Science Drivers for the European Extremely Large Telescope

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for

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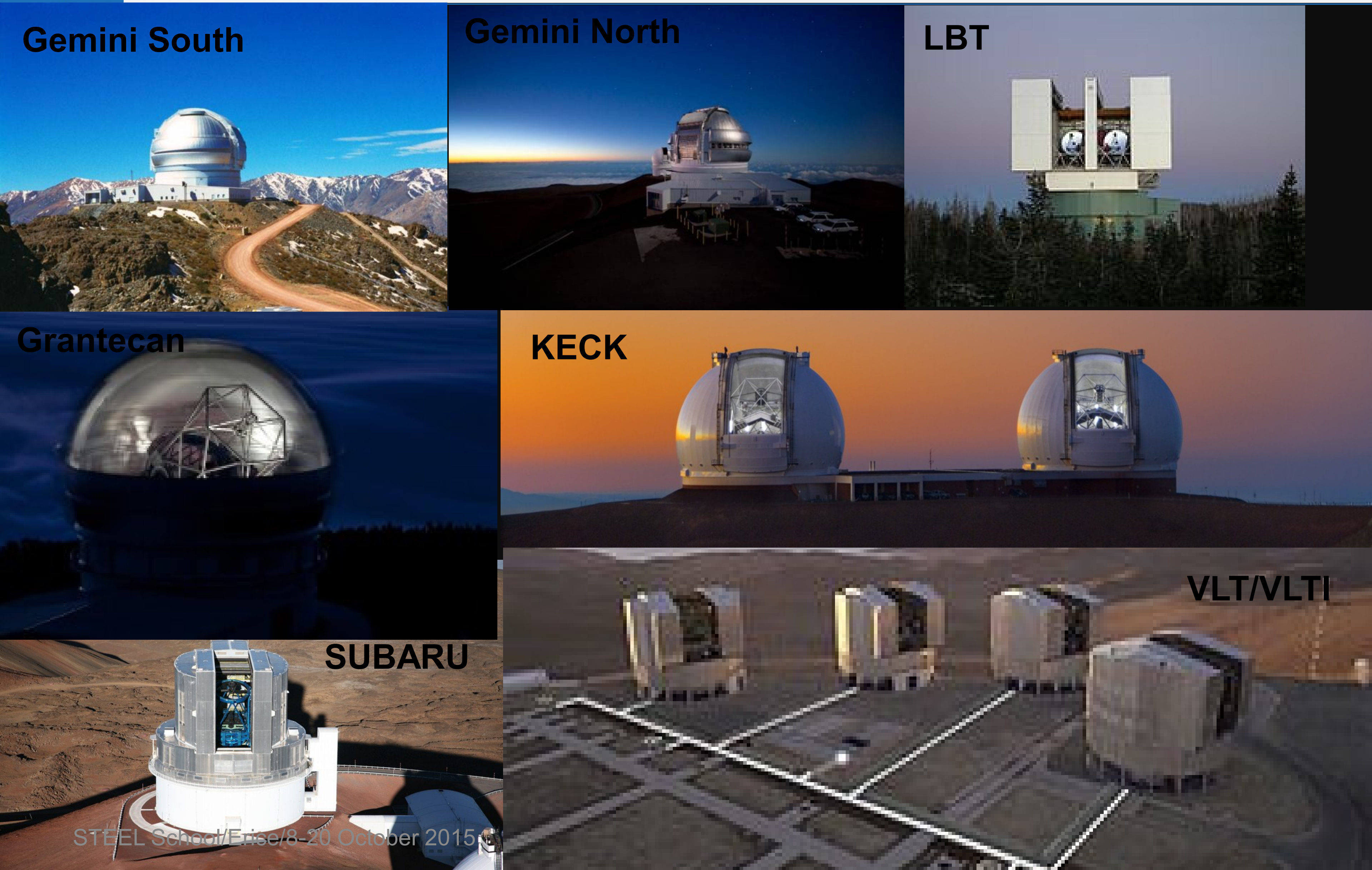
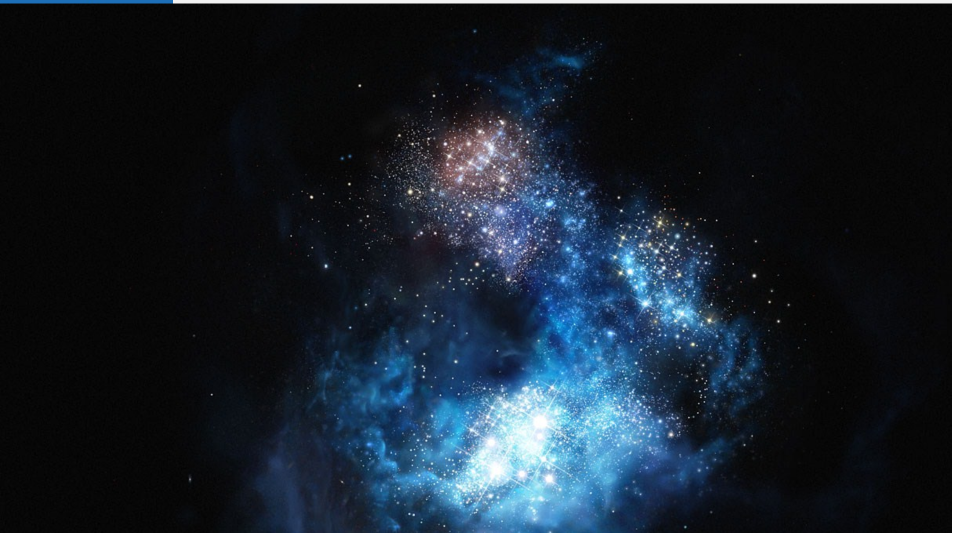
Outline of the talk

- From an scientific idea to scientific requirements
  - How to decide what to build
- Some recent scientific highlights
- The astronomical landscape
- How astronomers plan for an E-ELT
- A brief summary of E-ELT drivers

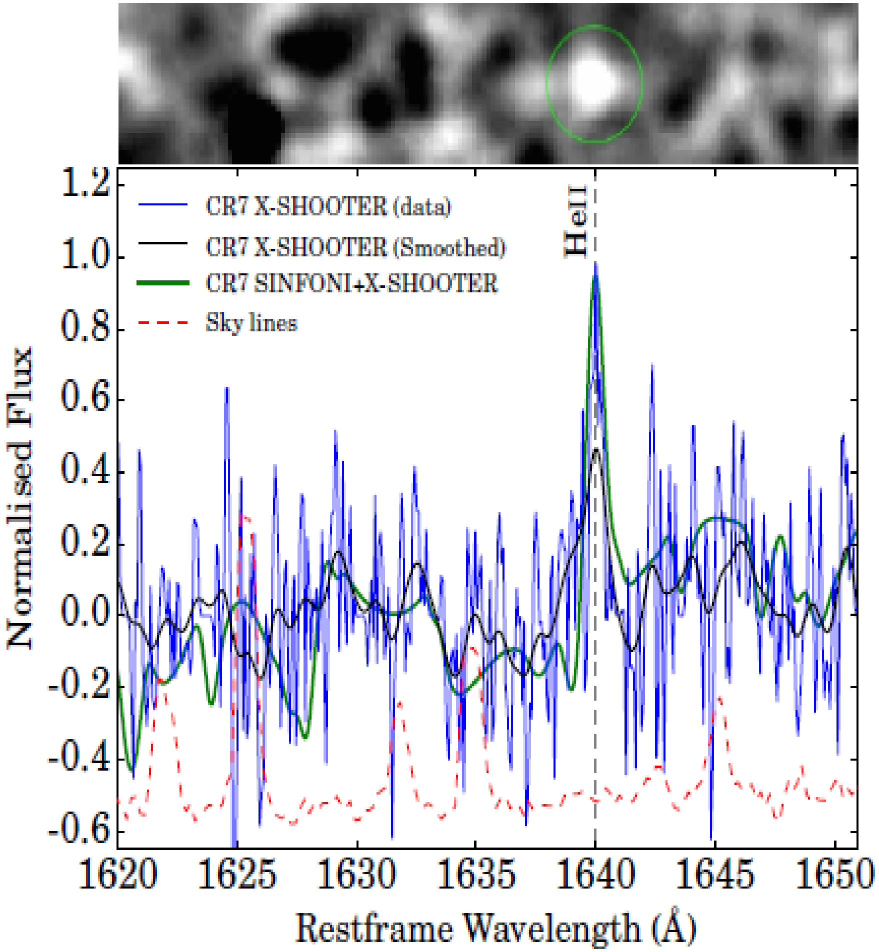
Where are we now?



Find evidence for Population III stars

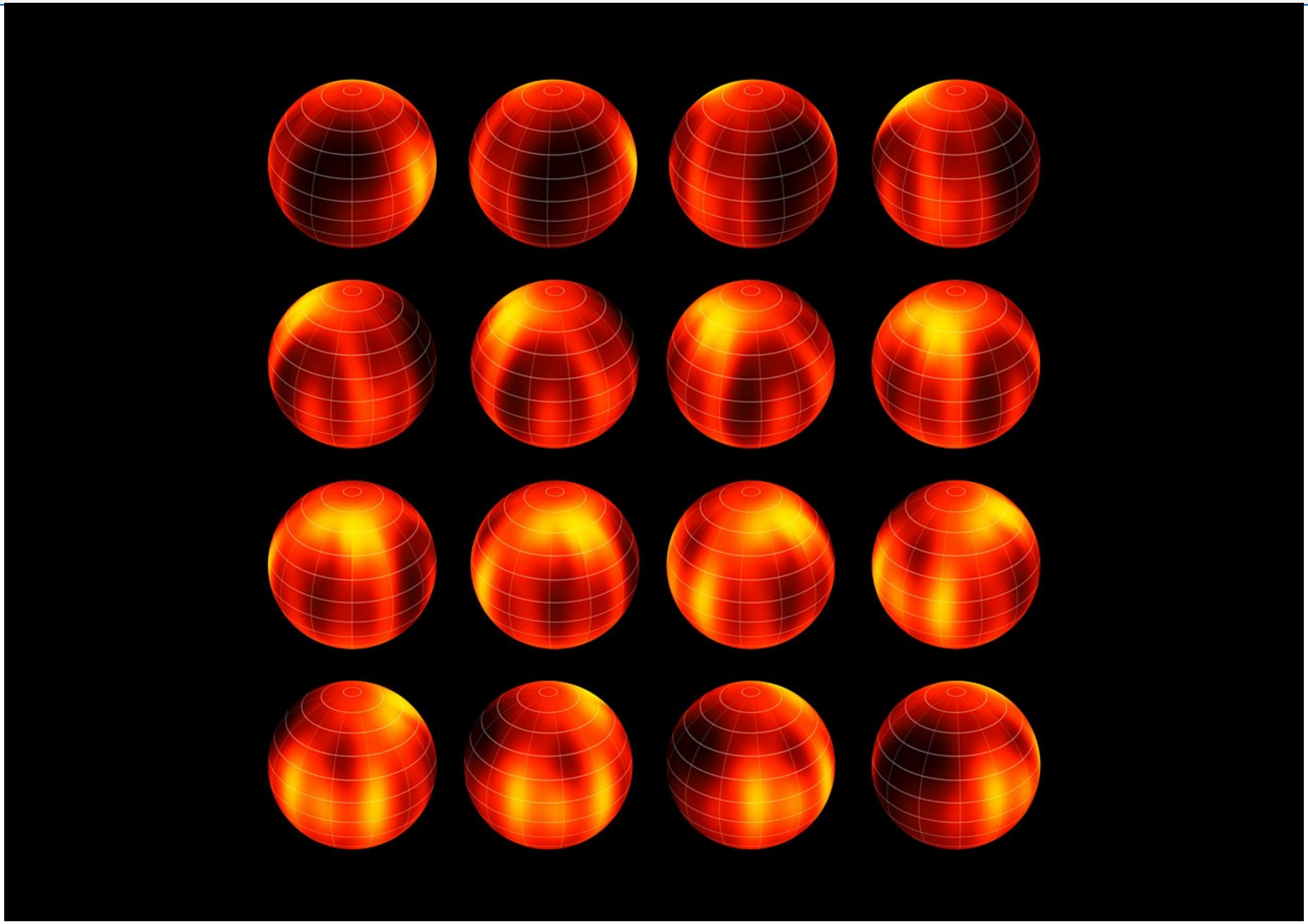


CR7 at z=6.604.
An artists impression of the brightest galaxy in the Universe (Sobral+ 2015)



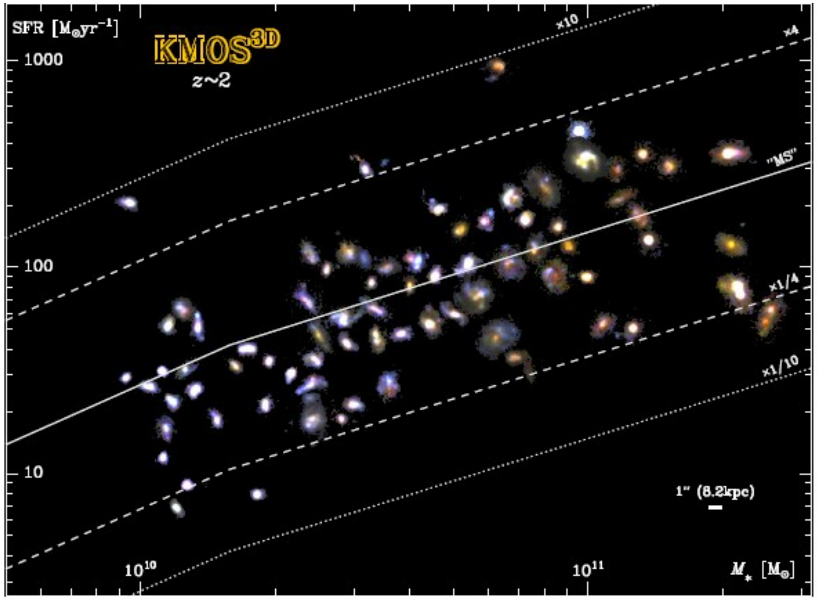
VLT SINFONI plus X shooter spectroscopy confirms the redshift of this brightest object from the COSMOS deep field. No evidence for heavy elements: integrated light spectrum indicates Population III stars.

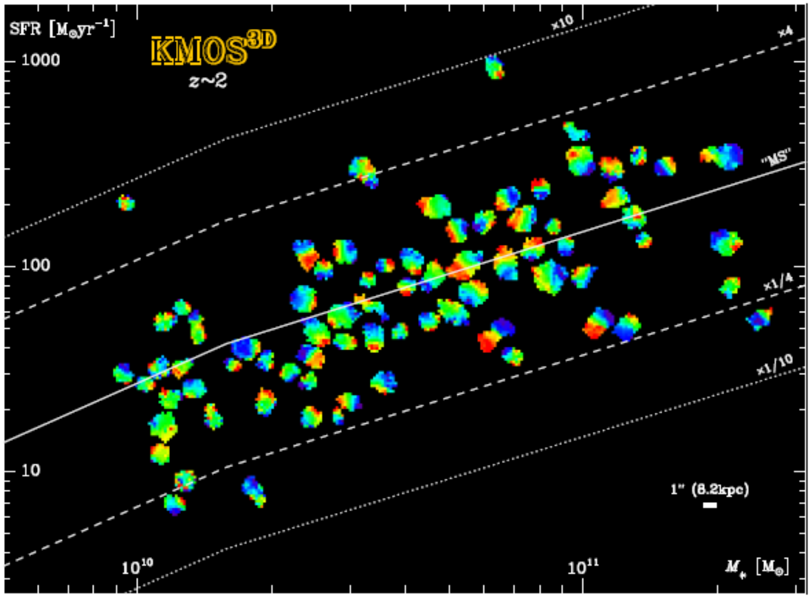
Check the weather on a brown dwarf

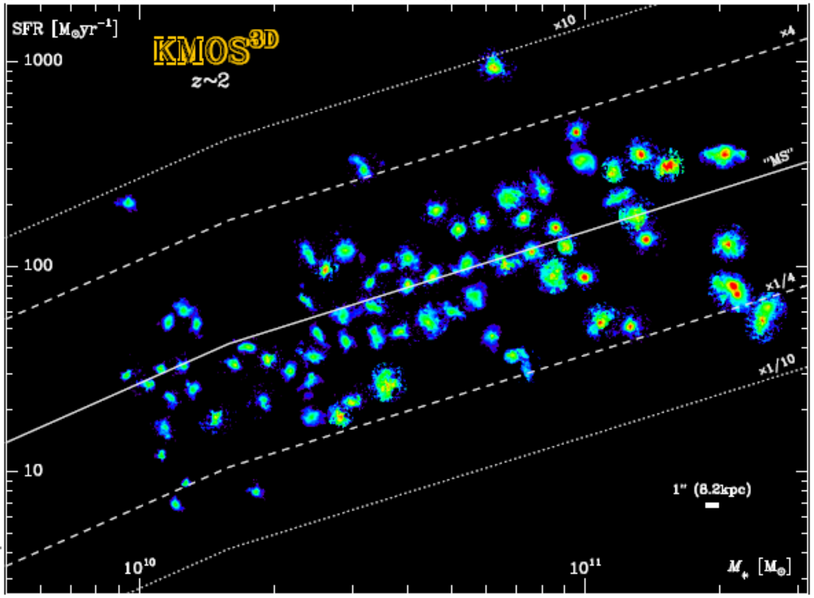


Crossfield+ 2013 VLT+CRIRES high spectral resolution monitoring observations in the NIR reconstructed to show cloud structure on Luhmann 16.

Study the formation of galaxies at z~1-2





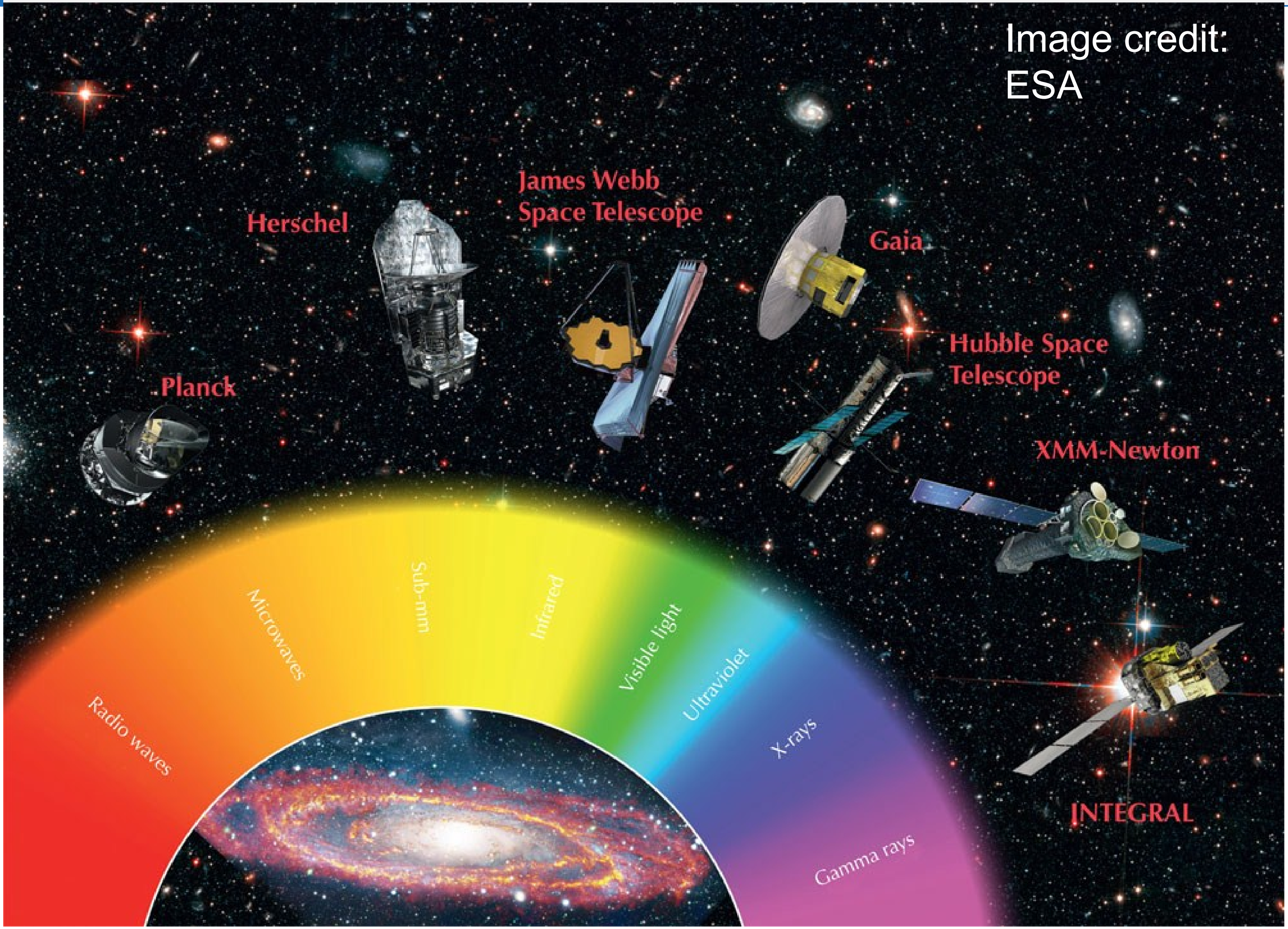


Wisnioski+ 2014: 191 galaxies of 600 in the total sample. HST imaging and KMOS spectroscopy. Kinematics from H-alpha and resolved stellar mass maps.

The case for an E-ELT

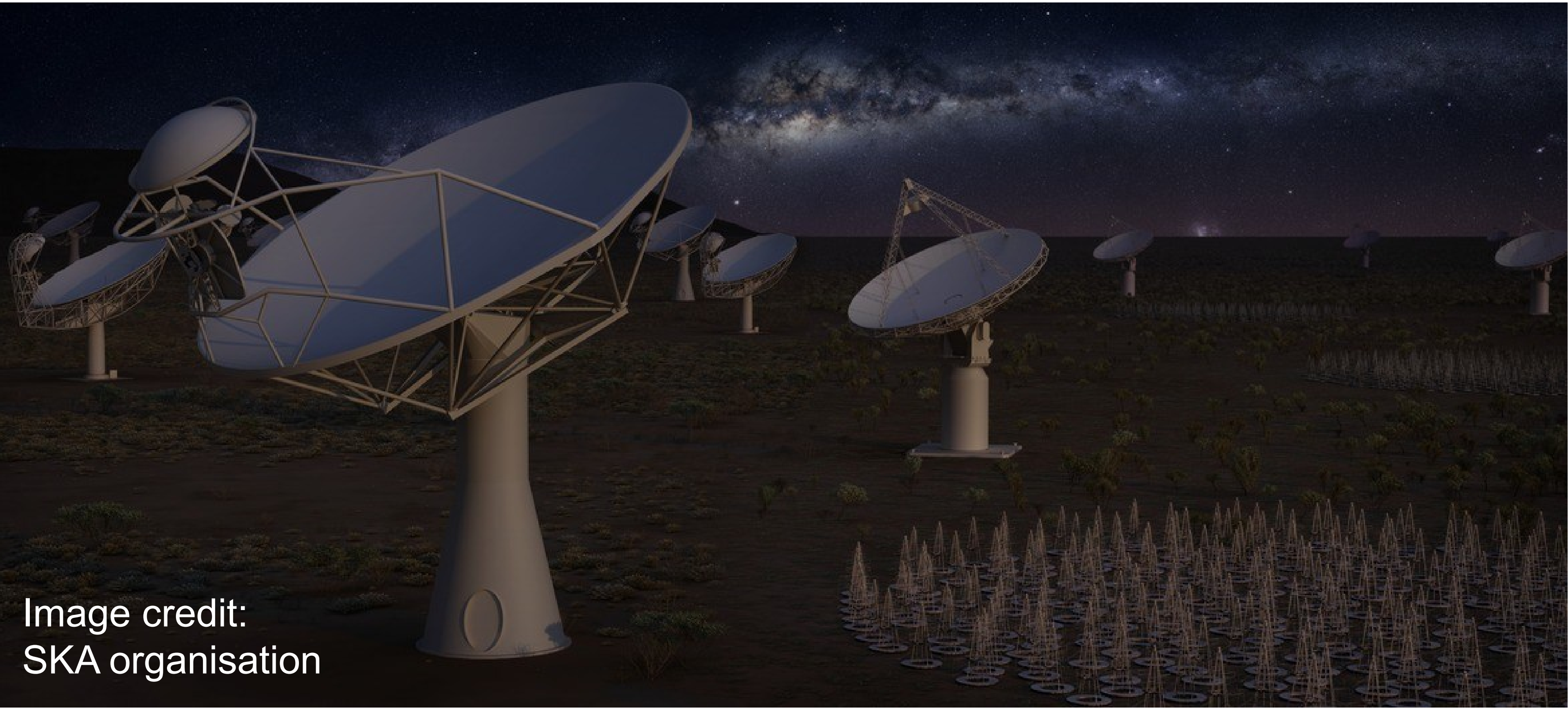
- Making progress requires
  - Opening up new parameter space: a new wavelength range?

Multi-wavelength coverage



The Square Kilometer Array

- SKA will dominate radio astronomy when it comes on line, beginning with early science in 2020+

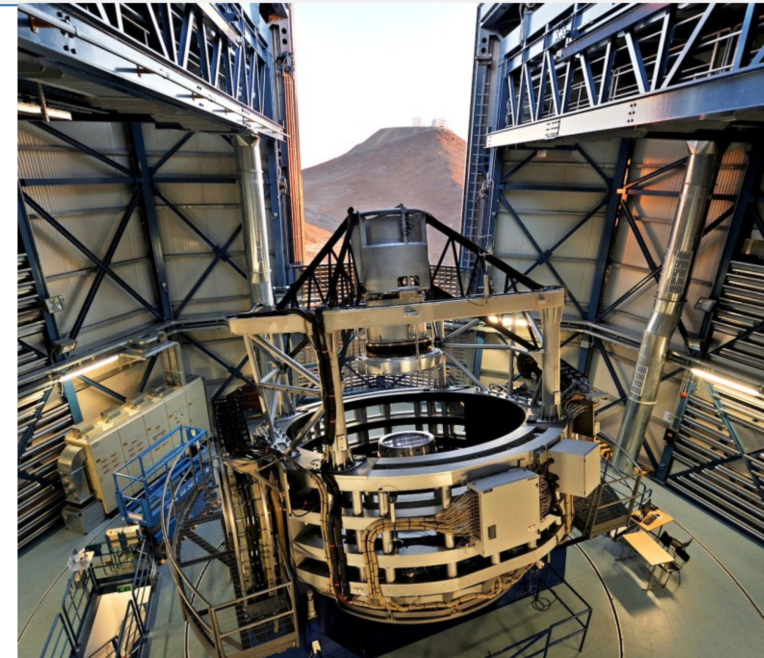


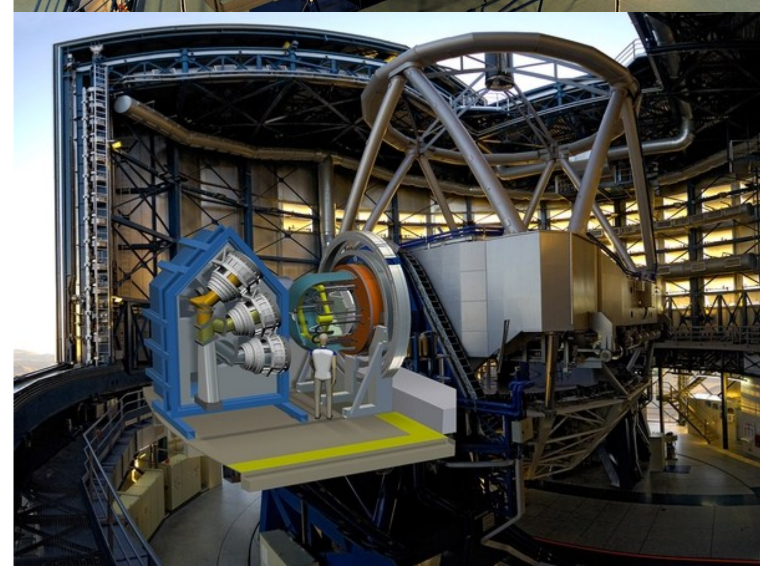
The case for an E-ELT

- Making progress requires
  - Opening up new parameter space: a new wavelength range?
  - Field of view: surveys!

Survey telescopes and instruments

- Many imaging and spectroscopic surveys are from small to medium sized ground based telescope exist or are planned
  - Imaging: VISTA, VST, CFHT, UKIRT, PANSTARRS, SDSS
  - Spectroscopic: MOONS, 4MOST, WEAVE (WHT)
- They provide a statistical picture of the universe and the detection of rare objects





The case for an E-ELT

- Making progress requires
  - Opening up new parameter space: a new wavelength range?
  - Field of view: surveys!
  - Temporal information: LSST

Time variability/the transient universe

- The Large Synoptic Survey Telescope currently under construction
- This 8.4-m telescopes will survey the visible sky every few nights for 10 years
- Millions of alerts to follow up

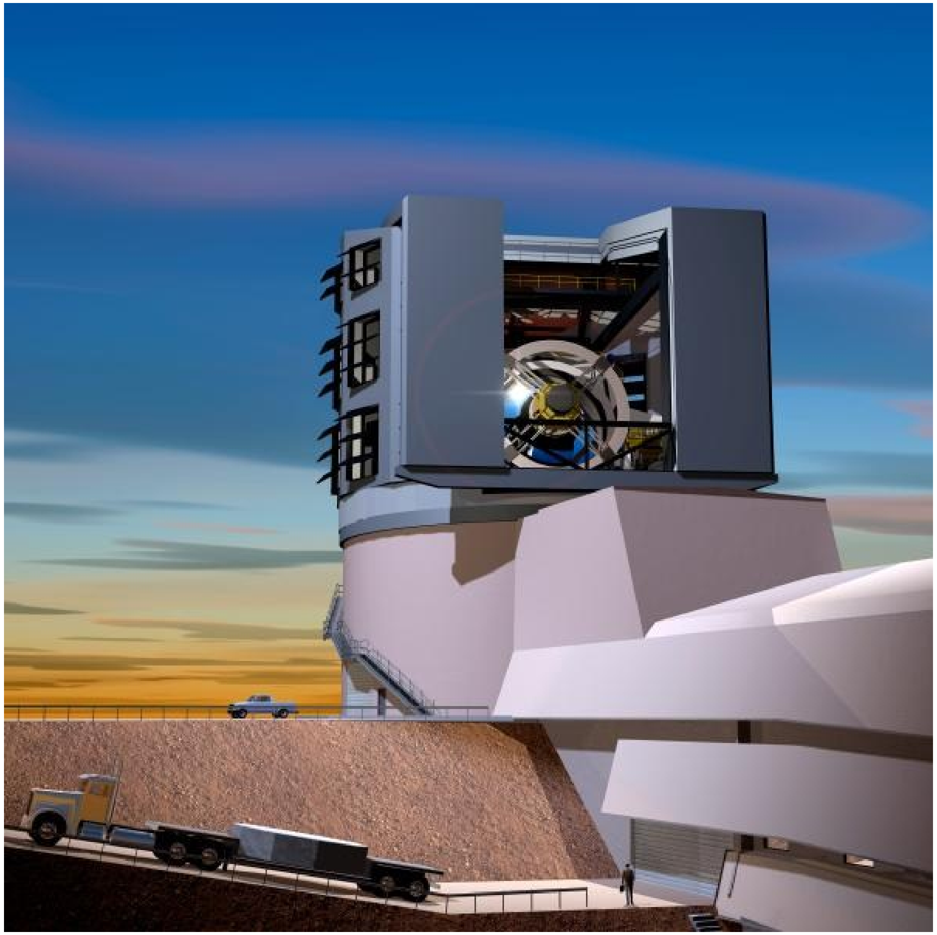


Image credit: LSST

The case for an E-ELT

- Making progress requires
  - Opening up new parameter space: a new wavelength range?
  - Field of view: surveys!
  - Temporal information: LSST
  - Sensitivity

James Webb Space Telescope

- Launch date October 2018
- 5-10 year mission
- 6.5m diameter mirror
- Wavelength coverage:

  0.6-28.5um

Image credit: ESA

A JWST deep field

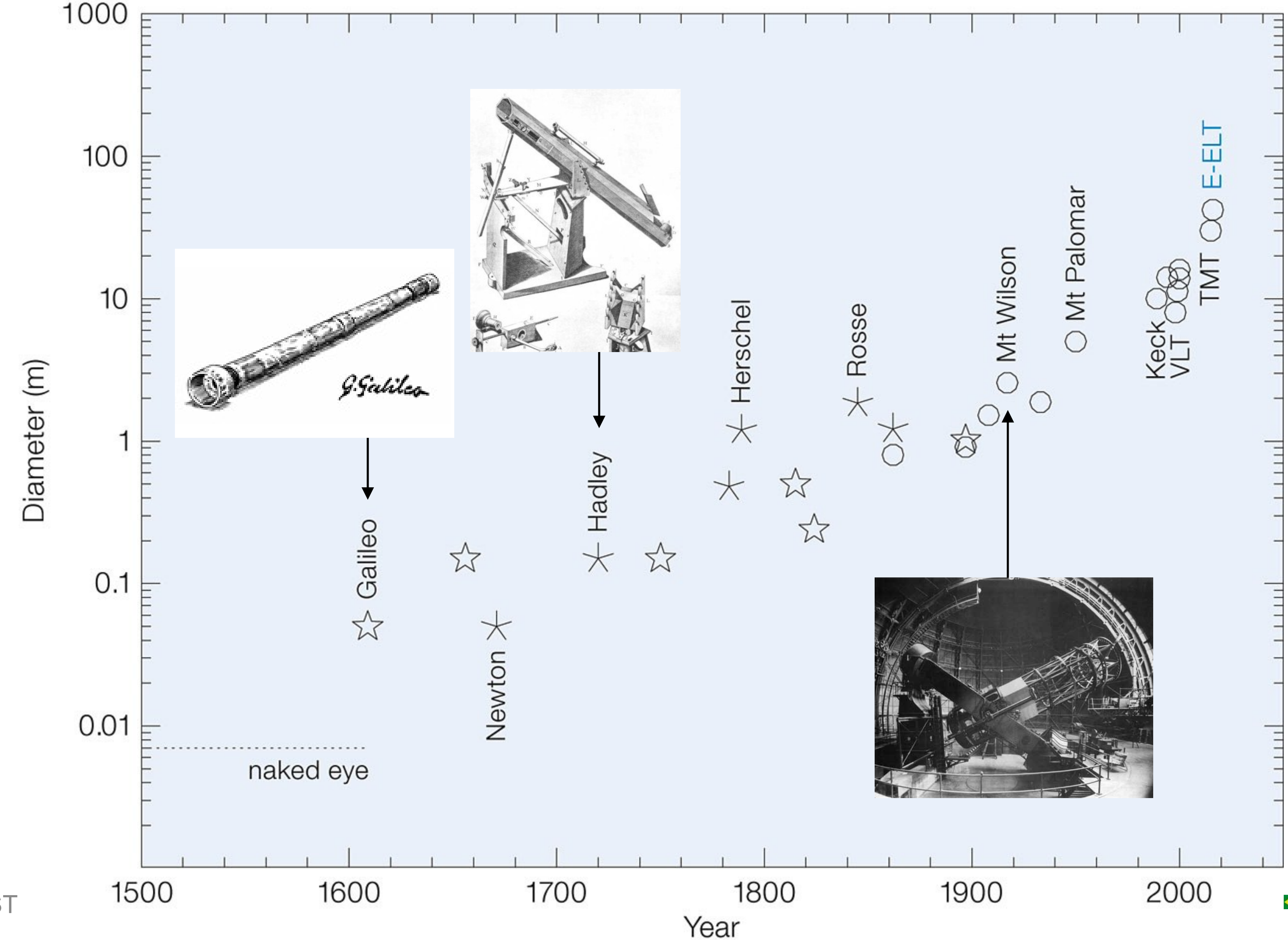
Image credit: ESA

How to follow up a JWST deep-field with limiting magnitude AB~31.5?

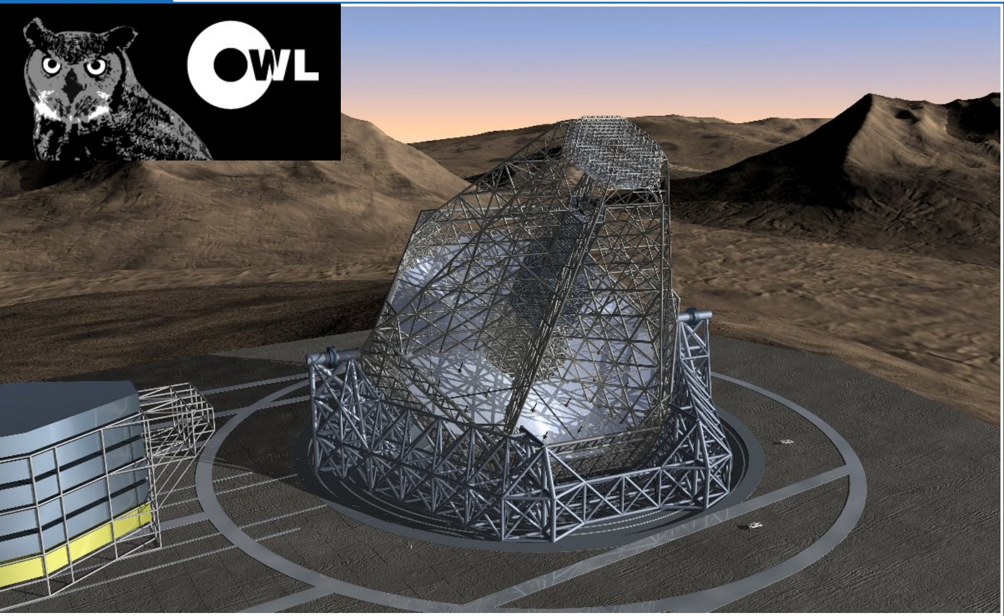
The case for an E-ELT

- Making progress requires
  - Opening up new parameter space e.g. a new wavelength range
  - Field of view
  - Temporal information: LSST
  - Sensitivity
  - Angular resolution

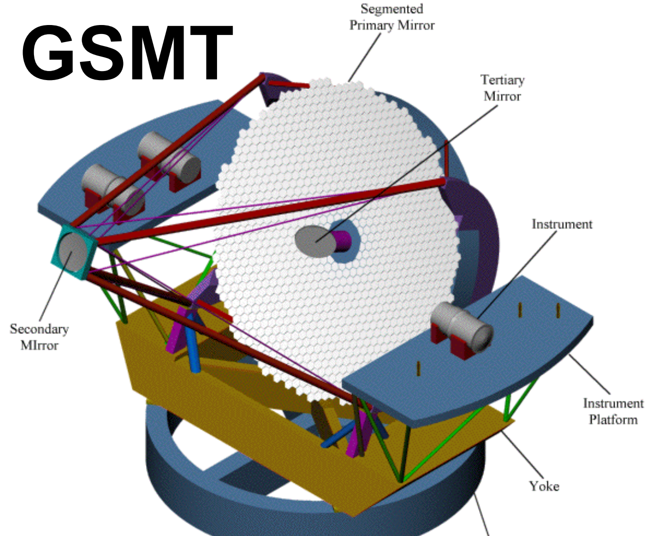
Telescope size



Enter the ELTS!



GSMT



See also the CELT (Californian Extremely Large Telescope), VLOT (the Very Large Optical Telescope), the Euro-50 Project….

Some simple scaling

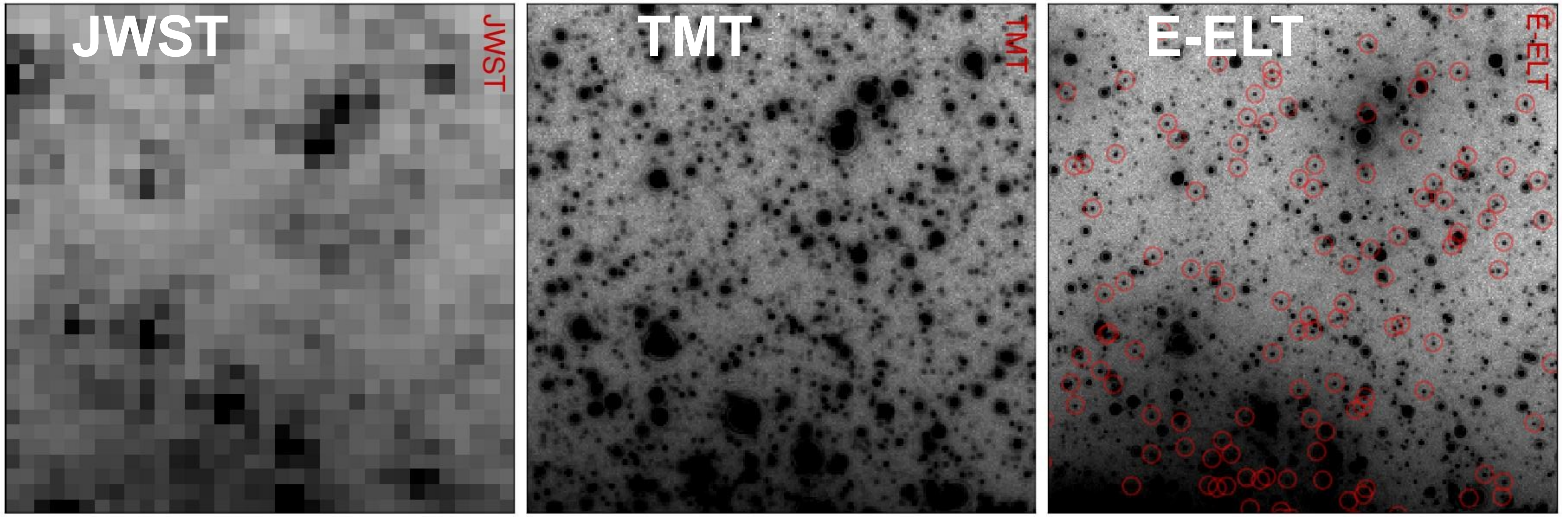
The ELTs excel in collecting power *and* angular resolution

For an adaptive optics assisted telescope observing near the diffraction limit:

Angular resolution scales with D (5x better for E-ELT versus VLT)

And for background limited observations:

Exposure time reduces with D^4 (500x faster for E-ELT versus VLT)

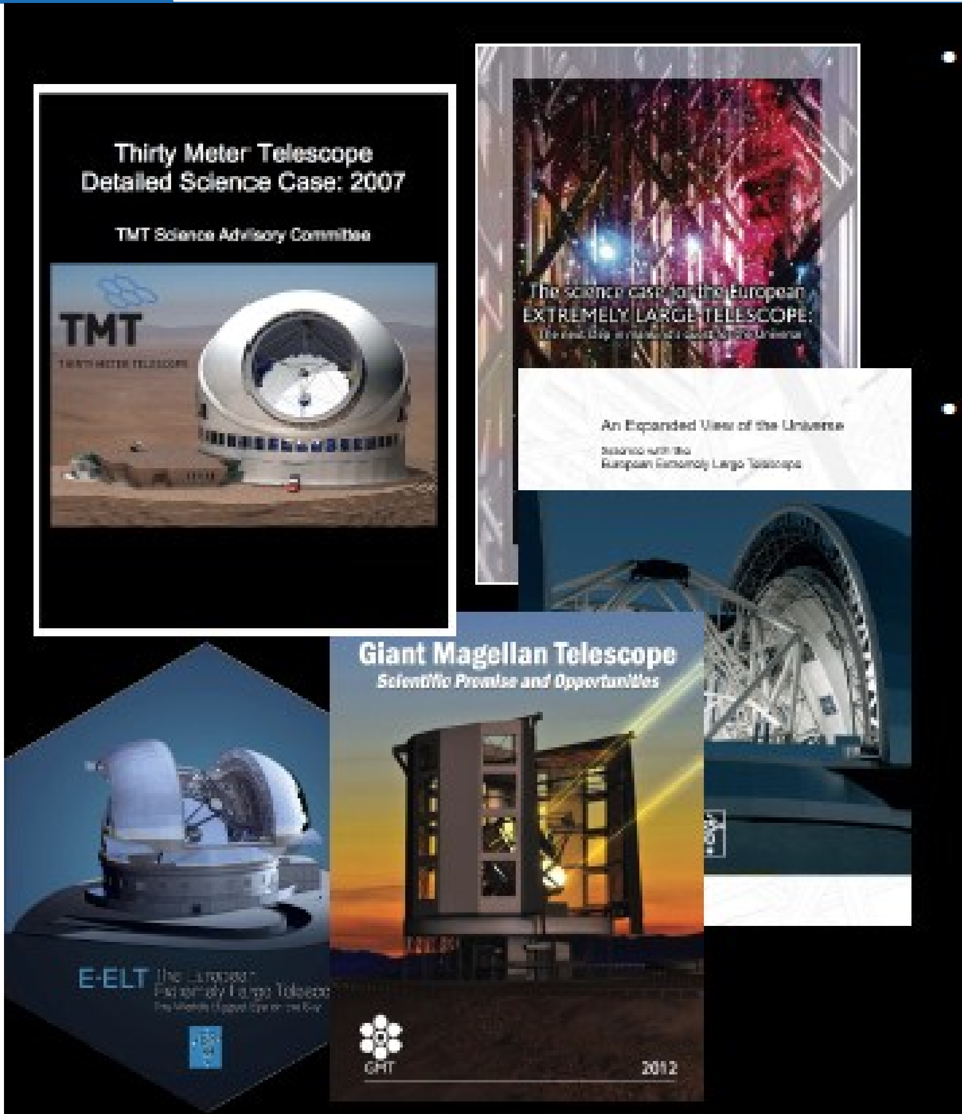


Gullieuszik et al 2014.

Why an ELT science case?

- It spells out in detail what the astronomy community wants to do with a new facility
- It is the basis on which the design of the facility is developed
- This is an ongoing process!

Developing ELT science cases



- All the ELTs have science teams drawn from their community
- The ELT science case was developed by
  - Expert working groups
  - The ELT Project Science Team
  - Community workshops
- Watch out for your chance to contribute!

Developing ELT science cases

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

Science cases and requirements

3.1.5.1 Detection from reflex velocity measurements

If the parent Jupiter-like planet is bright enough to allow medium-to-high resolution spectroscopy, the reflex motion of the Jupiter due to a potential terrestrial moon may be detectable. For an Earth-mass moon orbiting a Jupiter-mass planet at the same distance as the moon is from Earth, the reflex velocity range is about +/– 60 m/s over a period of ~1 day. At 5 pc, a 100m E-ELT could secure spectra of the parent planet at resolutions of a few times 10^4, with S/N ~ 20, in a couple of hours. To detect the reflex motion due to the moon would require a long observing campaign (~600 hours) to acquire many such spectra. These would be analysed in phase bins around a hypothetical orbit, after accumulating enough spectra to build up the signal-to-noise to the required level (~100 per pixel per phase bin).

Notes on Design Requirements

Observing type: Reflex velocity measurements via mid- to high-resolution spectroscopy of a Jupiter-like planet

Spectral Resolution: A few x 10,000

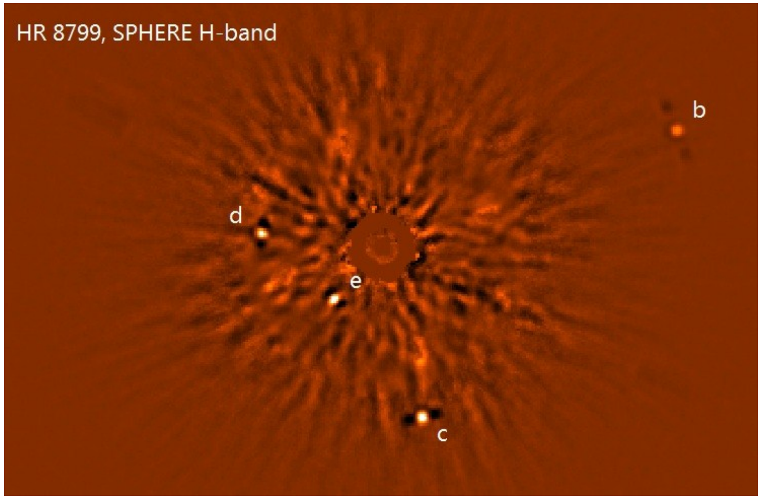
Observing time: 20 hrs per observation. Several observations needed at different phases. About 600 hrs total.

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?

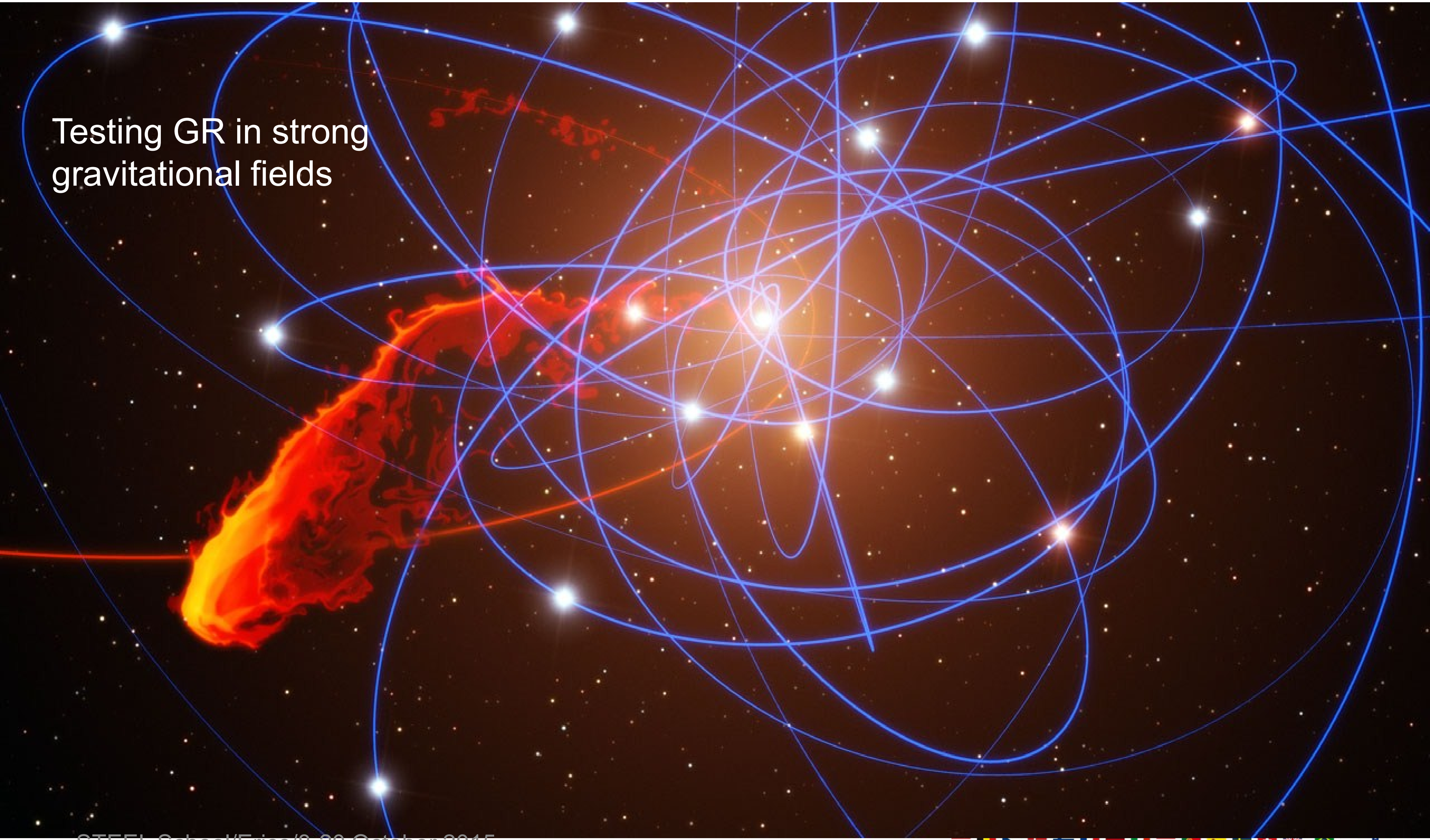
Direct imaging of exo-Earths

- Requires:
  - Contrast ratios as high as 10^{-9} at 0.1arcsecs angular separation
- Drives:
  - Telescope diameter (for angular resolution)
  - Primary mirror - gaps, phasing
  - Extremely high performance adaptive optics (XAO)
  - Specialised instrumentation



Current start of the art: SPHERE on VLT

Galactic Centre



Galactic Centre

Testing GR in strong gravitational fields

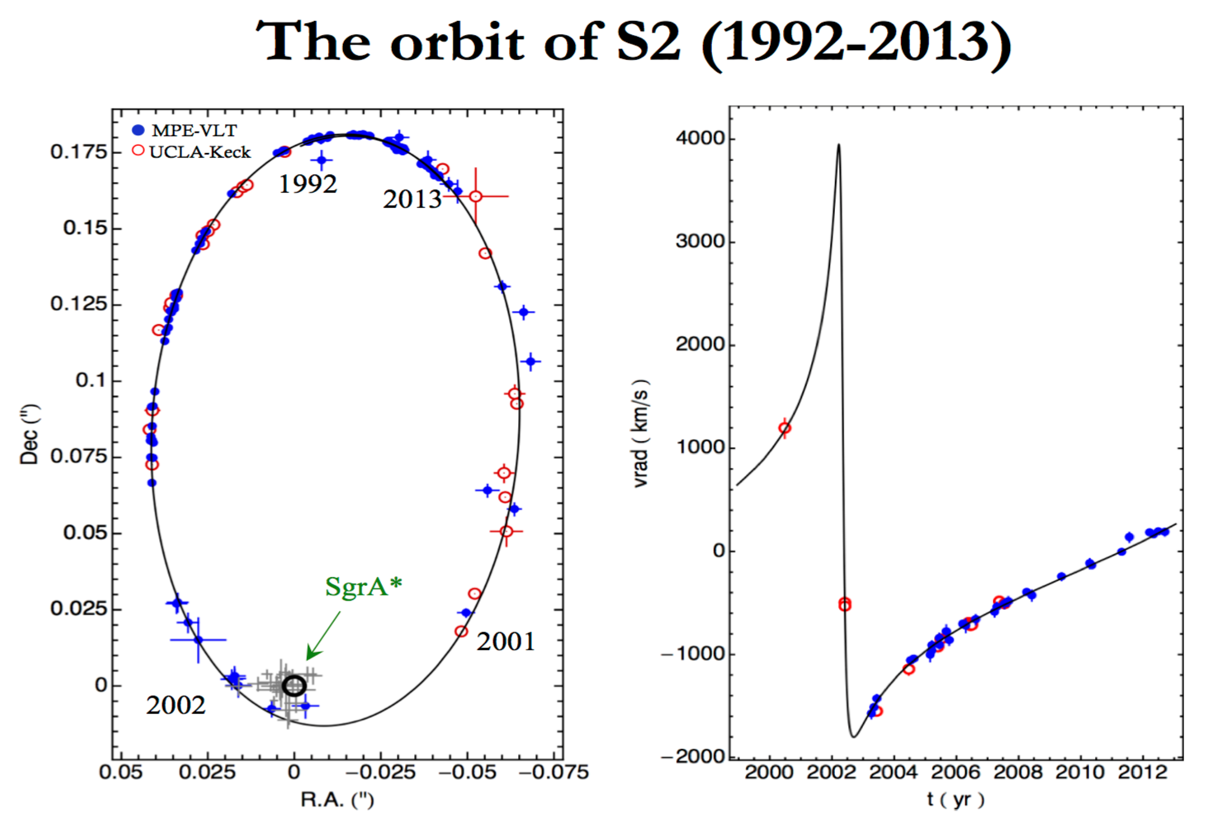
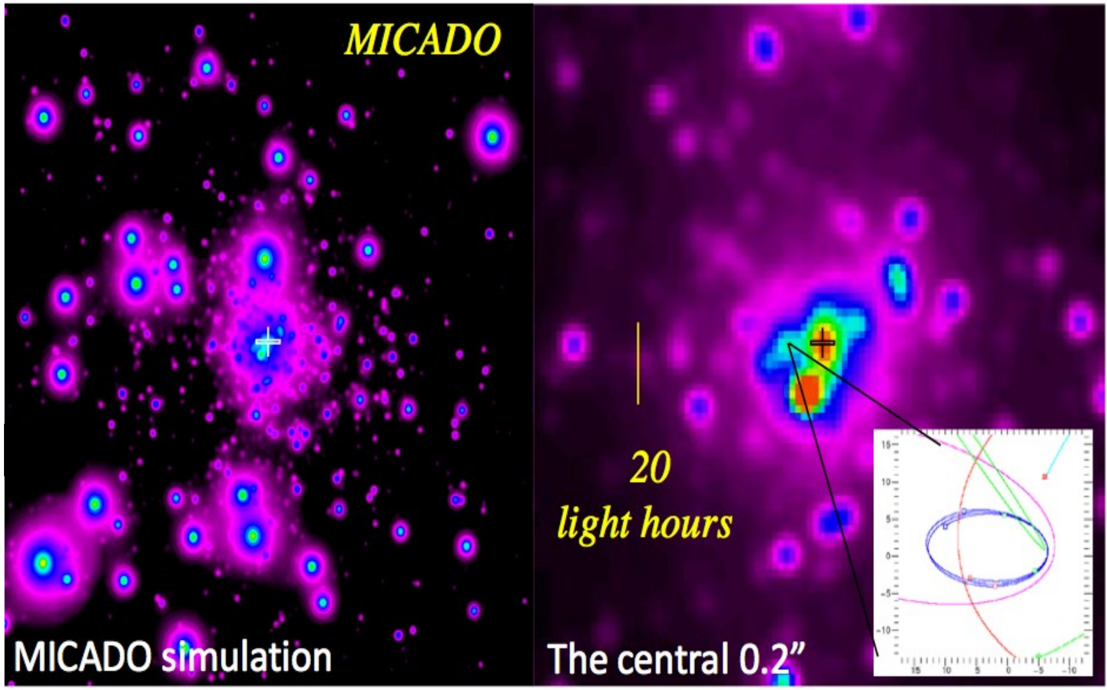


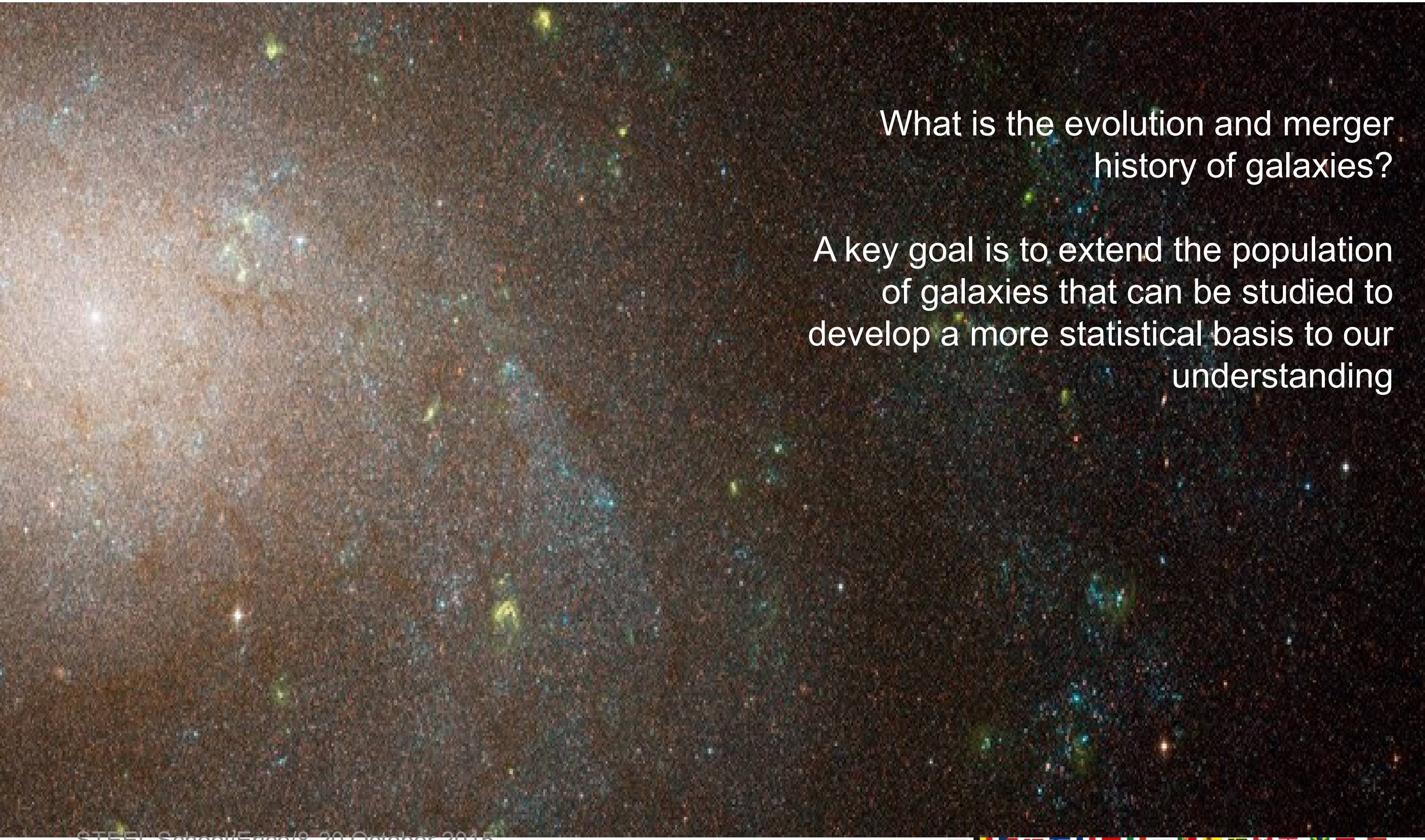
Image from MPE

Galactic Centre

- Requires:
  - To track stars at ~100 R_S around the BH in MW centre (10x closer than currently possible).
  - Astrometric precision at ~50 µarcsec (10 µarcsec would be nice)
- Drives:
  - High throughput and very good adaptive optics performance
  - Attention to stability plus carefull calibration



Resolved stellar populations



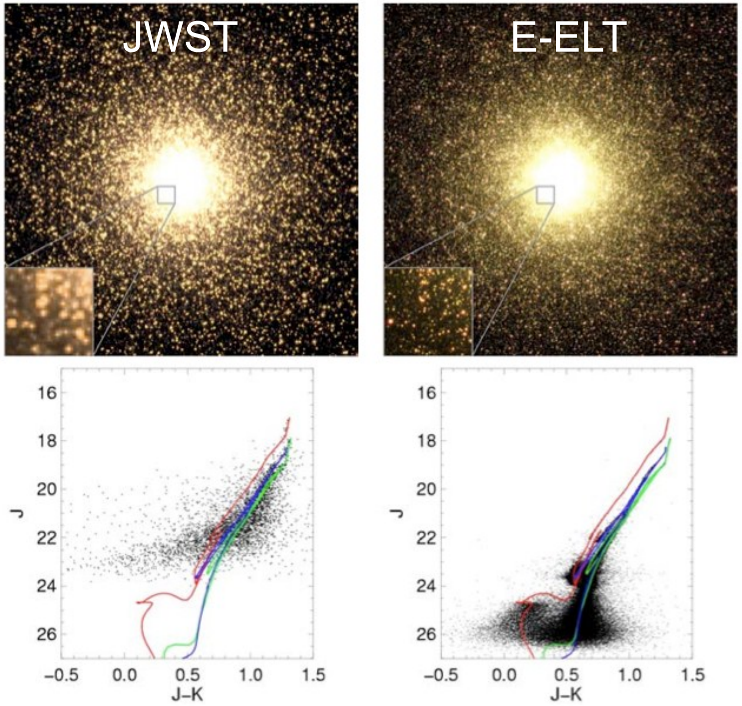
What is the evolution and merger history of galaxies?

A key goal is to extend the population of galaxies that can be studied to develop a more statistical basis to our understanding

Resolved stellar populations

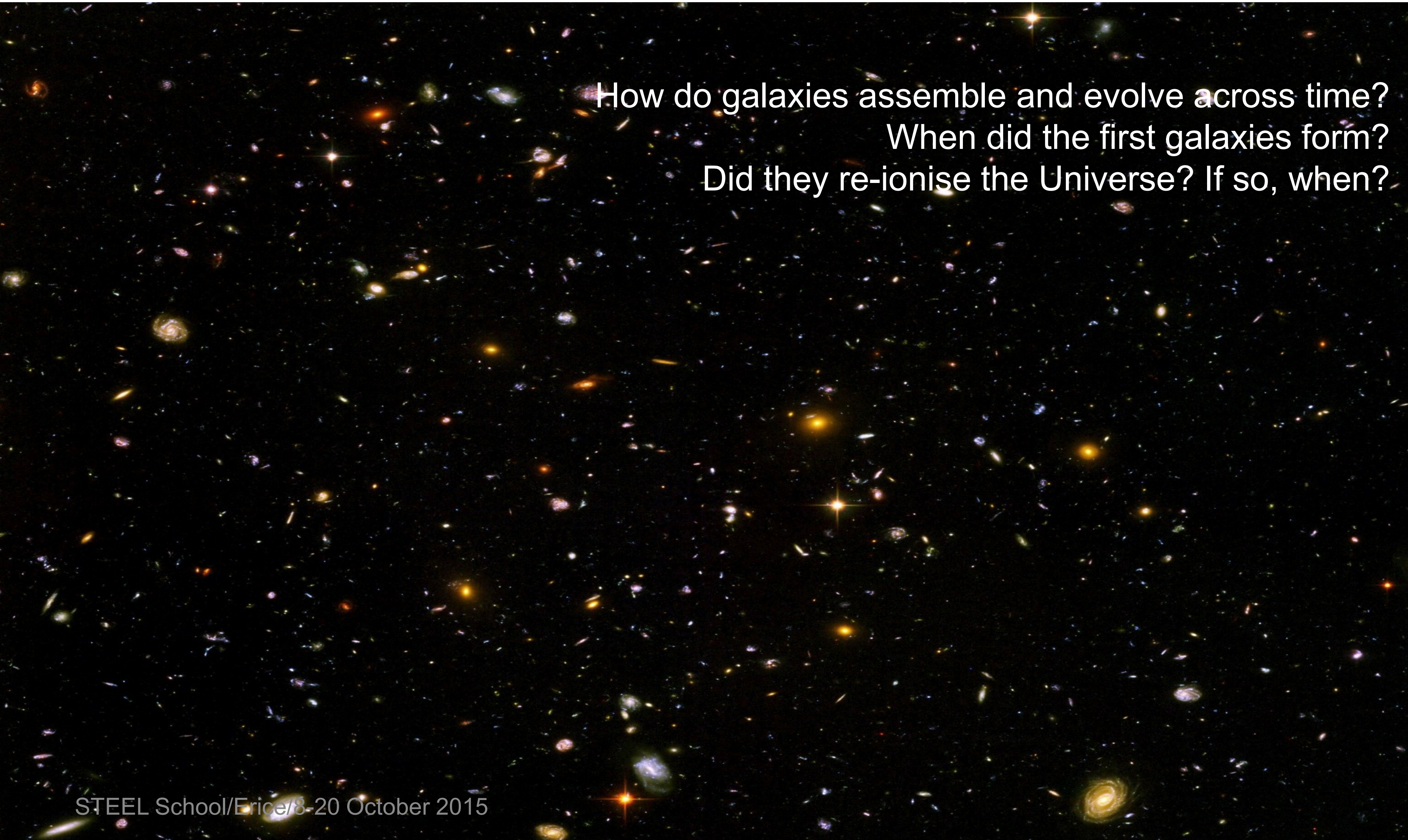
- Requires:
  - Deep photometry in crowded fields
  - R>~20000 spectroscopy of faint sources
- Drives:
  - Telescope diameter for sensitivity (and resolution)
  - Field of view
  - Diffraction limited performance (even into the optical….)

Colour-magnitude diagrams



Simulated observations of M32

High redshift Universe



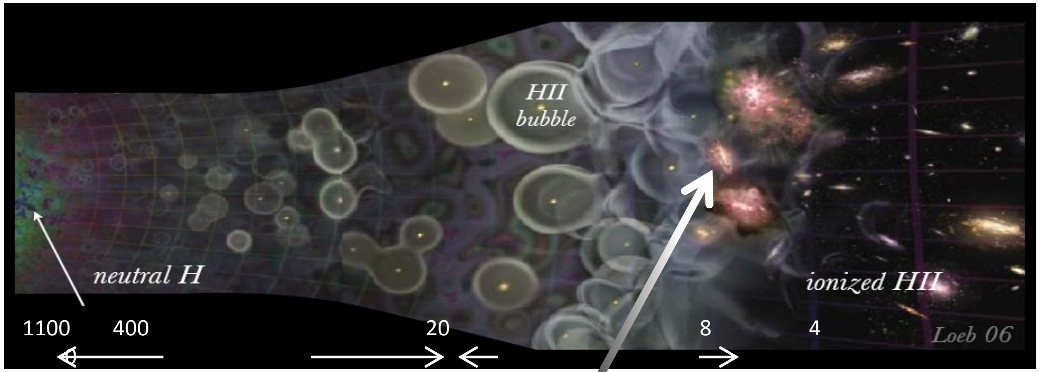
How do galaxies assemble and evolve across time?
When did the first galaxies form?
Did they re-ionise the Universe? If so, when?

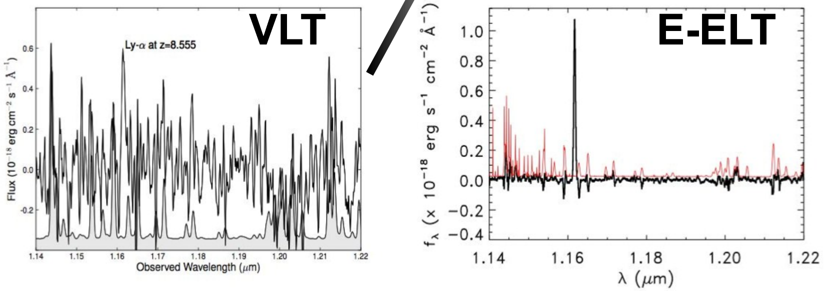
The end of the dark ages and the first galaxies

From QSO spectra and CMB constrain reionisation epoch 7 < z < 12 … but the sources are beyond current detection limits.

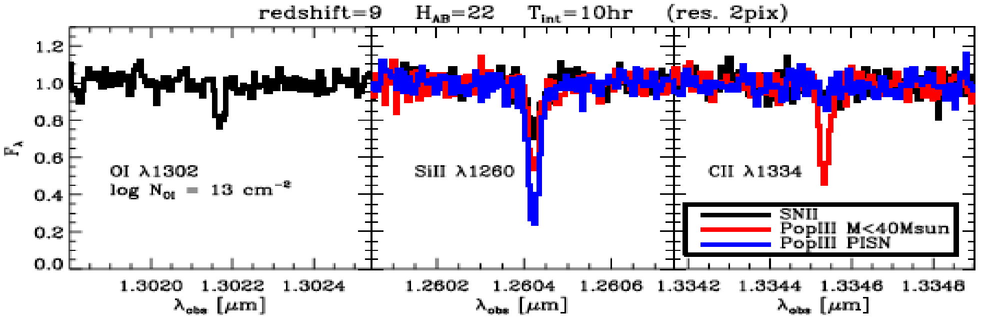
Goals are

- Redshift confirmation of the most distant galaxies
- line strengths, stellar populations, outflows
- Absorption-line spectra of QSOs at z>6 (isotropy & homogeneity of reionisation).
- Enrichment of IGM.





Galaxy at z=8.7 observed with VLT and and E-ELT

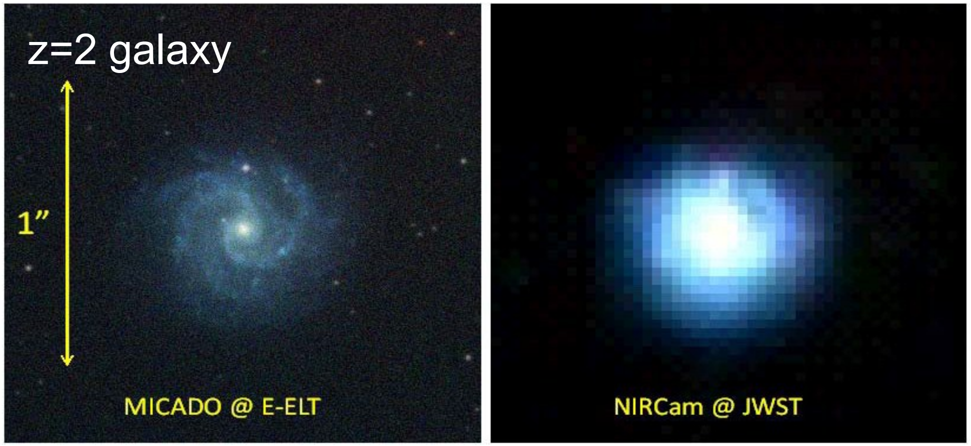


Simulated observations of absorption line systems towards high-z QSOs at z=9

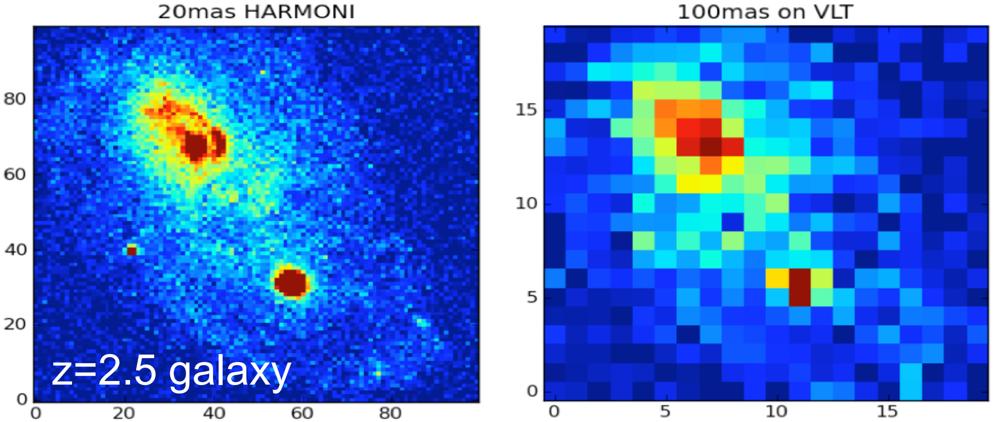
Mass assembly of galaxies

- Requires:
  - Imaging and (multi-object) spectroscopy of objects to Z~10
  - Near infrared sensitivity
- Drives:
  - Telescope diameter, coating for sensitivity
  - Field of view > 5x5arcmin
  - Moderate (30% Strehl) AO performance over wide field

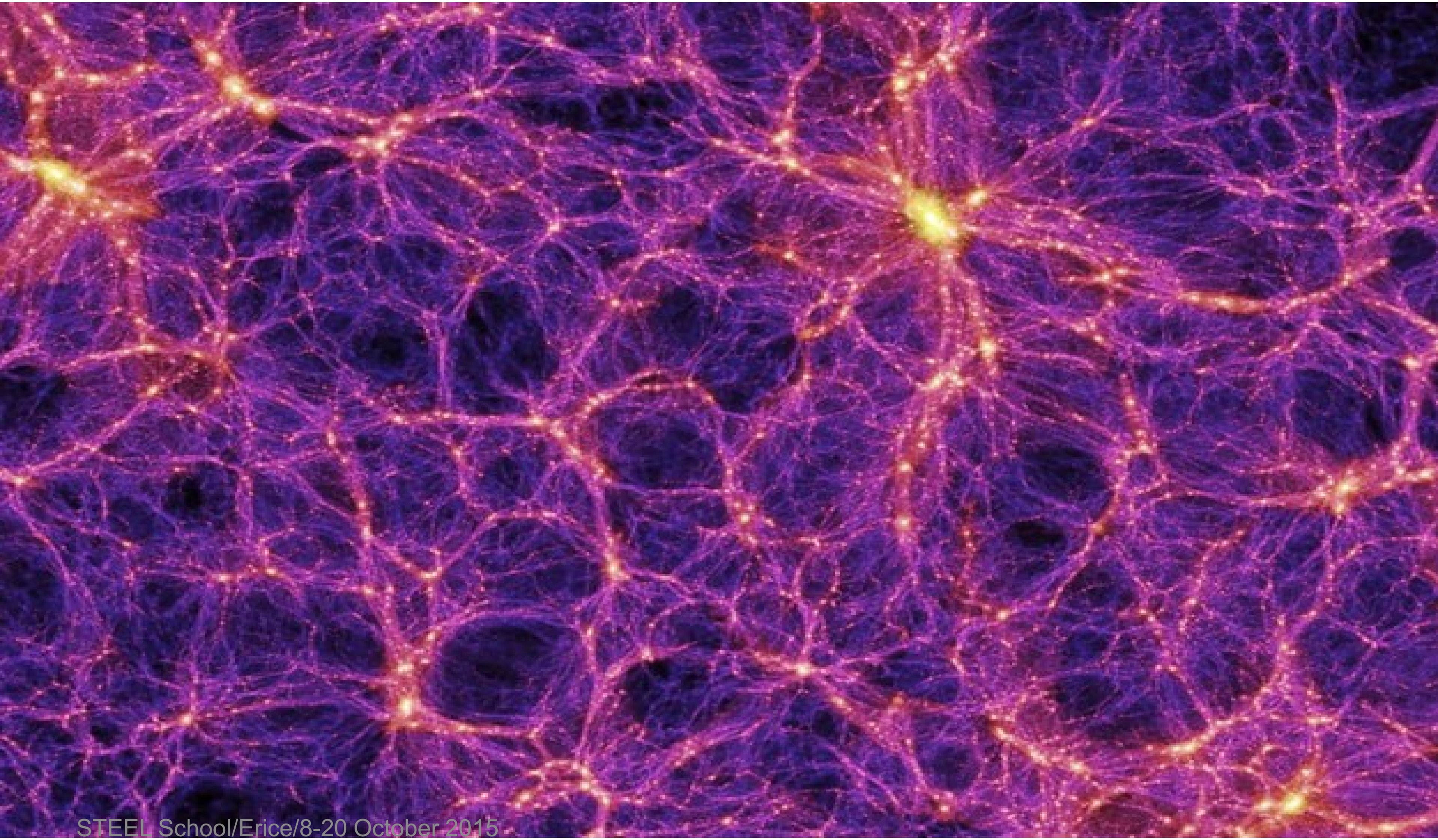
E-ELT CAM: Structure from high-resolution imaging



E-ELT IFU and MOS: Dynamics and physics from spatially resolved spectroscopy

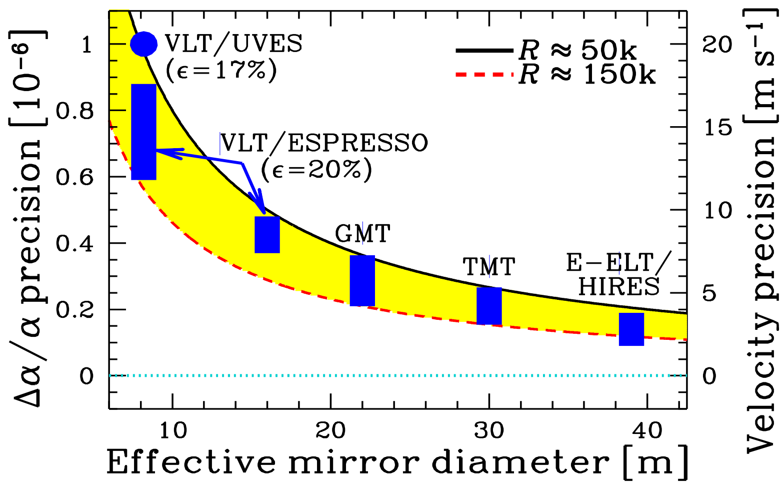


Cosmology and fundamental physics



Fundamental constants?

- Requires:
  - Stability over decades
- Drives:
  - Telescope diameter, coating for sensitivity
  - Wavelength coverage in the optical (Ly-alpha forest)
  - Provision of a coudé focus



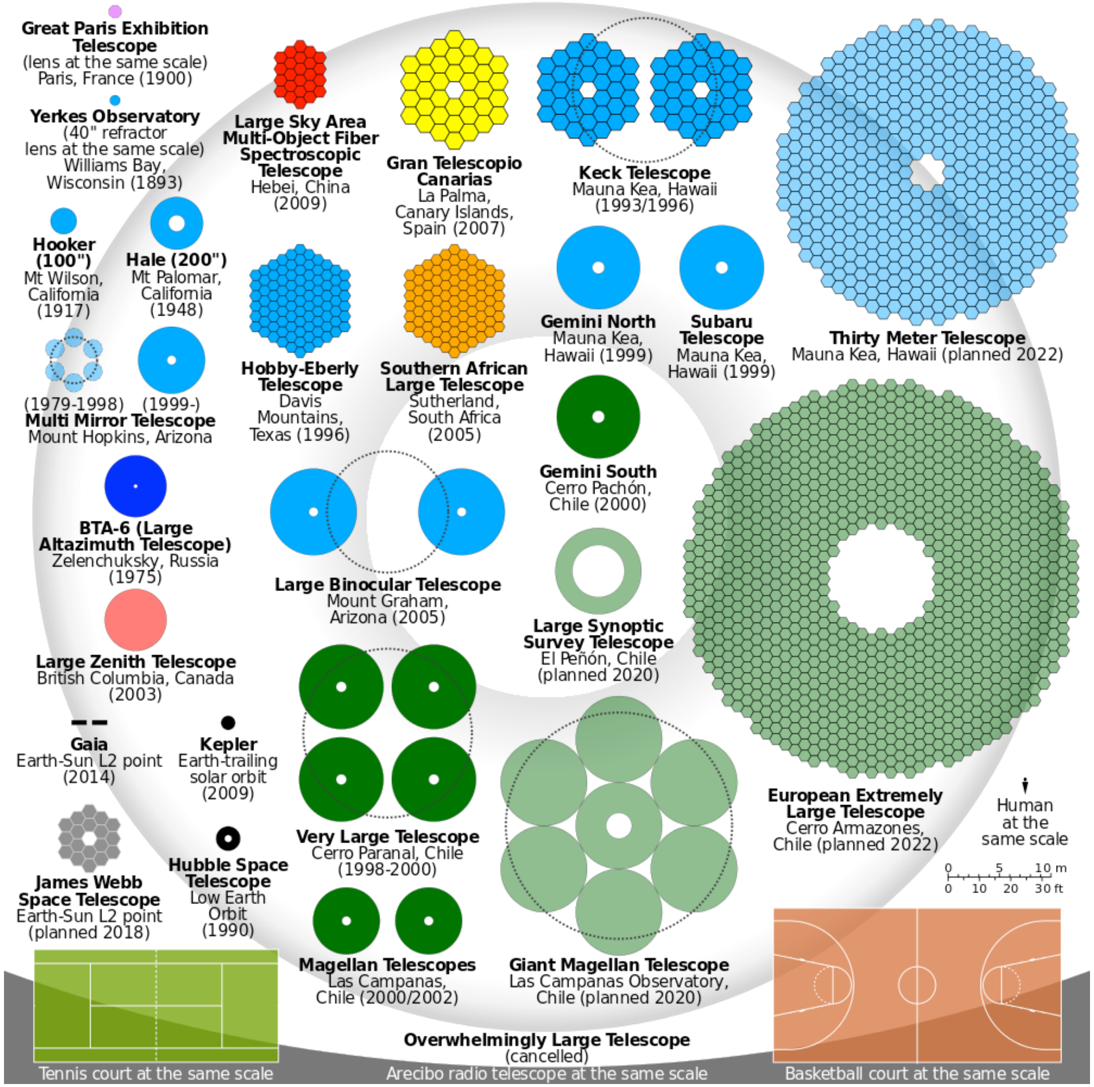
Fundamental Physics

- Variability of fine-structure constant (α) and electron-to-proton mass (μ): variations expected in string theory
- Sandage test: Direct measurement of the changing expansion of the universe via precise measurements of Ly-α line positions with time.

To summarise……

- The science cases for the E-ELT drives the design of the telescope.
  - Maintains a diameter >> 30m (to detect exo-Earths)
  - Keeps our attention firmly fixed on the image quality and adaptive optics
  - Leads to prioritization of the near and mid-infrared when selecting mirror coatings
  - Informs the engineering team of the aspirations of the astronomy community
- Much more detailed to follow during the school!

To summarise……



Some further reading

- Links to ELT pages
  - E-ELT: ww.eso.org/sci/facilities/eelt
  - TMT: www.tmt.org
  - GMT: www.gmto.org
- Some science conferences
  - ESO workshops page: www.eso.org/sci/meetings/conferences.html
  - Shaping the E-ELT Science and Instrumentation (Feb 2013) www.eso.org/sci/meeting/2013/eelt2013.html
  - Expolanet observations with E-ELT (Feb 2014) www.eso.org/sci/meeting/2014/exoelt2014.html
  - Speed and Sensitivity (May 2014) astro.nuigalway.ie/speedandsensitivity
  - Early E-ELT Science: Spectroscopy with HARMONI (Jul2015) harmoni2015.physics.ox.ac.uk
  - Science and Technology with E-ELT (Oct 2015) www.eso,org/sci/meetings/2015/EELT_EriceSchool2015.html)