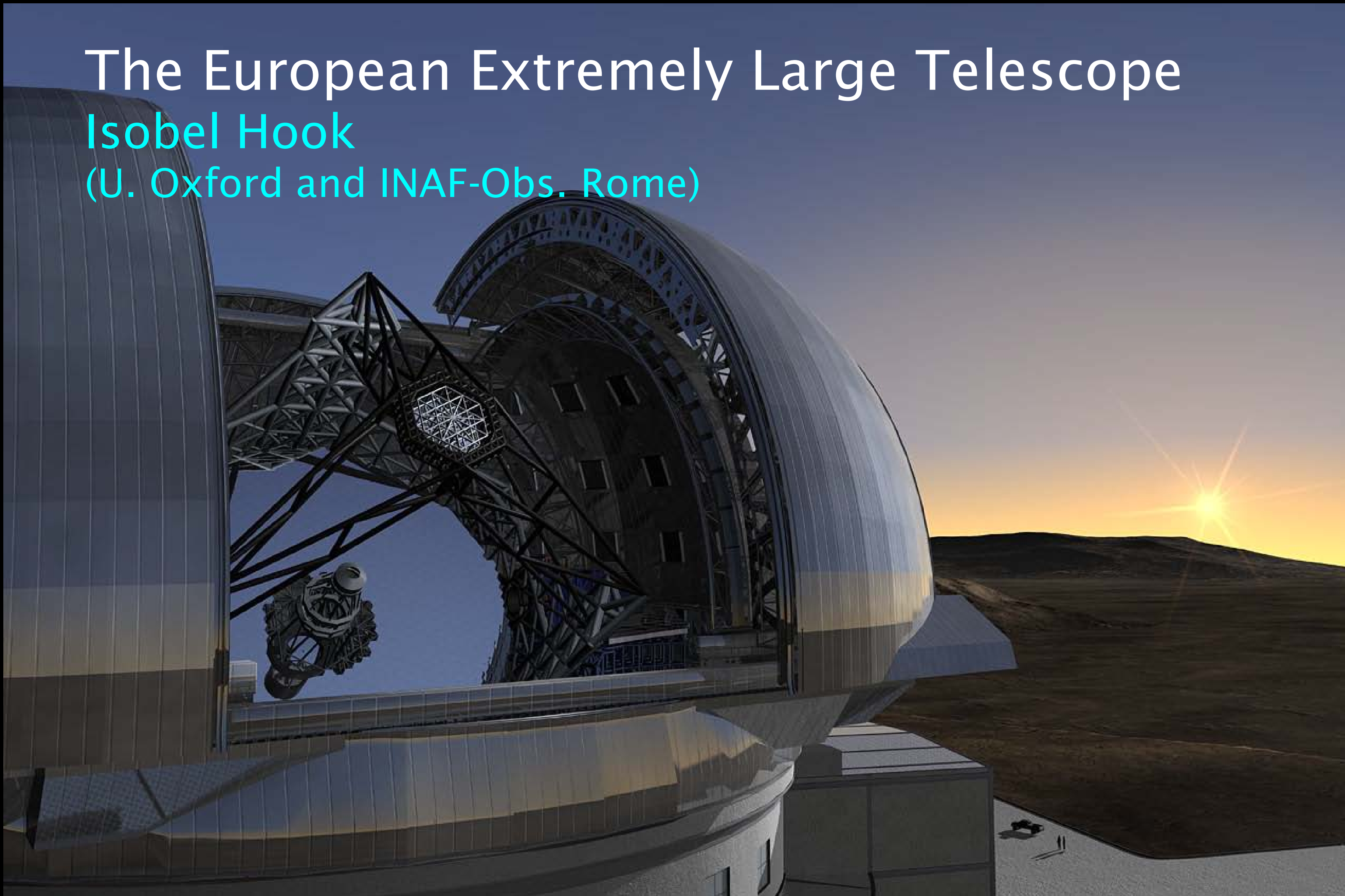
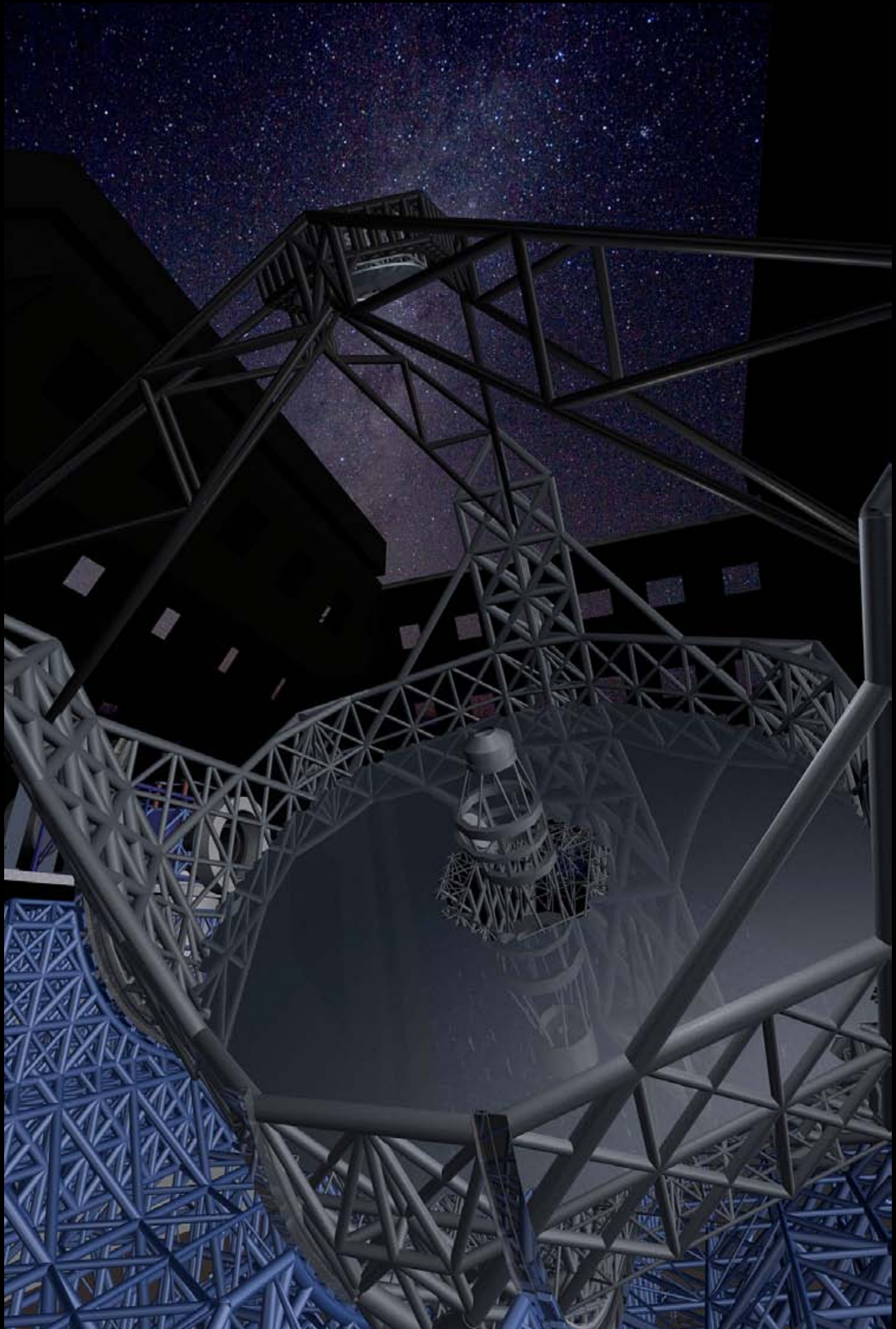
The European Extremely Large Telescope

Isobel Hook
(U. Oxford and INAF-Obs. Rome)



The European ELT

- A 42m diameter, adaptive telescope - the largest optical/IR telescope in the World
- Enables spectacular new science, complements other flagship facilities
- In detailed design phase with plan to start construction in 2011, and first light 7 years later
- Construction cost: ~ €1 billion
- A top priority of European ground-based astronomy



Other International ELT projects

TMT

30m telescope

U. California, Caltech, Canada (+Japan)

Construction proposal complete

First light ~ 2018

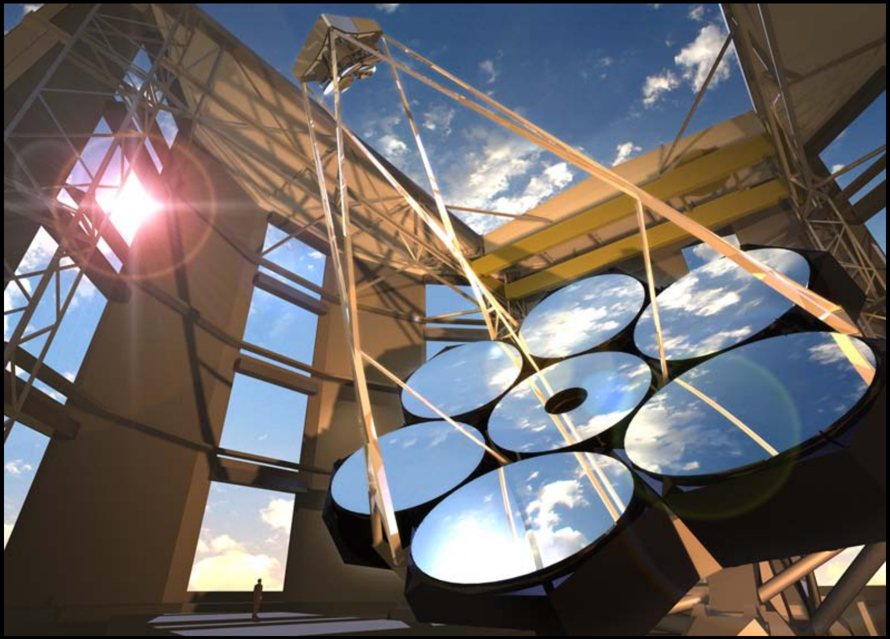
GMT

24m diameter (7x 8m segments)

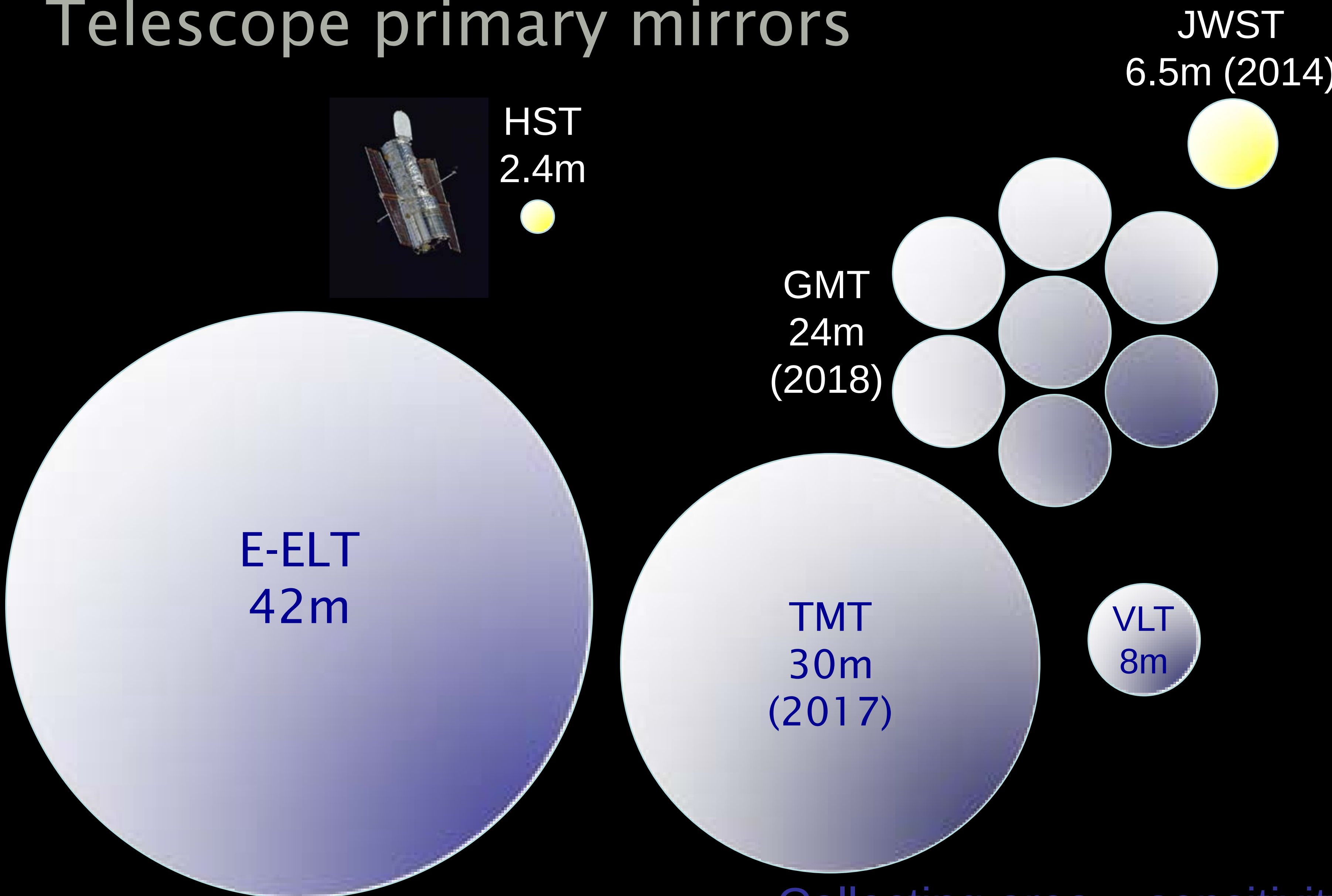
Collaboration of private US universities, Australia (ANU + AAL) + Korea

First mirror cast

First light ~ 2018



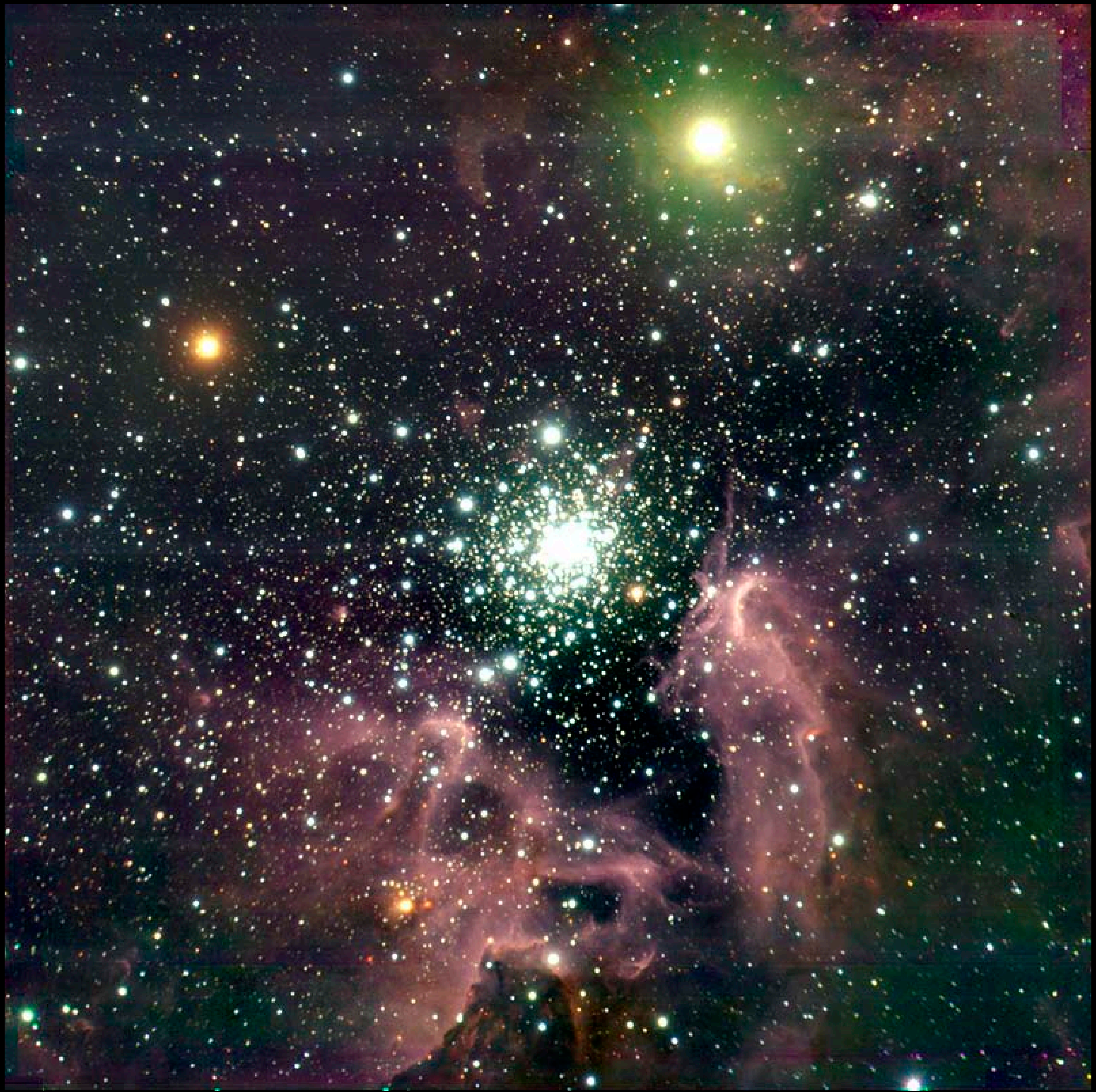
Telescope primary mirrors



Collecting area = sensitivity
Diameter = resolution (with AO)

Spatial Resolution

1 arcsecond



E-ELT
(diffraction limit a few milliarcsec in the near-IR)

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 with S/N reference area chosen to best match the simulated AO PSF

[* = 5mas pixel scale not well matched to PSF]

E-ELT Science

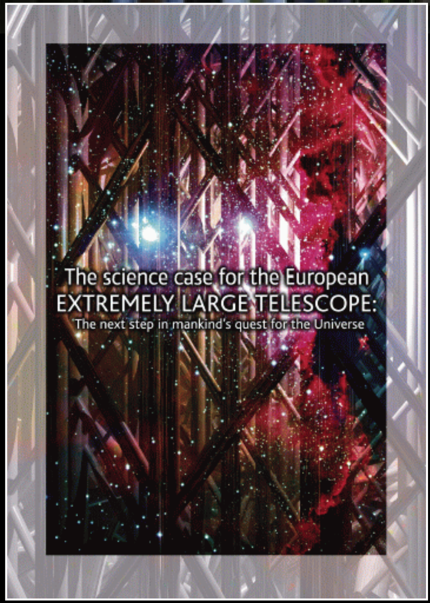
The Science Case against which we evaluate the project resides on three pillars:

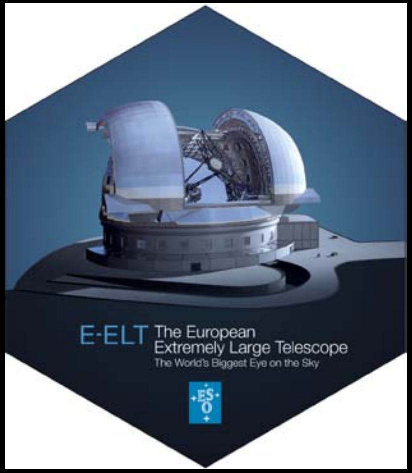
- Contemporary science cases:
  - European Astronomy Community via, e.g.:
    - Design Reference Mission
    - Design Reference Science Plan
  - Instrument teams
- Synergy with other facilities
  - 8m-class telescopes, interferometry, ALMA, JWST, LSST, SKA…
- Discovery potential
  - A new unique parameter space, be prepared for the unexpected…

ELT science case development in Europe

Florence 2004

Science case documents





Marseilles 2003

Marseilles 2006

E-ELT Science Working Group

Mark McCaughrean
Eline Tolstoy
Andrea Cimatti
Isobel Hook (Chair)
Hans-Uli Kaeufl
Rafael Rebolo
Sofia Feltzing
Piero Madau
Mike Merrifield

Christophe Lovis
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Jose Miguel Rodriguez Espinosa

Previous members:
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Bob Fosbury
Willy Benz
Marijn Franx
Vanessa Hill
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Bruno Leibundgut
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Daniela Villegas

Bram Venemans
Lise Christensen
Giuseppina Battaglia
Sune Toft
Mathieu Puech

SEVENTH FRAMEWORK PROGRAMME

Science Working Group Report, April 2006

http://www.eso.org/sci/facilities/eelt/

Planets and Stars

Solar system comets

Extrasolar-system comets (FEBs)

Extrasolar planets:

- imaging
- radial velocities

Free-floating planets

Stellar clusters (inc. Galactic Centre)

Magnetic fields in star formation regions

Origin of massive stars

LMC field star population

Circumstellar disks, young and debris

Stellar remnants

Asteroseismology

Stars and Galaxies

Intracluster population

- Colour-Magnitude diagrams
- CaII spectroscopy of IRGB stars

Planetary nebulae and galaxies

Stellar clusters and the evolution of galaxies

Resolved stellar populations:

- Colour-Magnitude diagram Virgo
- abundances & kinematics Sculptor galaxies
- abundances & kinematics M31- CenA

Spectral observations of star clusters:

- internal kinematics & chemical abundances
- ages and metallicities of star cluster systems

Young, massive star clusters

- imaging
- spectroscopy

The IMF throughout the Local Group

Star formation history through supernovae

- search and light curves
- spectroscopy

Black holes/AGN

Galaxies and Cosmology

Dark energy: Type Ia SNe as distance indicators

- search and light curves
- spectroscopy

Dynamical measurement of universal expansion

Constraining fundamental constants

First light - the highest redshift galaxies

Galaxies and AGN at the end of reionization

Probing reionization with GRBs and quasars

Metallicity of the low-density IGM

IGM tomography

- bright LBGs and quasars
- faint LBGs

Galaxy formation and evolution:

Physics of high-z galaxies

- integrated spectroscopy
- high resolution imaging
- high spatial resolution spectroscopy

Gravitational lensing

Deep Galaxy Studies at z=2-5

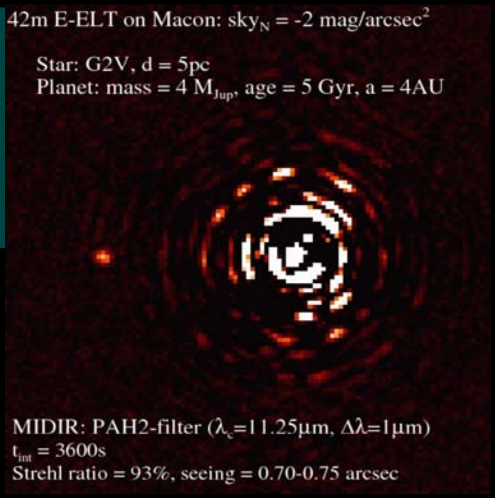
European ELT SWG
Prominent Science Cases

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

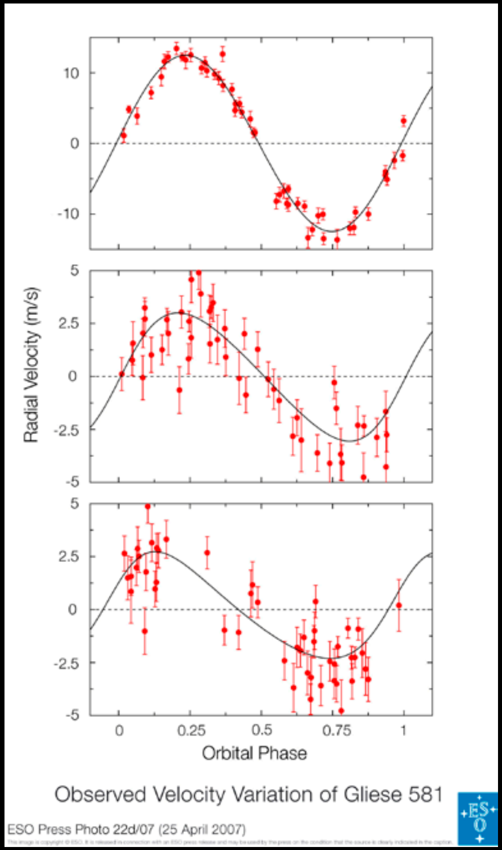
- Setected from larger set
- Not complete!
- Input to Design Reference Mission
  - Observing proposals
  - Simulated data (EScO)
- See www.eso.org

Exoplanets

Right: Simulation by the METIS team

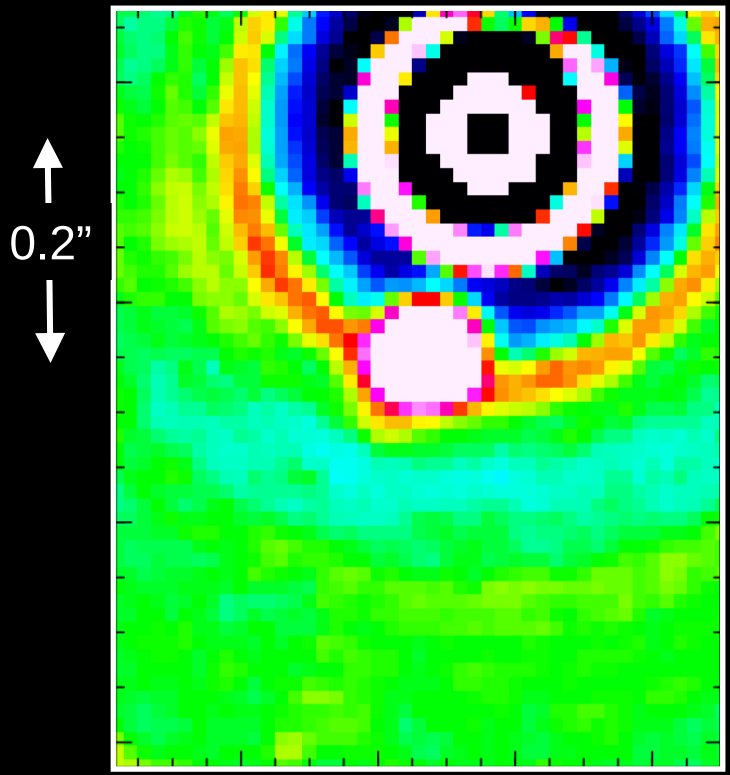


- How common are systems like ours?
- How do planetary systems form?
- Direct Detection
  - Spatial resolution with ExAO in NIR
  - Complemented by Mid-IR detection
- Radial velocity method
  - Potential to reach lower-mass planets
  - ELT provides required collecting area
  - cm/s precision required for Earth-like planets
- Atmospheres
  - High resolution NIR spectroscopy of transiting planets

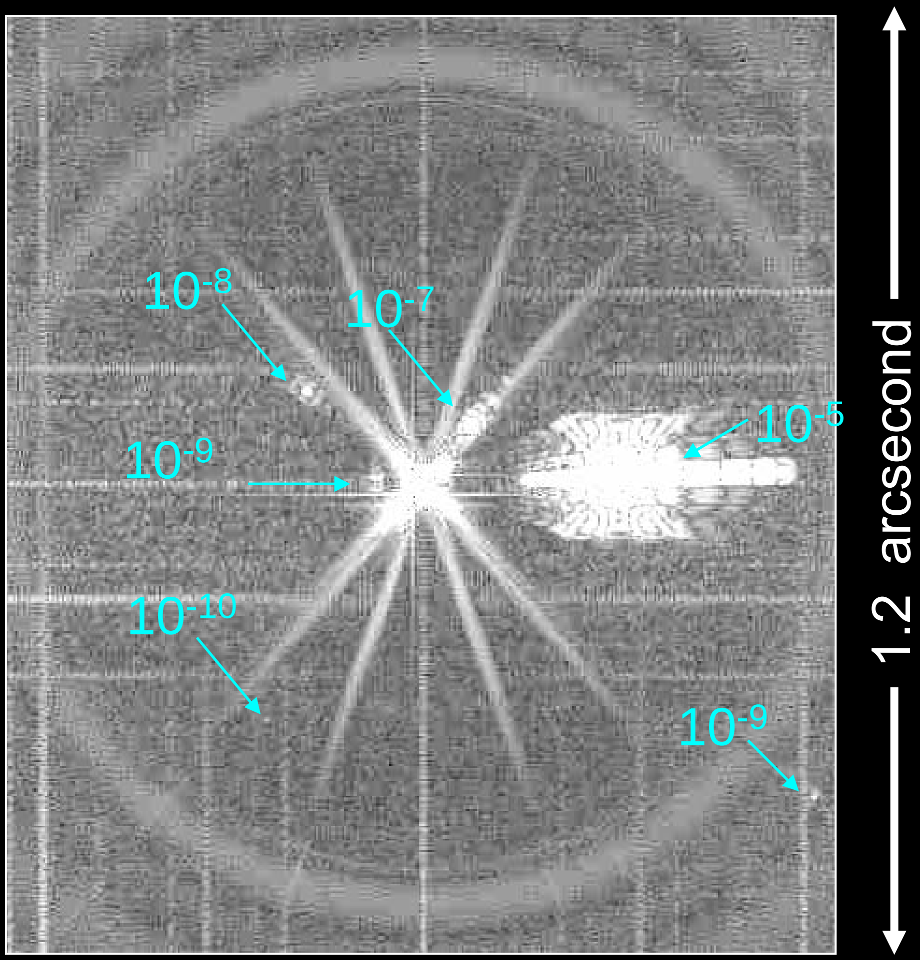


Direct detection of a "Super Earth"

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



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

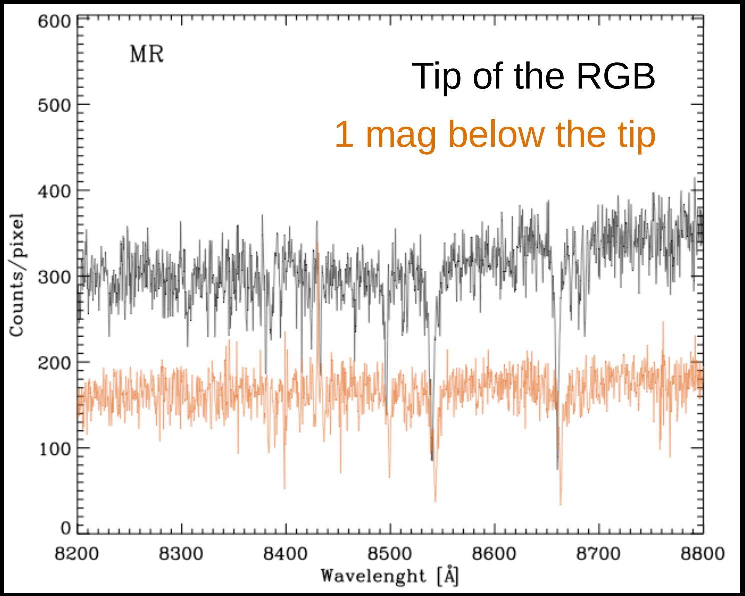


Simulated image courtesy of EPICS team.
10 hours, J band - PRELIMINARY

Intermediate Resolution Spectroscopy of resolved stellar populations

G. Battaglia and E. Tolstoy

- Goal: to measure large scale metallicity and kinematic properties of galaxies out to the Virgo cluster



Example: 20 min exposure for Local Group dwarf galaxy

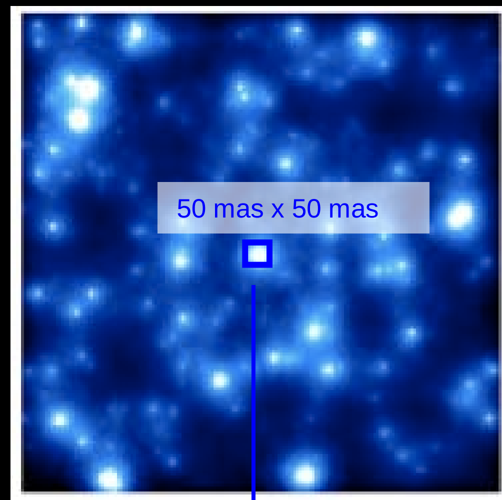
- Based on Ca triplet (860nm) spectroscopy of RGB stars
- Simulate stellar pops
  - galaxies at 800kpc, 4 Mpc, 17 Mpc
  - old, metal rich & metal poor
- Measure at various projected radii
- Vary parameters
  - Exposure time
  - Site
  - Mirror coating
- Attempt to recover input parameters

Centaurus A (4Mpc) : Example of spectra

Local Group dwarf and Cen A: CaT surveys of large numbers of individual stars are feasible

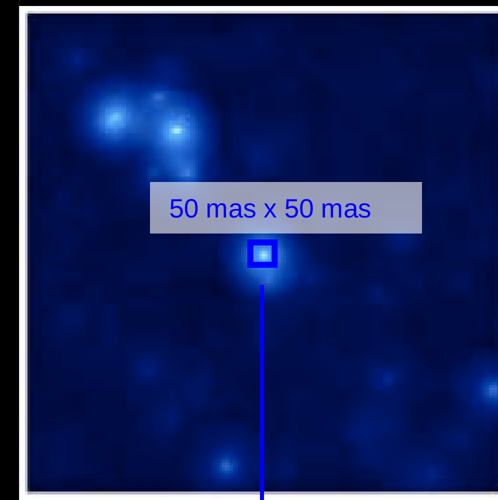
M87 (Virgo): borderline (crowding in the inner regions, and low s/n)

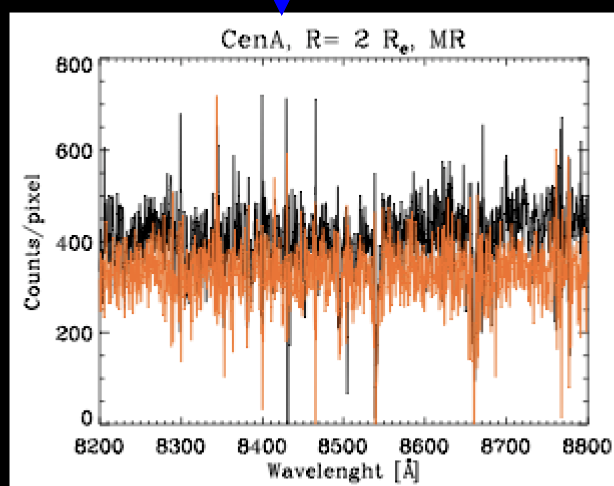
2 Re ” 12 kpc

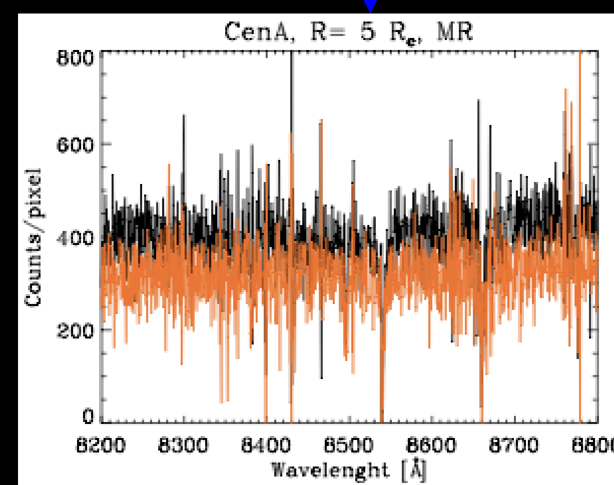


5”

5 Re ” 30 kpc





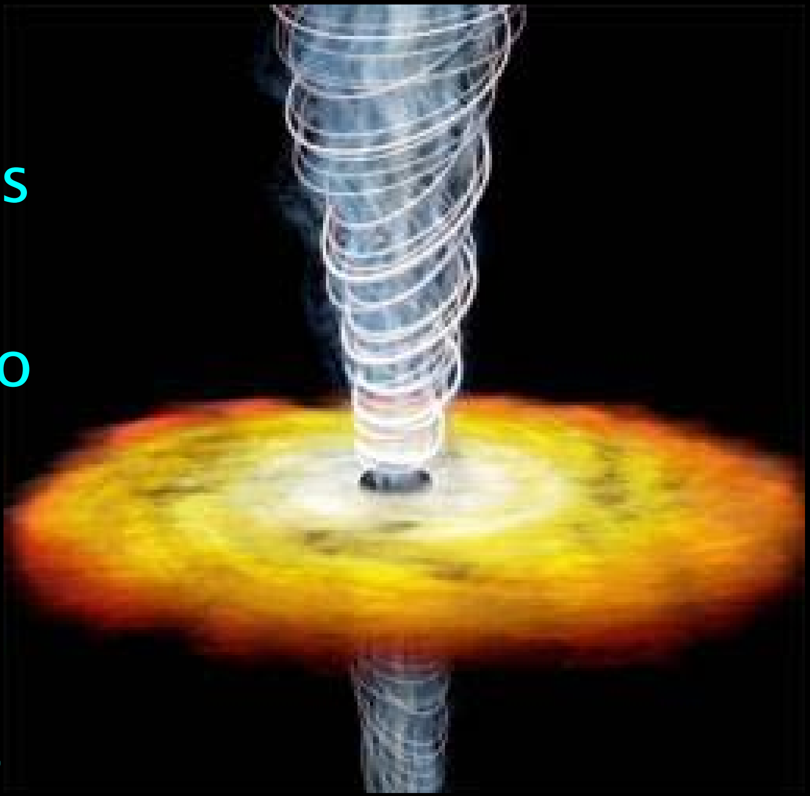


Targets: MR and MP RGB down to 0.5 mag below tip (I= 24.4)

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

Black Holes

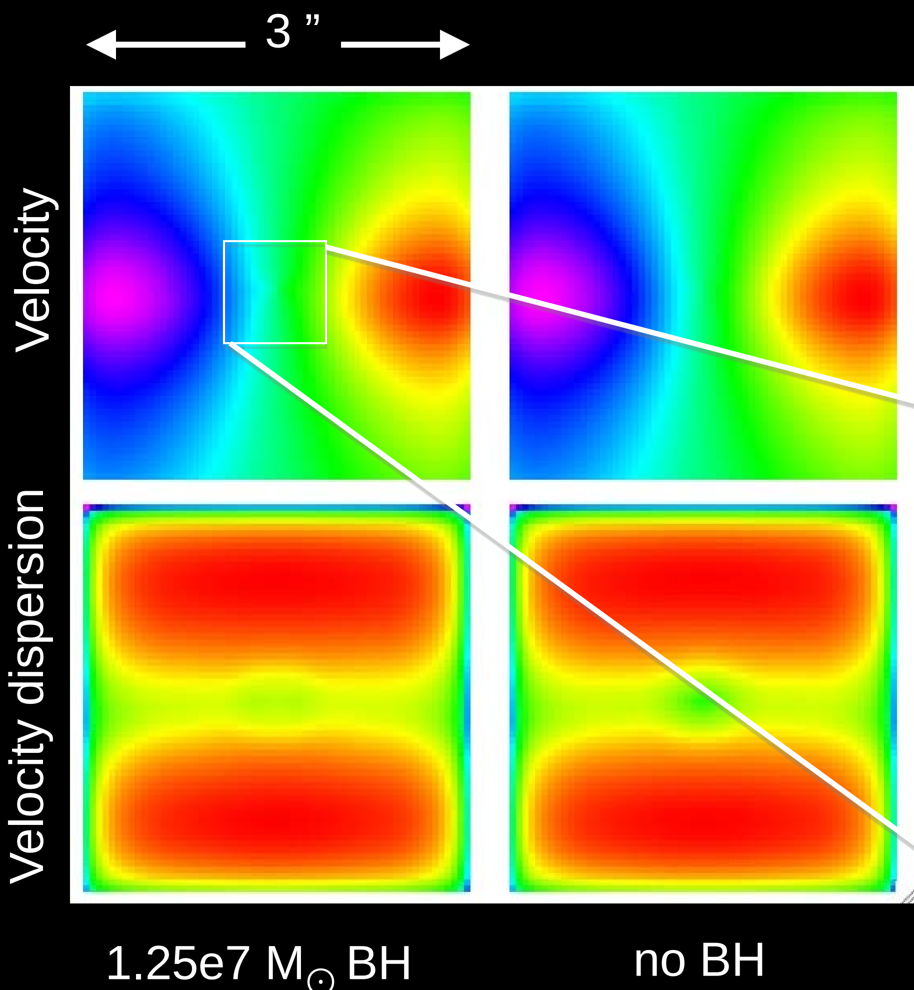
- Only a few black holes have accurate mass measurements
- How common are they?
- Why do their masses relate to that of host galaxy bulges?
- ELT provides resolution to probe sphere of influence
  - 10^9M BHs to 100Mpc
    - statistical samples (and perhaps to high-z..)
  - 10^6M BH @ Virgo distance

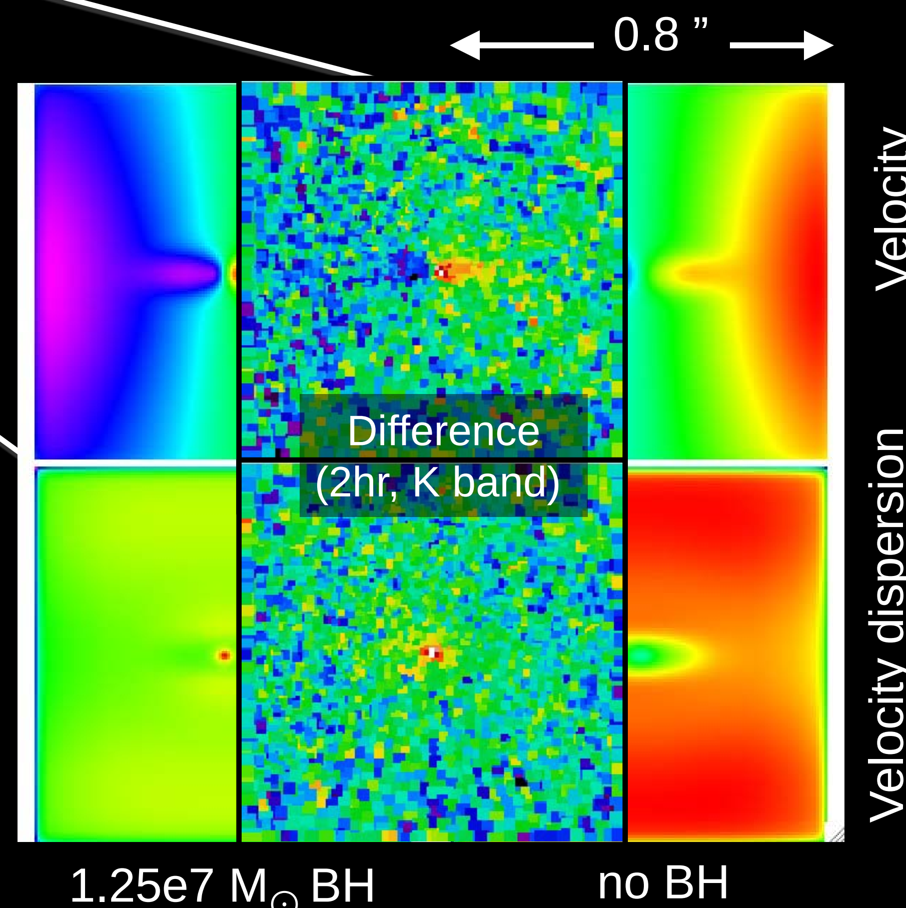


Test case: simulation of NGC4486 at 16Mpc (Virgo)

Left : resolution of SINFONI (50mas)

Below : resolution of ELT+LTAO (5 mas)

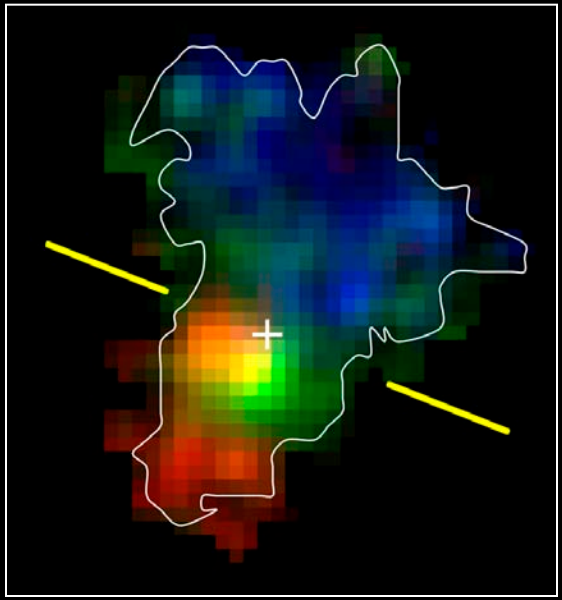




Simulations by A. Küpcü Yoldaş,
Models from Emsellem et al. 94,
Cappellari 2002, 2008.

Simulations of high-z galaxies

- Mergers or ordered rotation?
- Distinguish via velocity maps

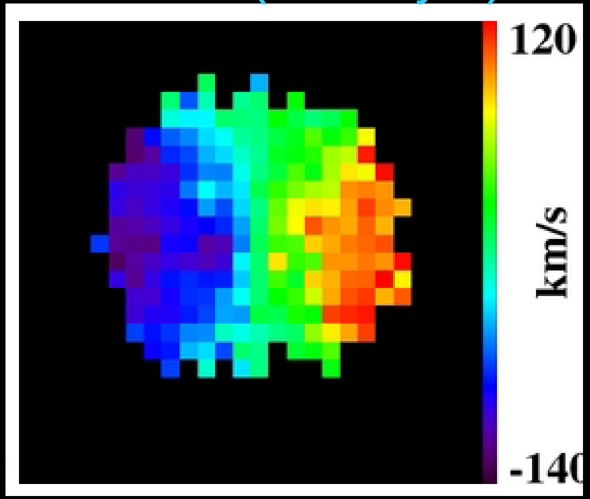


Massive, rotating disk galaxy 3 bn yrs after the Big Bang,

Observed with Adaptive Optics + IFU on VLT (Genzel et al 2006)

0.5” (4 kpc)

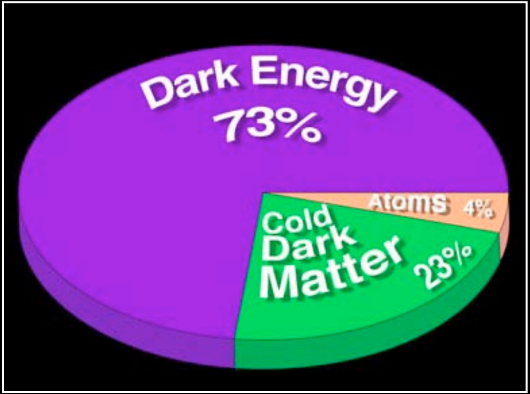
z ~ 4 (1.4bn yrs)



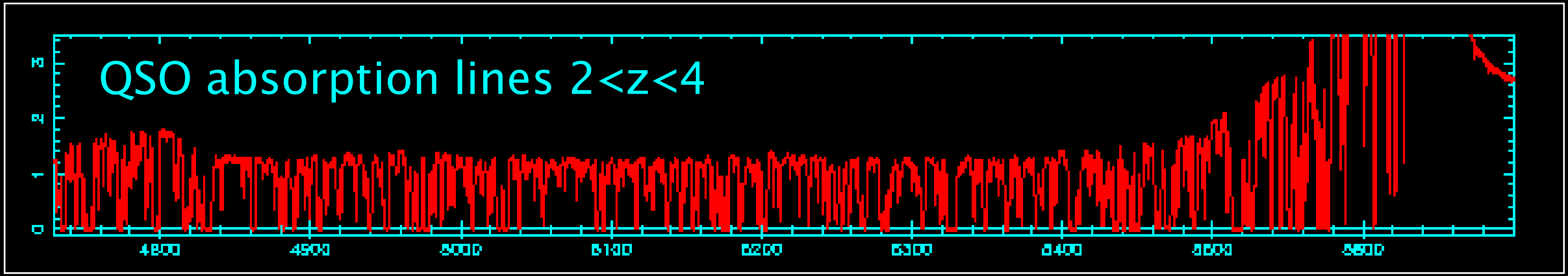
Simulation (M. Puech):
typical rotating disk
42-m ELT, 10-hr integration, MOAO

- Large, representative sample requires multiple-IFUs fed by AO
- Simulations compare AO modes etc – Final DRM report available

Watching the Universe accelerate in real time



- What is the Dark Energy?
- 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 (e.g. CODEX)

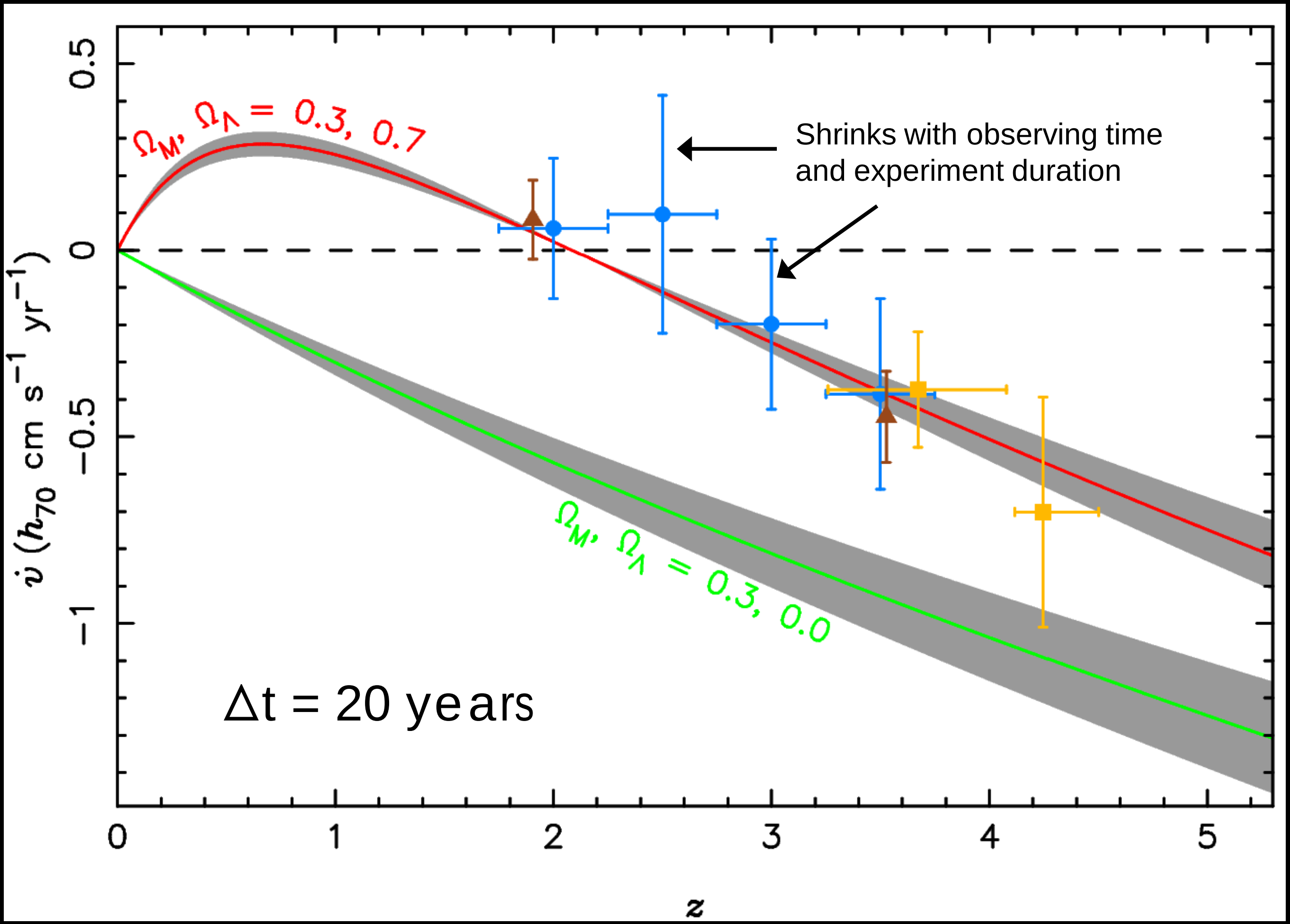


Cosmic Dynamics Experiment

Simulations:

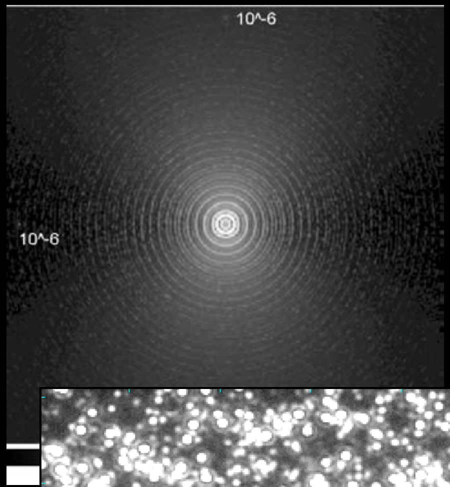
4000 hours over 20 years will deliver any *one* of these sets of points.

Different sets correspond to different target selection strategies.



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

E-ELT DRM Simulations



- Exo-planets
  - Direct detection
  - Radial velocity detection
- Initial Mass Function in stellar clusters
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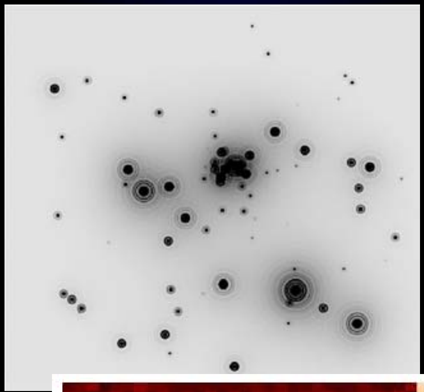
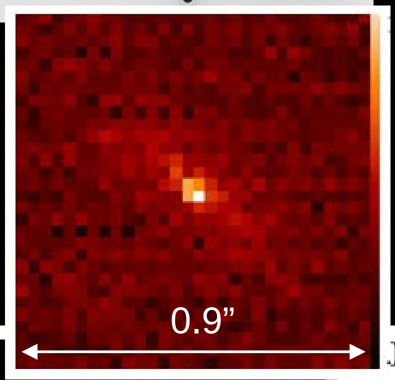
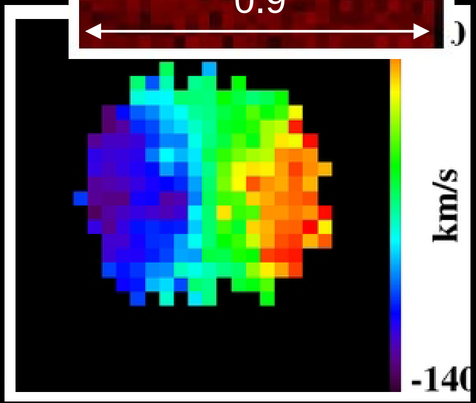
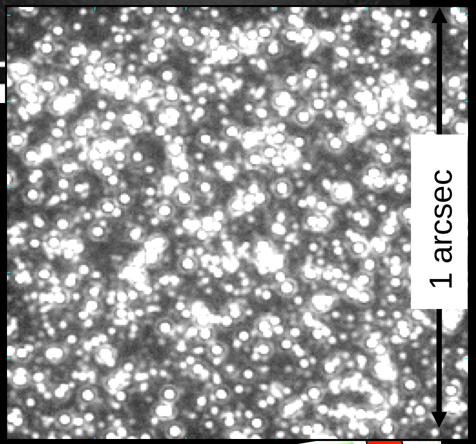
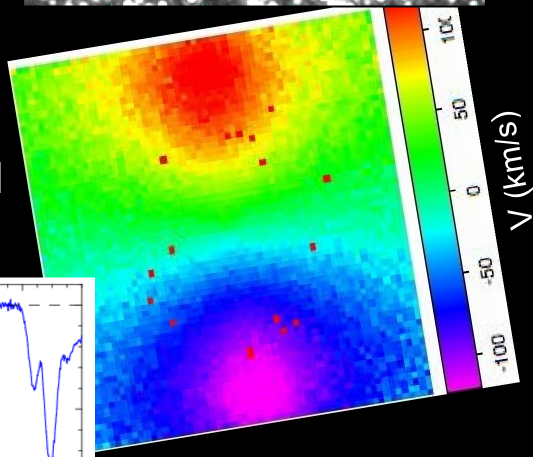
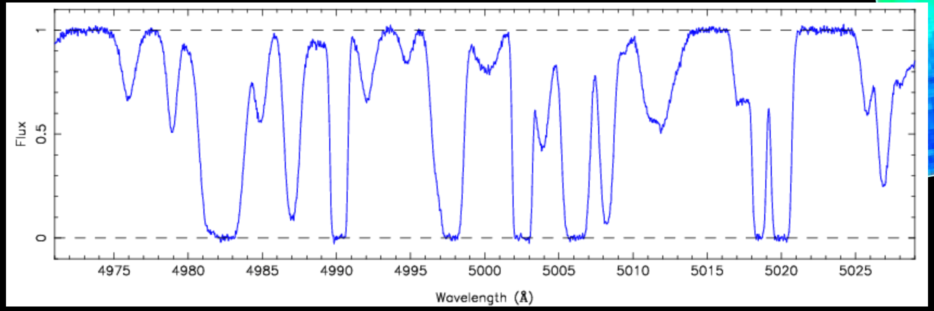












Design Reference Science Plan

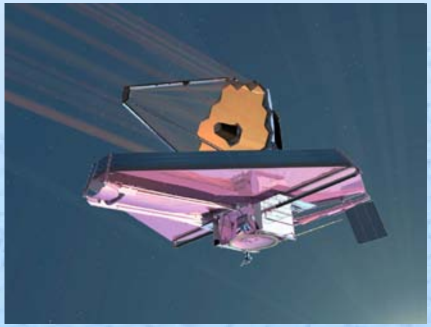
- Input provided by the community
  - ELT Science Office collected science cases & requirements
  - Broader science input than DRM
  - Provides further input to design choices
    - Instrumentation modes
    - Operations modes (service, visitor, eavesdropping..)

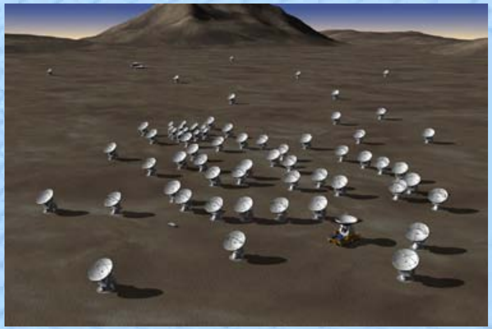
- Closed 5th June 2009
- 188 responses, being analysed now
- Initial report in ESO messenger

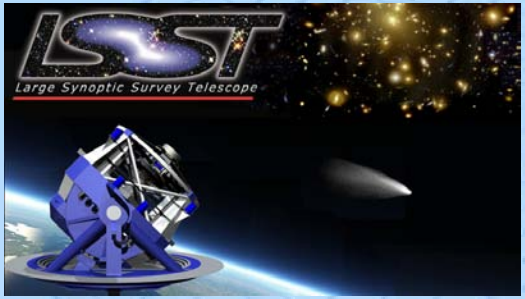
ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Synergy with Large Facilities

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







The Observatory

Laser Guide stars

- Adaptive optics needs a bright reference star
- Corrects a patch of sky around the reference
- Not always a natural star nearby
- Laser excites sodium atoms in the atmosphere to create an artificial star

Laser Guide star at the Keck Observatory

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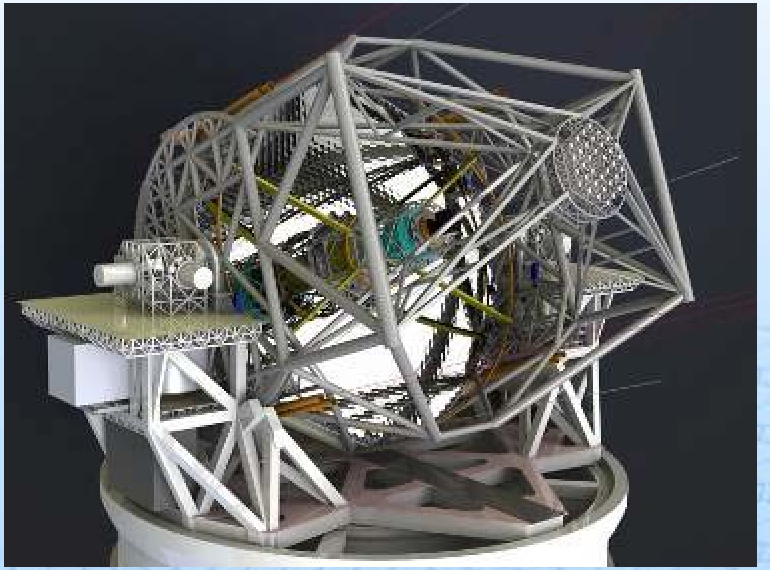
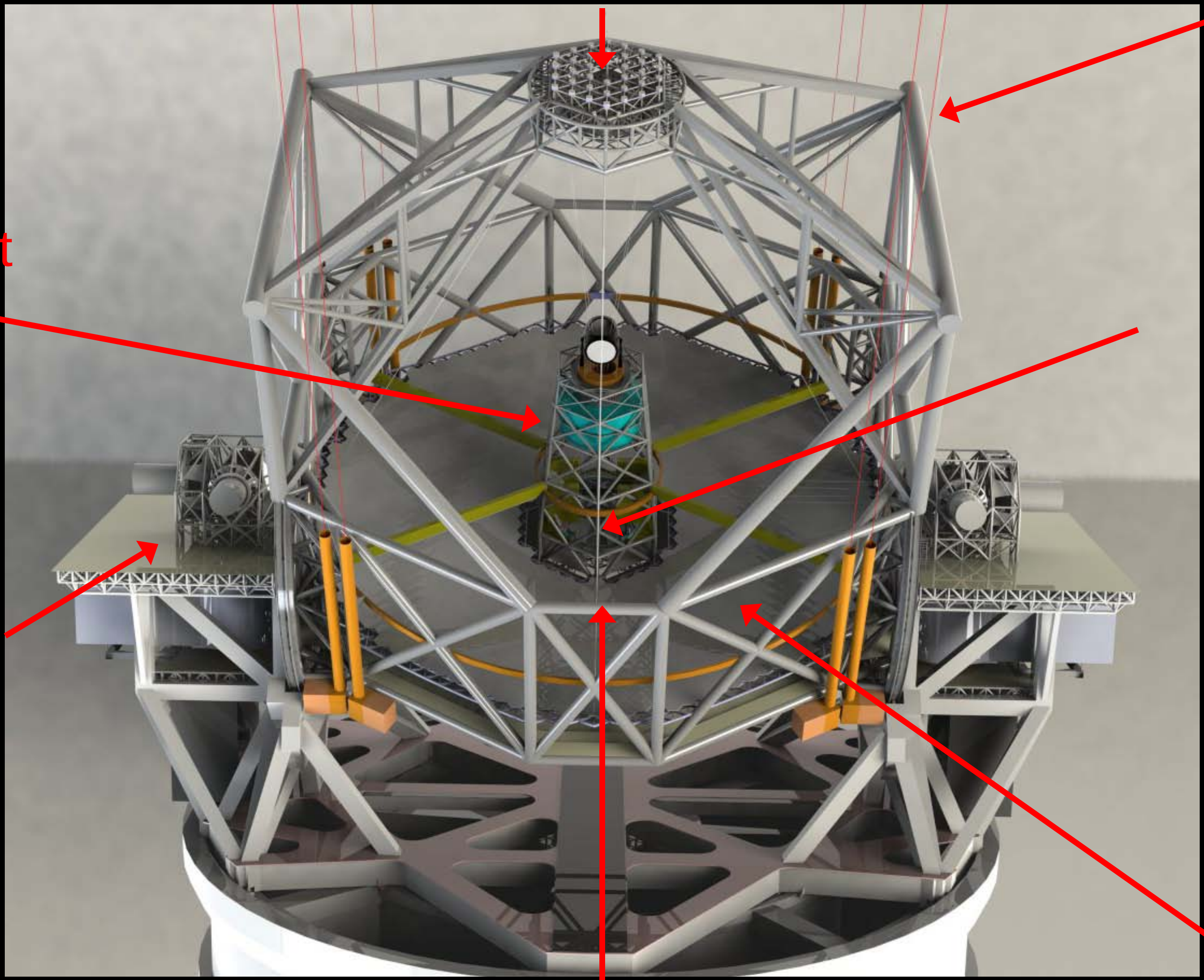
The Telescope



- Nasmyth telescope with a 42m diameter primary mirror
- Nearly 5000 tons of structure
- Two instrument platforms of the size of tennis courts
- Six laser guide stars

- Novel 5 mirror design to include adaptive optics in the telescope
- Classical 3-mirror anastigmat + 2 flat fold mirrors [M4,M5]
- Outstanding image quality

E-ELT Basic Reference Design v3



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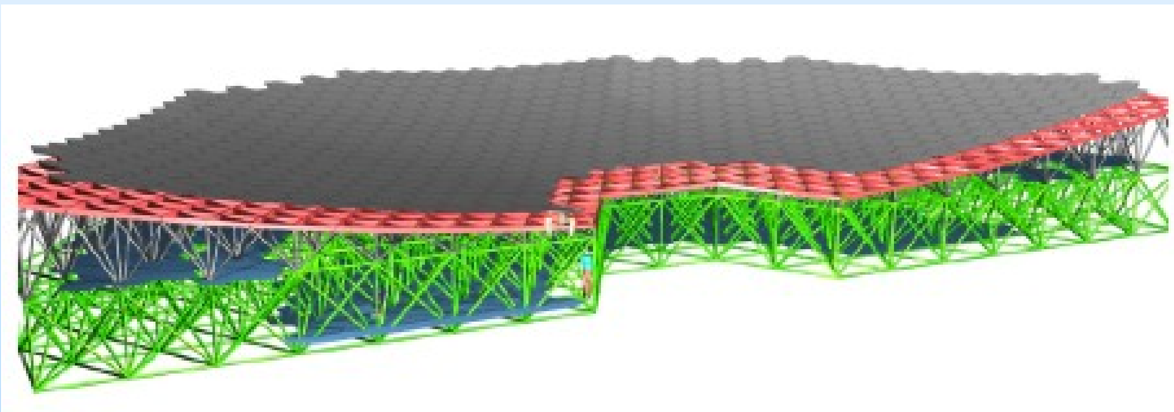
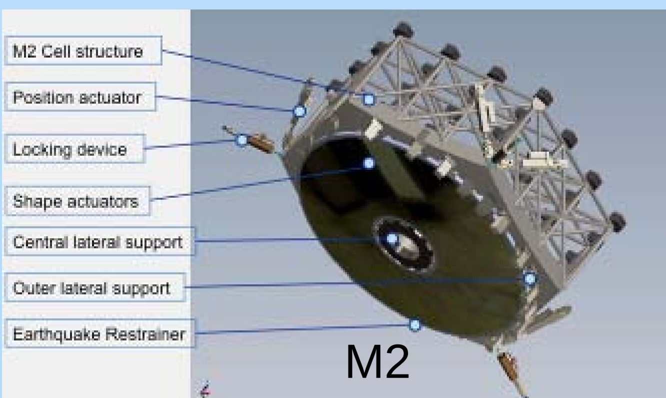
The Mirrors

- The Primary mirror: 42m ø, 984 segments of 1.4m, 1200 m^2





- Secondary: 5.6m ø, 156 axial supports
- Tertiary: 4m ø, controls f-ratio
- M4: 2.6m ø flat, adaptive with 6000-8000 actuators
- M5: 3x2.4m, flat, tip-tilt

The Site(s)

- Site decision by end of 2009
- Several sites tested in the Canary Islands, Chile, Morocco, Argentina, Mexico, …
- Recent down-select to 4 sites : La Palma + 3 in Chile
- Selection criteria: impact on science, outstanding atmosphere, but also construction and operations logistics (roads, water, electricity, nearby cities, ...)


Atacama

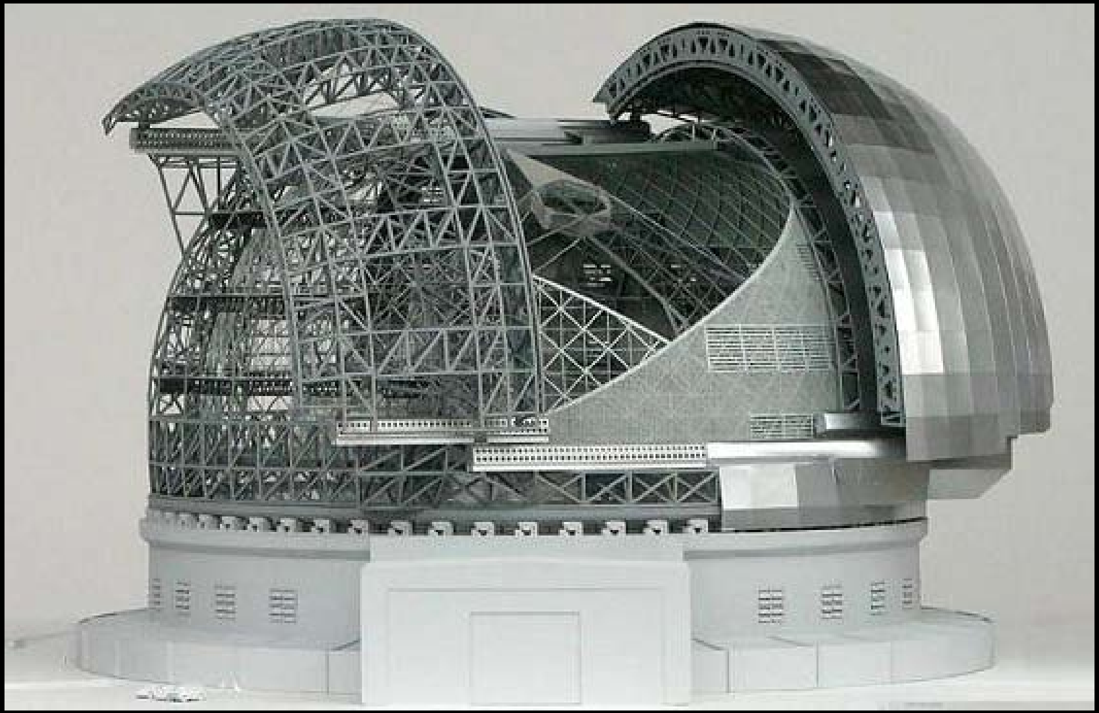

Morocco


La Palma


Argentina

E-ELT Dome

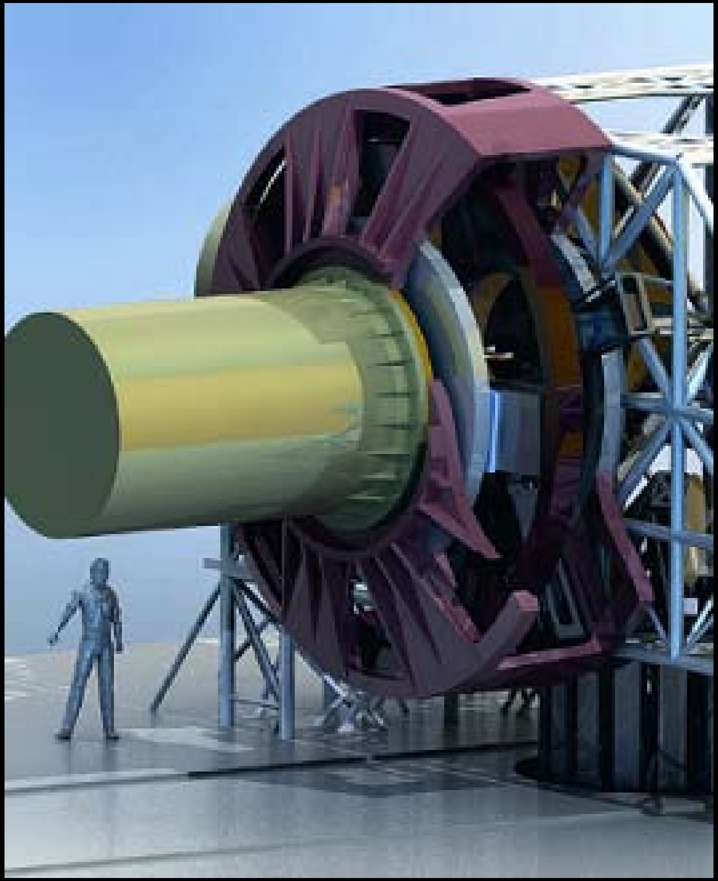
- 100m base
- 80m height
- ~4000 tons of steel
- Size of a football stadium
- Air conditioned
- Wind shielded
- Heavy duty cranes and lifting platform



Two dome design studies have been carried out, both chose spherical design

E-ELT instrumentation

- Phase-A studies underway in collaboration with institutes in ESO community
  - 8 instruments
  - 2 AO modules
- Studies end Spring 2010
  - Details may change!
- Two or three to be selected for first light
- Full instrument suite to be built up over first decade



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Phase A Instrument Studies

EAGLE	Multi-IFU, AO-fed near-IR spectrometer
EPICS	XAO imager/spectro-polarimeter for exo-planets
HARMONI	Diffraction-limited, near-IR IFU
METIS	Mid-IR (3-14μm) imager & spectrometer
OPTIMOS	Seeing-limited/GLAO high-multiplex spectrograph
CODEX	Ultra-high-resolution optical spectrograph
MICADO	Near-IR, high-resolution imaging camera
SIMPLE	Near-IR, high-resolution spectrograph

AO-relays	MAORY (MCAO relay) & ATLAS (LTAO relay)

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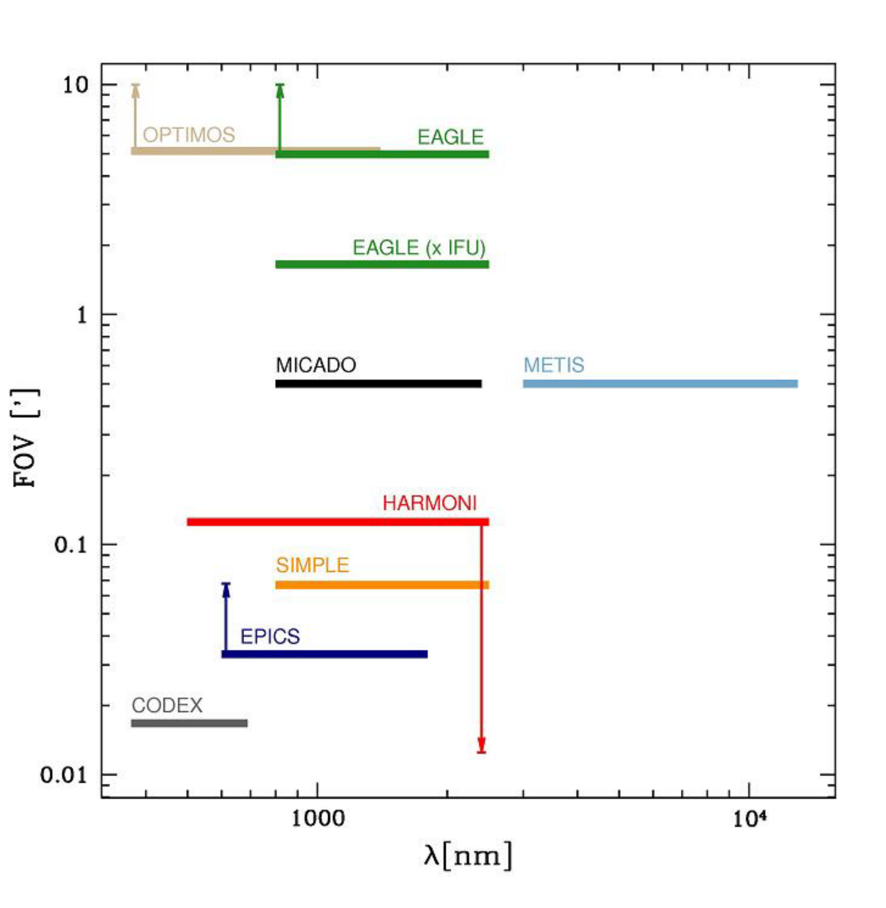
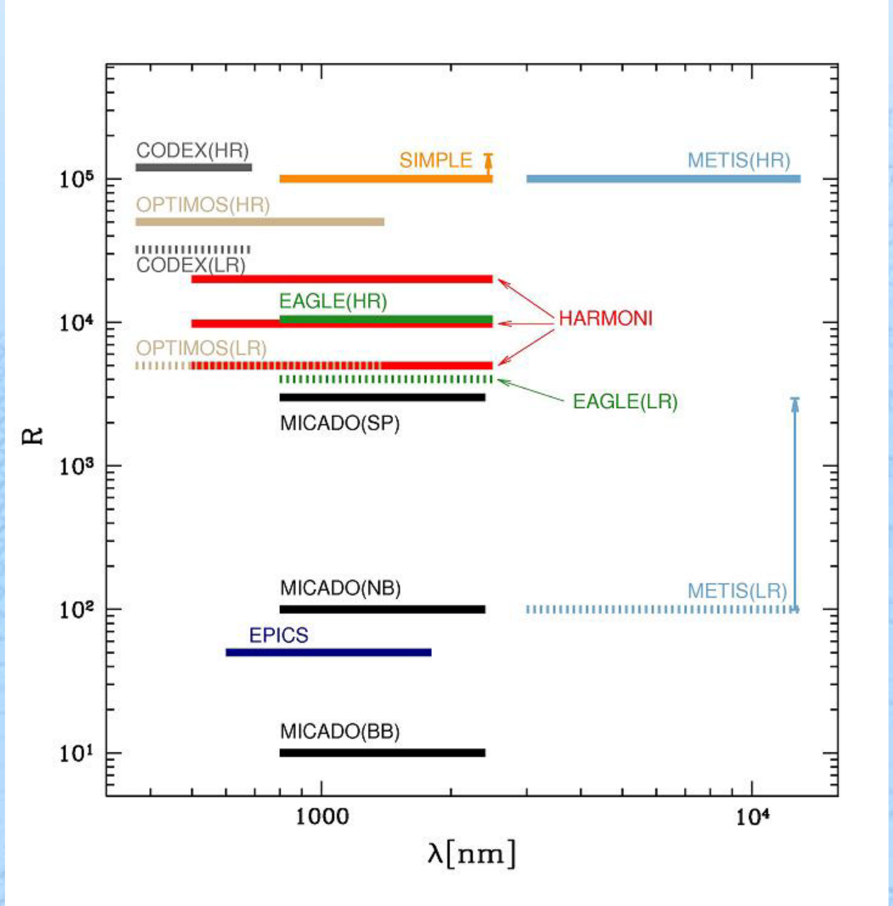
Phase A Instrument Studies

- Broad parameter space covered, e.g.:

Field-of-view



Spectral resolving power



EAGLE

A multi-IFU, near-IR spectrometer

- French/UK 50/50 partnership

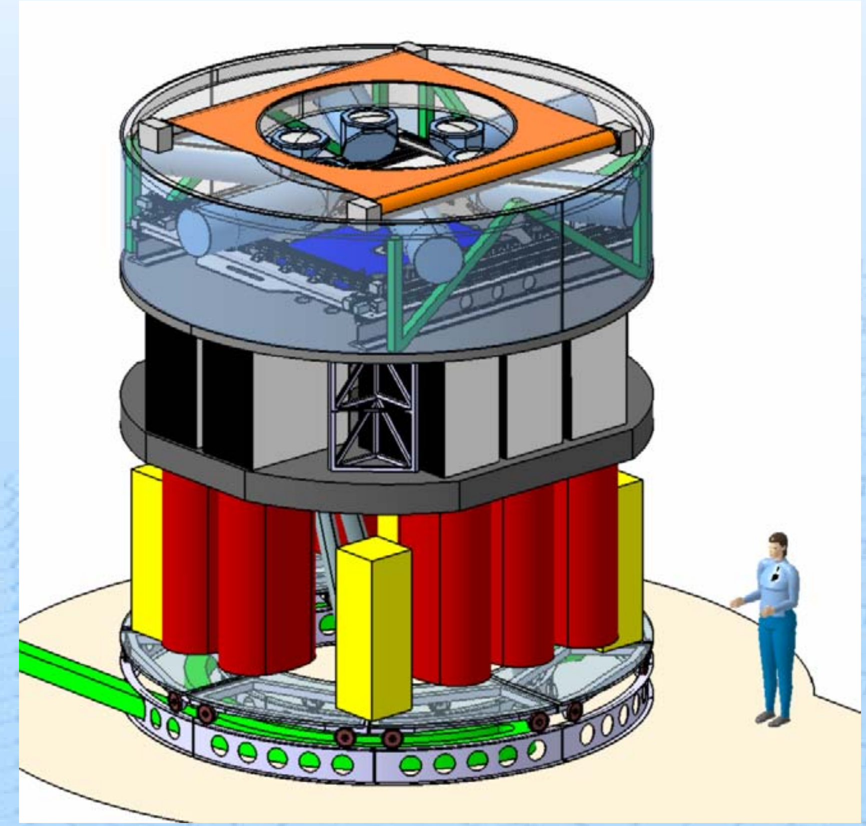
  PI: Jean-Gabriel Cuby (Marseille)

  co-PI: Simon Morris (Durham)

- Institutes: LAM (Marseille), Durham University, UK ATC, GEPI & LESIA (Paris)

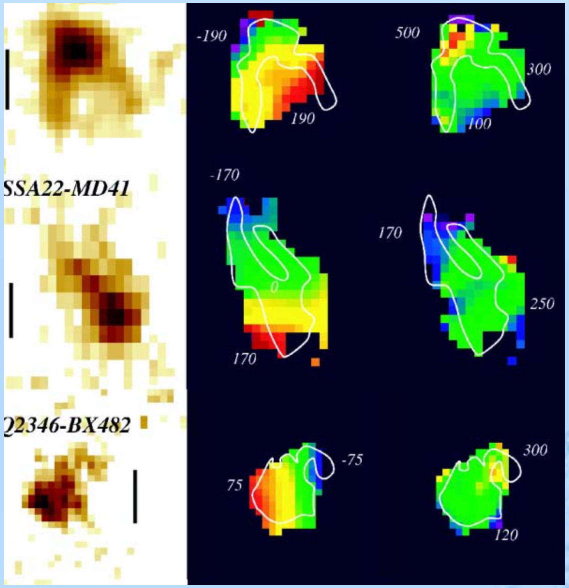
- 2-year study, started Q4 ’07

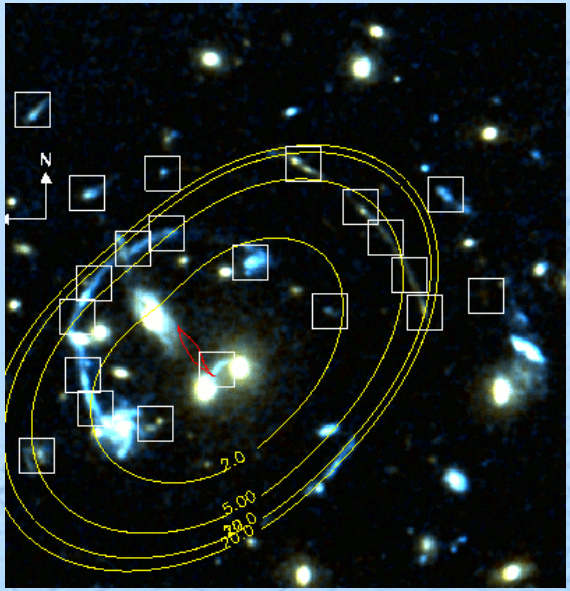
  - Moderate spectral R
  - Patrol field covers available FOV of telescope (7’)
  - Fed by Multi-Object AO

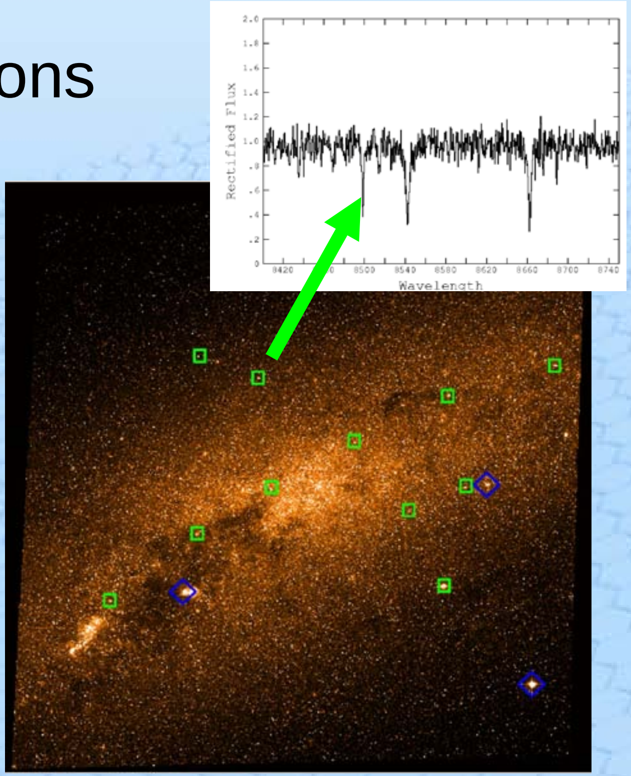


EAGLE Science

- Spatially-resolved spectroscopy of high-z galaxies
- Characterisation of first-light galaxies
- Spectroscopy of resolved stellar populations

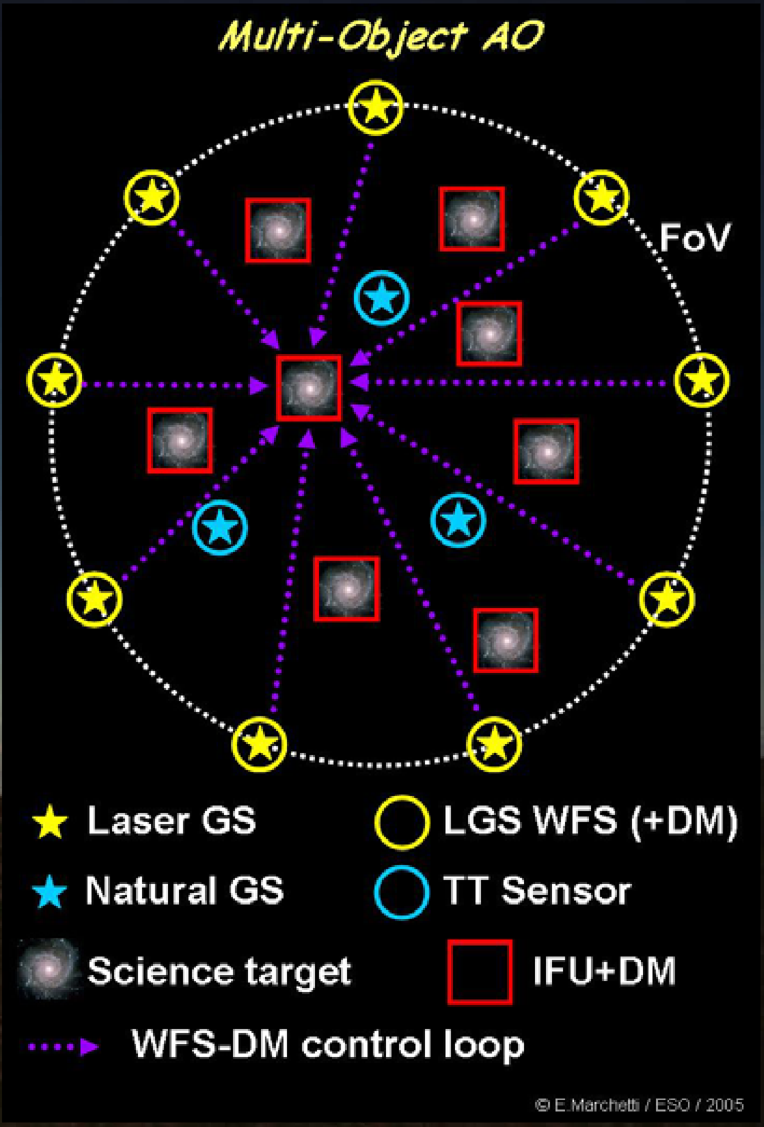






EAGLE Adaptive Optics

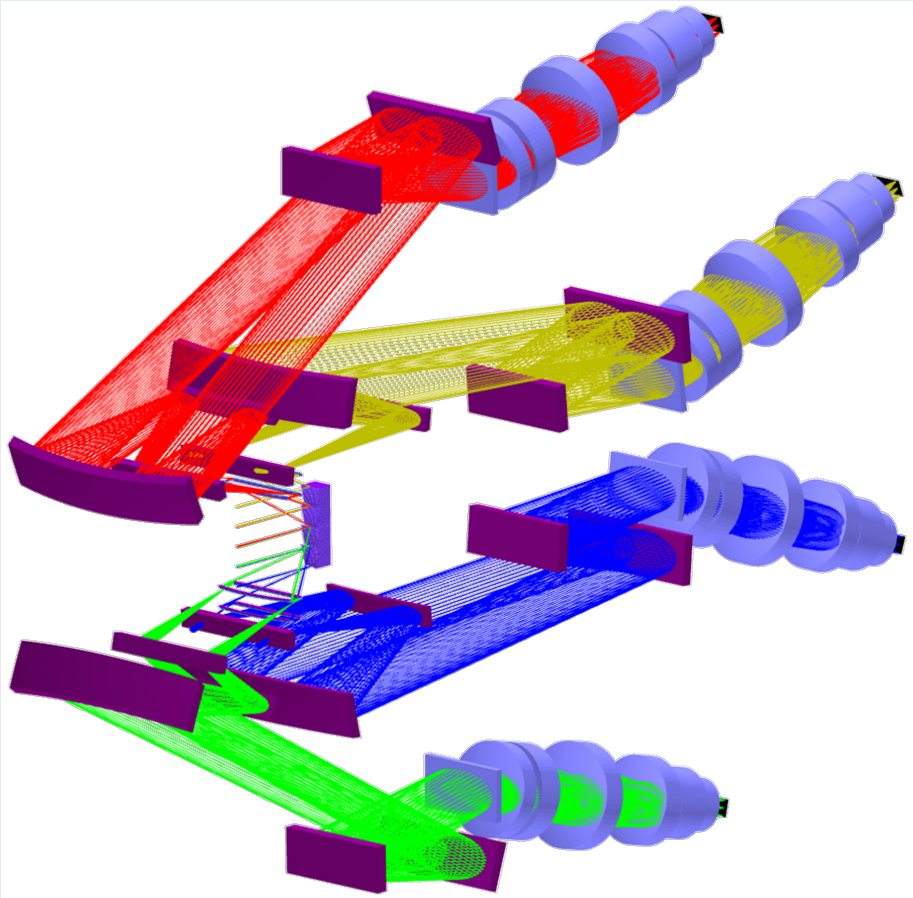
- Multi-Object Adaptive Optics (MOAO)
- Correct small sub-fields across a 5 arcmin field
- Extensive MOAO research in the UK and France



HARMONI

Single-field, wide-band IFU spectrometer

- PI: Niranjan Thatte (Oxford)
- Institutes: Oxford University, UKATC, Madrid, IAC (Tenerife), Lyon
- 18-mth study, started Q2 ’08
- Moderate spectral R
- Multiple spaxel scales
- NIR with possible optical extension



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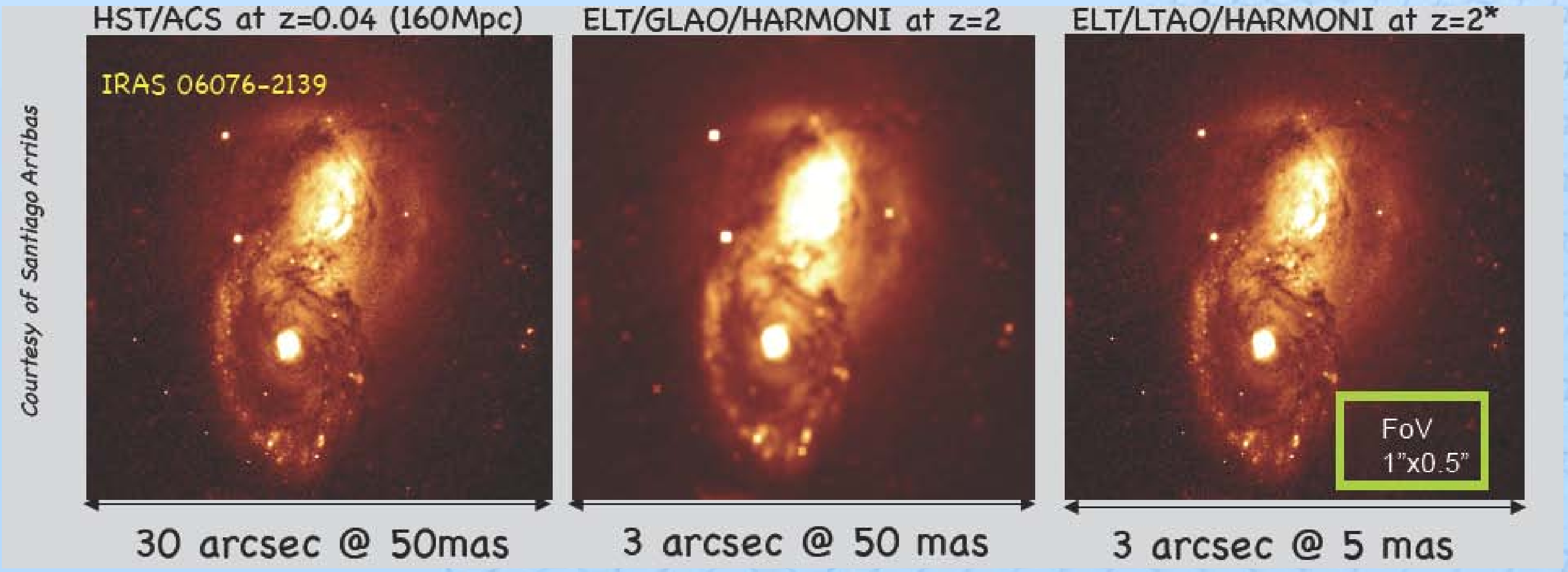
HARMONI Science

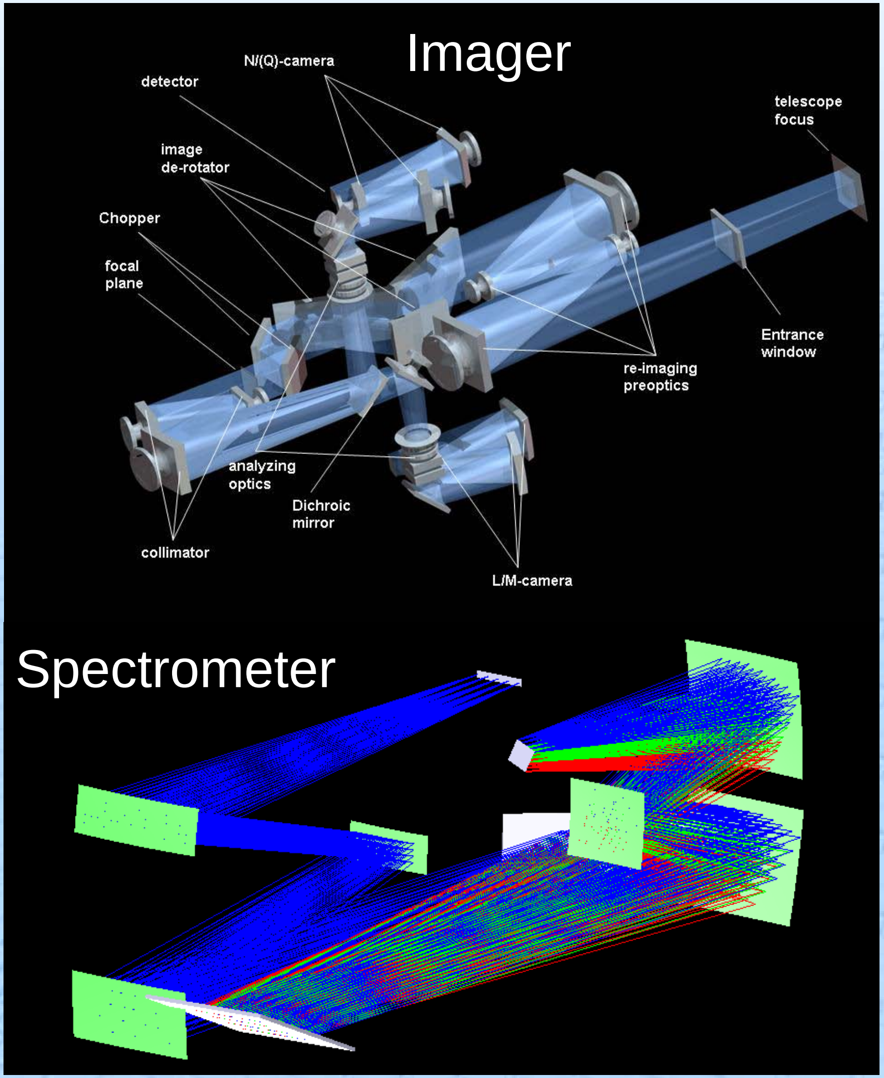
- Planetary science & circumstellar disks
- Resolved stellar populations
- Spatially-resolved spectroscopy of high-z galaxies



METIS

Mid-infrared ELT Imager & Spectrometer

- PI: Bernhard Brandl (Leiden)
- Institutes: Leiden, UKATC, MPIA (Heidelberg), Saclay, Leuven
- 18-mth study, started Q2 '08
  - 3-14μm
  - Range of spectral R (10 – 100000)
  - Imaging mode (FOV : 18")
  - IFU mode



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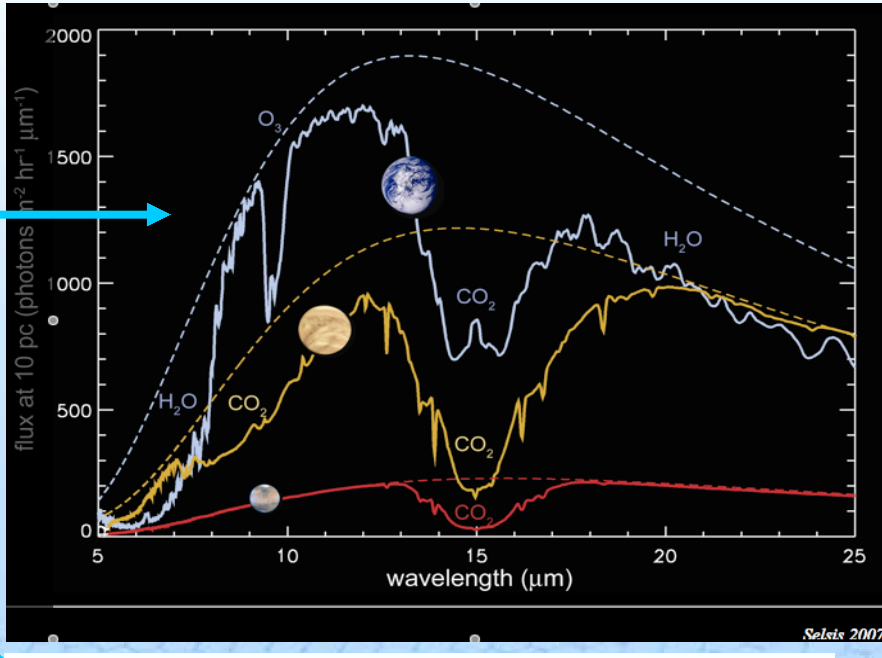
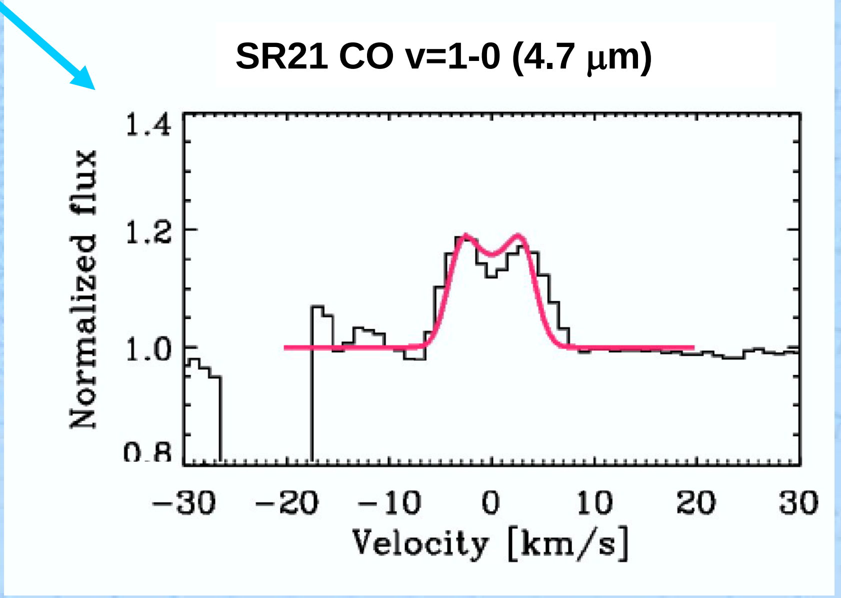
METIS Science

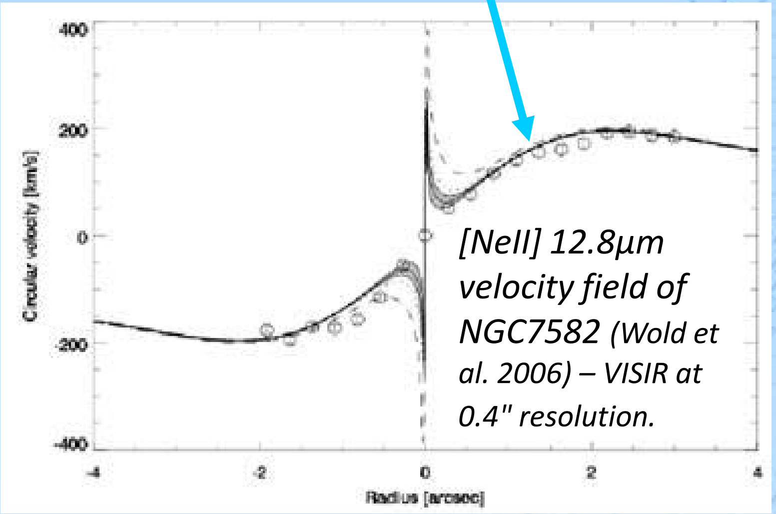
- Exo-planets:
  Direct detection of giants
  Differential spectroscopy of transits



- Protoplanetary disks



- Star formation
- Obscured extragalactic black holes and galaxies



[NeII] 12.8µm velocity field of NGC7582 (Wold et al. 2006) – VISIR at 0.4" resolution.

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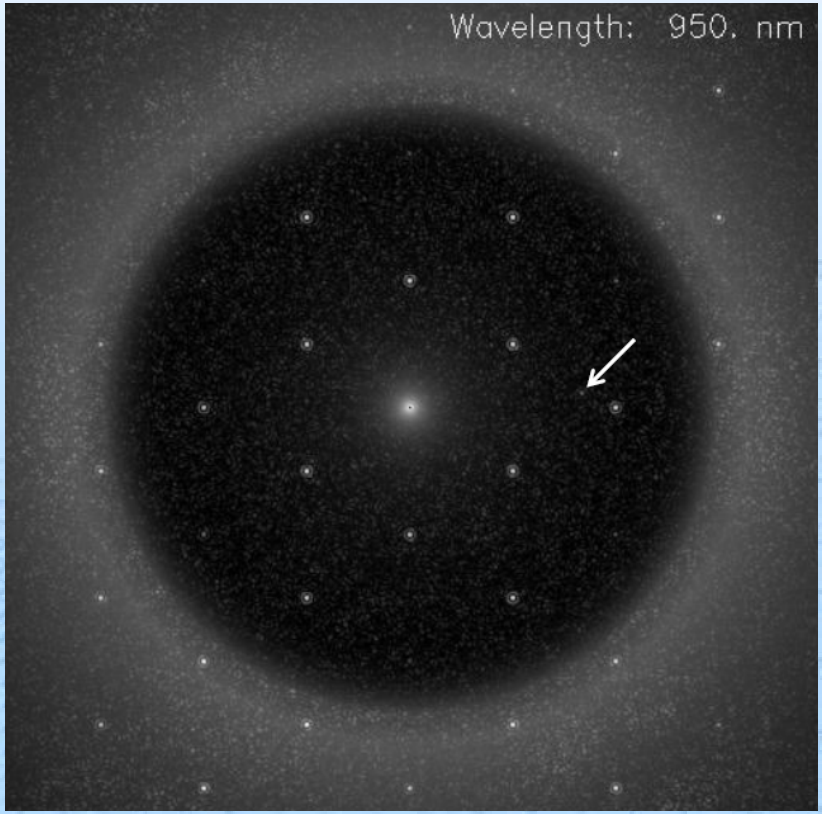
EPICS
E-ELT Planet-Finder

- PI: Markus Kasper (ESO)
- Institutes: ESO, Oxford University, Grenoble, Paris, Padua, IAC (Tenerife), Zurich
- Parameters (Phase I)
  - Extreme Adaptive Optics (XAO)
  - NIR wavelengths
  - Range of R (125-20000)
  - Differential imaging, polarimetry and IFU



Simulation by the EPICS team

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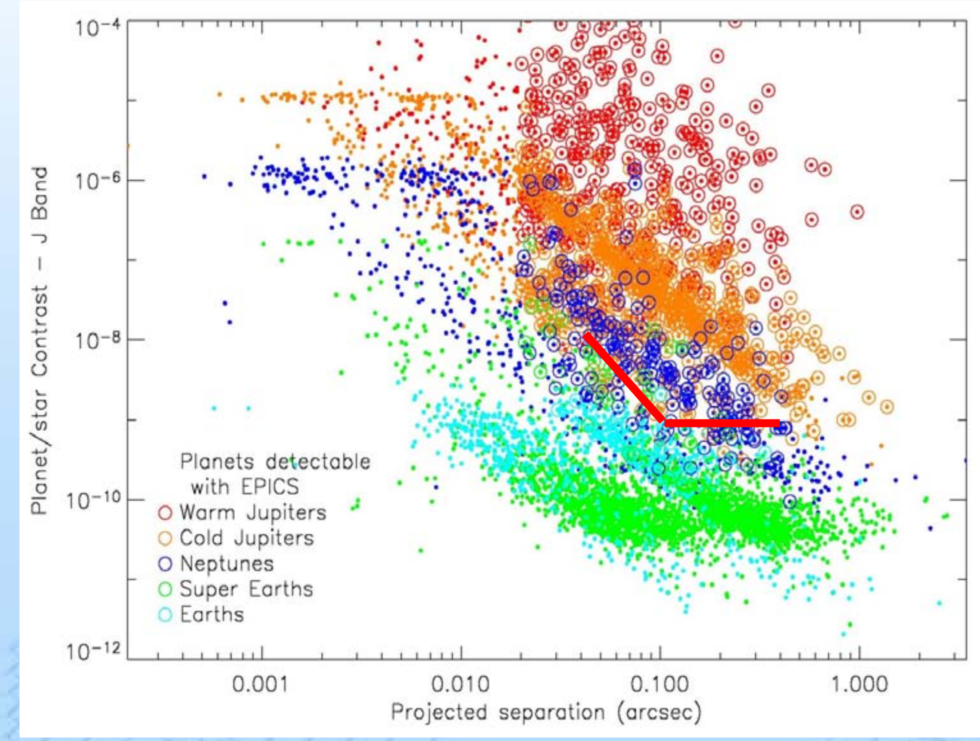
EPICS Science

- Coming soon: SPHERE (VLT) & GPI (Gemini) in ~2011:
  - Angular separation: 0.1” < α < 1”
  - Contrast (@1.6 μm): 10^{-4}-10^{-6}
  - Young gas planets
- EPICS (E-ELT):
  - Angular separation: 0.03” < α < 1”
  - Contrast (@1.6 μm): 10^{-7}-10^{-9}
  - Mature gas planets & massive rocky planets

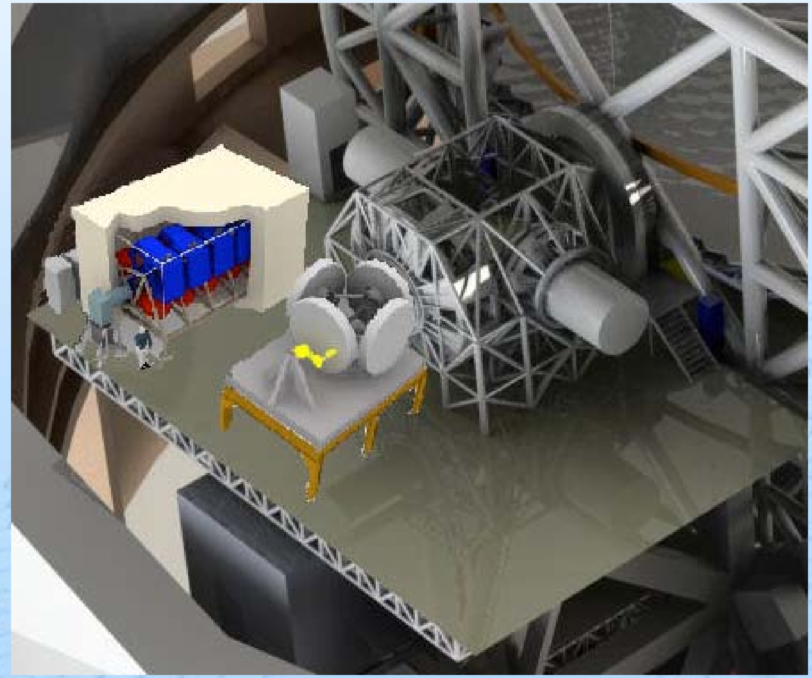


EPICS detection rates for nearby & young stars. Simulation by M. Bonavita (contrast requirements in red).

OPTIMOS

Wide-field visual+NIR multi-object spectrometer

- Co-PIs: Gavin Dalton (RAL)
  & Olivier LeFevre (LAM)
- Institutes: Rutherford Appleton Lab, Oxford University, LAM (Marseille), GEPI (Paris), University of Amsterdam, University of Copenhagen, Milan, Trieste



- Moderate R (range of options)
- MOS patrol FOV : 7’
- Natural seeing or GLAO

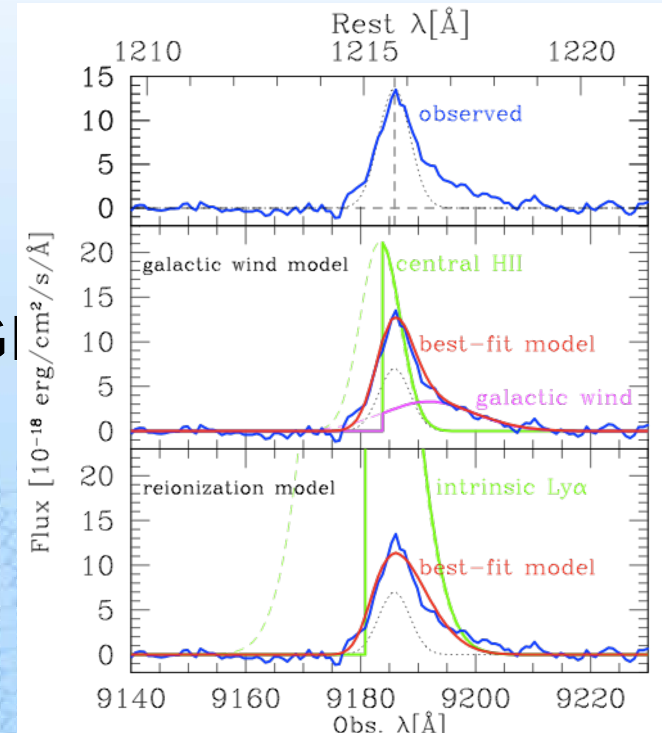
Two concepts being studied:

Multi-slit + imager (DIARAMUS)

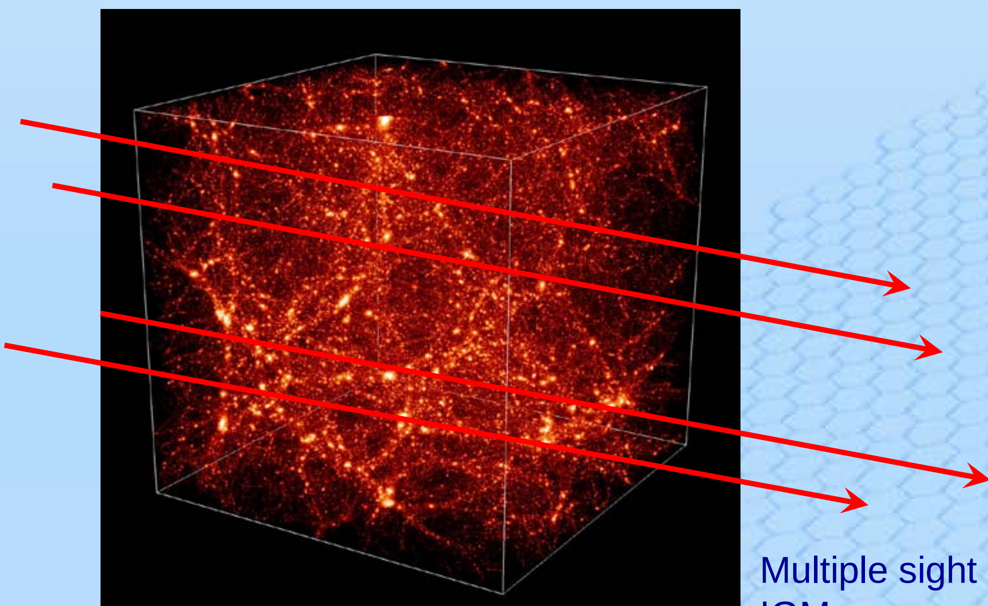
MULTI-IFU (EVE)

OPTIMOS Science

- Studies of stellar populations
- High-redshift galaxies
- Mapping the intergalactic medium (IG



Analysis of Ly-alpha at high-z (from EVE Science Case; Schaerer & Bunker)



Multiple sight lines through the IGM

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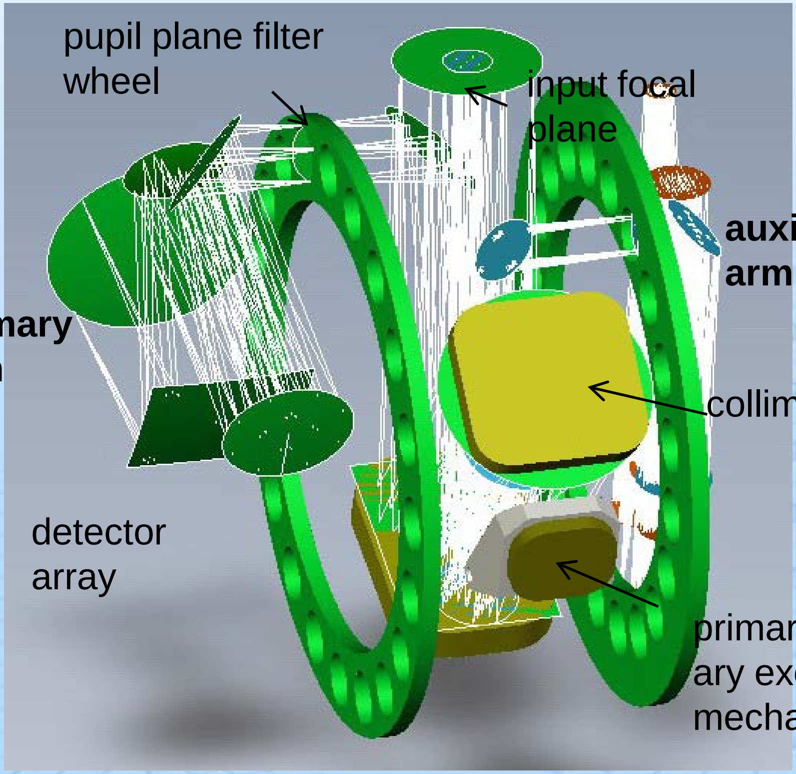
MICADO

Diffraction-limited Near-infrared imager

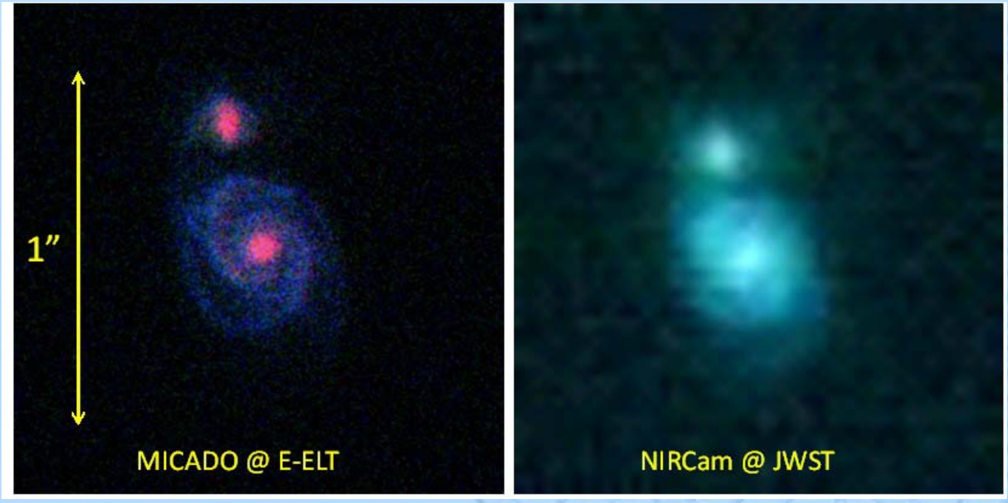
- PI: Reinhard Genzel (MPE)
- Institutes: MPIA Heidelberg; USM; INAF (Padova); NOVA (Leiden, Groningen, Dwingeloo)
  - FOV up to 53’
  - Aux arm: Possible slit spectroscopy, basic polarimetry, TF
  - Fed by MCAO (SCAO and LTAO)



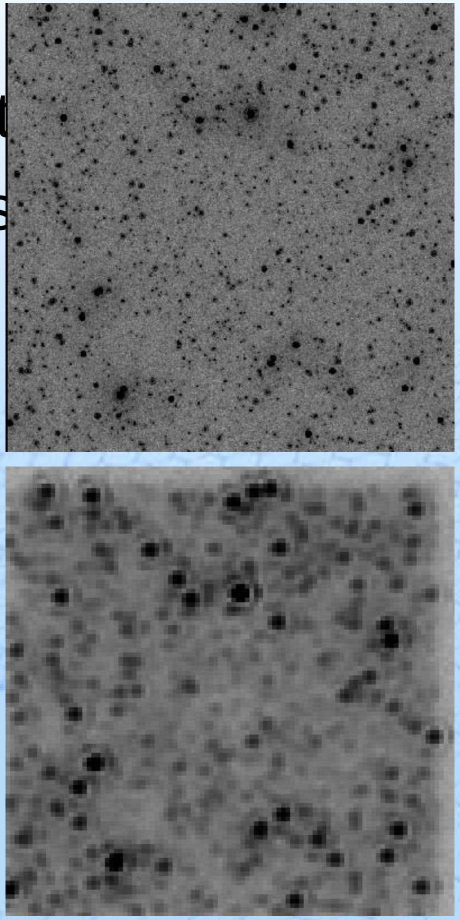
MICADO opto-mechanical overview

MICADO Science

- Young stellar objects in our galaxy
- Resolved Stellar populations to the Virgo clust
- Star formation and structure of high-z galaxies
- Astrometry (Galactic Centre, MW Globular clusters)



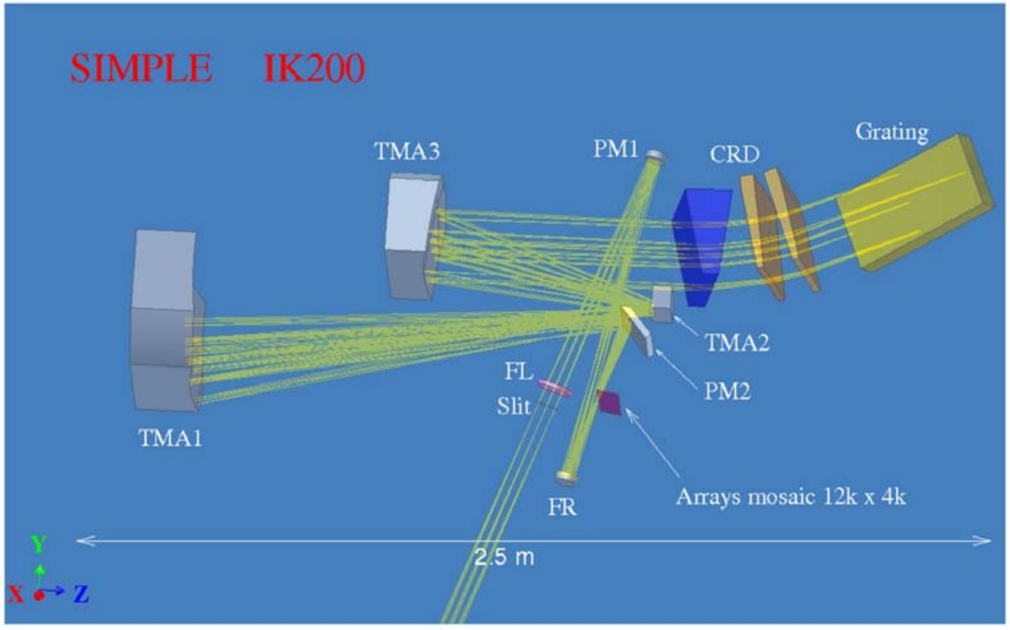
Simulation by MICADO team



Above : Comparison of a 5-hr K-band exposure of a simulated stellar field, observed with MICADO (top) and JWST (bottom). ~4x4 arcsec.

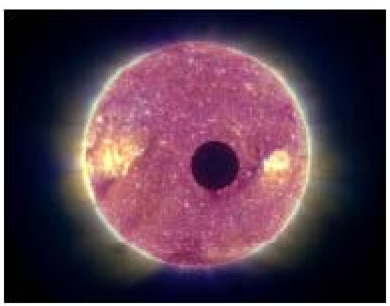
SIMPLE

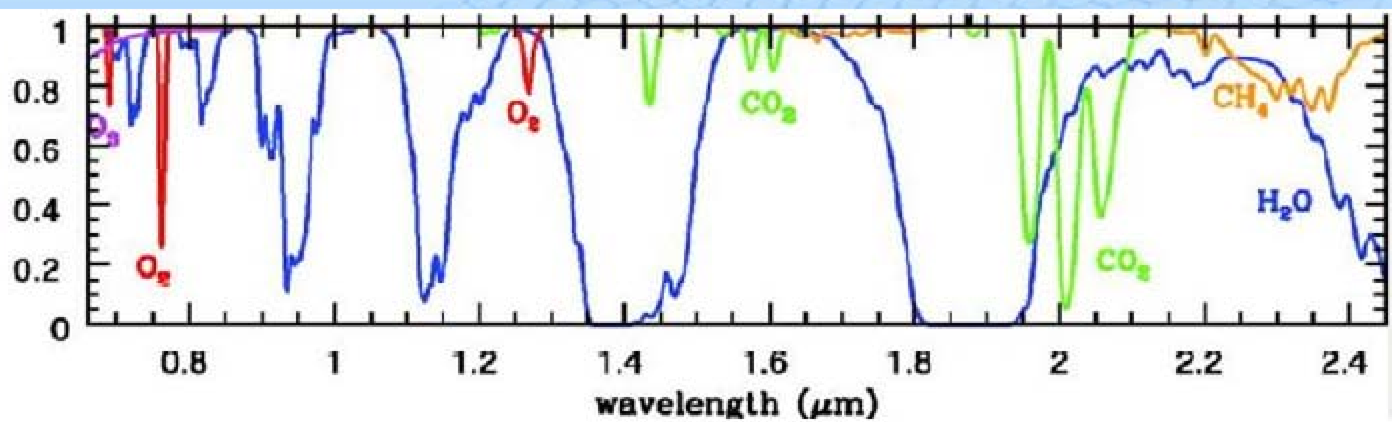
- PI: Livia Origlia, INAF, Osservatorio Bologna
- Institutes: INAF (Bologna, Arcetri and Roma); UAO, Thuringer Landessternwarte; Pontificia Universidad Catolica de Chile
- NIR, high-resolution (R>100000) spectrograph
- Coude focus
- Single slit fed by LTAO



SIMPLE Science

- Detection and characterization of exo-planet atmospheres
- Early nucleosynthesis and chemical enrichment in the inner Galaxy
- Chemical and dust enrichment of proto-galaxies in the early Universe at the reionization epoch.





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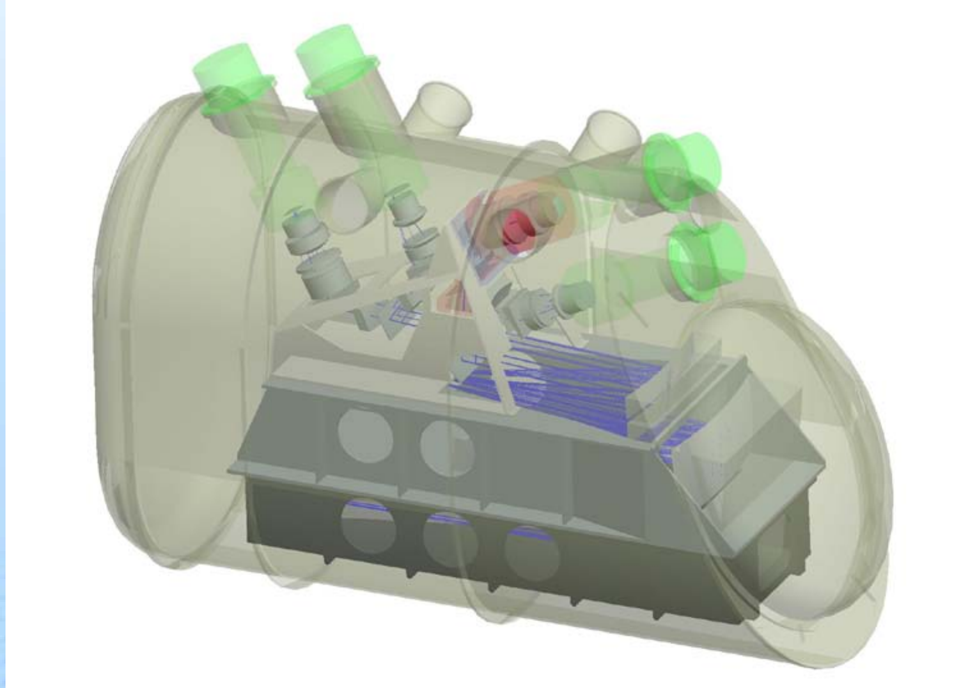
CODEX

Ultra-high resolution optical spectrograph

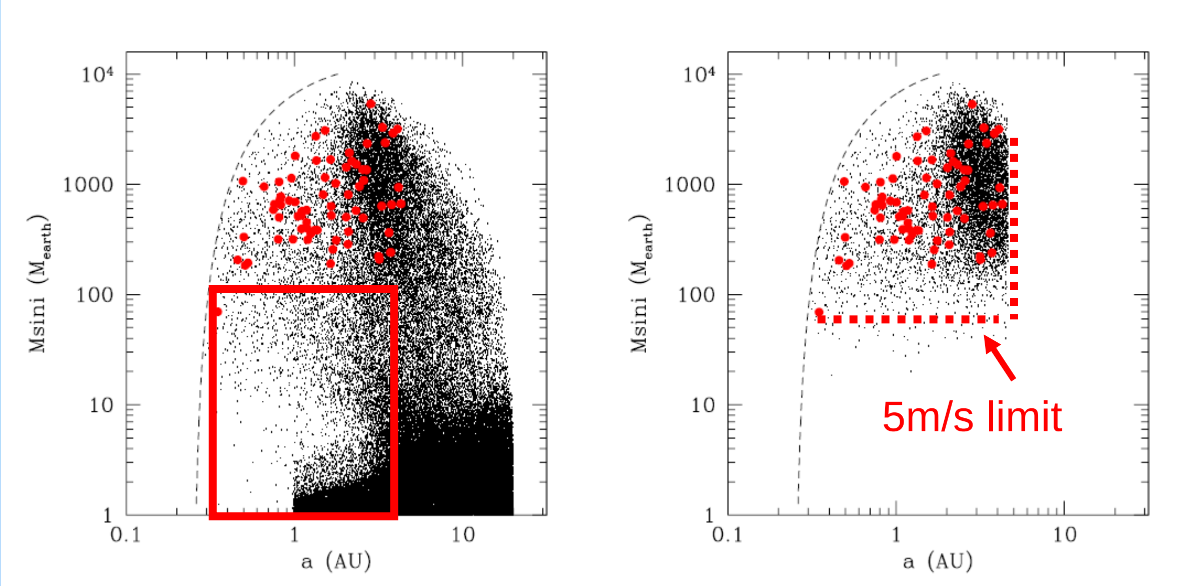
- PI: Luca Pasquini, ESO
- Institutes: INAF (Trieste, Brera); IAC; IoA, Cambridge; Observatoire Astronomique de l'Universite de Geneve;
    - Ultra stable : 2cm/s rv precision
    - At Coude focus
    - No AO required



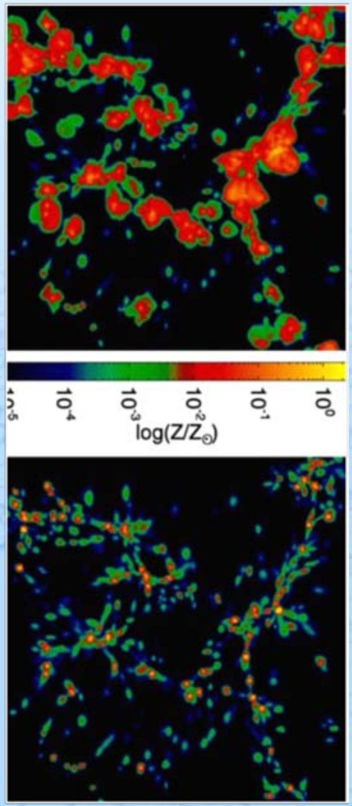
CODEX mechanical concept

CODEX Science

- Dynamical measurement Universal expansion
- Extrasolar Twin Earths
- Variability of Physical Constants
- Metallicity of the low density IGM



RV exoplanet detection - Figure: Benz, Mordasini, Alibert & Neaf, 2005



Metallicity of a 11 × 11 Mpc^3 slice at redshift z = 3 with (*left*) and without (*right*) galactic superwinds (Cen et al 2005)

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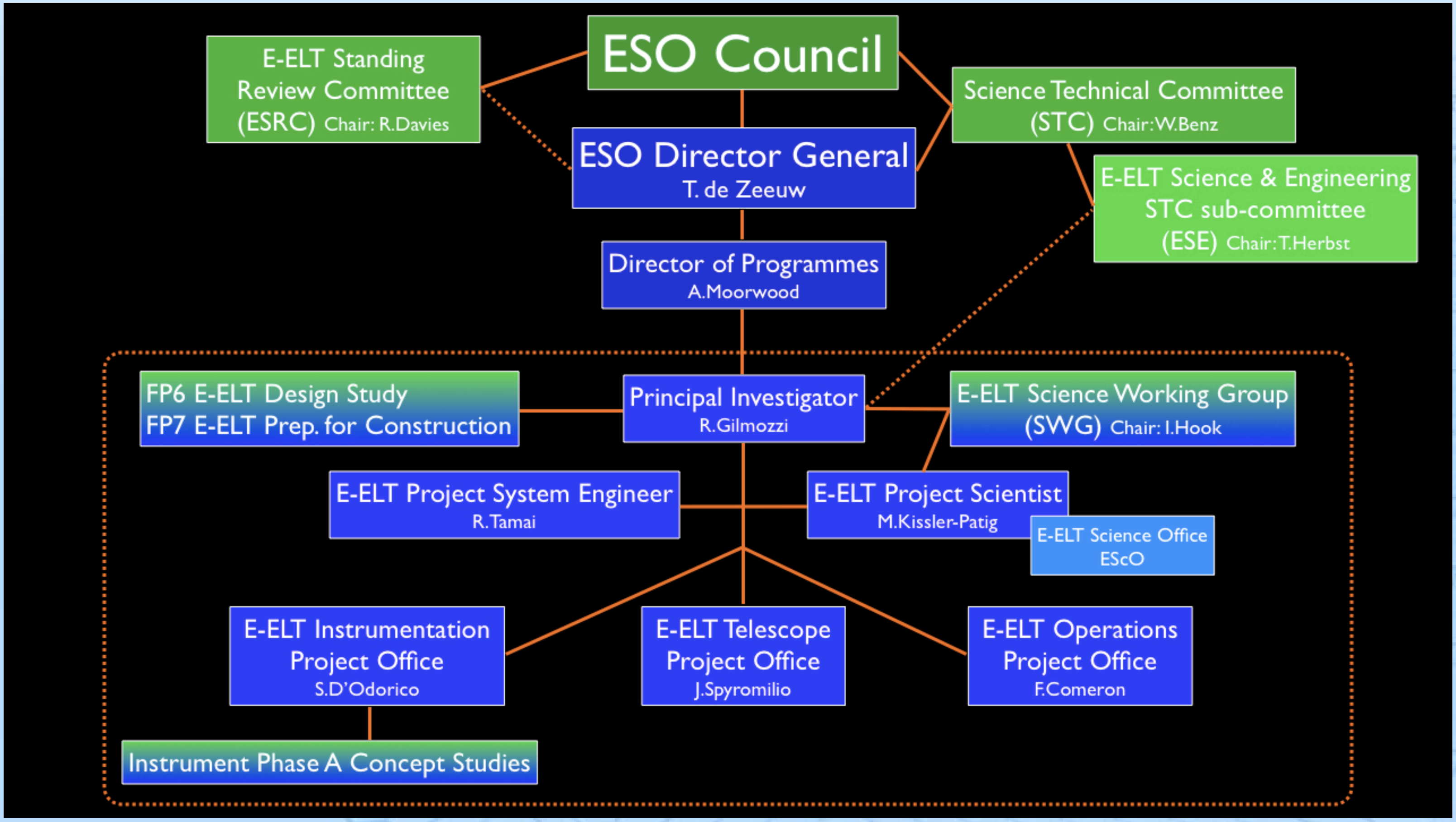
Project Organisation

- Project led by ESO on behalf on its 14 member states
- Strong involvement of member state industries and scientific communities

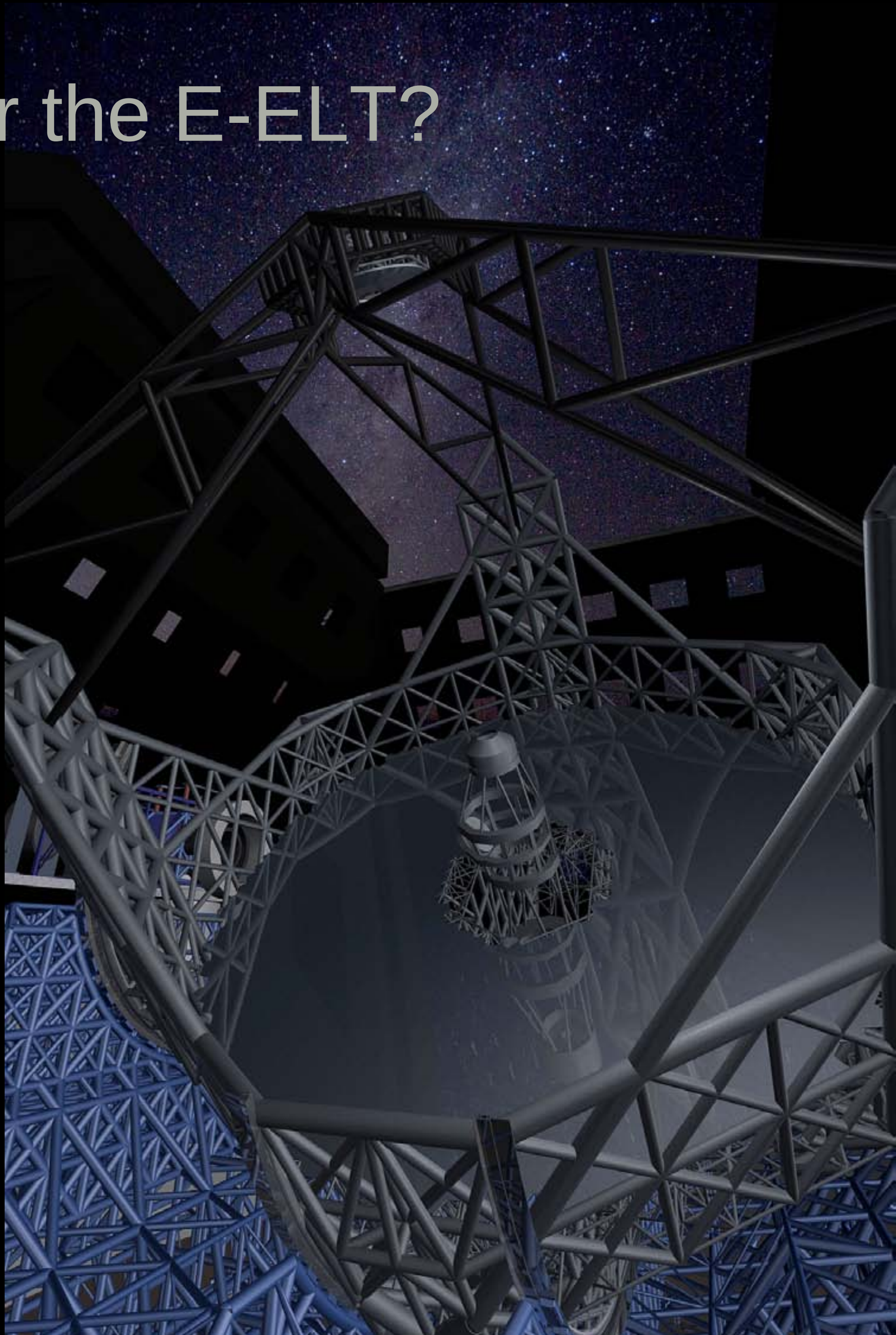


Community

ESO

What happens next for the E-ELT?

- Site selection by end 2009
- Phase B complete by end 2010
- Construction proposal to be presented to ESO Council – Dec 2010
  - Final cost estimate based on industrial studies
- Plan for 'first light' in 2018



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More information?

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

- The public web pages:
  http://www.eso.org/public/astronomy/projects/e-elt.html

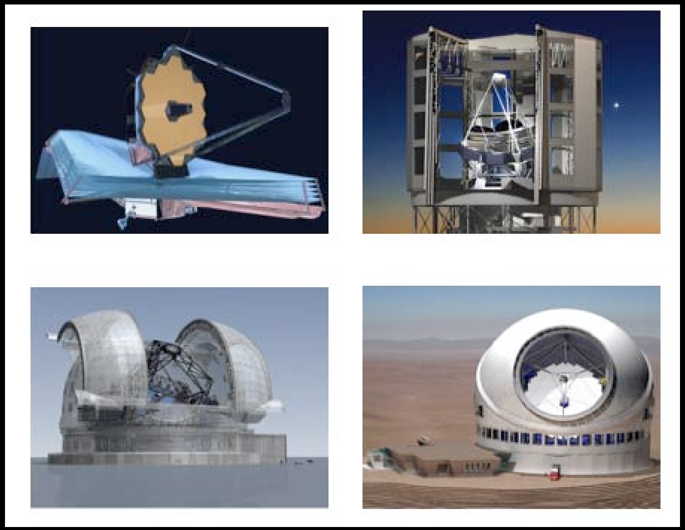
- Brochures, Posters, etc:
  http://www.eso.org/public/outreach/products/publ/brochures/index.html

- Gallery: **http://www.eso.org/gallery/v/ESOPIA/EELT**

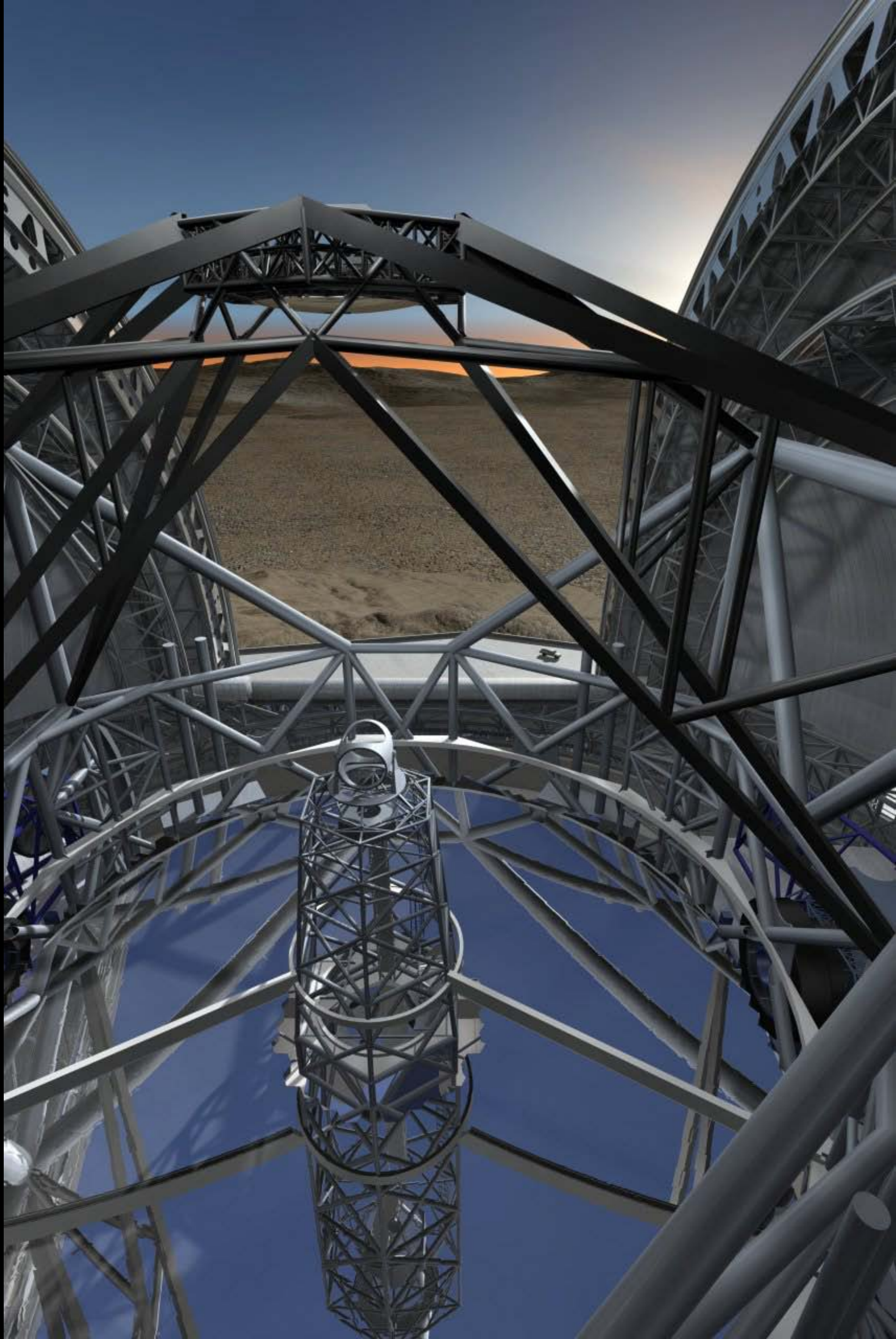
- Watch out for science meetings every year

Upcoming events

- ELT + JWST joint ESO/ESA workshop
  - 13-16 April 2010
  - Registration open
- "Astronomy with Megastructures"
  - 10-14 May 2010, Crete
  - Joint OPTICON + Radionet workshop



The End



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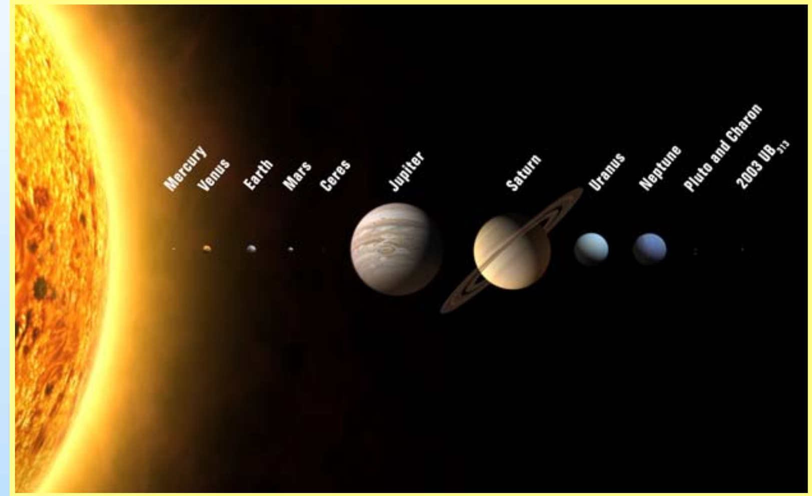
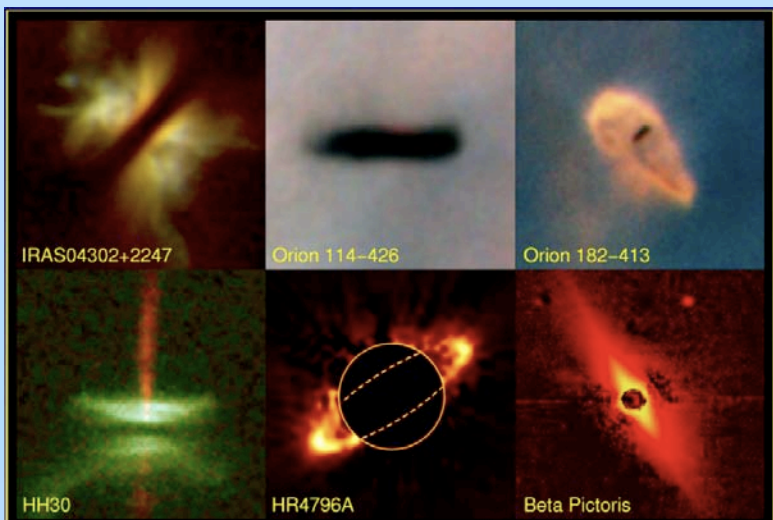
Planets & Stars

From giant to terrestrial exo-planets:

- Direct detection via high-contrast imaging
- Indirect detection via radial velocity variations





Circumstellar disks

Young stellar clusters and the initial mass function

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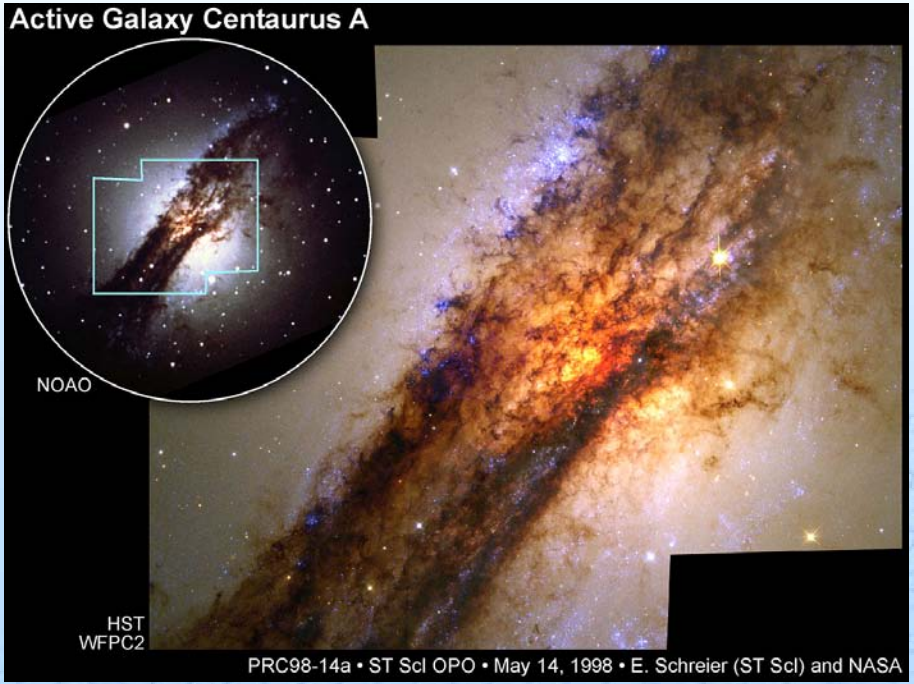
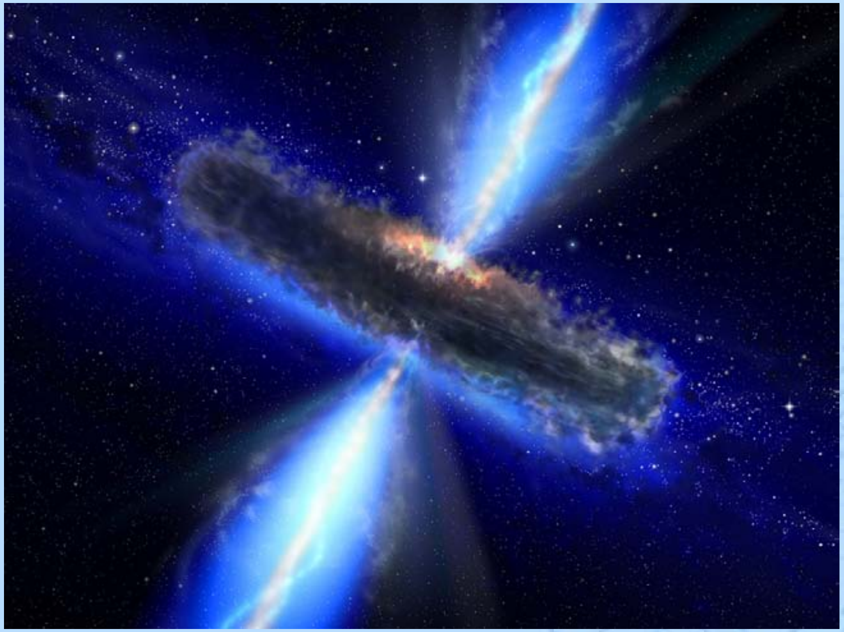
Stars & Galaxies



Imaging and spectroscopy of extragalactic resolved stellar populations



Studies of black holes and active galactic nuclei (AGN)

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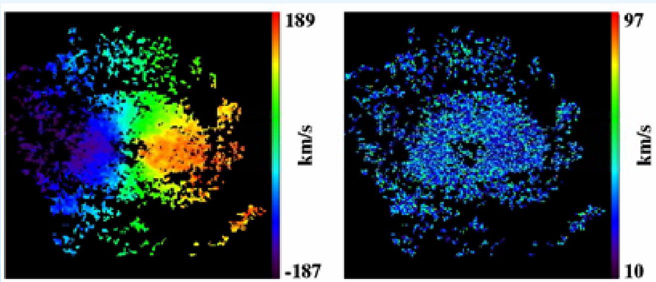
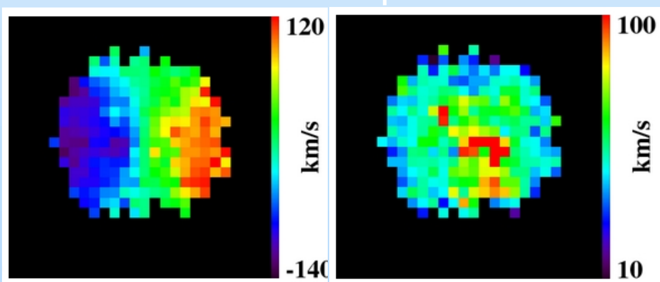
Galaxies & Cosmology

V σ

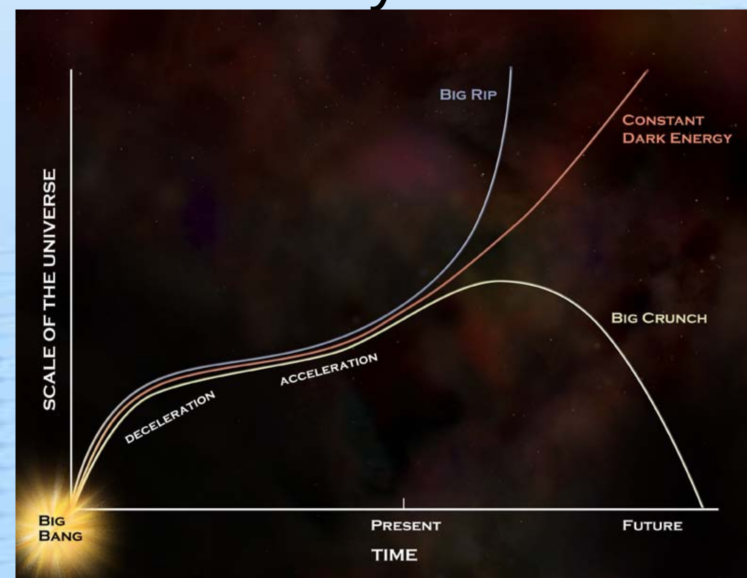


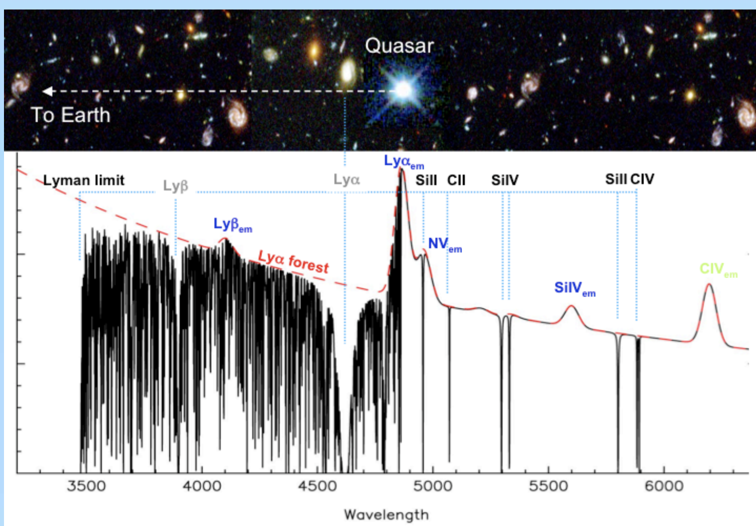
z ~ 4 50 mas pixels



First-light: The physics of the highest redshift galaxies

A dynamical measurement of the expansion history of the Universe





Studies of the intergalactic medium (IGM) and metal enrichment

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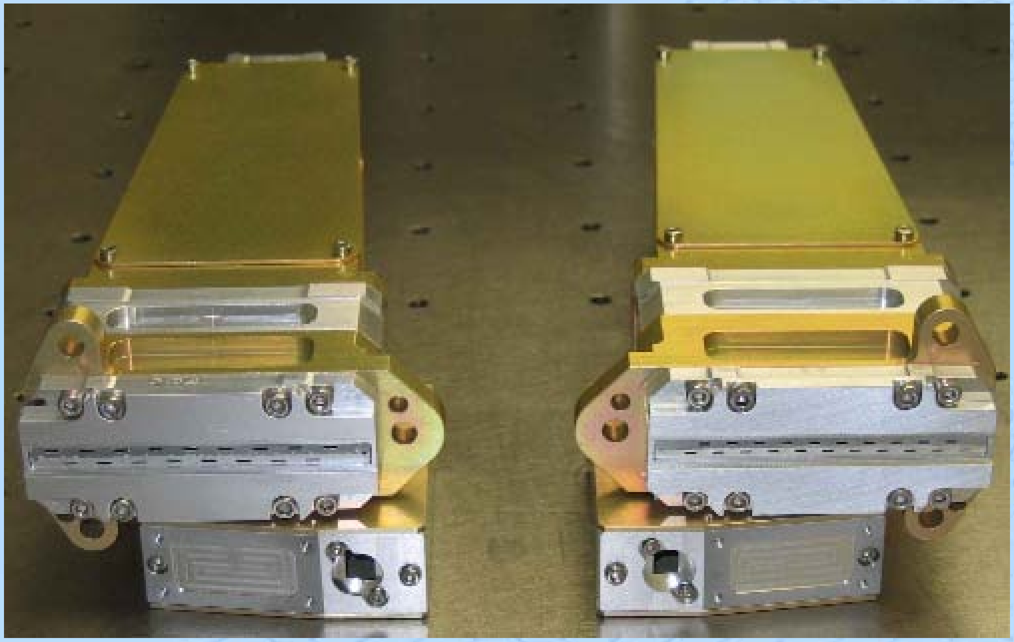
METIS

UK Contribution

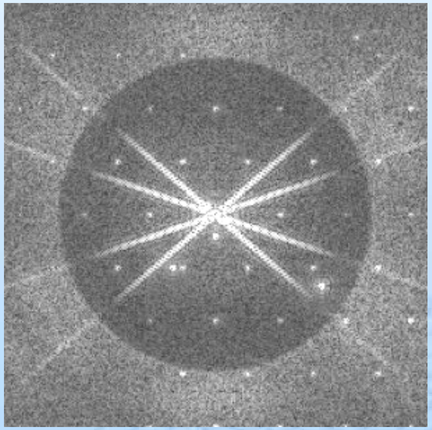
- The JWST-MIRI spectrometer pre-optics have been developed, built and tested by the UKATC – similar concepts to be used in METIS.
- Includes 4 all-reflective, diffraction-limited IFUs



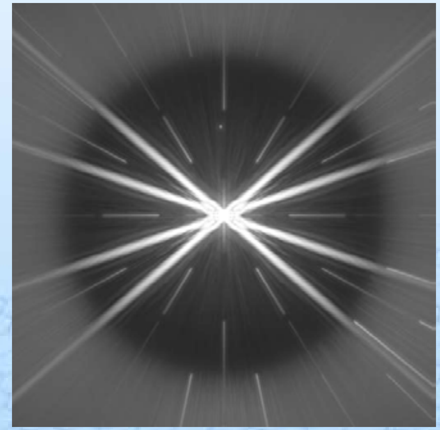
EPICS
UK Contribution

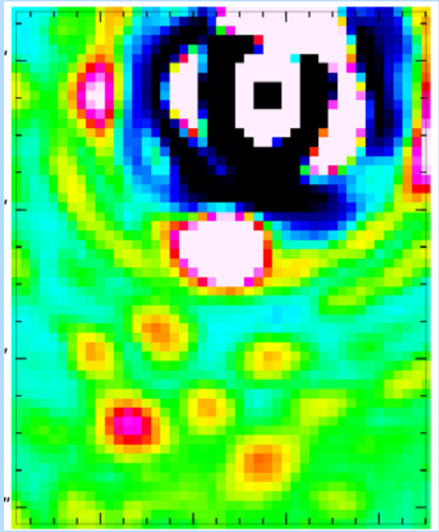
- Image-slicing methods can be used to remove “speckles” – spots from coherent interference.
- Speckles can appear as real objects, but scale with λ.

Speckles

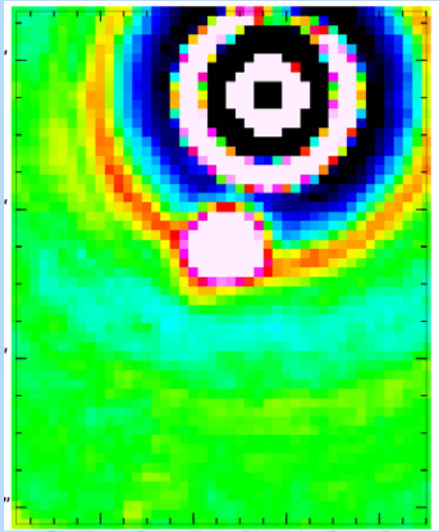


Speckles vs. λ





BEFORE



AFTER

- Concept proven with VLT-SINFONI (left)
- Thatte et al MNRAS, 378, 1229 (2007)

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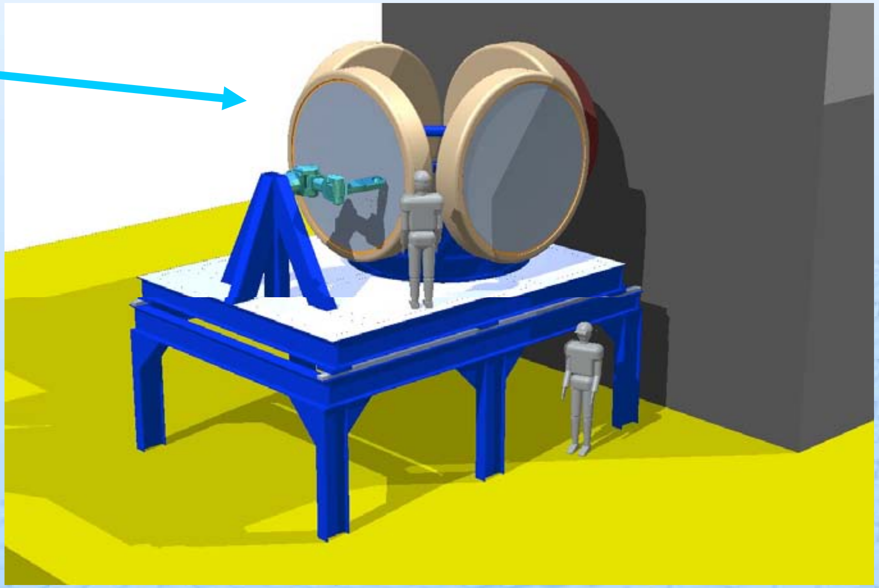
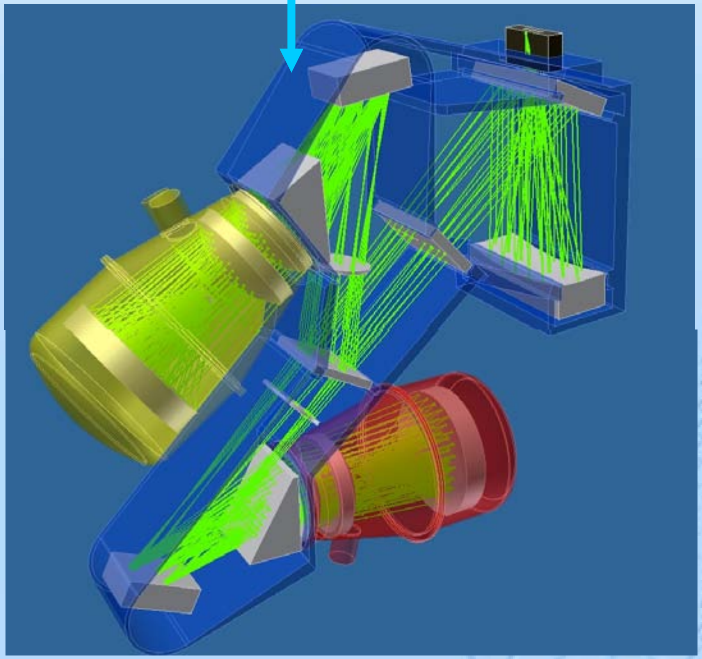
OPTIMOS
UK Contribution

- Fibre-positioner study
- Input to spectrometer design





- Electronics design
- Detector control design

S9-1: Imaging of circumstellar disks

Daniela Villegas

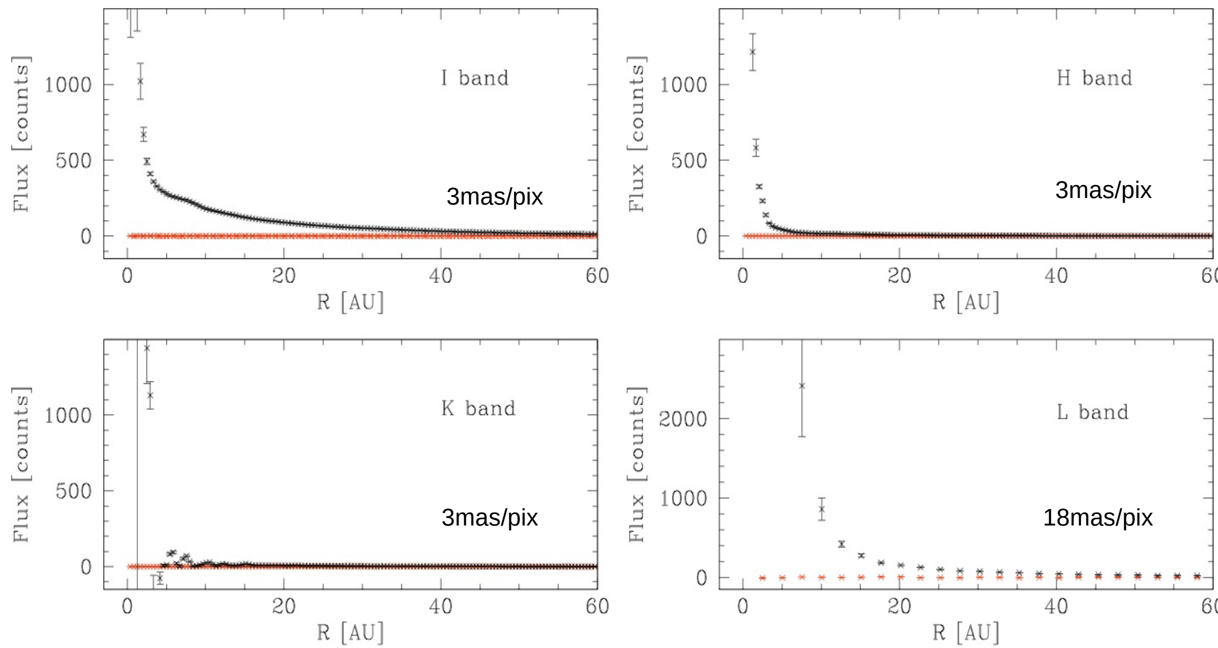
<u>Model</u> (C. Pinte)

Star: TTauri, 3900°K, $3R_\odot$

Disk: - face-on, 10^{-3} $M_\odot$
- R_{in}= 0.8AU
- R_{out}= 400AU

Gap: - Gaussian shape
- R = 10AU
- width = 2AU

<u>Disk Detection</u>: 140pc, image PSF known

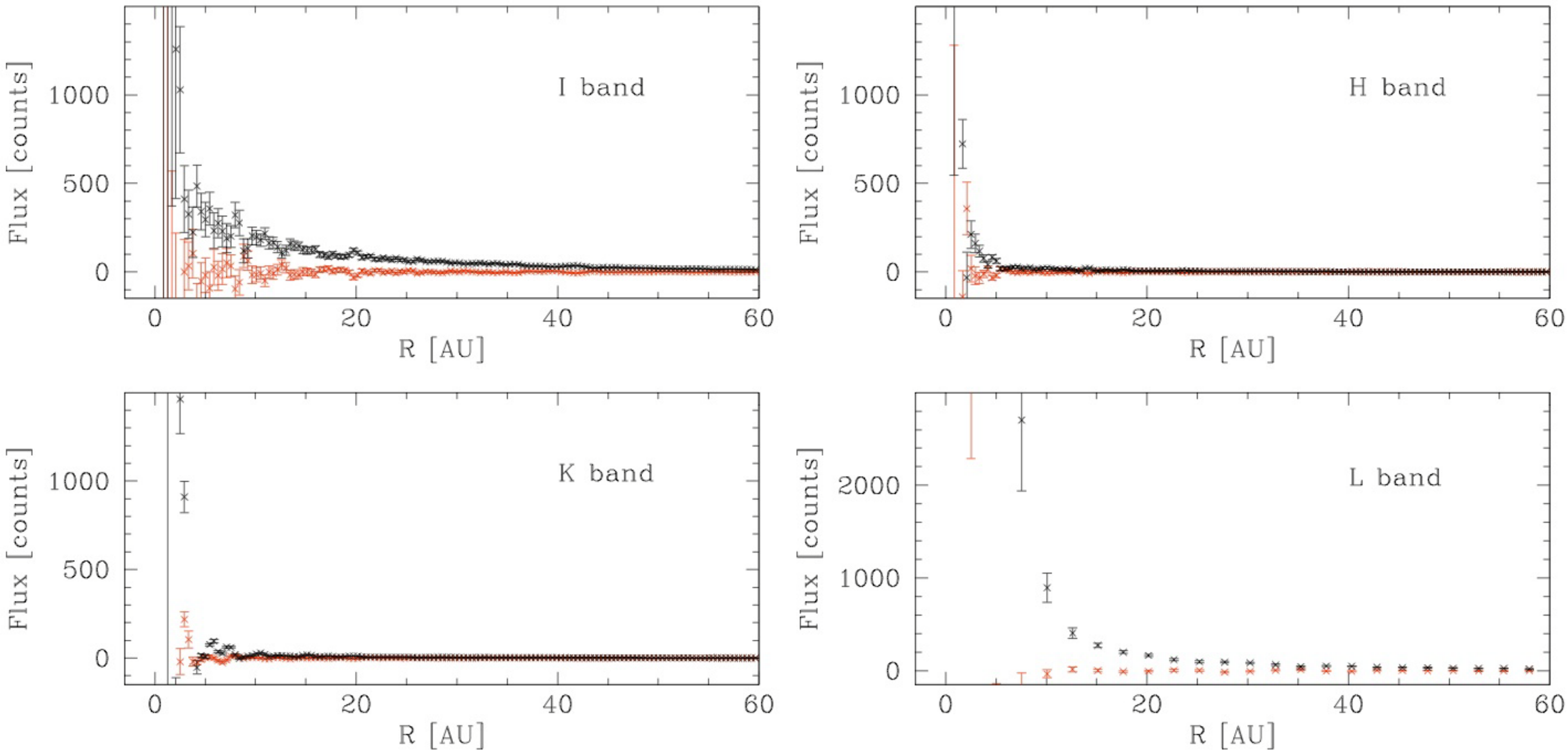


<u>Gap detection</u>
2AU gap -> ~5pix at 140pc (IR only)
Requires the use of precise deconvolution techniques.
Currently testing best deconvolution approach.

- Imposes requirement on minimum exposure time of instruments (~0.01s in K band).
- Requires good PSF knowledge to be feasible at larger distances.

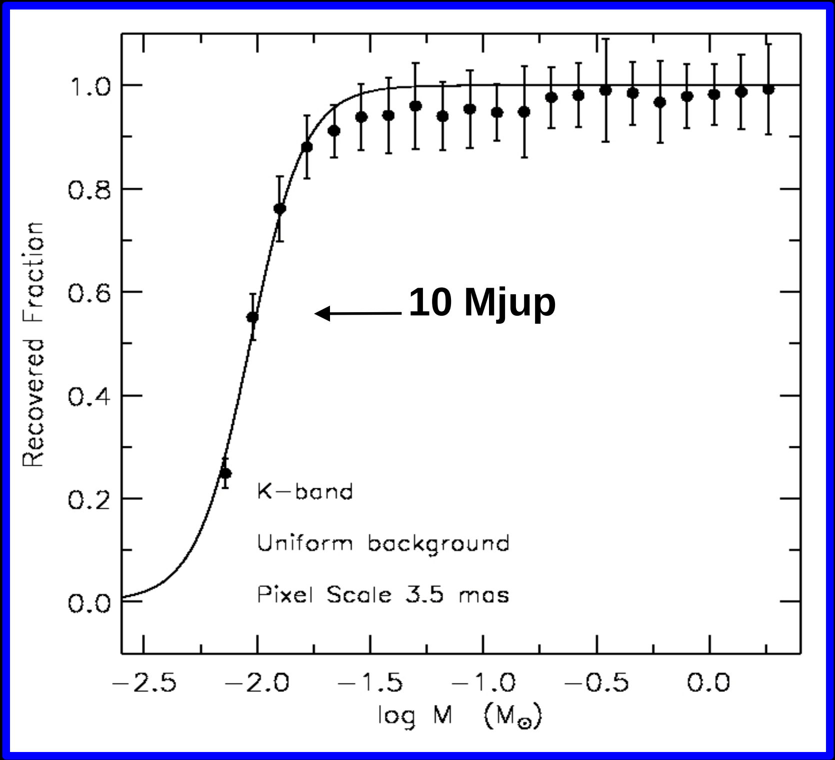
S9-1: Imaging of circumstellar disks

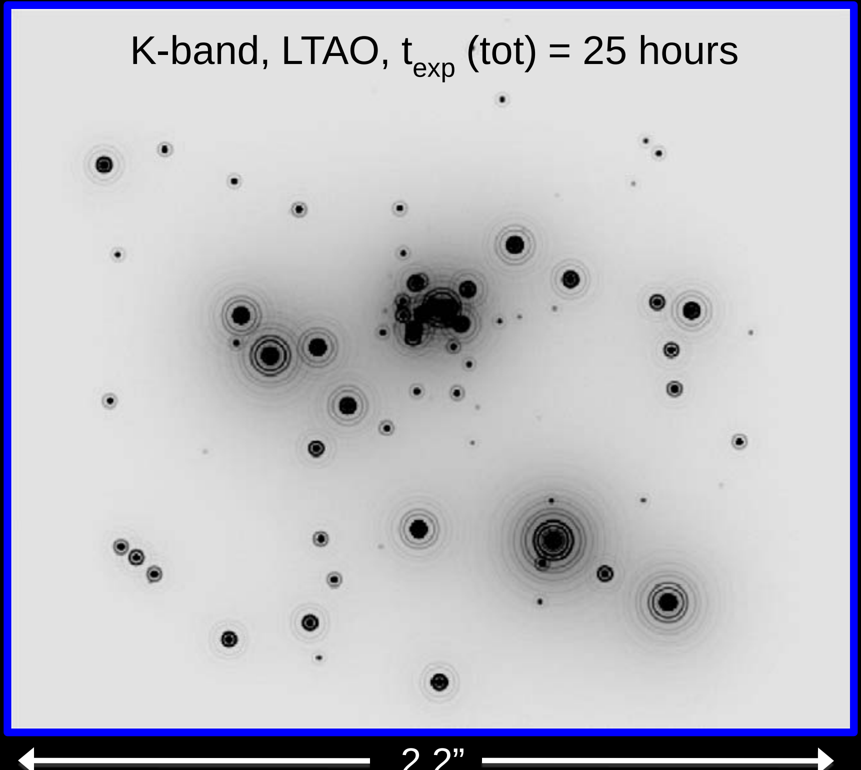
<u>Disk Detection</u>: 140pc, image PSF rotated by 90 deg



Young Stellar Clusters & the IMF
(F. Comeron and A. Calamida)

- To probe the complete substellar mass regime of a young star forming region in LMC down to 5 M_J
- To reveal the lowest-mass IMF

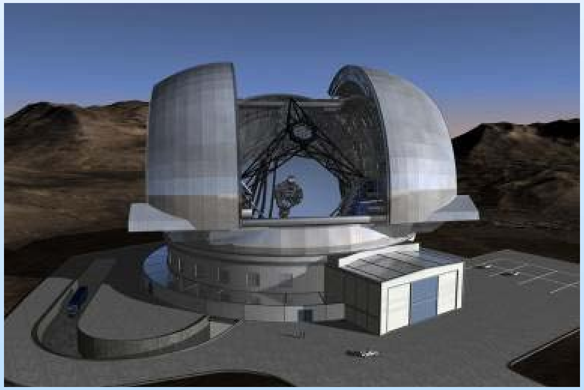




- **Issues**
  - crowding (~20 star/arcsec^2)
  - Dynamic range (Δmag ~ 11)
- **Need to reach J~29.1, K~28.2 (10σ)**

METIS

E-ELT METIS vs. JWST-MIRI



E-ELT METIS:

- Comparable PS spectral sensitivity
- 5-8 times higher angular resolution
- High spectral resolution (kinematics)
- Shorter response times
- Optional polarimetry
- Follow up as for HST →VLT

JWST-MIRI:

- Continuous spectral coverage
- Larger FOV with constant PSF
- Better imaging sensitivity
- Much better LSB sensitivity
- Better spectro-photometric stability
- 100% sky coverage, good weather

Space and Ground are Complementary