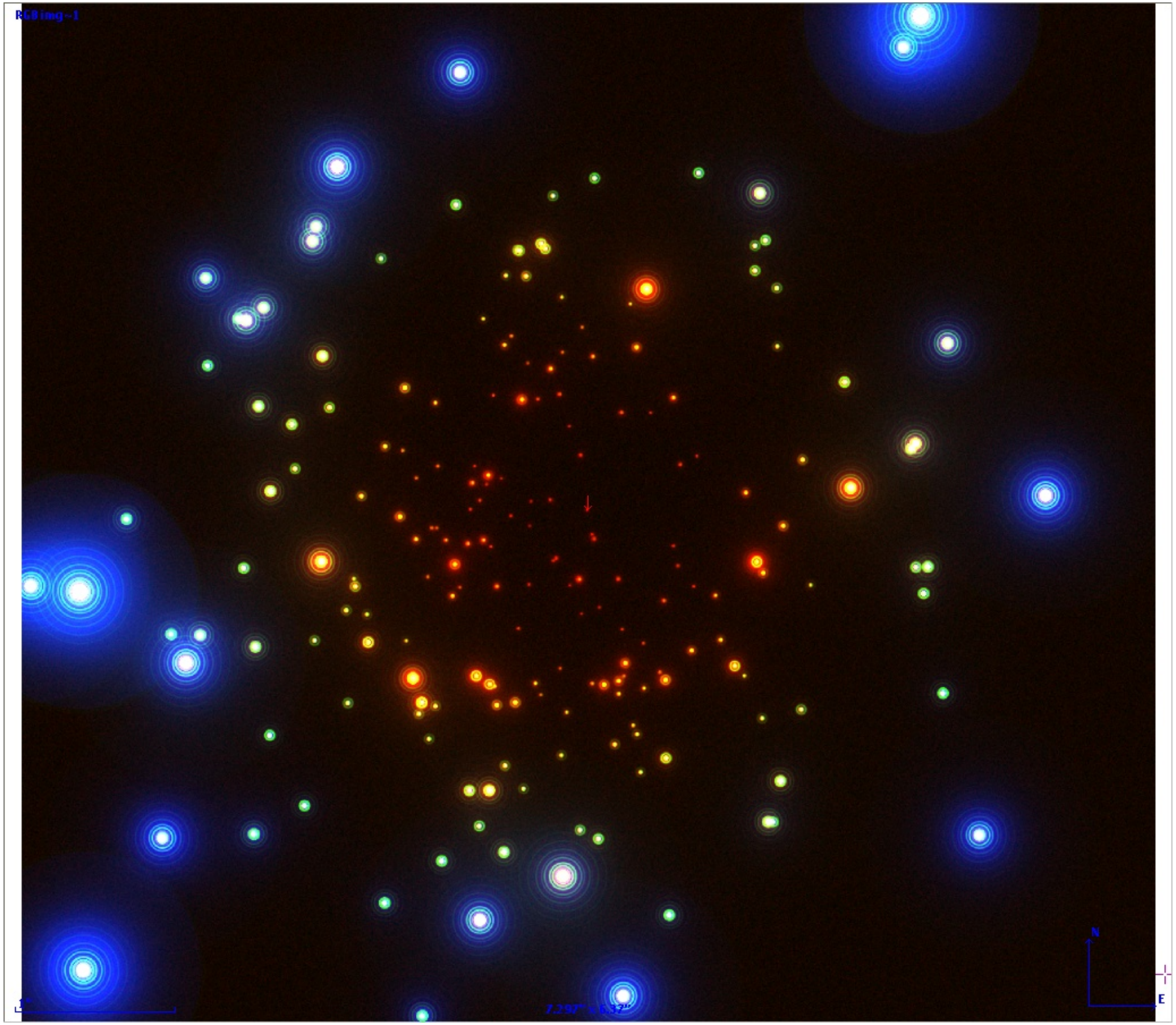
  L ~ 27 mag

  M ~ 18 mag

576 clumps of 50 Av on a top of 150 Av uniform reddening distribution

FoV: ~ 6" × 6 ", ~ 0.2pc at ~ 7 kpc

Gaussian reddening distribution

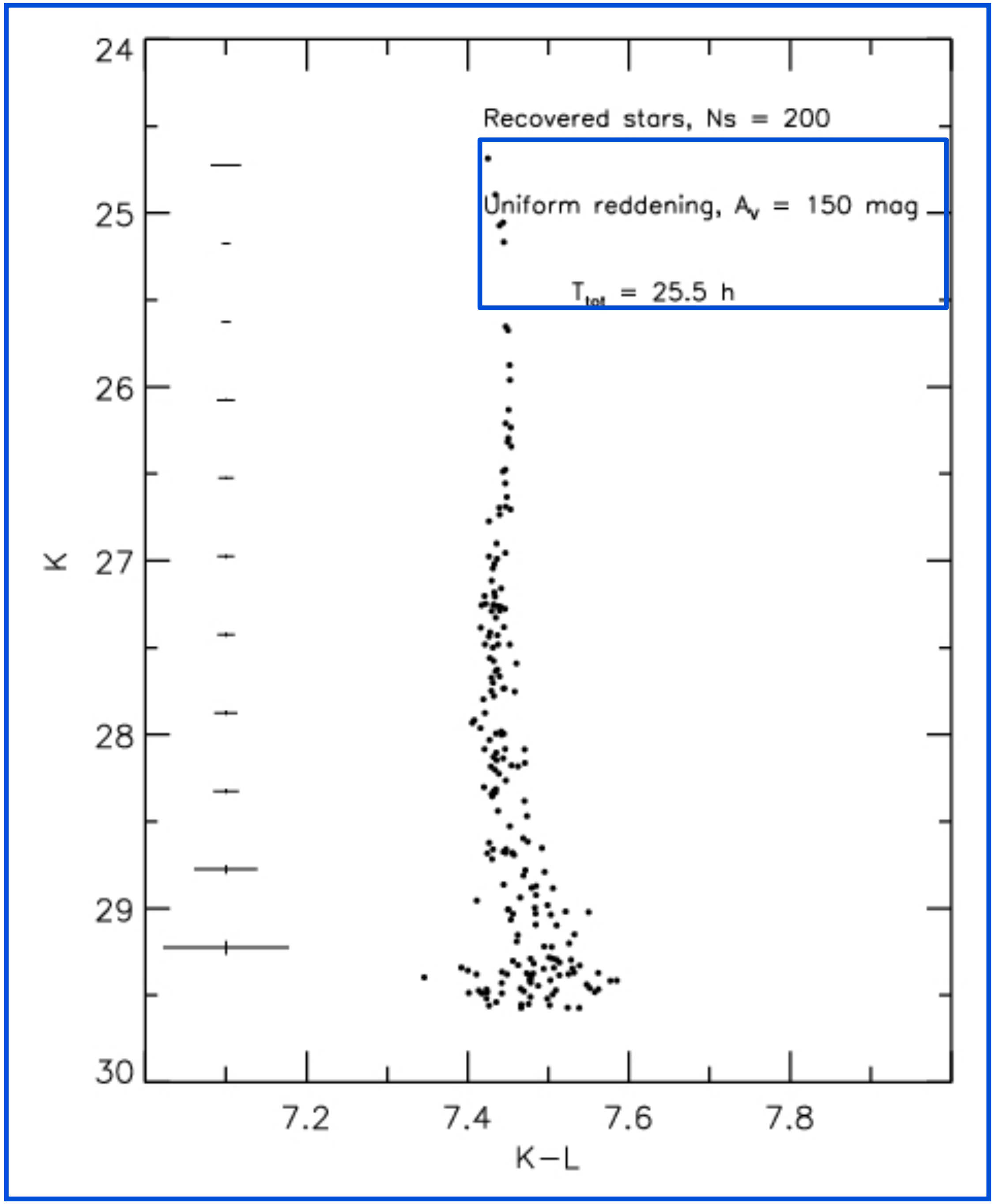


Faintest star:
K ~ 29 mag
L ~ 22 mag
M ~ 16 mag

Peak = 150 Av

FWHM = 6"

Color-Magnitude Diagrams



K (25h) ~ **29.5** mag with

S/N ~ 7

L (0.5h) ~ **22** mag with

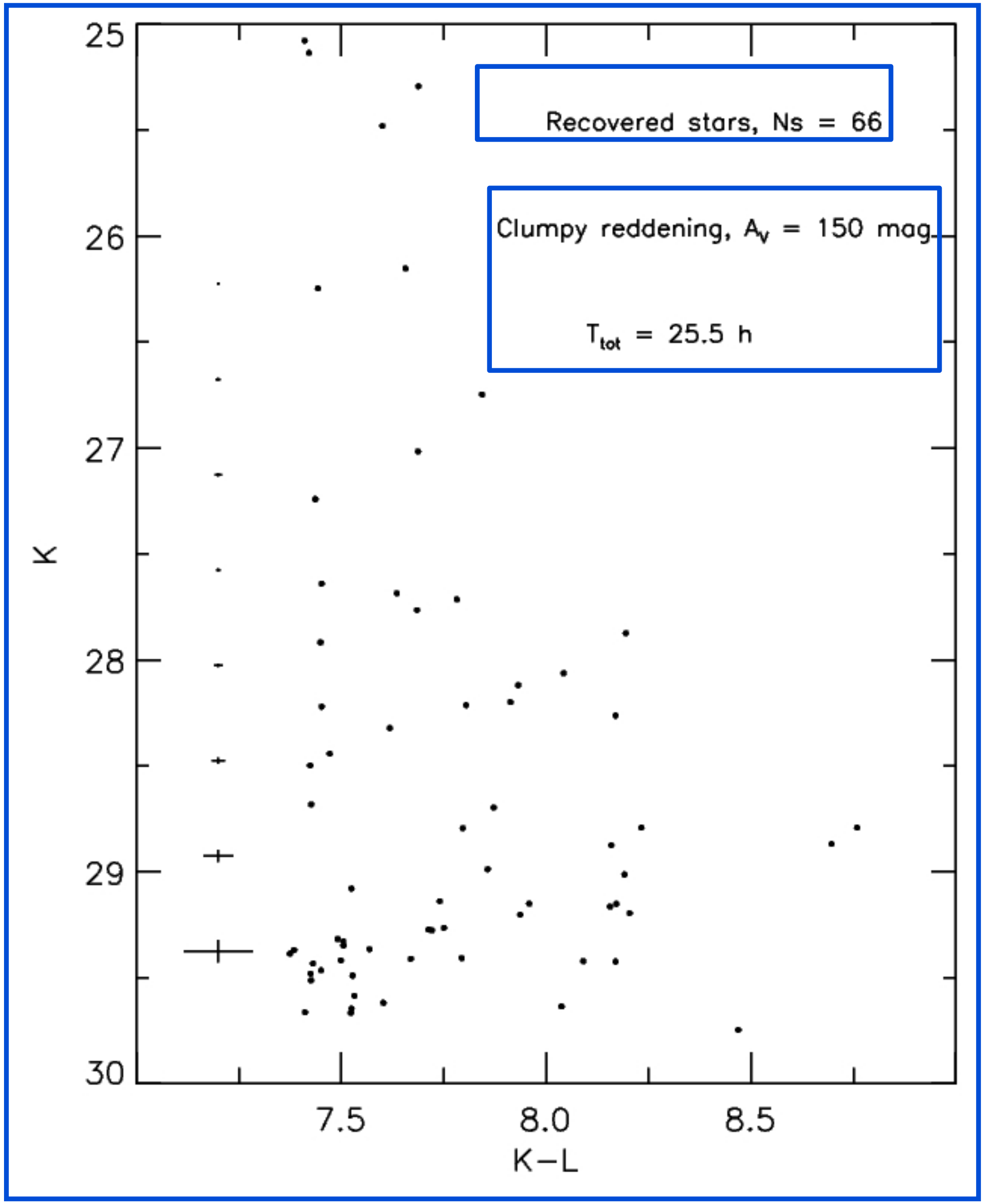
S/N ~ 10

M (80s) ~ **16** mag with

S/N ~ 50

We recover 100% of stars in all bands

Color-Magnitude Diagrams

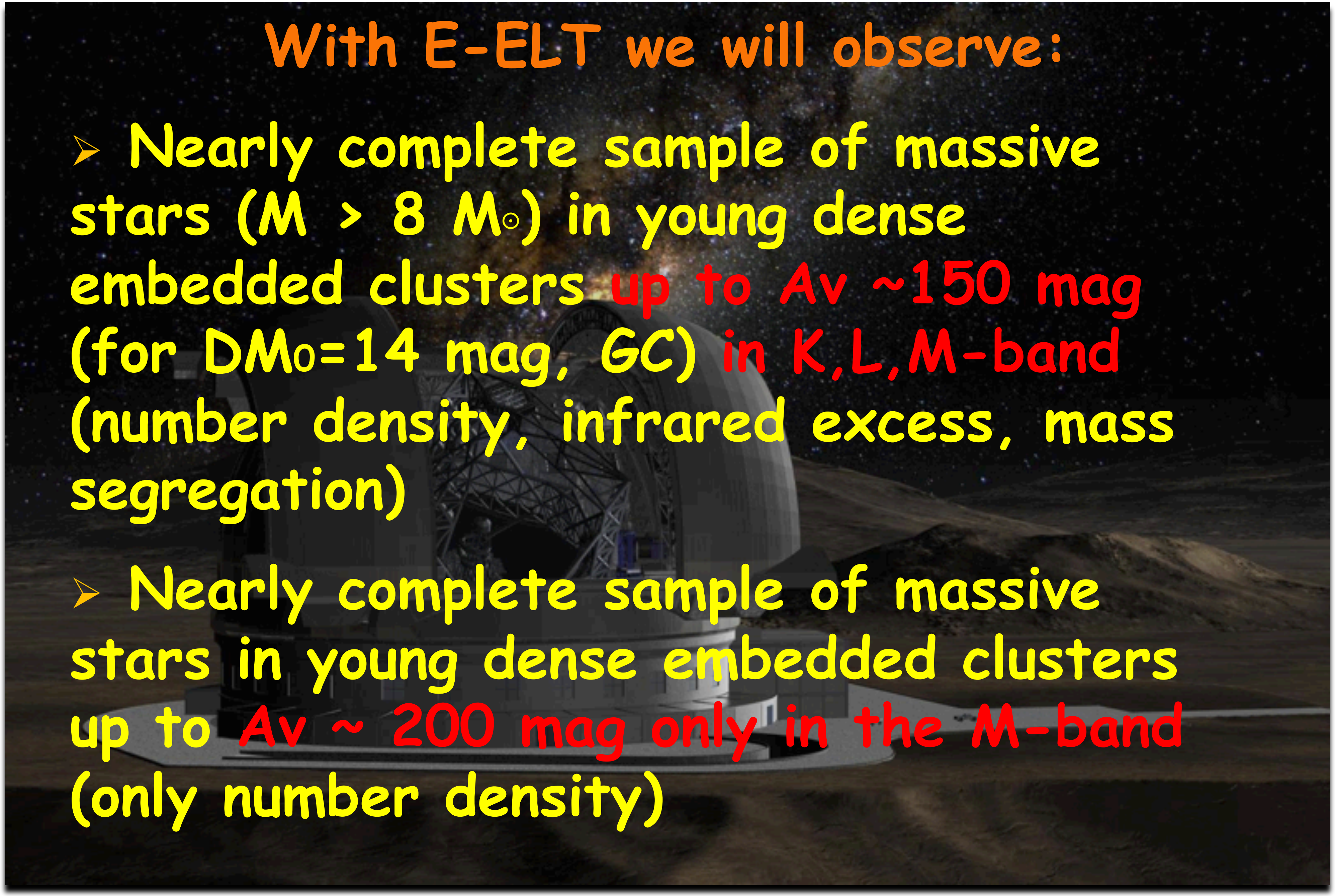


K (25h) ~ 29.5 mag with S/N ~ 5

L (1.1h) ~ 22.5 mag with S/N ~ 5

M (175s) ~ 17 mag with S/N ≳ 10

We recover 33% of stars in K, 63% in L, 100% in M



With E-ELT we will observe:

- Nearly complete sample of massive stars ($M > 8\ M_\odot$) in young dense embedded clusters up to $A_v \sim 150$ mag (for $DM_0 = 14$ mag, GC) in K,L,M-band (number density, infrared excess, mass segregation)
- Nearly complete sample of massive stars in young dense embedded clusters up to $A_v \sim 200$ mag only in the M-band (only number density)

What happened the last 2 years?

- Phase B completed in Sep 2010
  - Passed an external review (report available online)
- **Delta Phase B completed in June 2011**
  - Goal: reduce risk to ESO program overall
- Sep 2011: Cost review -> approved
- **Construction could partially start (road, M4,..)**

Only option to reduce total cost substantially was:

- **Smaller M1** (**39.3 m**, outer 2 segment rings removed)
- Smaller instrument platforms (→ **smaller dome, smaller Armazones platform**)
- **Removal of gravity invariant focus** (→ simpler structure)
- **M2 < 4.2m**: more suppliers, simpler polishing (further reduction of telescope length and width)

Outlook

  - **Brazil** parliament must ratify the joining of ESO

- **June 2012: Construction proposal to ESO Council for final approval of the programme**

- **2021: First light**

  - Schedule driven by spending profile

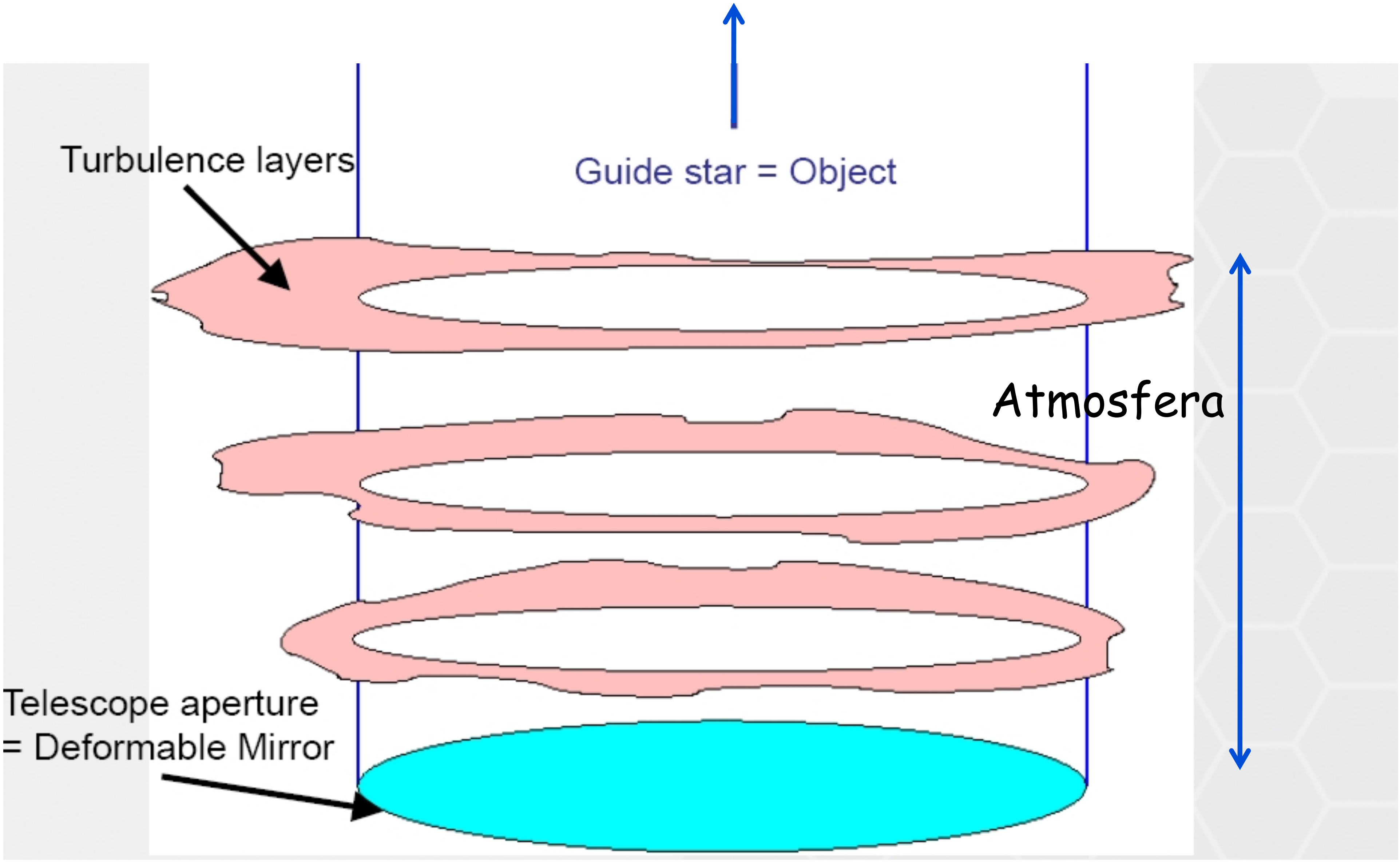
  - First science 6-9 months later

ESO
European Organisation
for Astronomical
Research in the
Southern Hemisphere

More information?

- Public web-page: http://www.eso.org/public/astronomy/projects/e-elt.html
- In Italiano: http://www.eso.org/public/italy/index.html
- Science users web-page: http://www.eso.org/sci/facilities/eelt/
- Brochures, Posters, etc: http://www.eso.org/public/outreach/products/publ/brochures/index.html
- Gallery: http://www.eso.org/gallery/v/ESOPIA/EELT

L'oggetto osservato si trova molto vicino alla stella guida

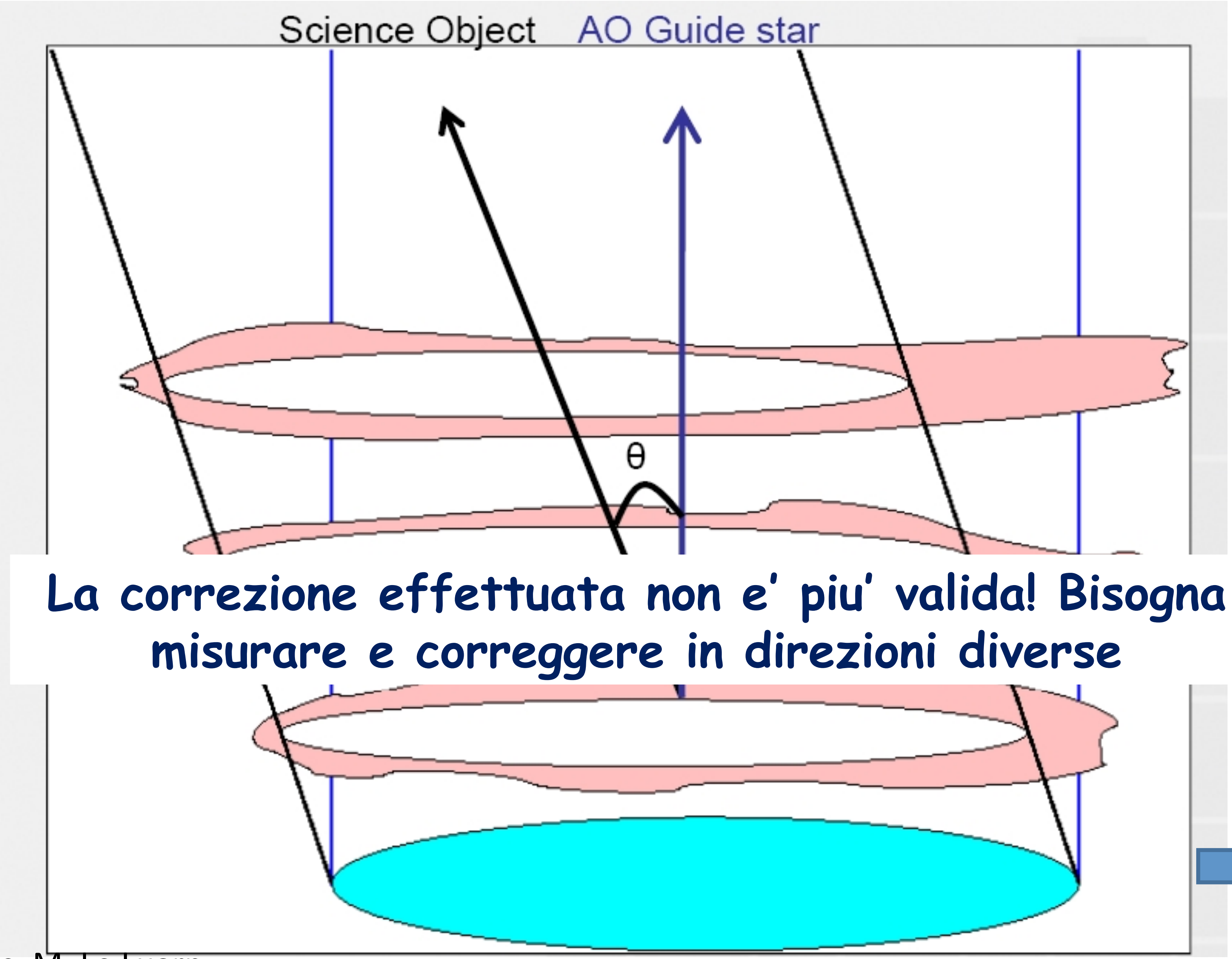


La correzione effettuata e' valida per l'oggetto osservato

Credits: M. Le Luarn

Single-conjugate adaptive optic (SCAO)

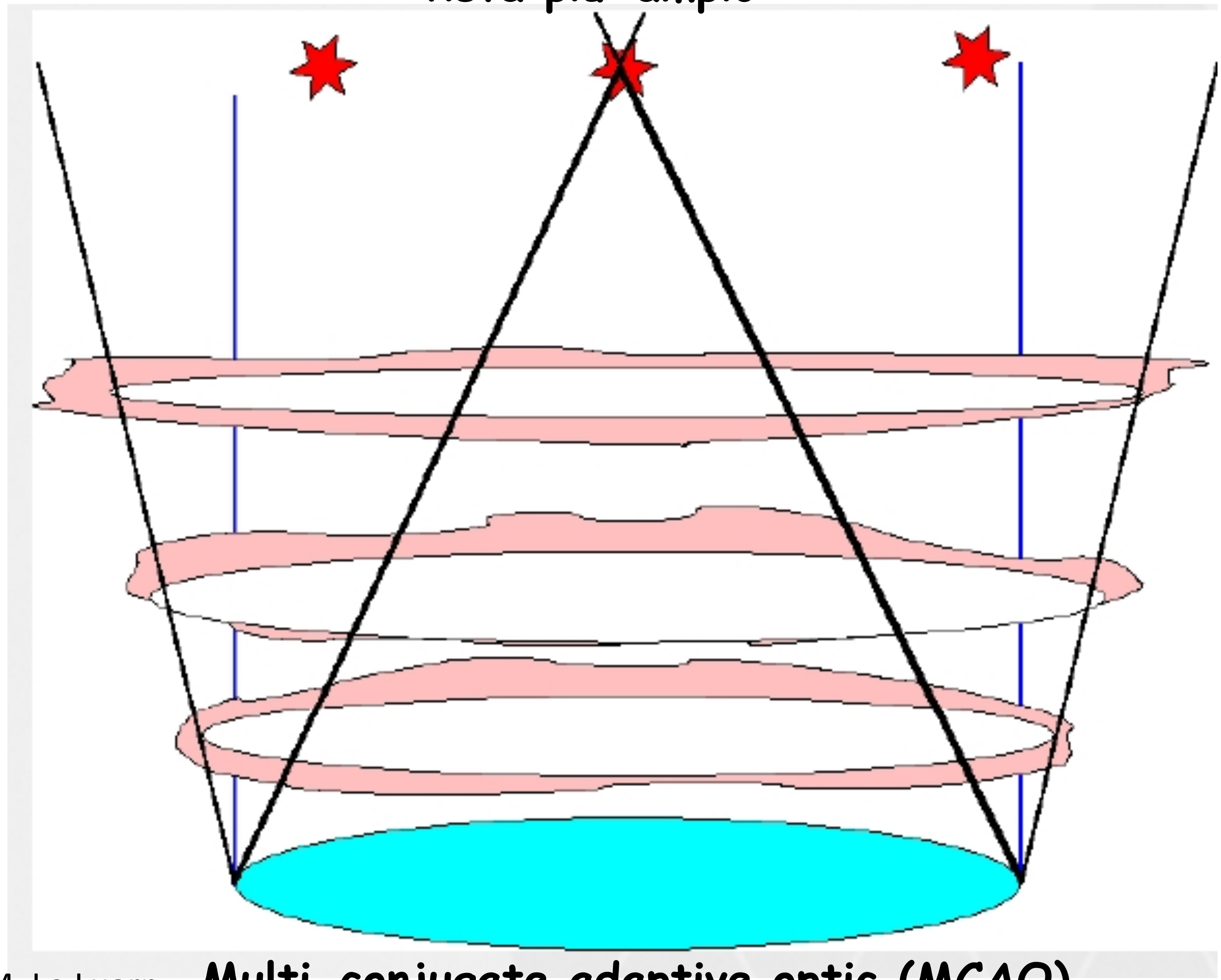
L’oggetto osservato si trova distante dalla stella guida



La correzione effettuata non e’ piu’ valida! Bisogna misurare e correggere in direzioni diverse

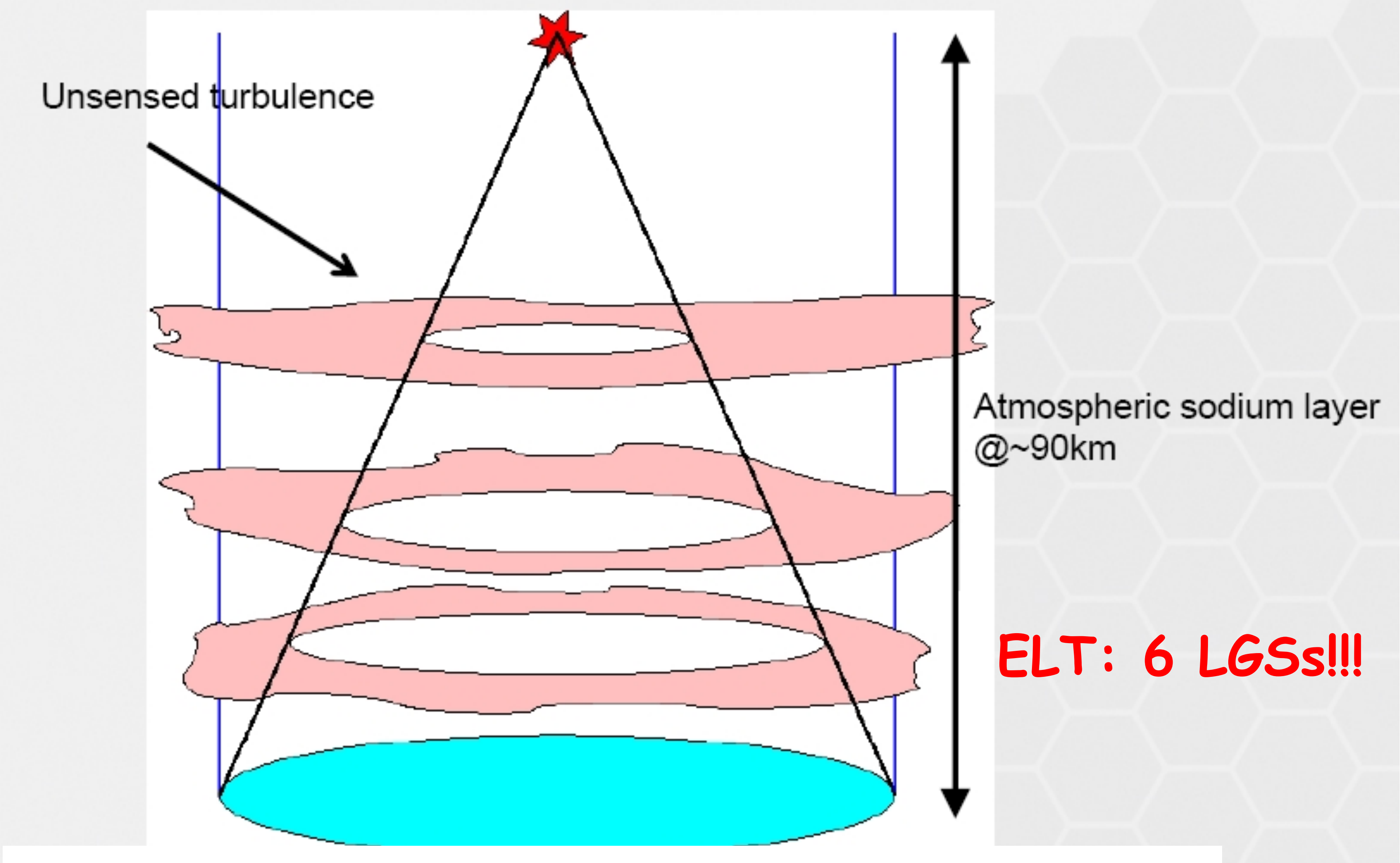
Credits: M. Le Luarn

Si osservano piu’ stelle guida per correggere in un campo di vista piu’ ampio



Credits: M. Le Luarn **Multi-conjugate adaptive optic (MCAO)**

Solo utilizzando delle stelle "laser" (laser guide stars, LGSs) e' possibile sfruttare al meglio la tecnica di MCAO



ELT: 6 LGSs!!!

Usando piu' LGSs si riesce a diminuire questo effetto

Credits: M. Le Luarn