The European Extremely Large Telescope

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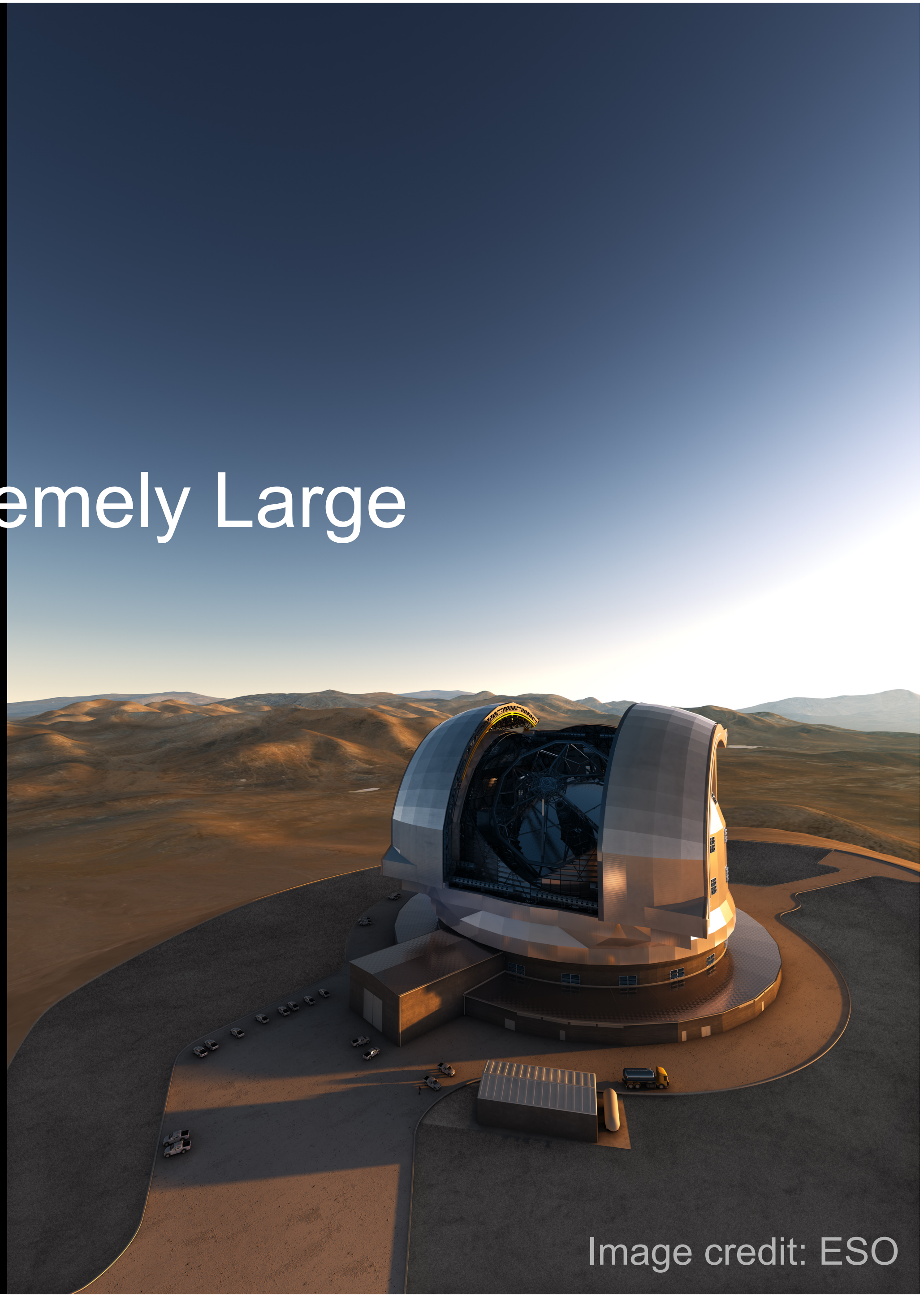


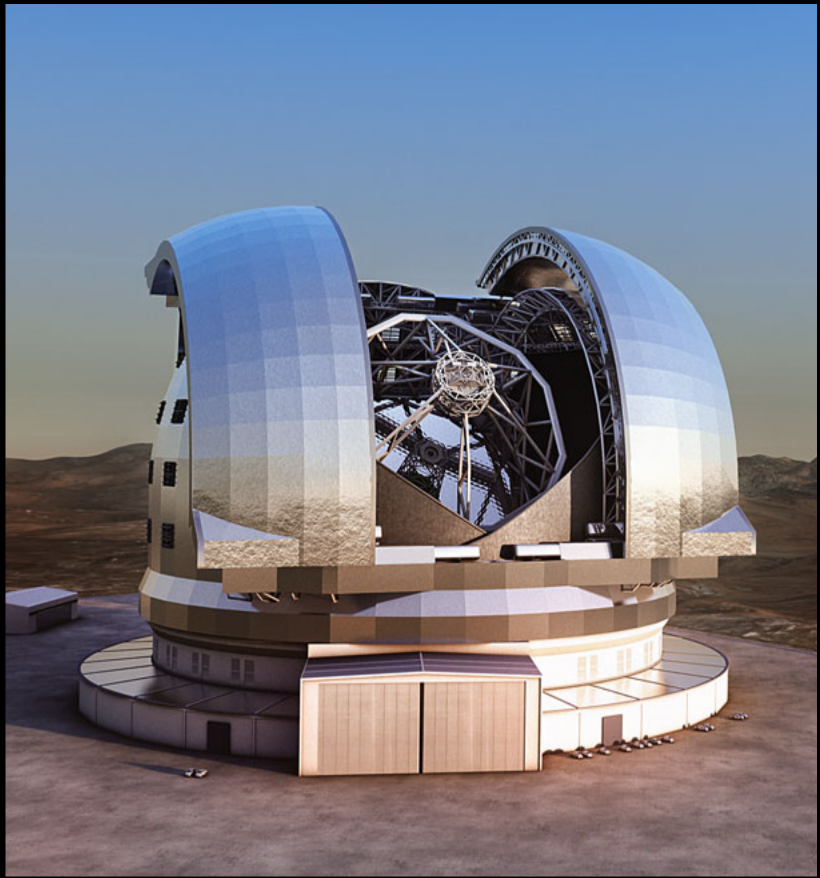
Image credit: ESO

Acknowledgements

- Community science cases
- Observatory & Instrument science cases
- Instrumentation white papers
- E-ELT Science Working Group
- E-ELT Project Science Team

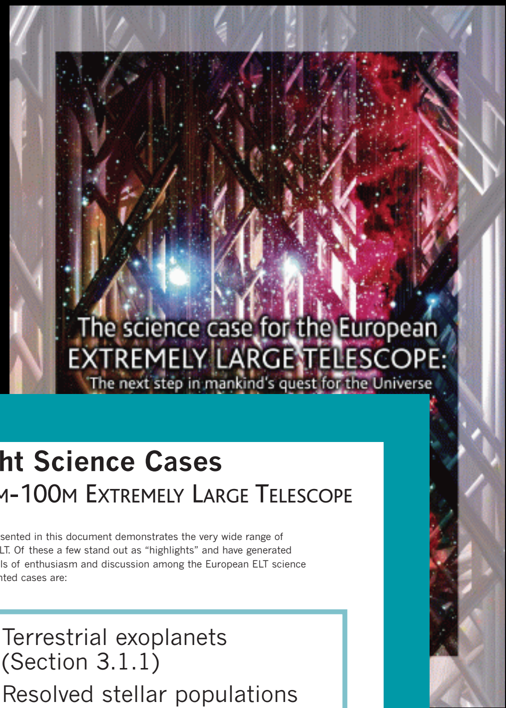
E-ELT Project and Status

- 39m diameter telescope with adaptive optics built in
- Dec 2014: ESO Council gave green light for E-ELT construction in two phases
  - funding approved for Phase I
  - Still expectation that both phases will be completed
  - Plan does not diverge from previous baseline until 2017
- Preparatory work already well underway
- Expected first light 2024



Some history (of science drivers)

- 1990s: Early work ELTs: OWL and Euro-50
  - Versatile, optical-IR telescopes
  - Excellent image quality, steerable, range of instrumentation
- Community meetings
  - E.g. Backaskog 1999
- 2005: OPTICON science case document
- 2006: E-ELT SWG formed
  - Chair M. Franx, later IH
  - Report in April 2006
- 2006: Marseilles meeting
  - Baseline 40m design presented
- 2011: Construction proposal published – Dec
  - Science case, DRM report
- 2012: SWG replaced by PST at end of Phase B
  - Chair G. Bono
- 2012: ESO Council approved E-ELT programme – June



Highlight Science Cases

FOR A 50M-100M EXTREMELY LARGE TELESCOPE

The science case presented in this document demonstrates the very wide range of applications for an ELT. Of these a few stand out as "highlights" and have generated particularly high levels of enthusiasm and discussion among the European ELT science group. These highlighted cases are:

(1) Terrestrial exoplanets (Section 3.1.1)

(2) Resolved stellar populations in a representative section of the Universe (Sections 4.2 and 4.3)

(3) First light and the re-ionisation history of the Universe (Section 5.2)

These are seen as some of the most exciting prospects for ELTs precisely because they push the limits of what can be achieved, and they will provide some of the most technically challenging specifications on telescope design. The boundaries of what is achievable in these scientific areas (and others) will not be known exactly until the ELT is in operation, although more precise feasibility assessments will be possible when the technical studies described above are complete. We now present the science case that we believe is within range of a 50–100m ELT based on our current understanding of the technical issues.

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

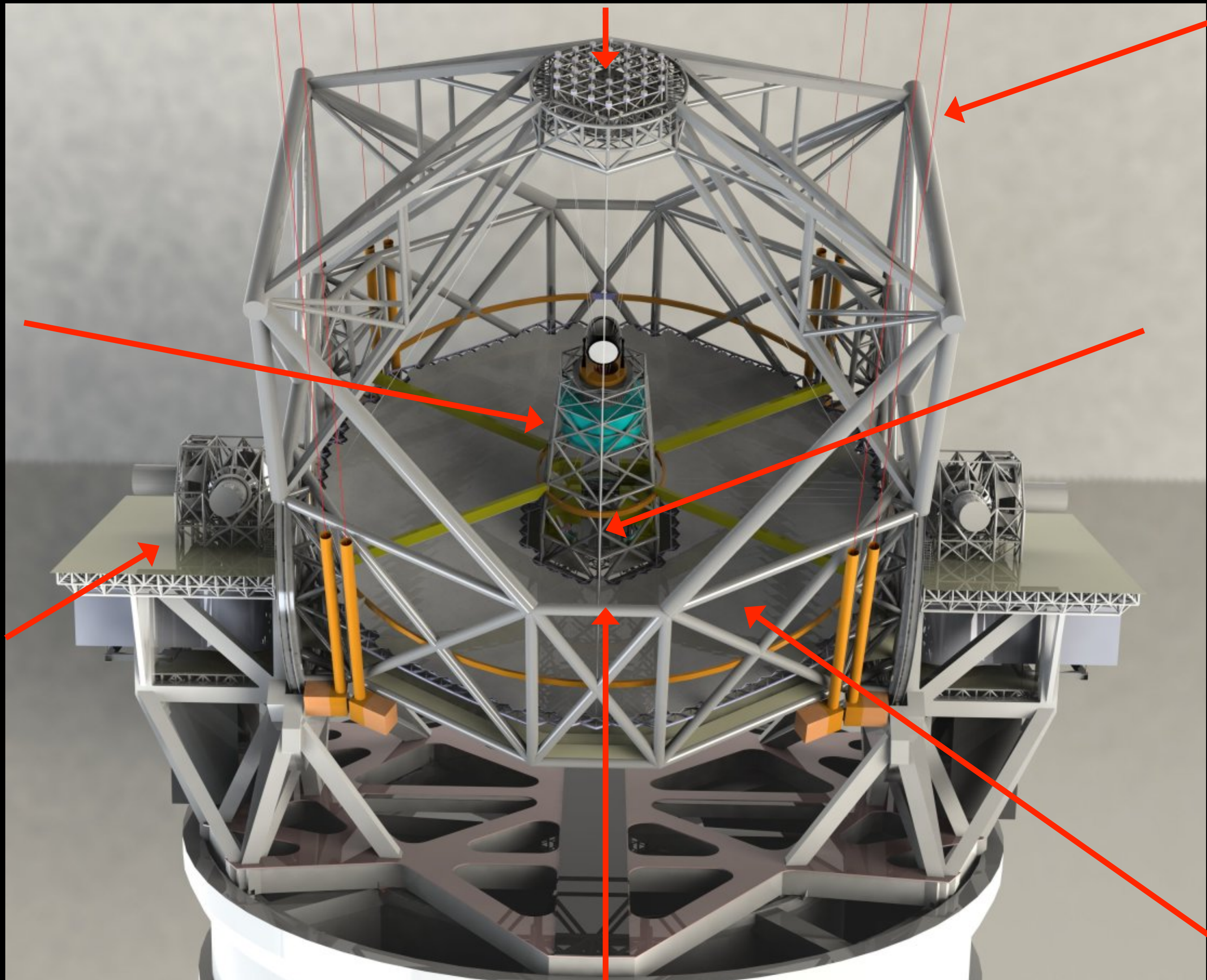
Deep Galaxy Studies at z=2-5

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

- Selected from larger set
- Not complete!
- Basis for Design Reference Mission
  - Observing proposals
  - Simulated data (EScO)
- Note also DRSP 2009
- See www.eso.org

E-ELT Revised baseline design



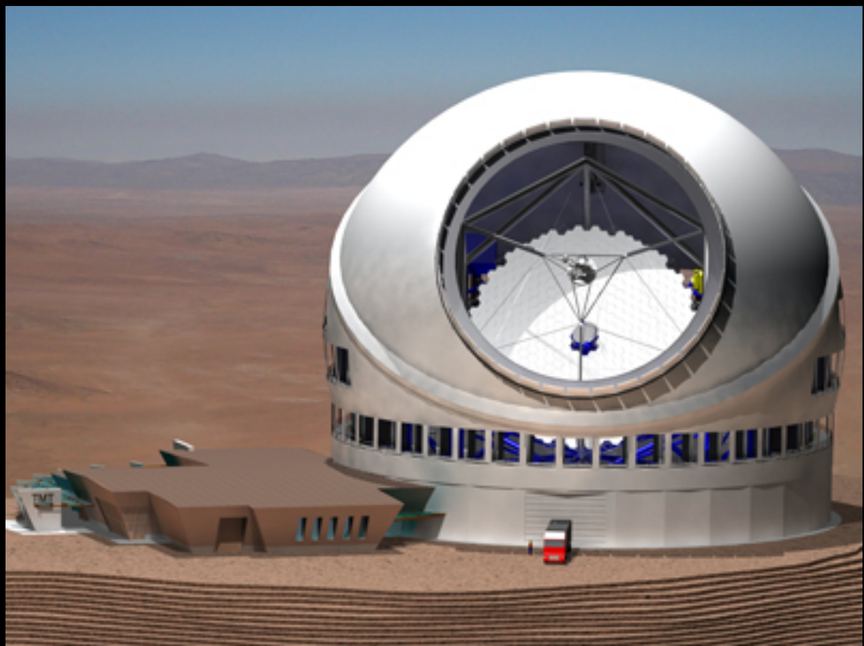
Other International ELT projects

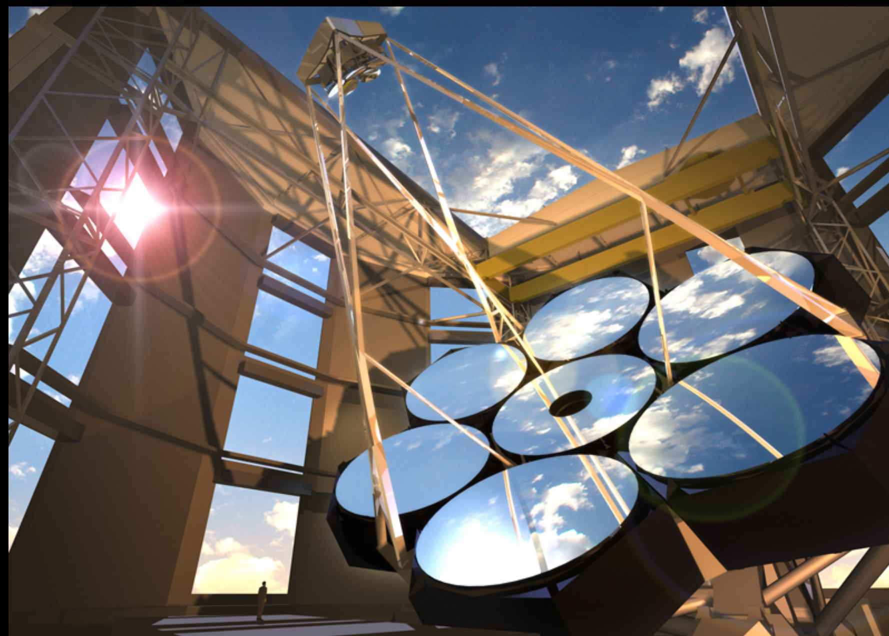
TMT

- 30m telescope
- Institutes in US, Canada, Japan, India, China
- Master agreement signed July 2013
- Groundbreaking Oct 2014
- First light planned 2022 Q4
- Begin science operations 2023

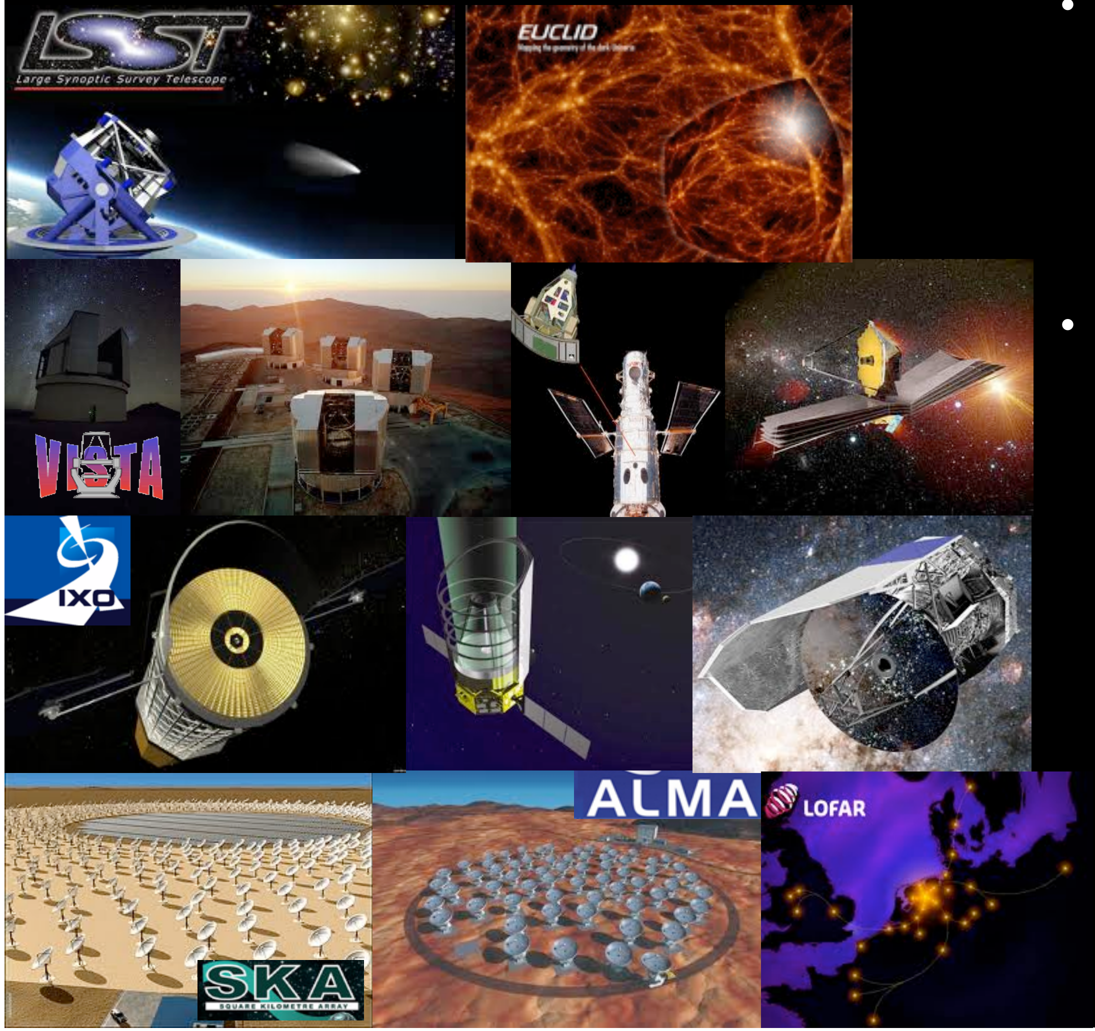
GMT

- 24m diameter (7x 8m segments)
- Collaboration of private US universities, Australia (ANU + AAL) + Korea
- 3rd mirror cast August 2013
- First light (4 segments) planned 2019
- Begin full science operations ~2023





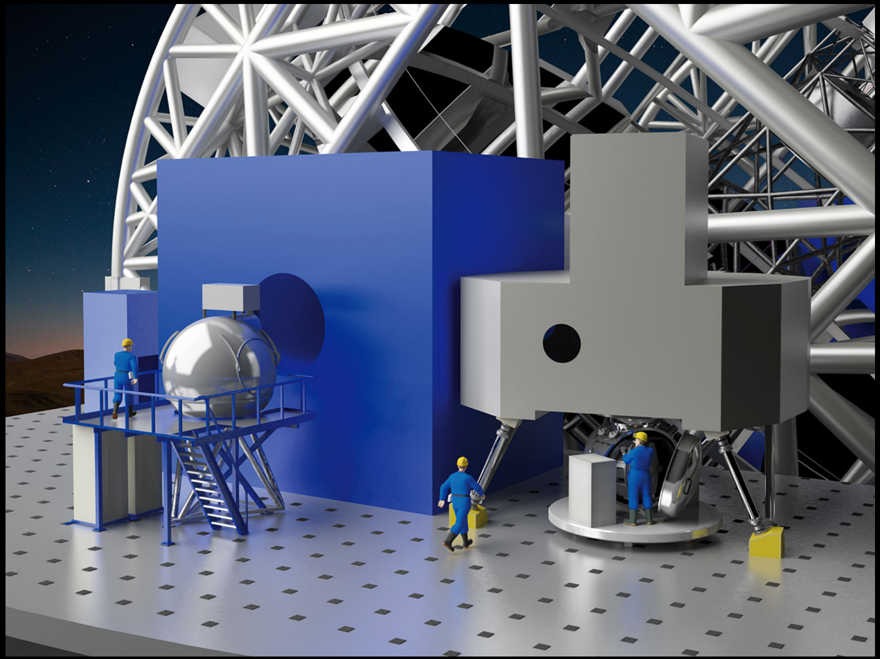
Synergies with major facilities



- Sensitivity
- High angular resolution
  - matched to ALMA and SKA
  - 7x sharper images than JWST
- Follow-up of sources discovered by other telescopes
  - Spectroscopic and high angular resolution
  - Identification and physics

Slide from A. Verma

E-ELT Instrumentation



- Phase-A studies completed 2010
  - 8 instruments, 2 AO modules
- Two selected for first light
  - ELT-CAM (MICADO)
  - ELT-IFU (HARMONI)
  - With associated AO systems
- Full instrument suite to be built up over first decade
  - At least one each of MID-IR, MOS & HIRES
  - Exo-planet instrument
  - Open slot 6
- Future decision points specified
  - roadmap updated periodically

E-ELT Instrumentation Roadmap (Jan 2015)

Year	ELT-IFU	ELT-CAM	ELT-MIR	ELT-MOS	ELT-HIRES	ELT-6	ELT-PCS
2014	Decide science requirements, AO architecture.		VISIR start on-sky	Develop science requirements for MOS/HIRES			Start ETD
2015				Cal for Proposals Start Phase A			
2016				Consortium Selection for construction		Call for proposals	
2017							
2018							TRL check
2019						Selection	Start when ready
2020							
2021							
2022							
2023							
2024							

Pre-studies

Decision point

Development of tech specs, agreement, Instrument start

- Top level requirements being developed with PST
- Instrument science cases used as starting point
- Within each instrument, prioritisation of cases + modes still to be done

Exoplanets: Are we alone?

How do planetary systems form?

How common are systems like ours?

What atmospheres do planets have?

Are there other Earths?

Can we detect signs of life?

E-ELT

Direct Detection

Spatial resolution & sensitivity

Resolution of dusty disks in which they are forming

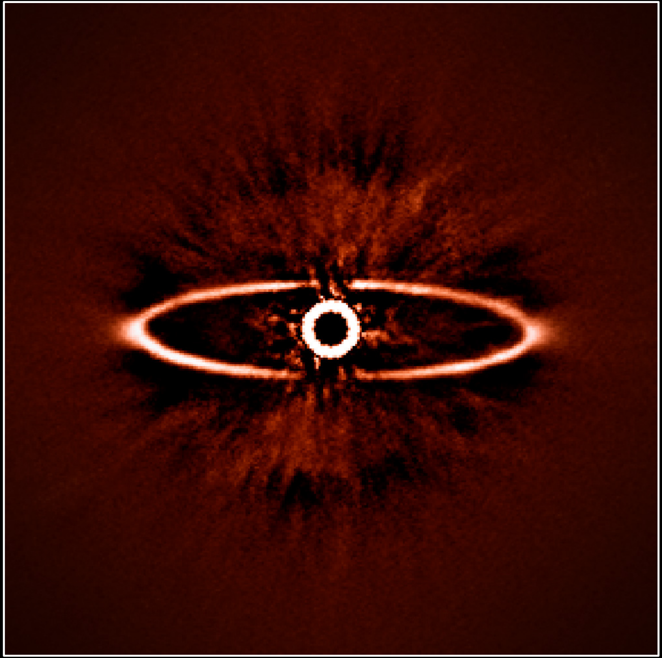
Indirect methods: Radial velocity and astrometry

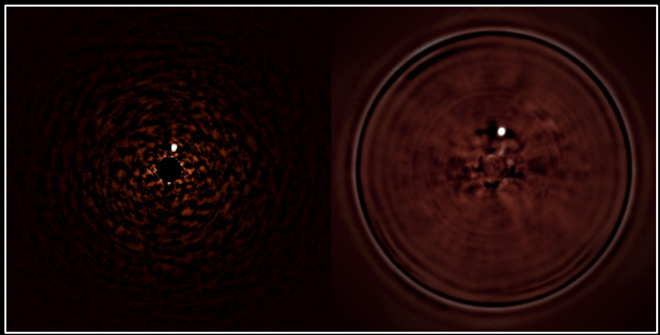
Potential to reach lower-mass planets, including Earth-mass

Characterise atmospheres

Constituent elements, signs of life

Direct detection of exo-planets

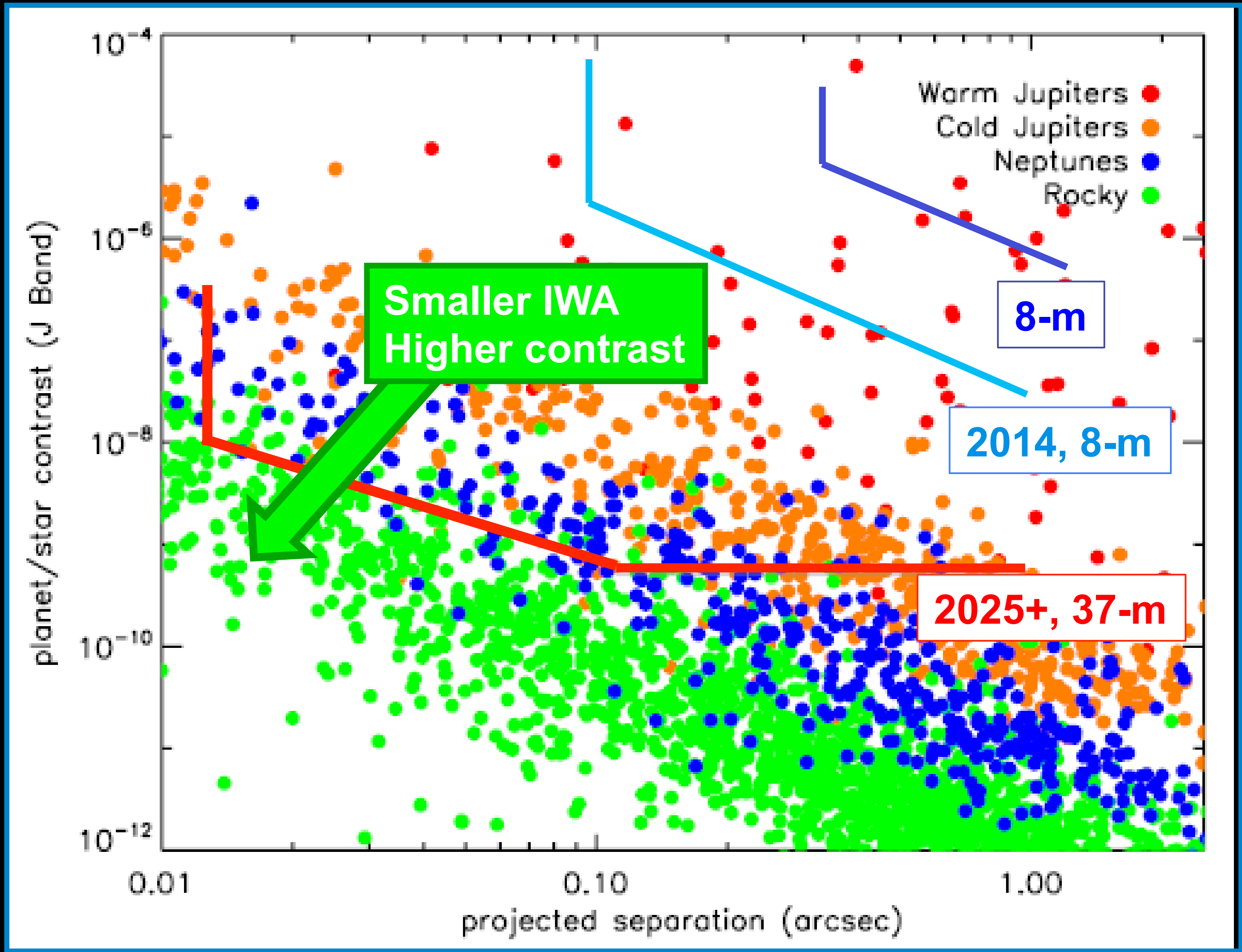




- Now: self-luminous (young) exoplanets
  - direct detection
  - direct spectra
  - New: SPHERE and GPI
- E-ELT + MICADO
  - Moderate contrast search for planets at smaller separation / more distant systems
- E-ELT + HARMONI, METIS
  - characterisation of planets discovered by SPHERE and GPI
- E-ELT + EPICS
  - Specialised exo-planet instrument (XAO)
  - Rocky exoplanets
  - In habitable zone

Early SPHERE results, top: dust ring around the nearby star HR 4796A, bottom: of faint companion to HR 7581. Top: dual imaging camera, bottom: IFS.
Image credit: ESO/J.-L. Beuzit et al./SPHERE Consortium

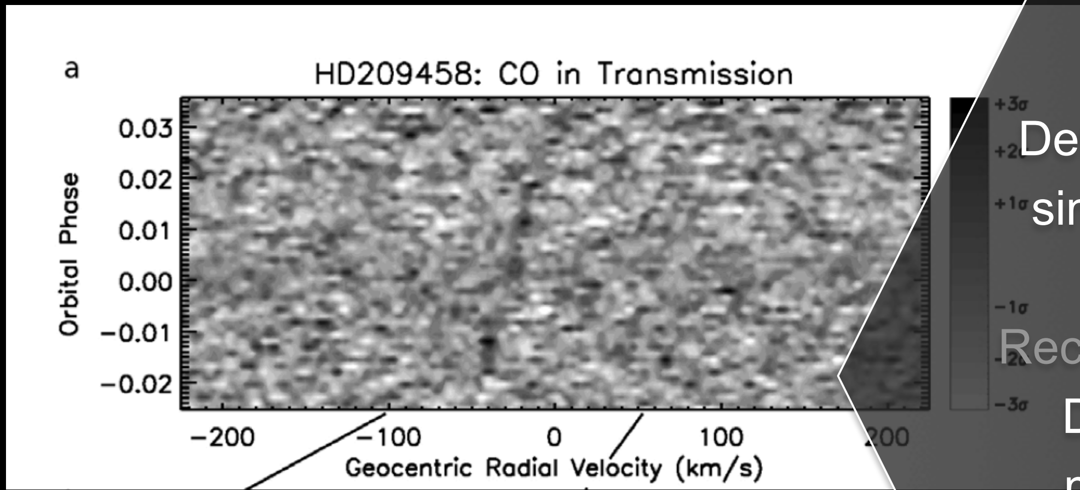
Exo-planet detection parameter space



Models form Bonavita et al. 2012
Slide from M. Kasper

Exo-planet atmospheres

- High resolution spectroscopy can detect features in the planet atmosphere itself
  - Exploit much higher radial velocity shifts than in the parent star
- Absorption strength and shape > chemistry and wind patterns



Cross correlation spectra vs template containing 56 CO lines, as a function of phase during one transit. Star mass ~1Msun, planet 0.6M_J. [Observations made using VLT/CRIRES at 2μm - Snellen et al 2010 Nature]

E-ELT

Detect CO, CO_2, H_2O CH_4 simultaneously for Jupiter sized planets

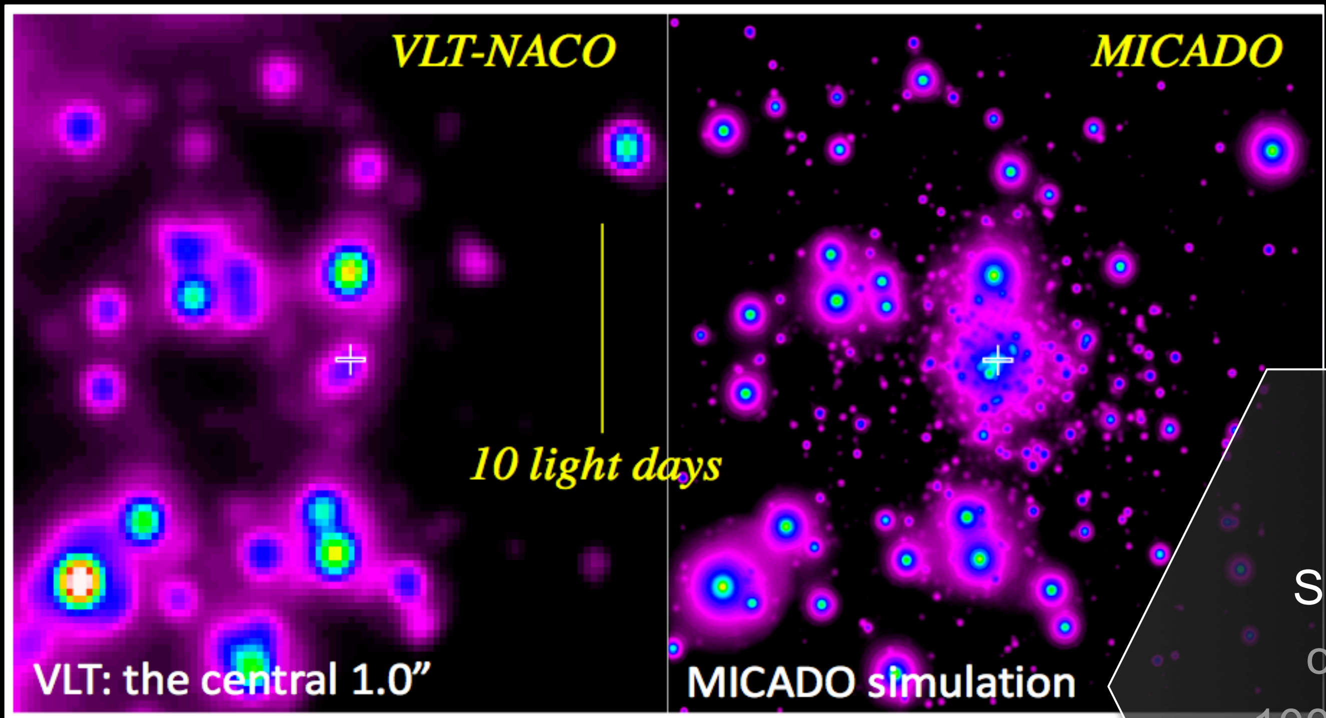
Reconstruct planet spectrum

Detection of biomarker molecules (e.g. O_2) for Earth-size planets orbiting mid-M dwarfs

(HIRES, METIS)

The Galactic Centre

AO observations imply supermassive Black Hole with mass of $\sim 3 \times 10^6\ M_\odot$
VLT (Genzel et al), Keck (Ghez et al)

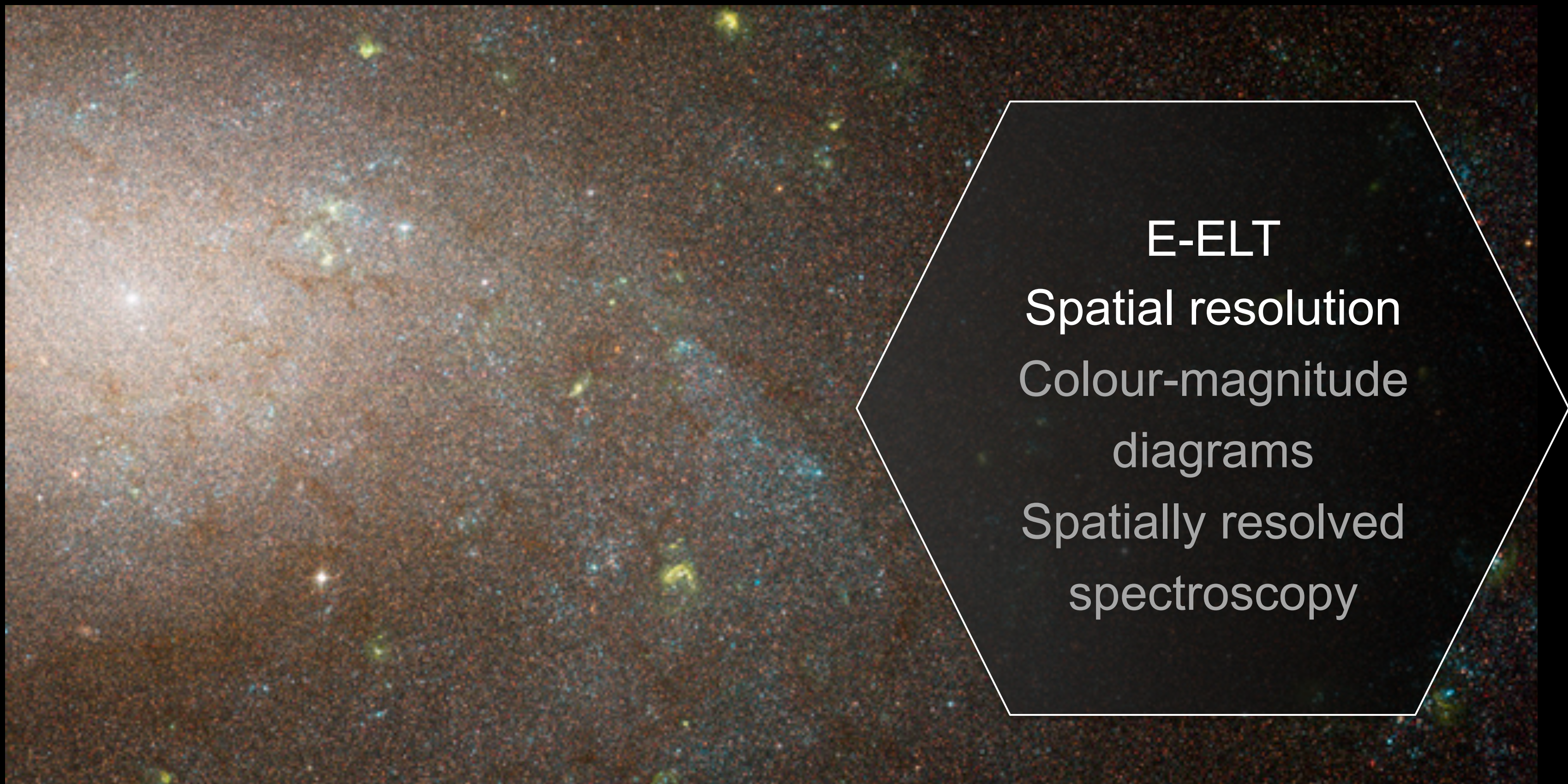


Simulations by MICADO group
e.g. Trippe et al 2010

E-ELT
Spatial resolution
orbits of stars at
100-1000 x BH event
horizon: sensitive to
SR and GR effects

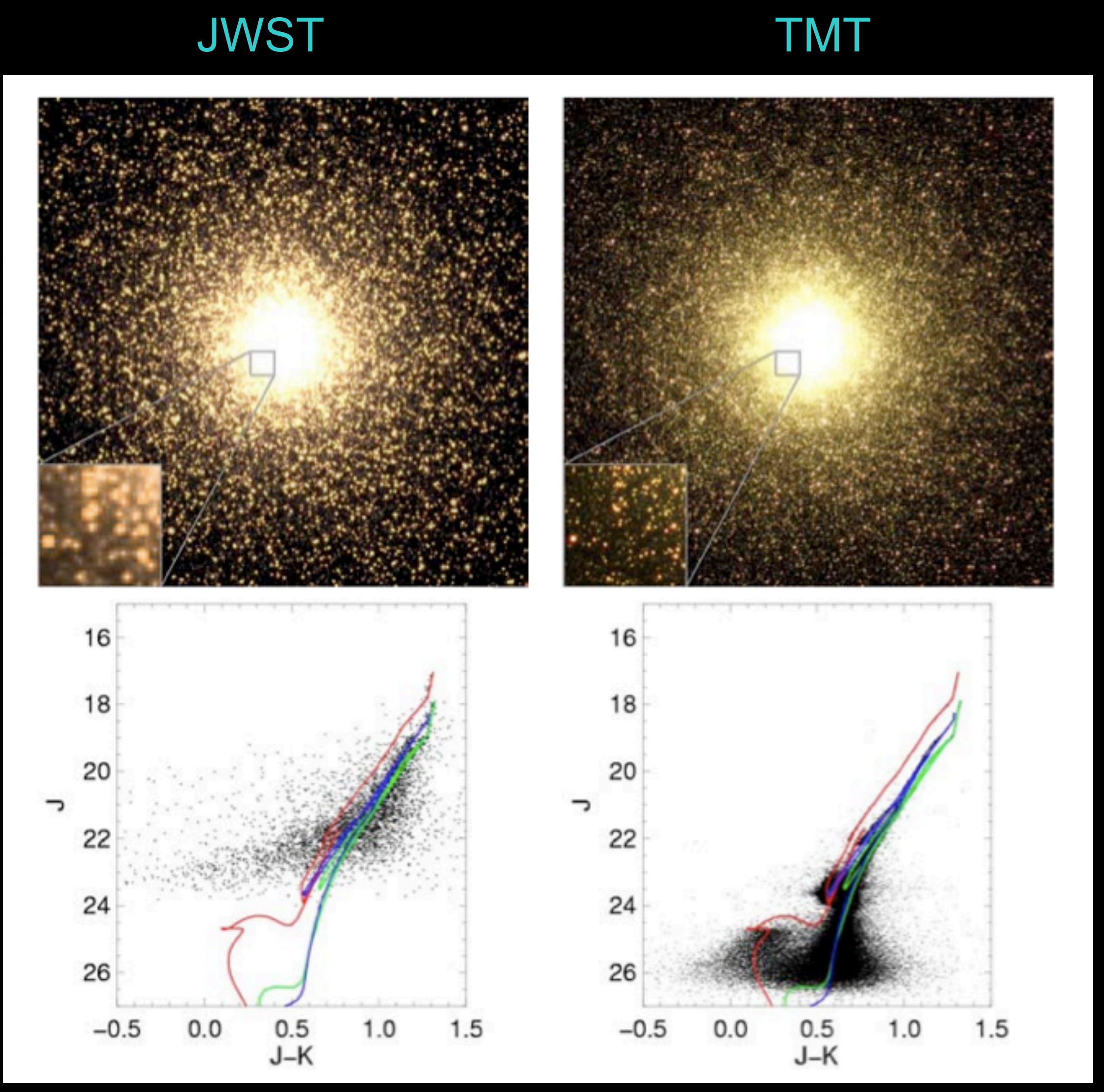
Resolved Stellar Populations

- Understand the merger history of galaxies by measuring properties of individual stars
- Aim for representative galaxies – implies representative volume



HST image of NGC300, a spiral galaxy at 2 megaparsecs,

Spatial resolution

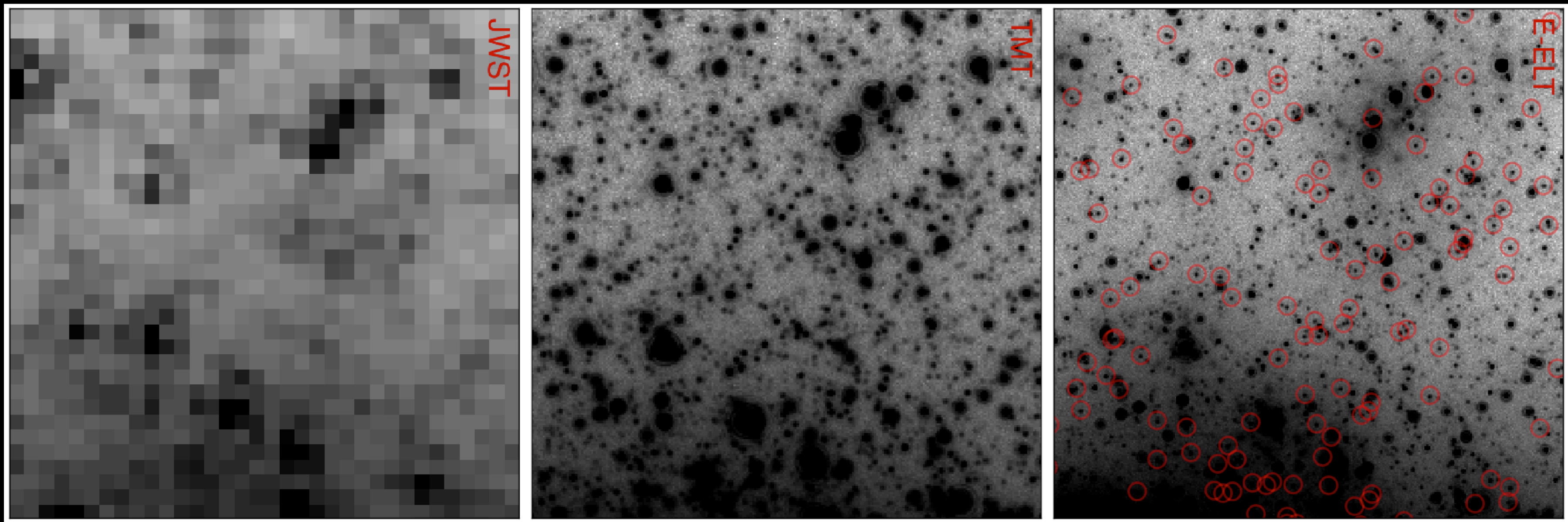


Simulated observations of M32: From TMT science case

Resolution comparison

Gullieuszik et al 2014

JWST TMT E-ELT



1″ × 1″ E-ELT (top panel), TMT (middle panel), and JWST (bottom panel) images at $6r_e$ from the centre of the 1 Gyr old NSC at 2 Mpc. Red circles show J = 28 mag stars, corresponding to the MSTO magnitude.

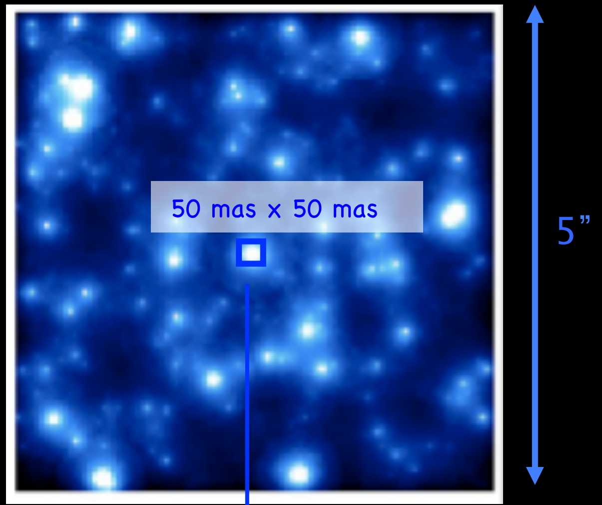
Centaurus A (4Mpc) : Example of spectra

Example:
Measure large-scale metallicity and kinematics in representative galaxies using Ca Triplet

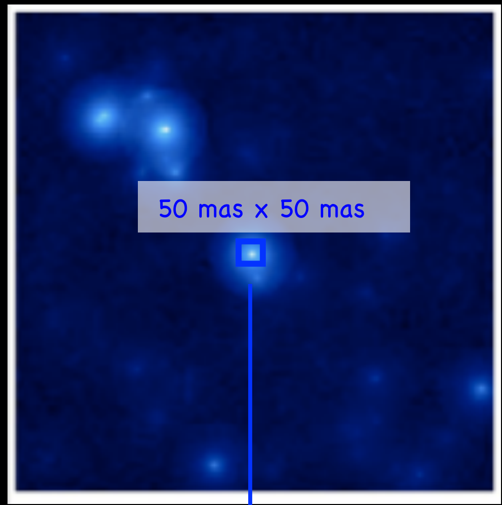
Local Group dwarf and Cen A: CaT surveys of large numbers of individual stars are feasible

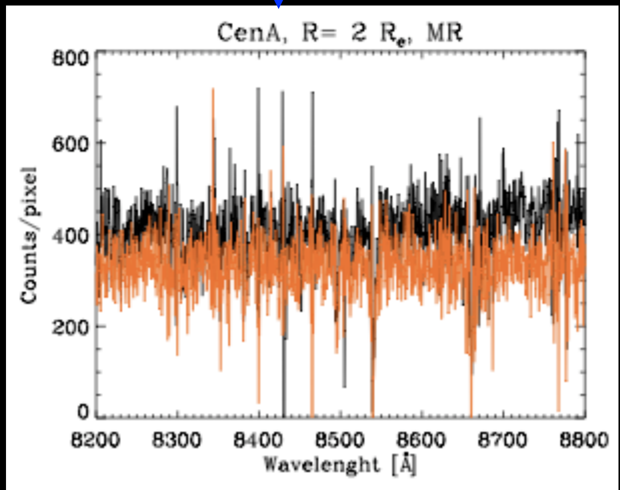
M87 (Virgo):
borderline (crowding in the inner regions, and low s/n)

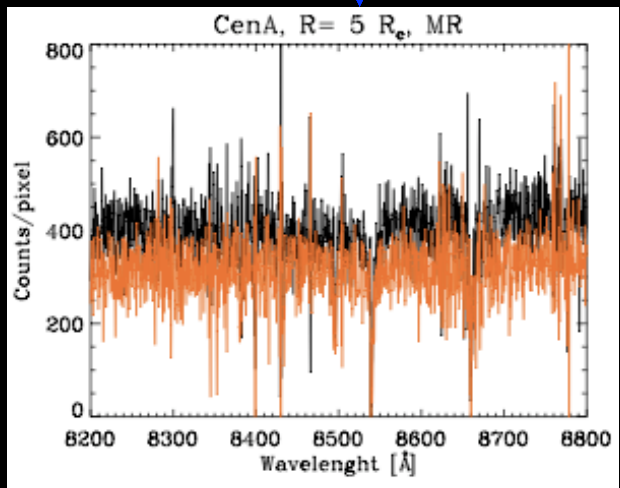
2 Re ⍰ 12 kpc



5 Re ⍰ 30 kpc







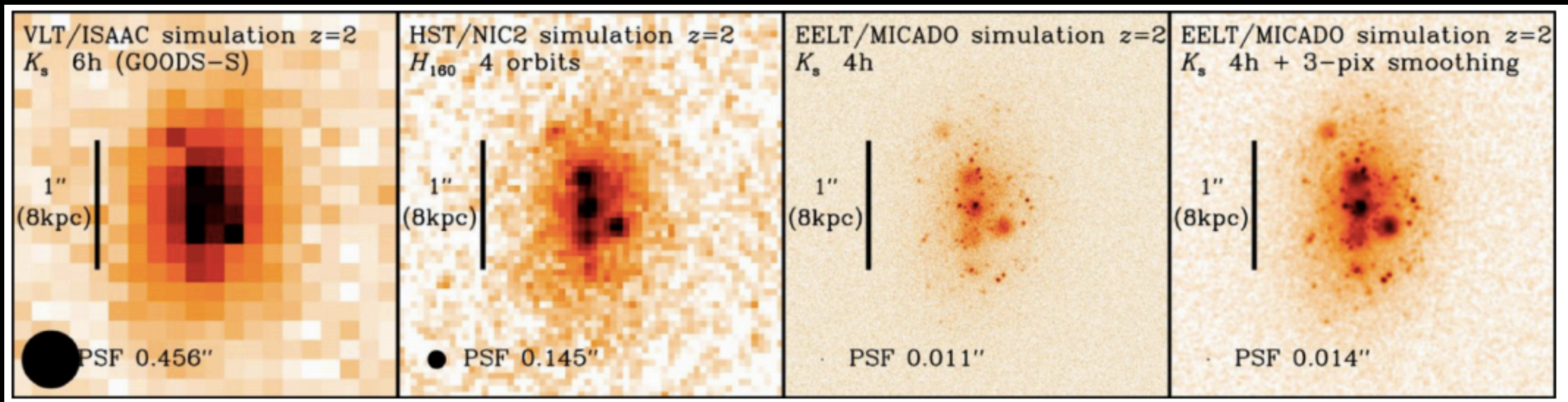
Targets: MR and MP RGB down to 0.5 mag below tip (I= 24.4). Assumes LTAO, 5h exposure time, Paranal-like, Ag/Al coating. Taken from E-ELT DRM case G. Bataglia & E. Tolstoy

High-z galaxies

E-ELT
Resolution and sensitivity

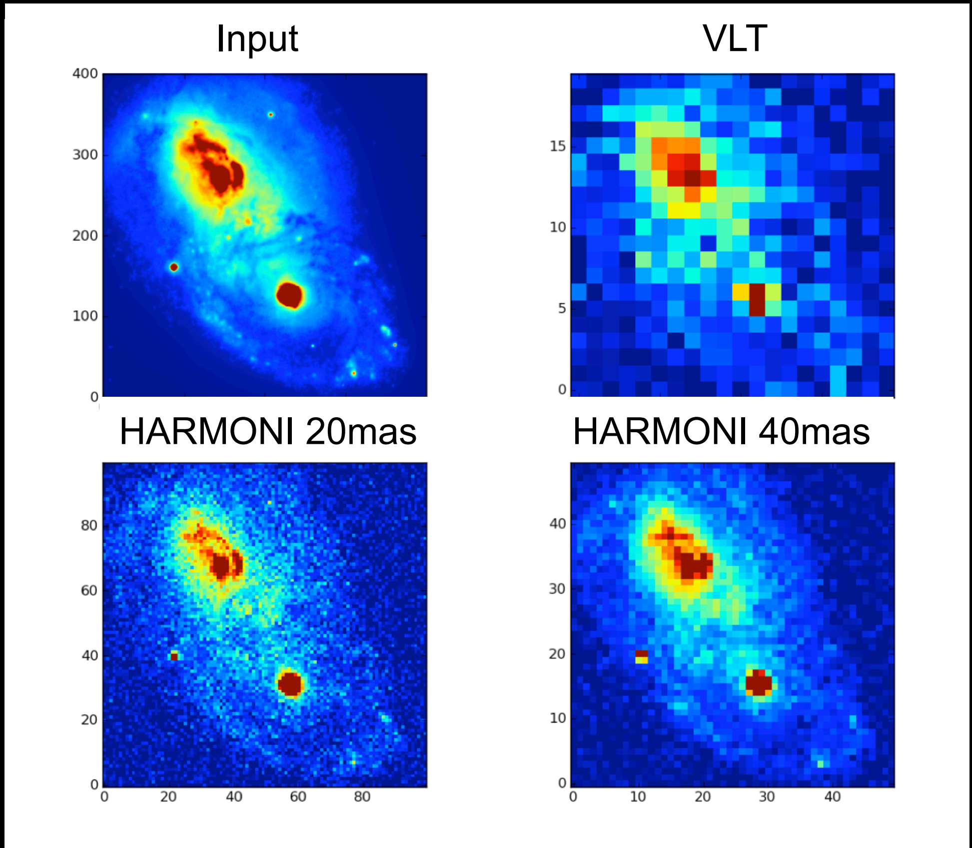
Structure from high-resolution imaging

Dynamics and physics from spatially resolved spectroscopy



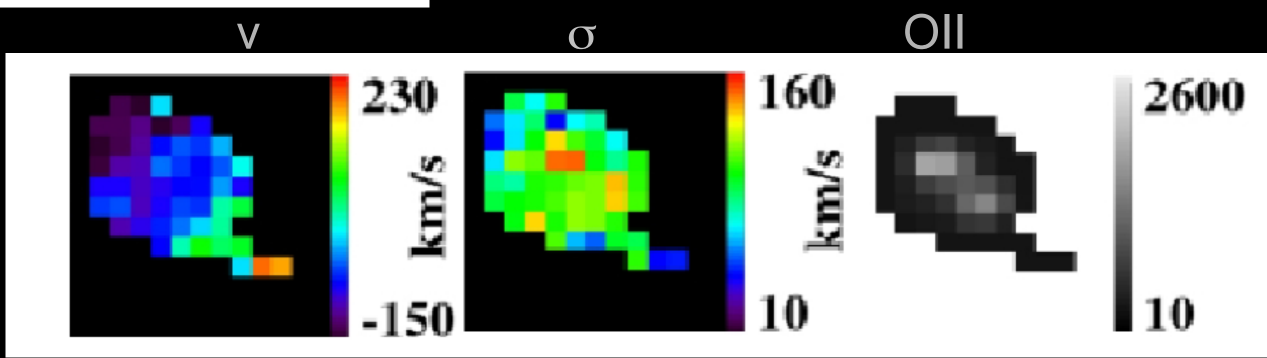
Simulated observations of a z=2 galaxy. MICADO science case

E-ELT Dynamics of high-z galaxies



- Measure
  - shocks, winds, interaction with IGM
  - dynamical masses
  - rotation (kinematics)
  - chemical composition
  - Distribution of dust

Left: Simulated HARMONI observation of Hα in ULIRG at z~2. Credit: HARMONI consortium (simulations by Tim Goodsall)



Right: simulated MOAO+ MOS observation of major merger at z ~ 4 (1.4bn yrs) (Puech et al 2008)

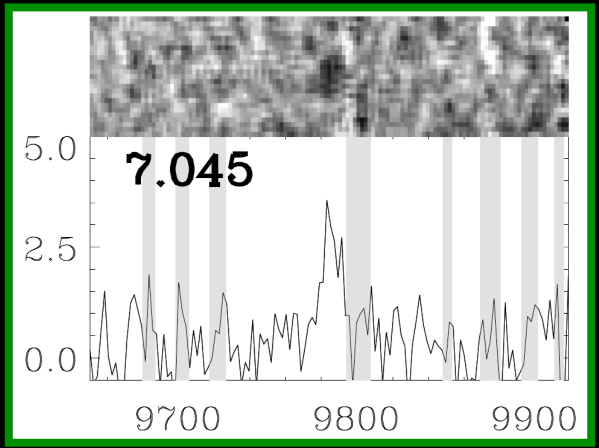
The most distant galaxies

- When did the first galaxies form?
- Did they re-ionise the Universe? If so, when?
- Faintest HST galaxies too faint for 8m spectroscopy
- Then JWST!

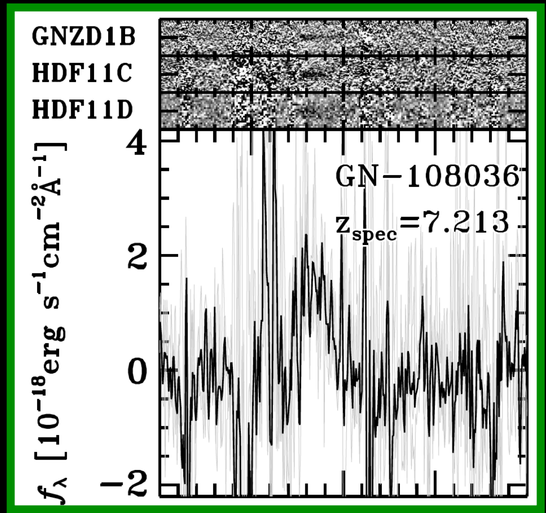
HUDF12 image reaching AB mag~30. Credit: NASA, ESA, R. Ellis and the HUDF12 team

Spectroscopic confirmation at z >7

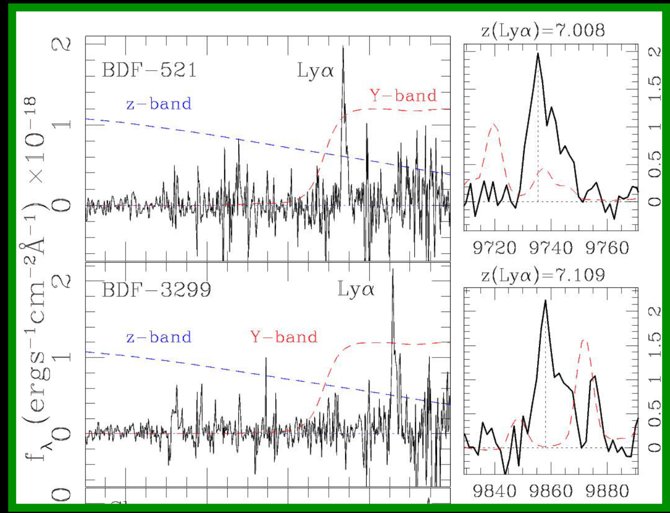
compilation from Jim Dunlop



Schenker et al. (2012)
(5 hours on KECK)



Ono et al. (2012)
(10 hours on KECK)



Vanzella et al. (2011)
(16 hours on VLT)

E-ELT
Sensitivity
Identification,
redshifts and
physics of faint
sources

Reionisation

- QSO spectra and CMB constrain reionisation epoch $6 < z < 10$
- Sources are beyond current detection limits
- Reionisation history unknown

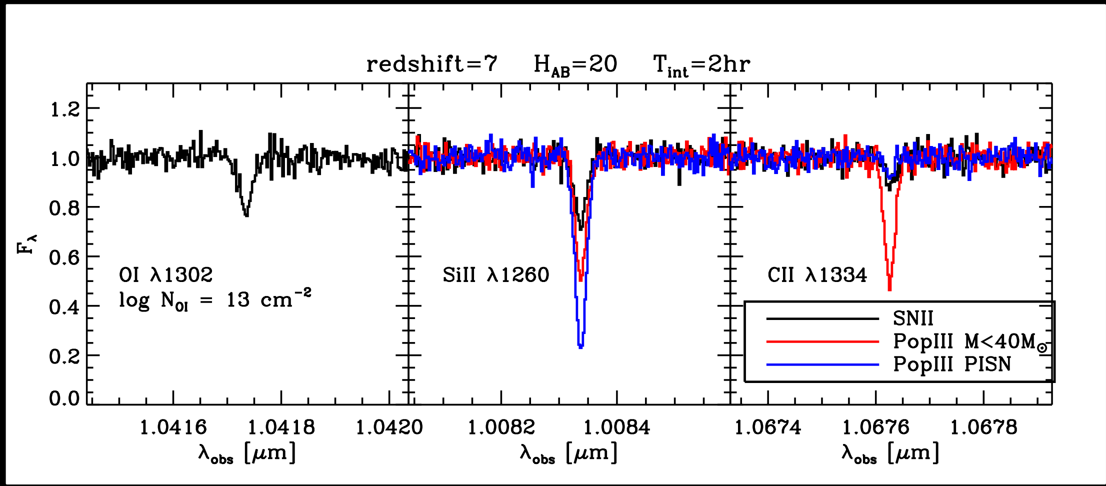
E-ELT

- Ly-α emission fraction in LBGs
- Absorption-line spectra of QSOs at z>6 (isotropy & homogeneity of reionisation)
- Enrichment of IGM

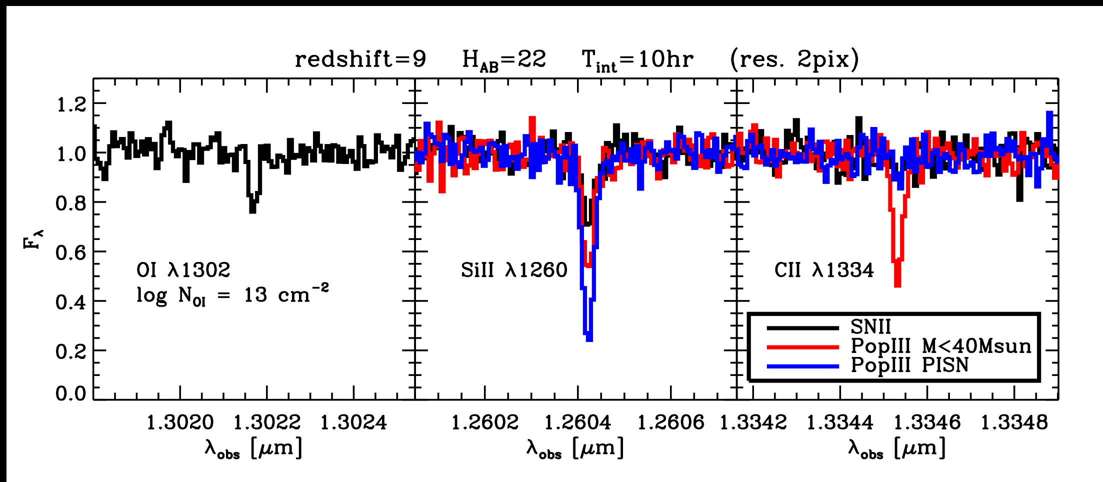
Image credit: Avi Loeb, 2006

Chemical enrichment of the IGM

z = 7



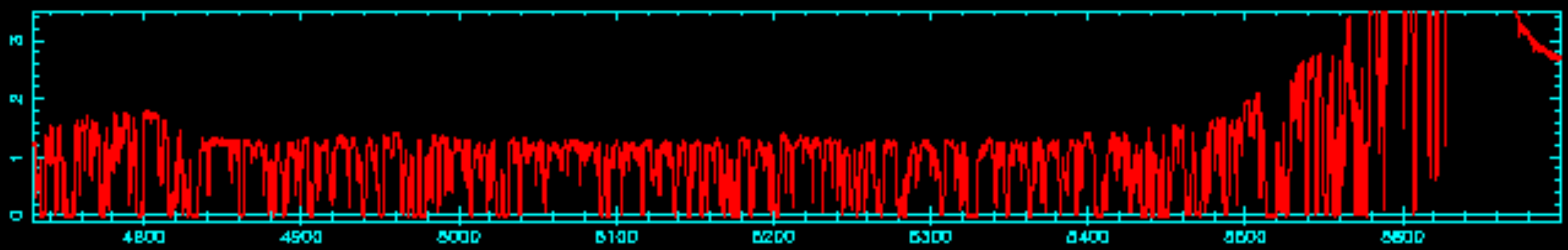
z = 9



Simulated observations of absorption line systems towards high-z QSOs – sensitive to different chemical enrichment patterns from SNe associated with different precursors. Credit : HIRES team.

Cosmology and Fundamental physics

- Constancy of fundamental coupling constants
  - Test for variations of α, μ : variations expected in string theory
  - Possible detection of variation in α – or instrumental effect? (Whitmore et al 2015)
  - ESPRESSO then E-ELT will make leaps in sensitivity
  - Future constraints can provide constraints on Dark Energy models (e.g. Calabrese et al 2013)
- Sandage test (redshift drift)
  - Direct measurement of the changing expansion of the universe via precise measurements of Ly-α line positions with time
  - Very demanding stability (2cm/s absolute calibration)
  - (See Liske et al 2008)



More information

- See www.eso.org for more on E-ELT, its science case and future events

http://harmoni2015.physics.ox.ac.uk/

The End

Credit:ESO/G. Hüdepohl (atacamaphoto.com).

The End

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