High resolution spectroscopy: what's next?

Valentina D'Odorico
INAF – Osservatorio Astronomico di Trieste
on behalf of the
ESPRESSO@VLT and HIRES@E-ELT teams

Lesson learned from the HARPS instruments

Besides the importance of increasing the photon collecting area to observe fainter and fainter objects, the relevance of high precision has emerged as a crucial element in spectroscopy.

Dec 2007 ESO Council endorses the recommendation of the ESO STC of the development of additional 2nd generation VLT instruments;

March 2008 ESO issues a call for proposal to carry out the Phase A study for a high-resolution, ultra-stable spectrograph for the combined-Coudé focus, with these main scientific drivers:

- Measure high-precision radial velocities (RV) for search for rocky planets;
- Measure the variation of physical constants;
- Analyse the chemical composition of stars in nearby galaxies;

Feb 2011 Kick-off of the ESPRESSO project whose proposal was accepted by ESO.

ESPRESSO@VLT

Pepe et al. AN 2014

Echelle Spectrograph for Rocky Exoplanet and Stable Spectroscopic Observations

Consortium: Switzerland (F. Pepe P.I, Observatoire de Genève, Geneva and Bern Universities); Italy (S. Cristiani co-PI, INAF-OATs, INAF-Brera); Spain (R. Rebolo co-PI, IAC); Portugal (N. Santos co-PI, Lisbon and Porto Universities).

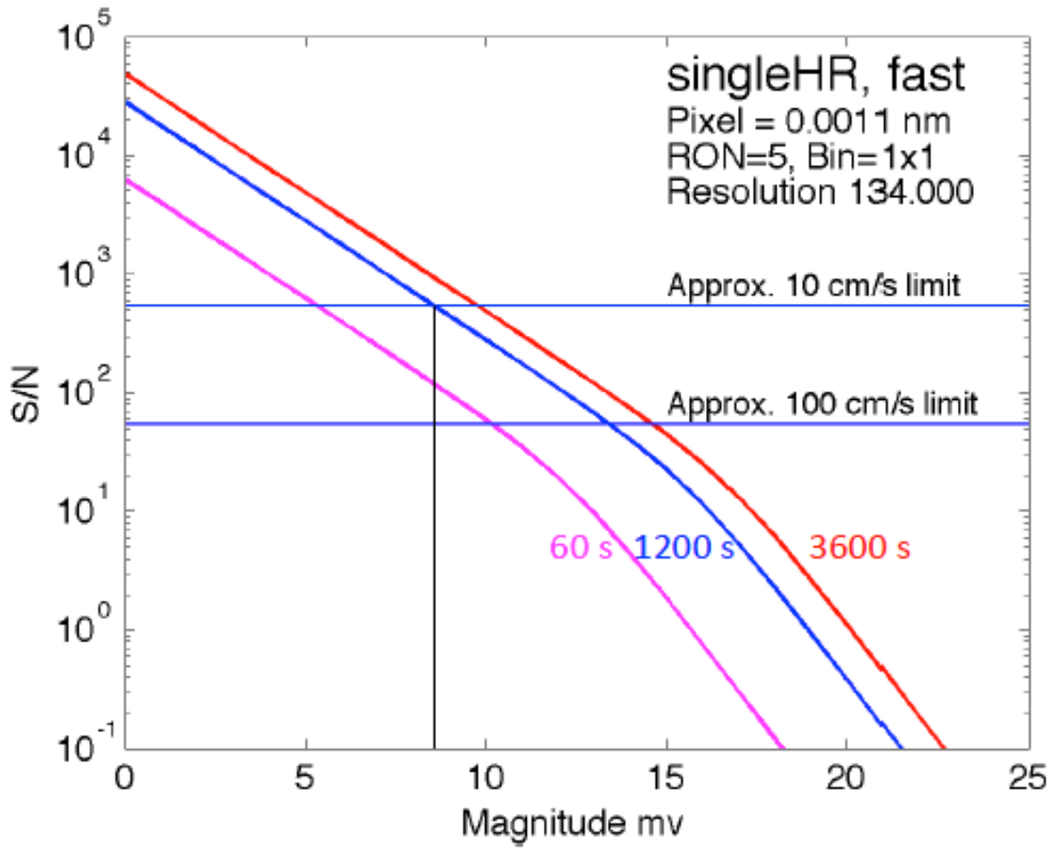
ESPRESSO is a fiber-fed, cross-dispersed, high-resolution, echelle spectrograph, which will be located in the Combined-Coudé Laboratory (incoherent focus) where a front-end unit can combine the light from up to 4 Unit Telescopes (UT) of the VLT.

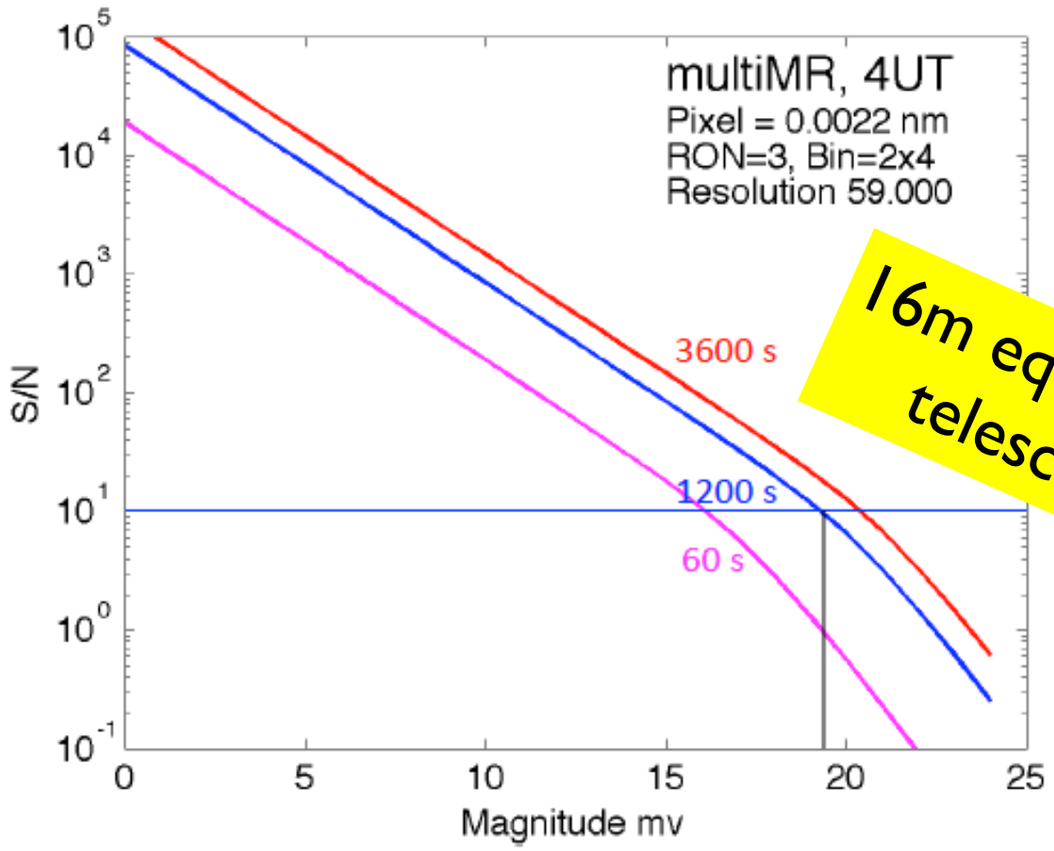
New concepts

- Use of the incoherent combined focus (any or all the UTs can feed the instrument);
- Use of the anamorphic pupil slicer unit (APSU) to minimize the size of the optics;
- Use of the laser frequency comb for an extremely precise wavelength calibration;
- ESPRESSO as a science generating machine: the goal is to provide scientific data as precise as possible in a short time after the end of an observation.

ESPRESSO modes and performances

Parameter/Mode	singleHR (1 UT)	multiMR (up to 4 UTs)	singleUHR (1 UT)
Wavelength range	380-780 nm	380-780 nm	380-780 nm
Resolving power	134'000	59'000	225'000
Aperture on sky	1.0 arcsec	4x1.0 arcsec	0.5 arcsec
Spectral ampling (average)	4.5 pixels	5.5 pixels (binned x2)	2.5 pixels
Spatial sampling per slice	9.0 (4.5) pixels	5.5 pixels (binned x4)	5.0 pixels
Simultaneous reference	Yes (no sky)	Yes (no sky)	Yes (no sky)
Sky subtraction	Yes (no sim. ref.)	Yes (no sim. ref.)	Yes (no sim. ref.)
Total efficiency	11%	11%	5%
Instrumental RV precision	< 10 cm s^{-1}	~ 1 m s^{-1}	< 10 cm s^{-1}





16m equivalent telescope

ESPRESSO science

Searching for rocky planets in the habitable zone (singleHR, singleUHR)

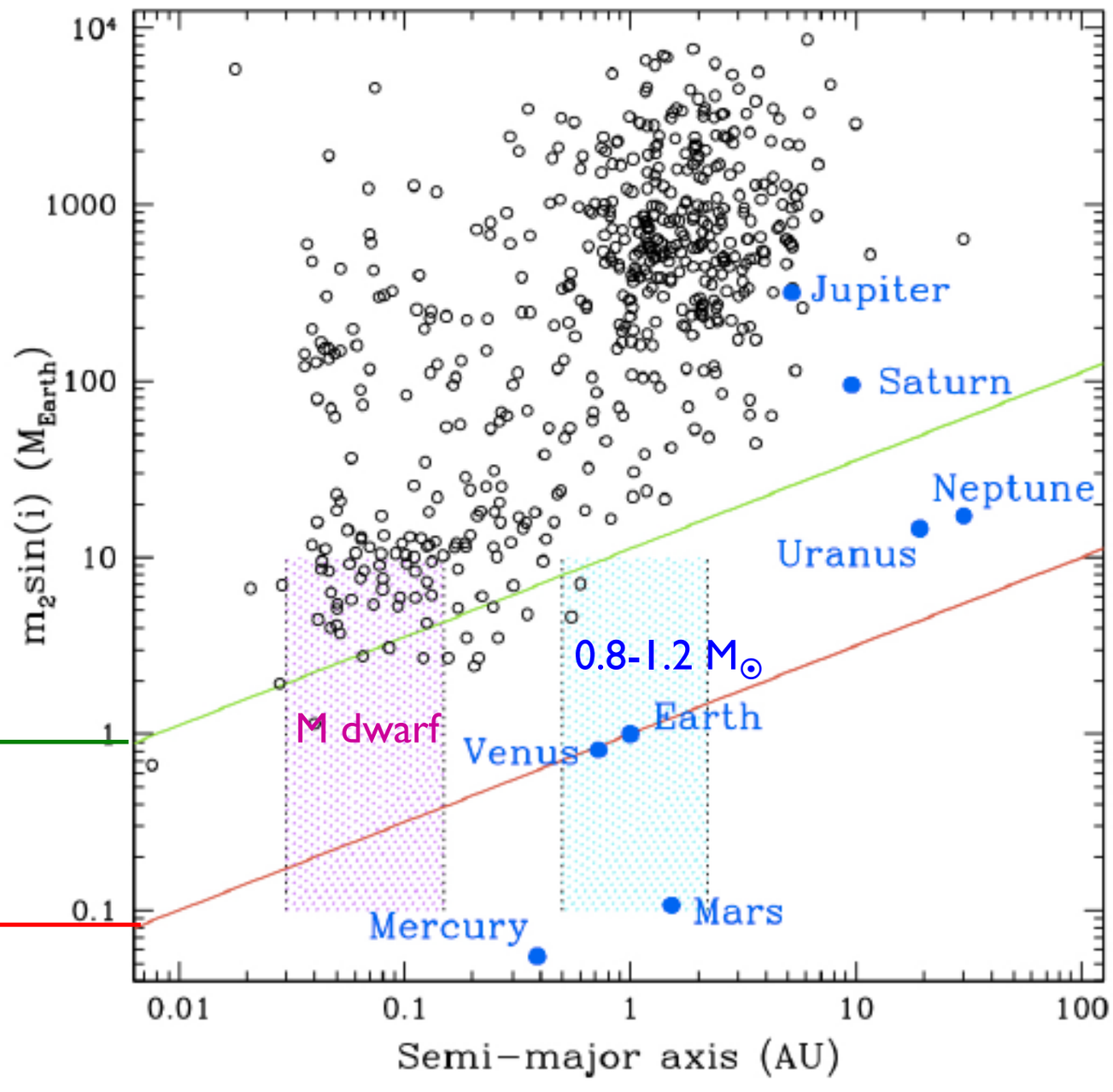
ESPRESSO will achieve a precision of 10 cm s^{-1} (about one order of magnitude better than the HARPS instruments) this will allow:

- to measure in RV the effect of an Earth-like planet in the habitable zone of nearby solar-type stars and around stars smaller than the Sun;
- to follow-up and characterize planets discovered with the transiting technique (e.g. by Kepler)

ESPRESSO detectability

Star of 1 $M_\odot$

Star of 0.08 $M_\odot$

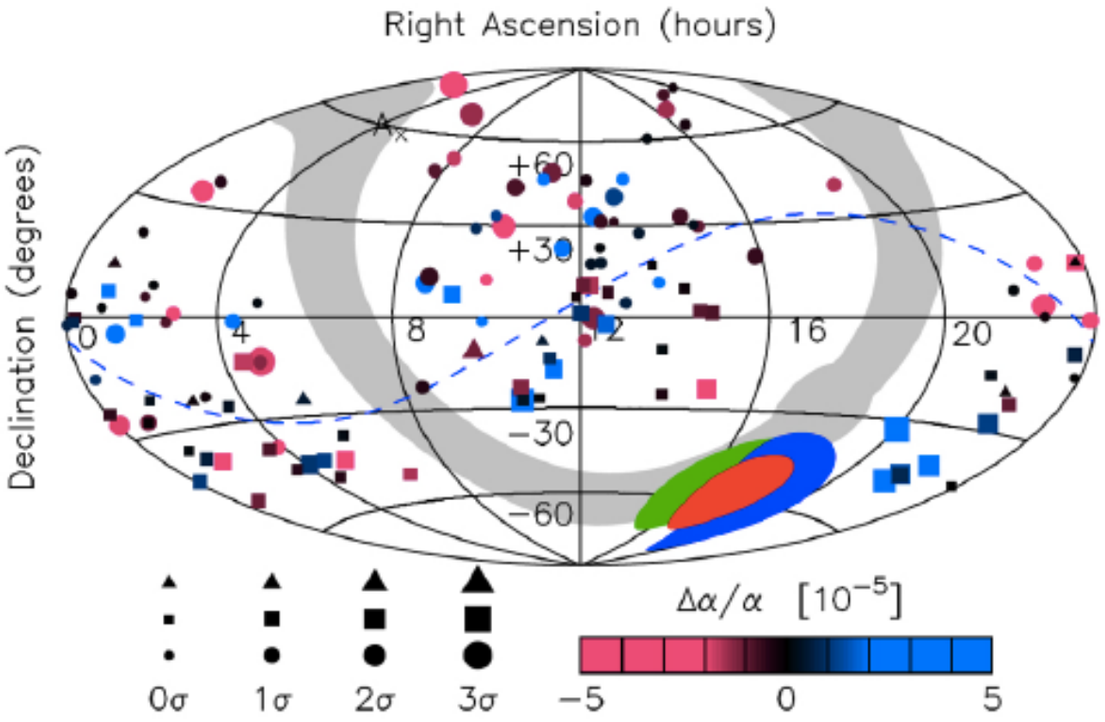


ESPRESSO science

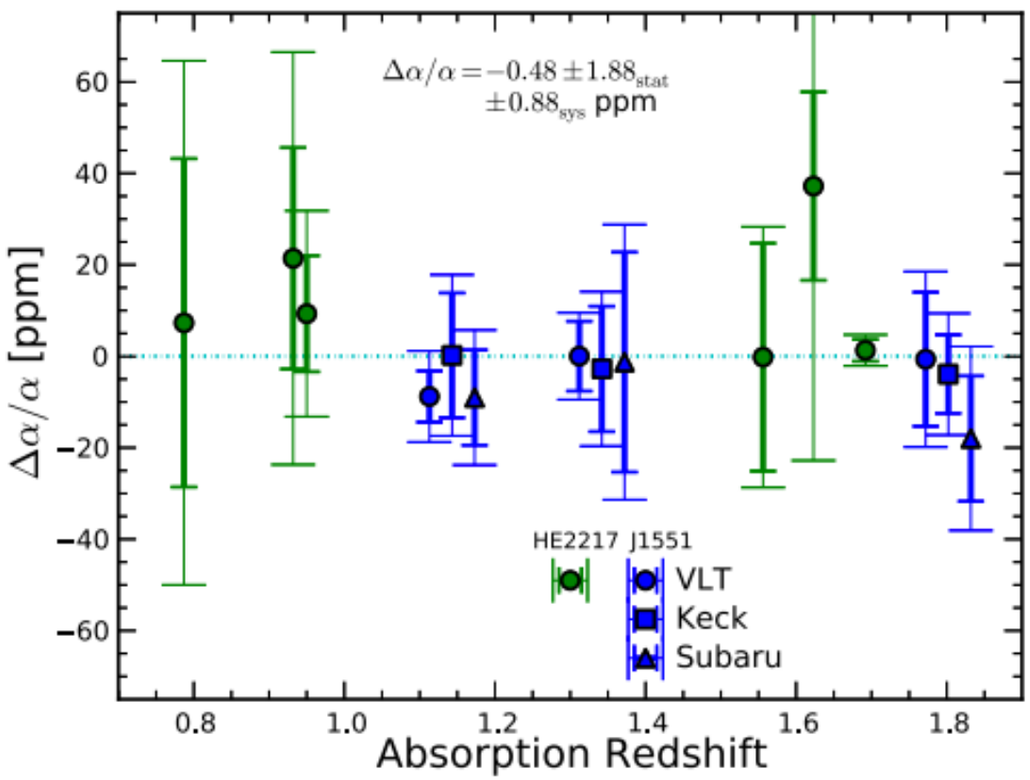
Do physical constants vary? (singleHR)

Most of the modern extensions of the standard model of particle physics predict a variation of the fundamental constants of nature. With the precise determination of the position of absorption lines in spectra of quasars it is possible to constrain the variability of the fine structure constant, α and the proton-to-electron mass ratio, μ. Present measurements obtained with 10m class telescopes are affected by systematic errors.

ESPRESSO will improve of more than one order of magnitude the accuracy of the measurement of α and μ.



Webb et al. 2011



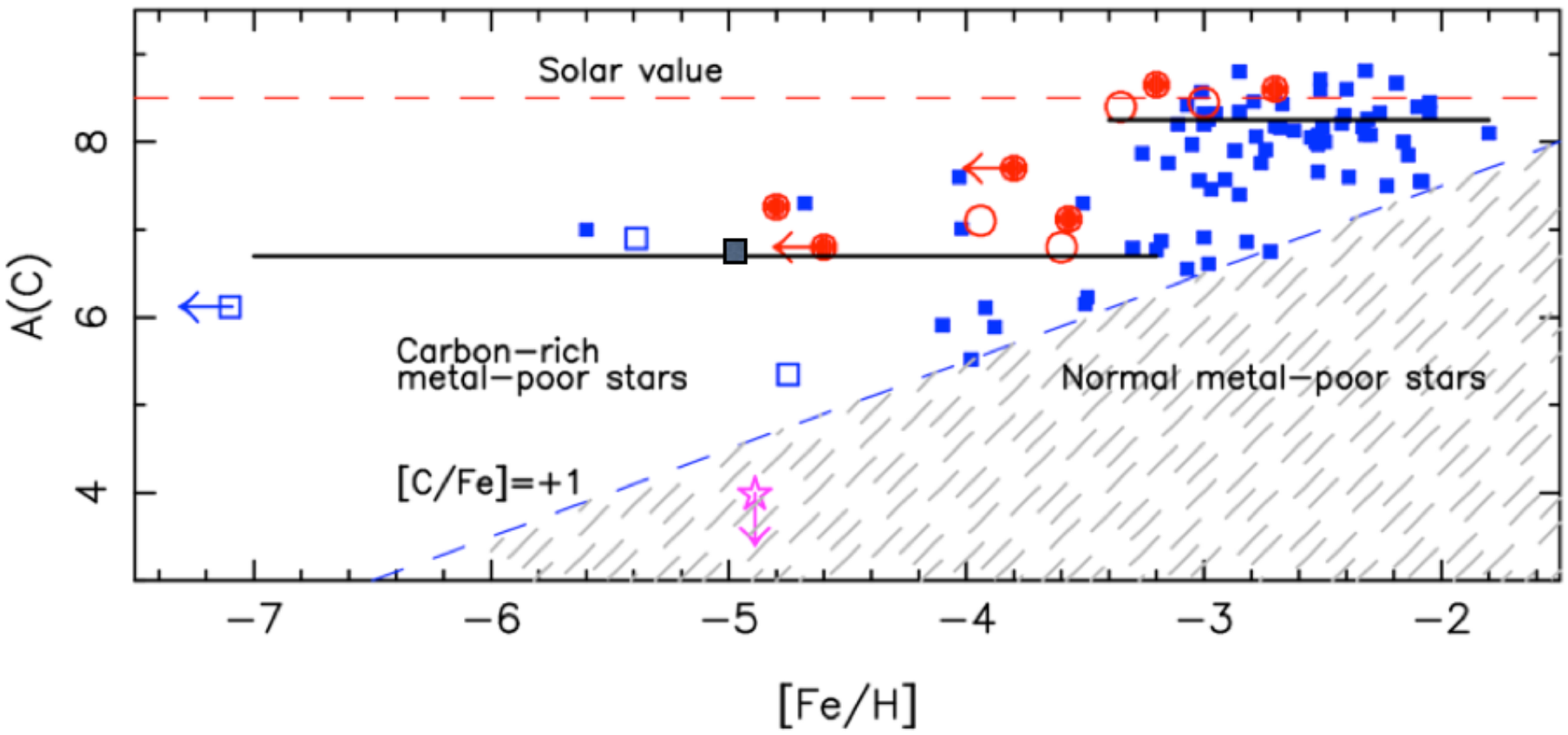
Evans et al. 2014

ESPRESSO science

A scientific Pandora box (1UT and 4 UT mode)

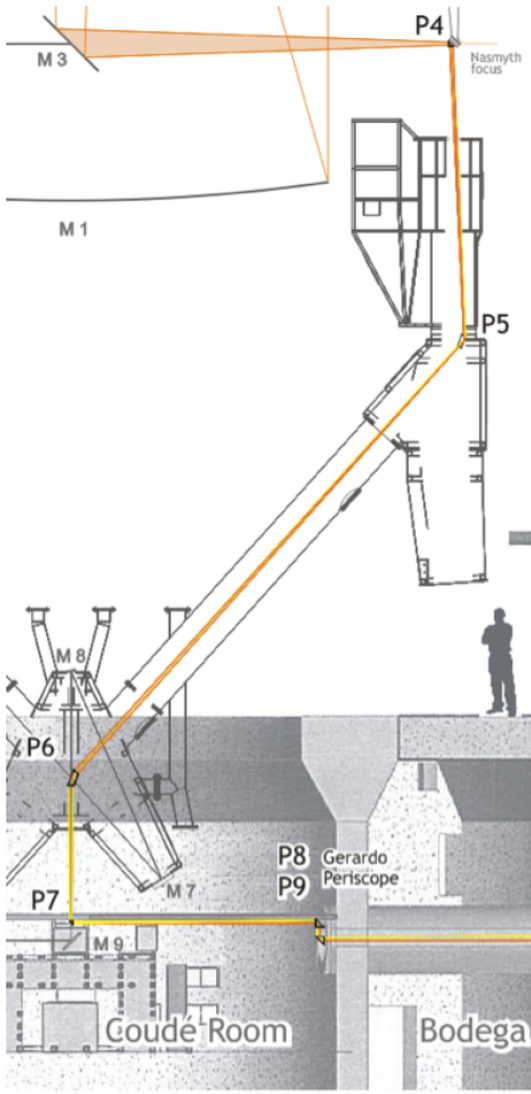
- The chemical composition of stars in local galaxies
- The most metal poor stars in our Galaxy as fossil records of PopIII stars
- Stellar oscillations, asteroseismology and variability
- The nature of galactic winds constrained with tomography of small fields with close quasar lines of sight
- The physical and chemical properties of the tenuous gas
- The expansion of the Universe studied with the Sandage test, ESPRESSO could provide a first epoch measurement.

The search for the most metal poor stars: the range 380-450 nm is fundamental for this case.



ESPRESSO latest news

Instrument integration ongoing in Geneva
March 1st: beginning of the Acceptance Europe process
First light in Paranal end of 2017



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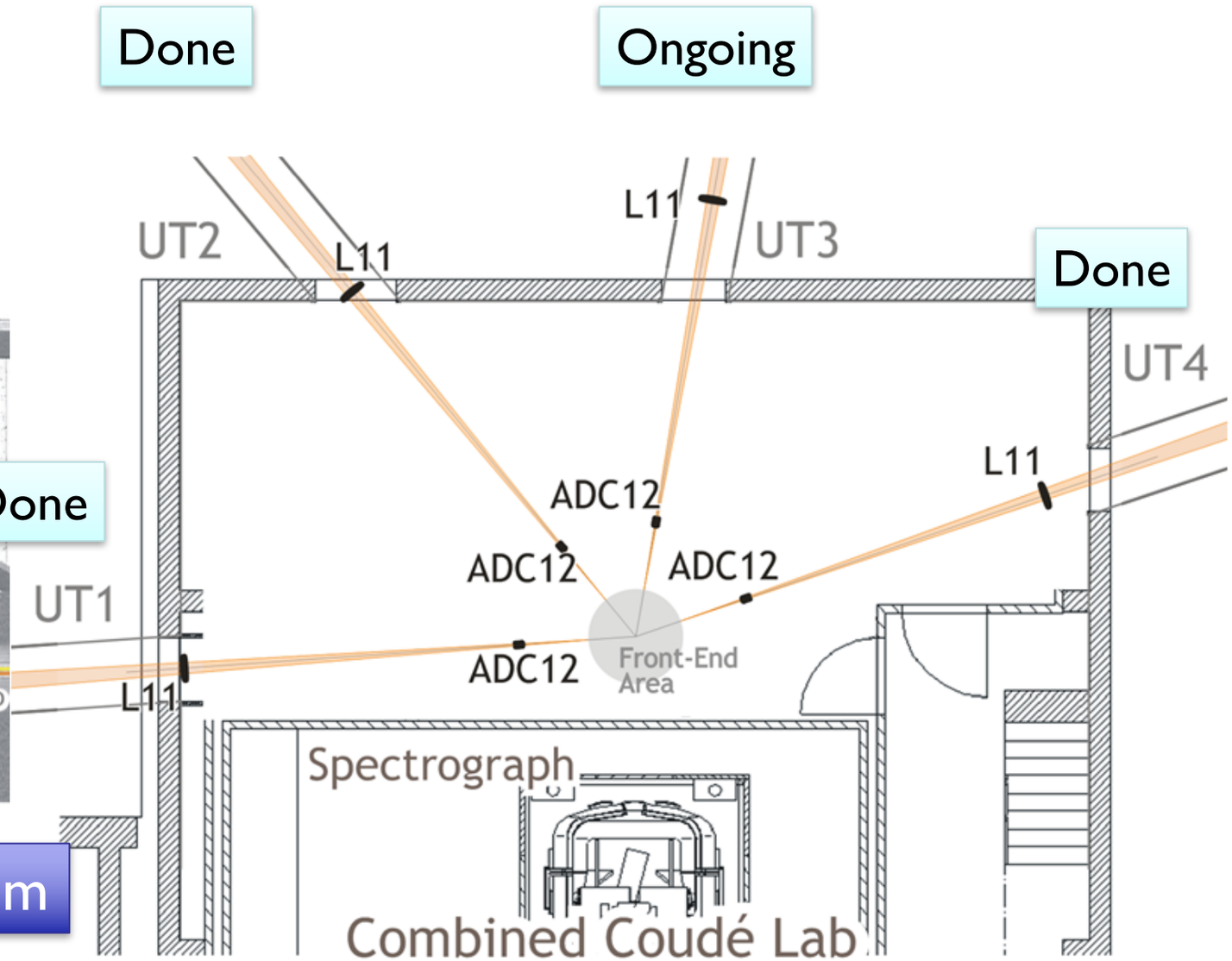
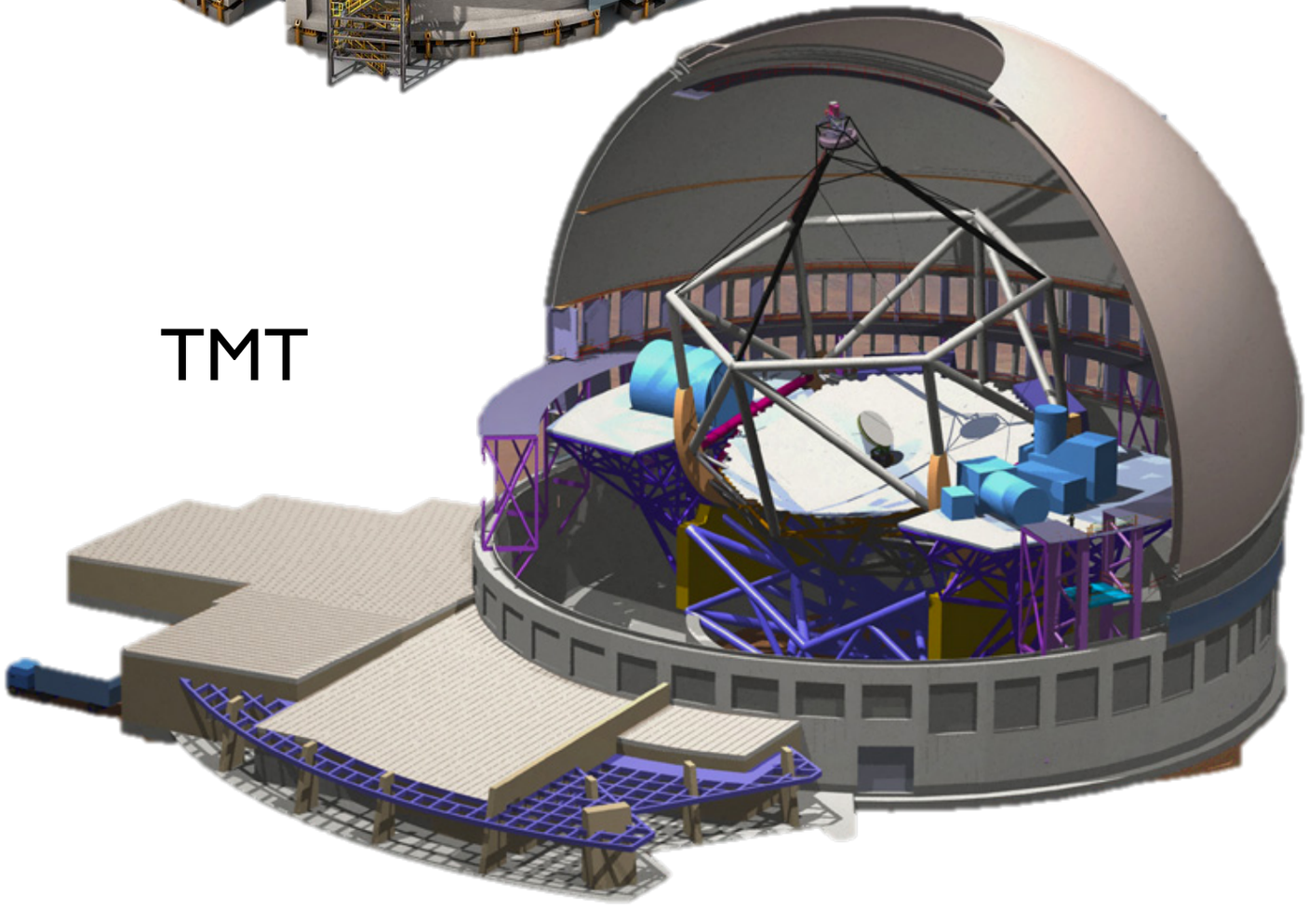


Coudé trains are built by the consortium

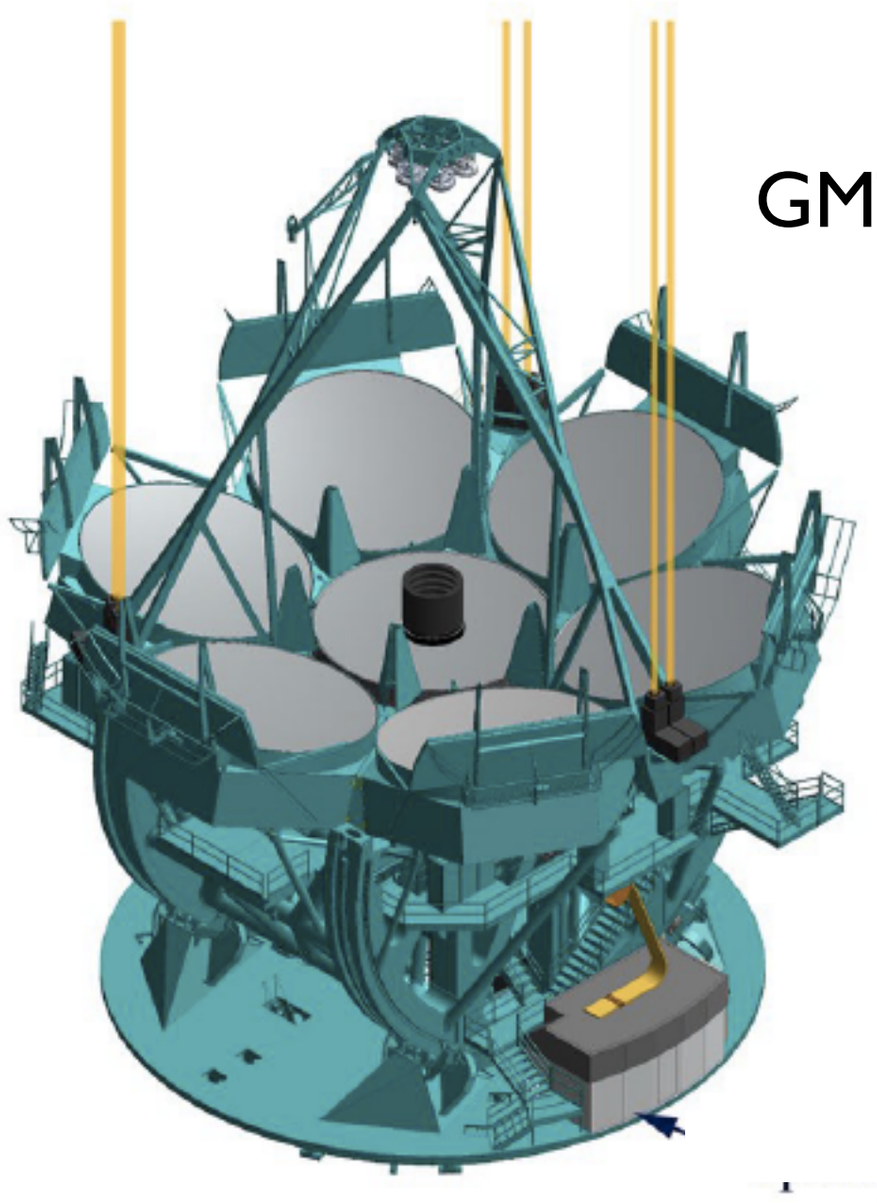
ELT generation

E-ELT

TMT



GMT



HIRES@E-ELT

Marconi et al. SPIE 2016

HIRES is a high resolution spectrograph capable of providing a spectrum at R~100,000 over 0.4-2.5 μm

International Consortium

- Italy INAF lead institution, A. Marconi PI
- Chile (Pontificia Universidad Catolica+), France (Laboratoire d'Astrophysique de Marseille+), Germany (Leibniz-Institute for Astrophysics Potsdam+), Portugal (Institute of Astrophysics and Space Sciences), Spain (Instituto de Astrofisica de Canarias+), Sweden (Uppsala University+), Switzerland (Observatoire de Genève+), United Kingdom (University of Cambridge+), Brazil (Theoretical and Experimental Physics of the Natal University), Denmark (Niels Bohr Institute Copenhagen +), Poland (Nicolaus Copernicus University Toruń +)

- 2010 Two separate spectrographs proposed for the E-ELT Phase A instrument studies;
- 2015 ESO issued a Request for Information on the unified concept: HIRES
- March 22, 2016 Kickoff of Phase A study (max duration 2 years).

HIRES@E-ELT

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Not a first light instrument

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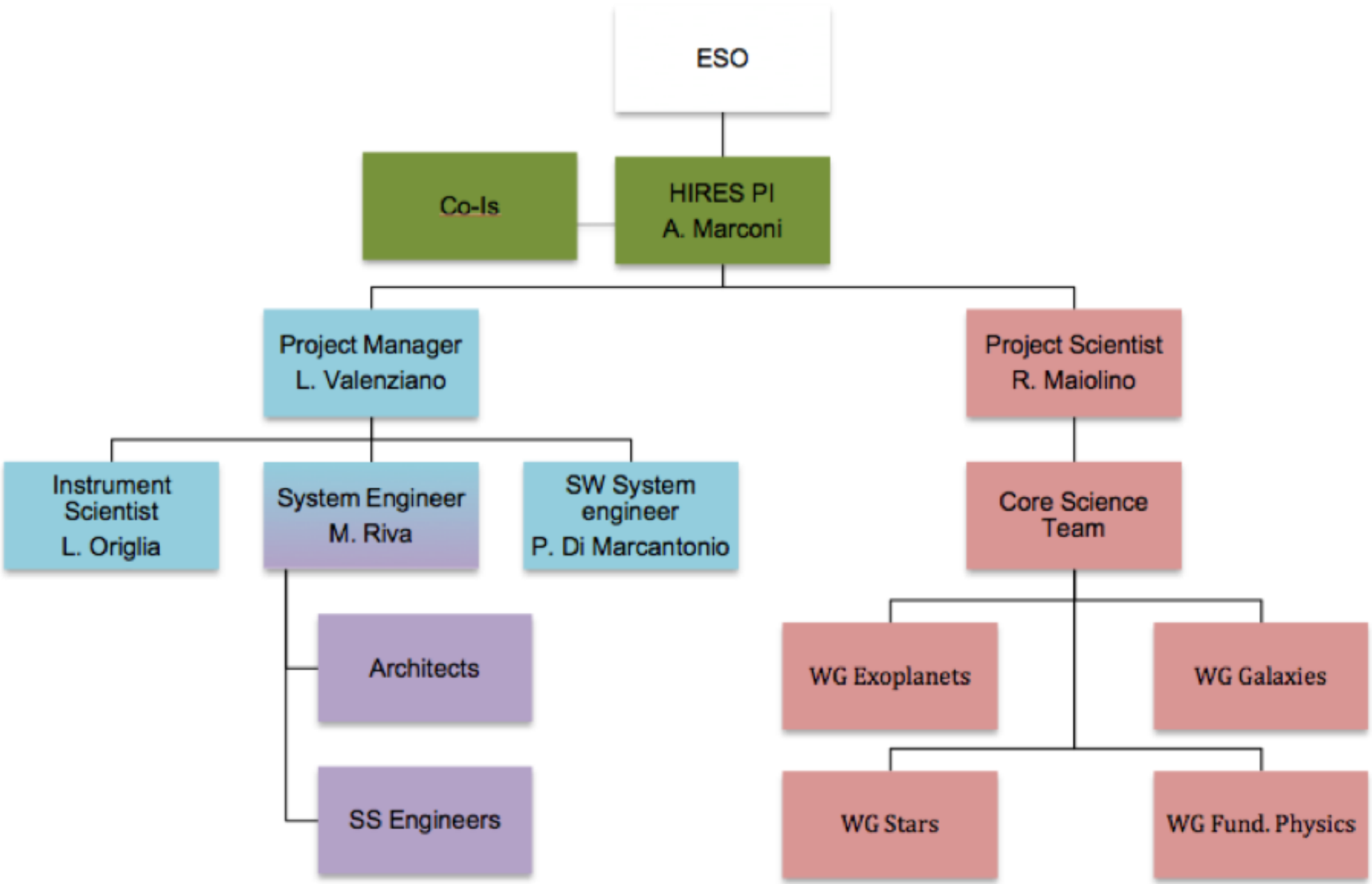
HIRES Project Structure



HIRES Science

- Exoplanets (characterization of planetary atmospheres and the detection of life signatures, exoplanets debris)
- Star and planet formation (Protoplanetary disks)
- Stellar physics, chemistry and astro-archaeology (3D structure of stellar atmospheres, solar twins, stellar magnetic fields, isotope ratios and nucleosynthesis for the earliest and the latest stages of stellar evolution, chemical enrichment in the local group, extremely low metallicity stars, resolved stellar populations in extragalactic star clusters)
- Galaxy formation (Population III stars, reionization, intergalactic medium, massive galaxies evolution, supermassive black holes)
- Fundamental Physics and Cosmology (variation of fundamental constants, constraints on Dark Matter and Dark Energy, constraints on non-standard physics, Sandage Test)

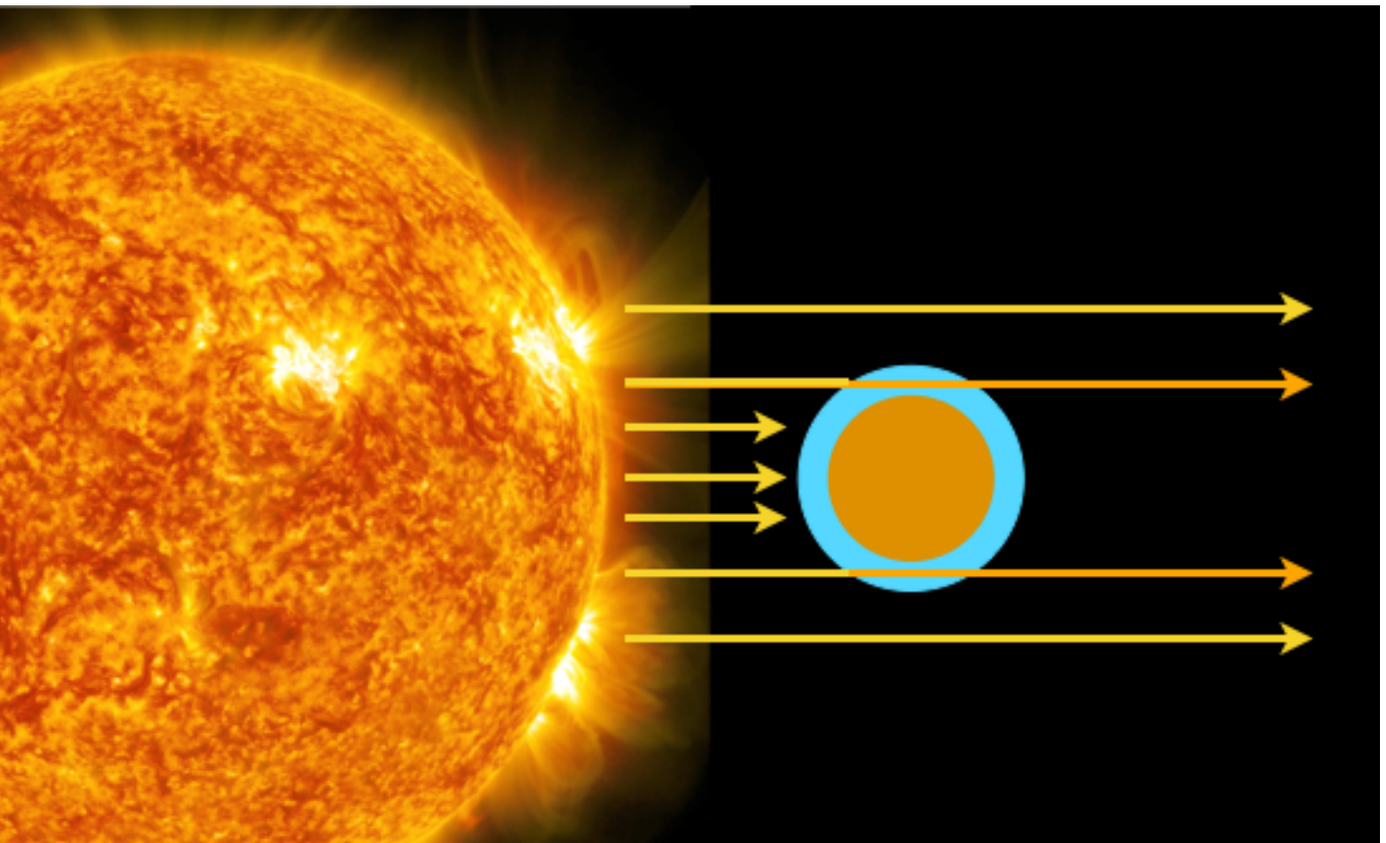
Community White Paper: Maiolino et al. 2013, ArXiV:1310.3163

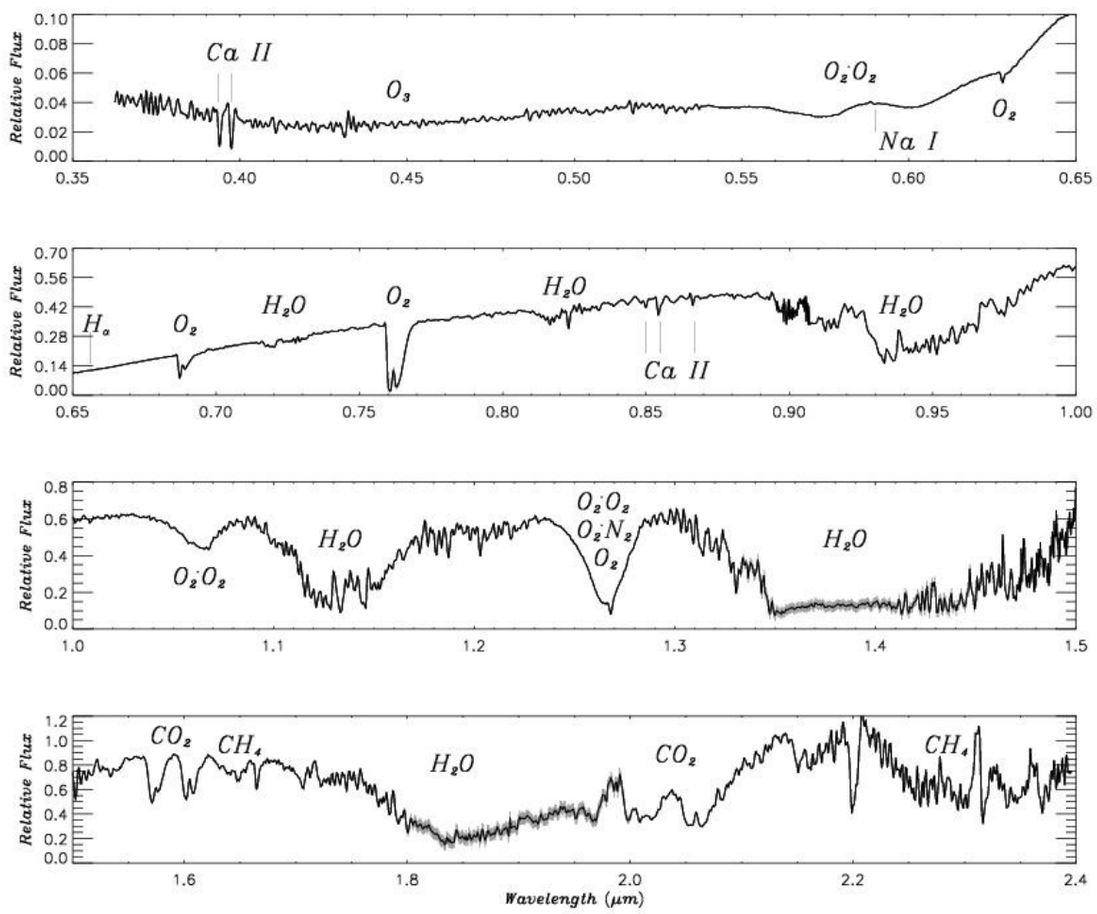
Exoplanet atmospheres in transmission

Characterisation of the atmospheres of Earth-like planets around late type stars (e.g. Snellen+13)

Example: in Trappist 1 & 2, HIRES can detect:

- H_20 (1.3-1.7 μm) in 2 transits
- H_20 (0.9-1.1 μm) in 4 transits
- CO_2 in 4 transits
- O_2 in 25 transits





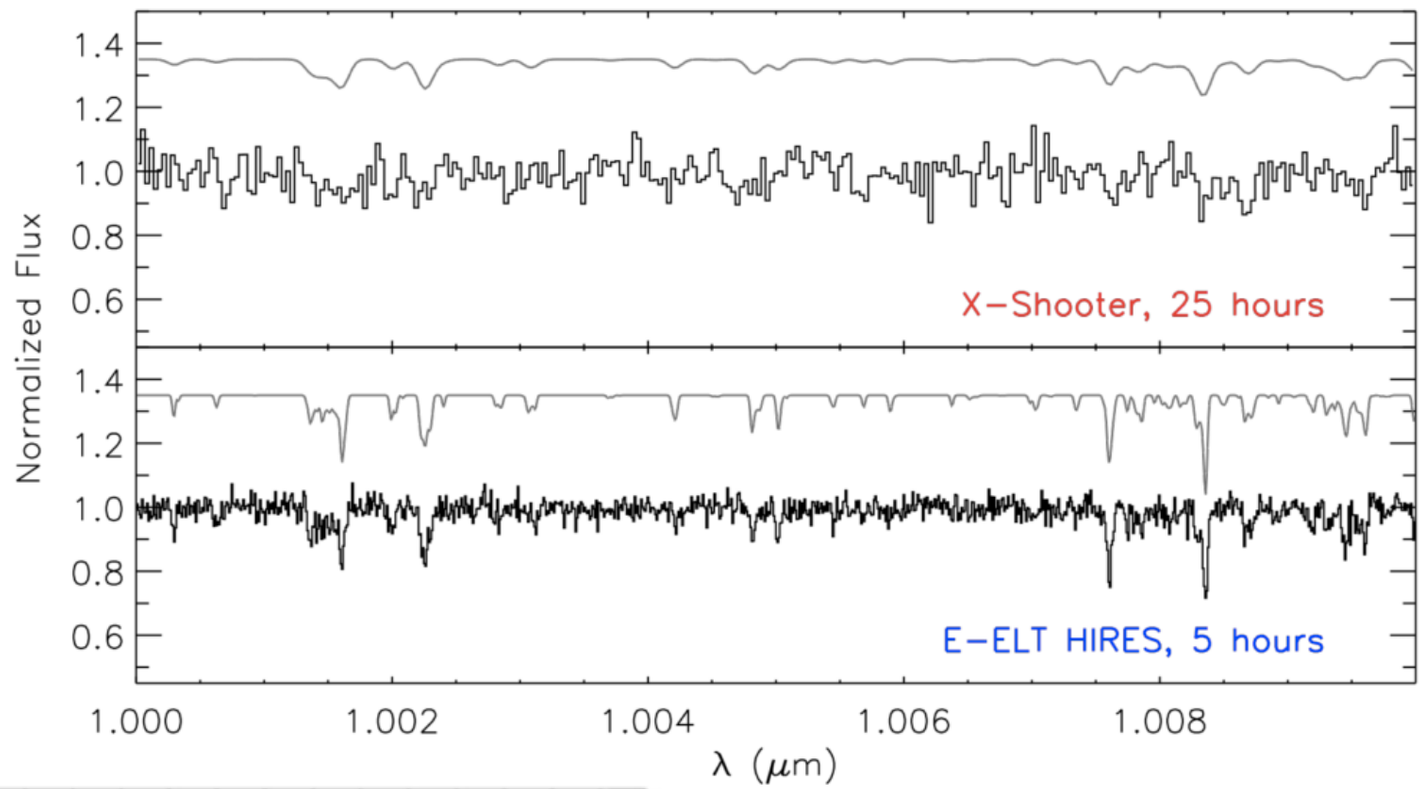
Earth transmission spectrum from lunar eclipse obs. (Pallè+2009)

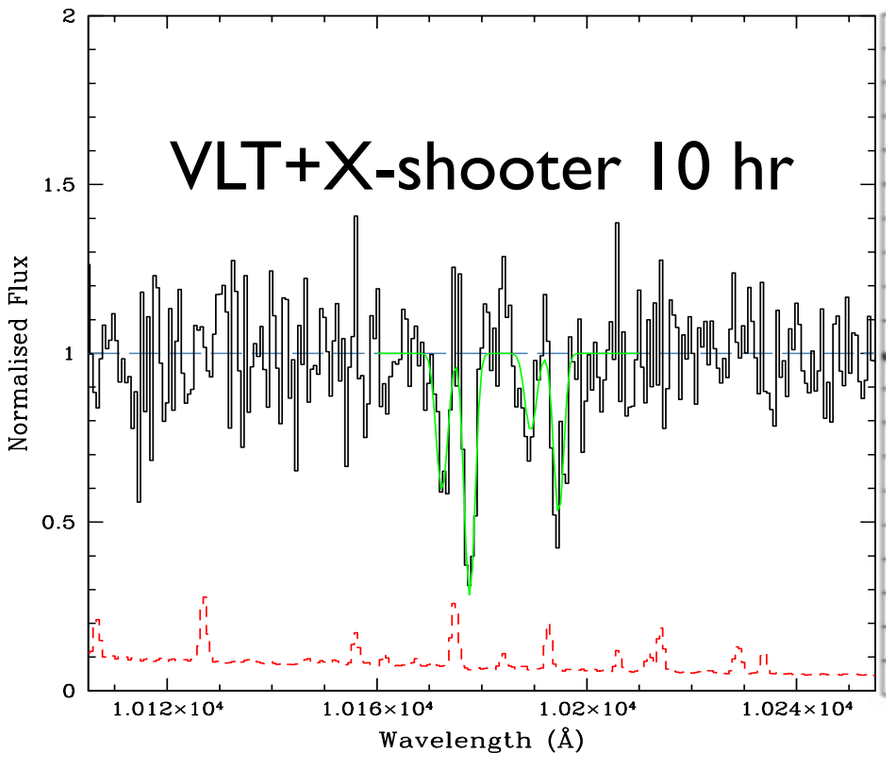
Reionization of the Universe

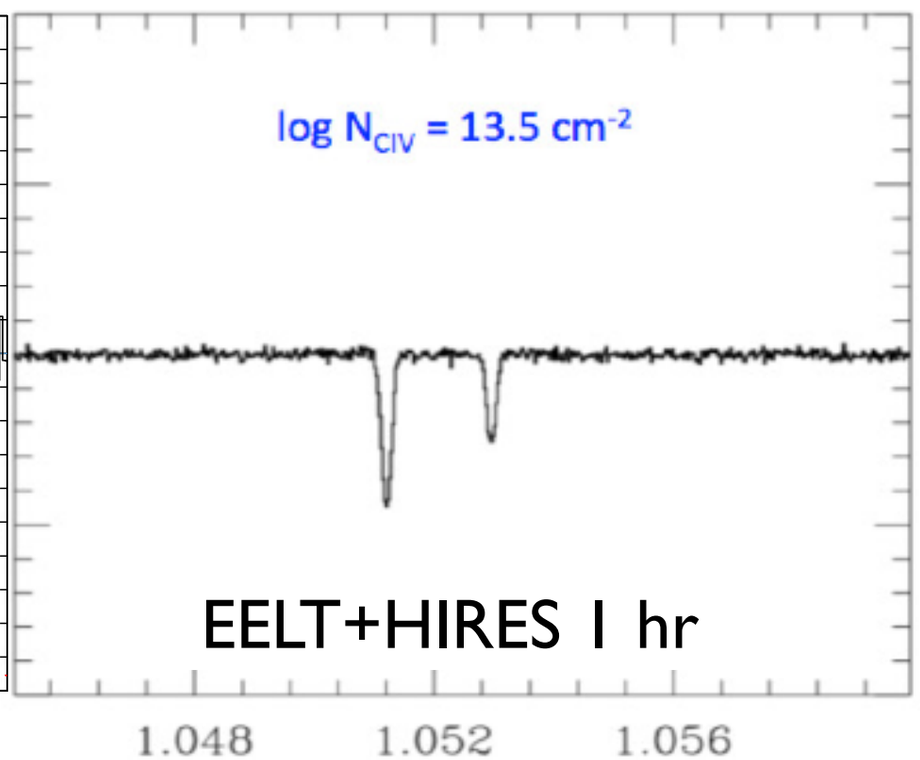
Characterization of the late stages of reionization with quasar absorption lines.

Detect the O I forest at z~6-7 as a proxy of the H I distribution to constrain the reionization history

NIR spectral range







Detect lines due to several ionic transitions at z ≥ 6 to constrain the shape and intensity of the ionzing background and the enriching sources

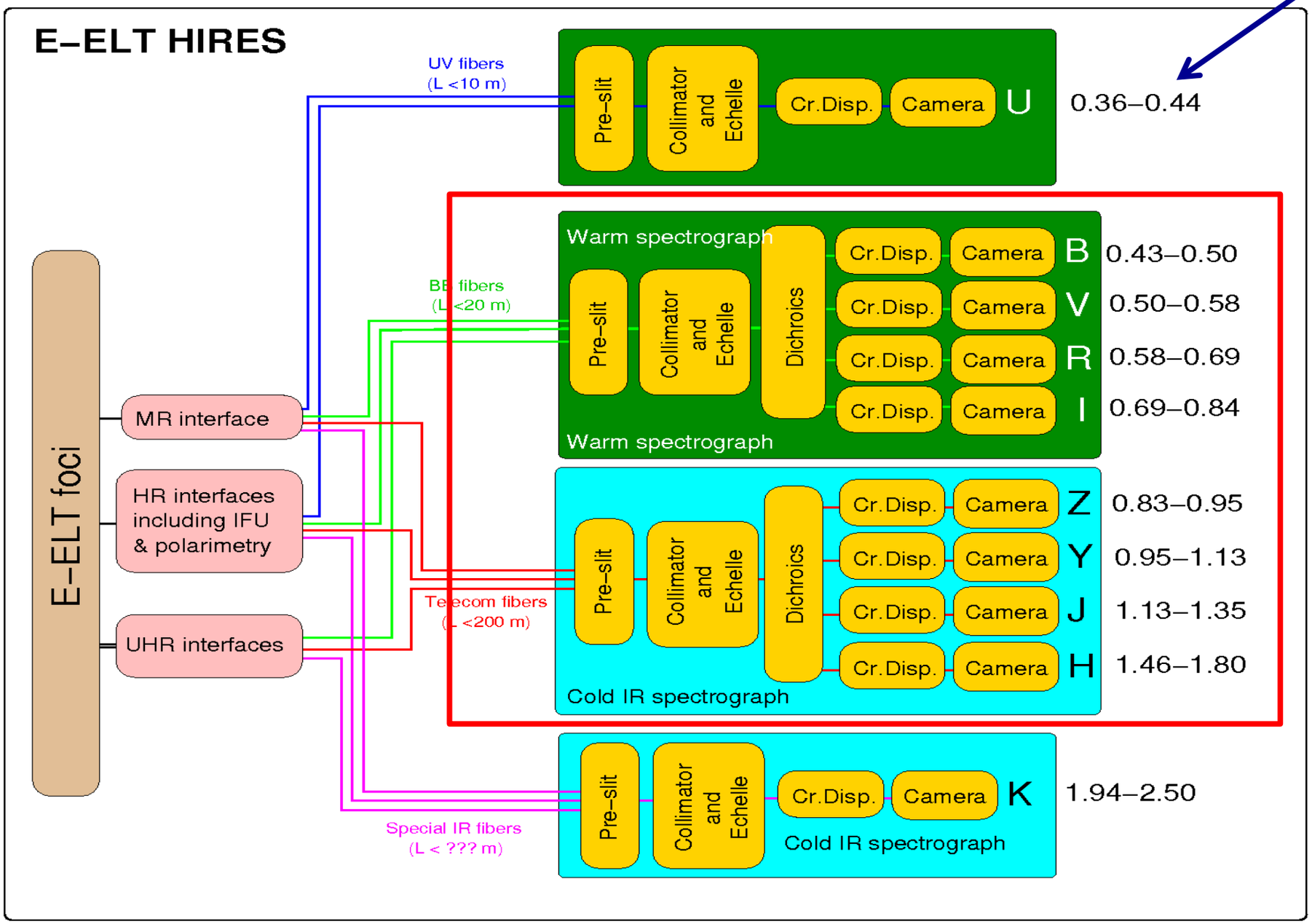
HIRES Science

Prioritisation of Science cases ➔ Top level requirements ➔ instrument design

Science Case	Wavelength range	Resolution	Precision	Other enabled science cases
1. Exoplanet atmospheres in transmission	0.5 – 1.8 μm	≥ 100,000	1 m/s (wav. calib.)	-Reionization of the Universe -Characterization of cool stars -Detection and investigation of near pristine gas -3D reconstruction of the CGM -Extragalactic transients
2. Variability of fundamental constants	0.37 - 0.67 μm	80,000	2 m/s (wav. calib.)	-Cosmic variation of the CMB temperature -Determination of the deuterium abundance -Investigation and characterization of primitive stars
3. Exoplanet atmospheres in emission	0.5 – 1.8 μm	≥ 100,000	AO + IFU	-Planet formation in protoplanetary disks -Characterization of stellar atmosphere -Search of low mass Black Holes -Characterization of the physics of protoplanetary disks
4. Sandage test	0.37 - 0.67 μm	100,000	2 cm/s (wav. calib.) (stability)	-Mass determination of exoplanets (in particular of Earth-like objects) -Radial velocity search for exoplanets around M-dwarf stars

HIRES preliminary design

Telescope efficiency??

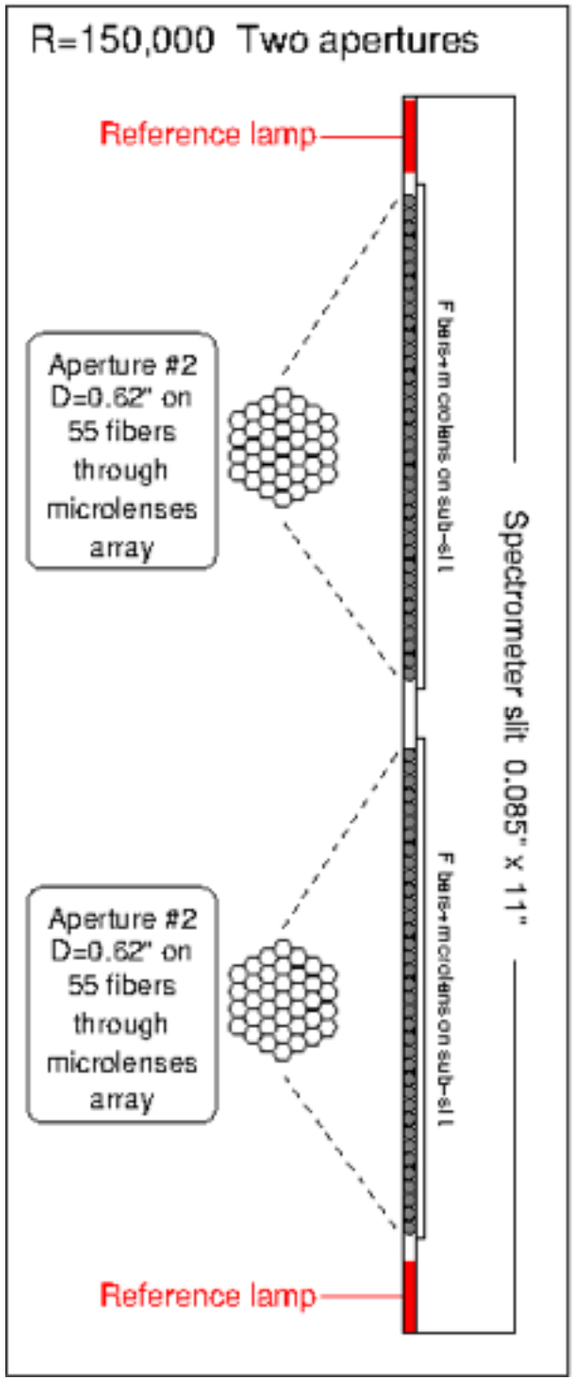


Baseline design

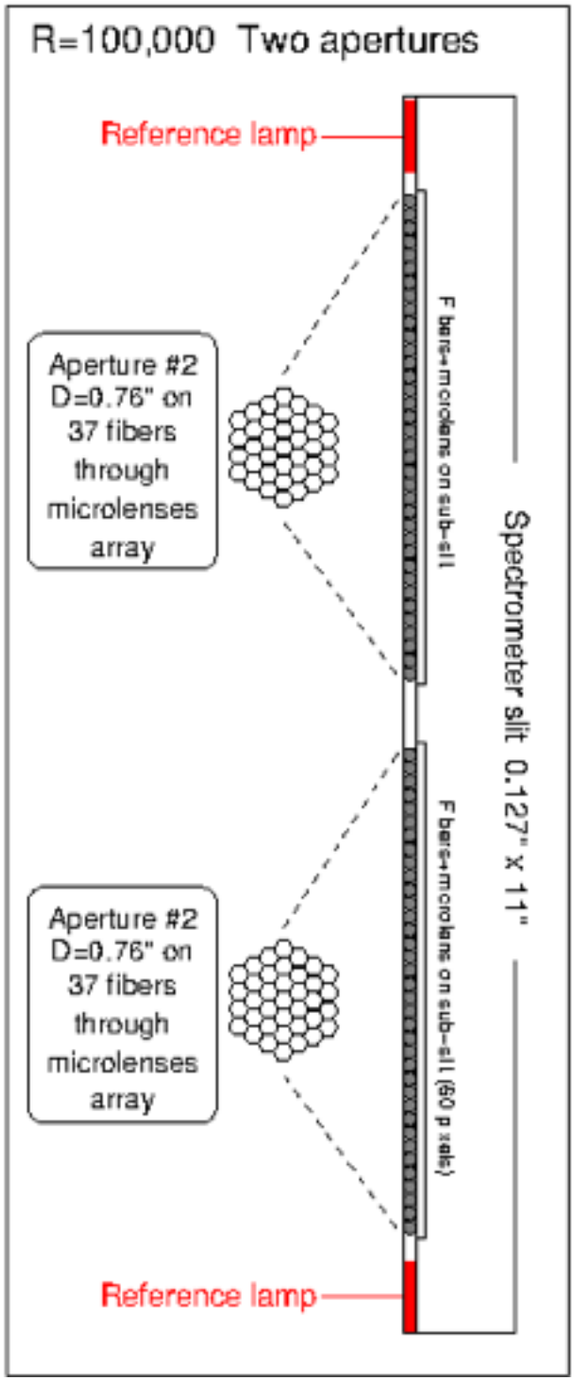
Credits M. Riva, E. Oliva

HIRES preliminary design

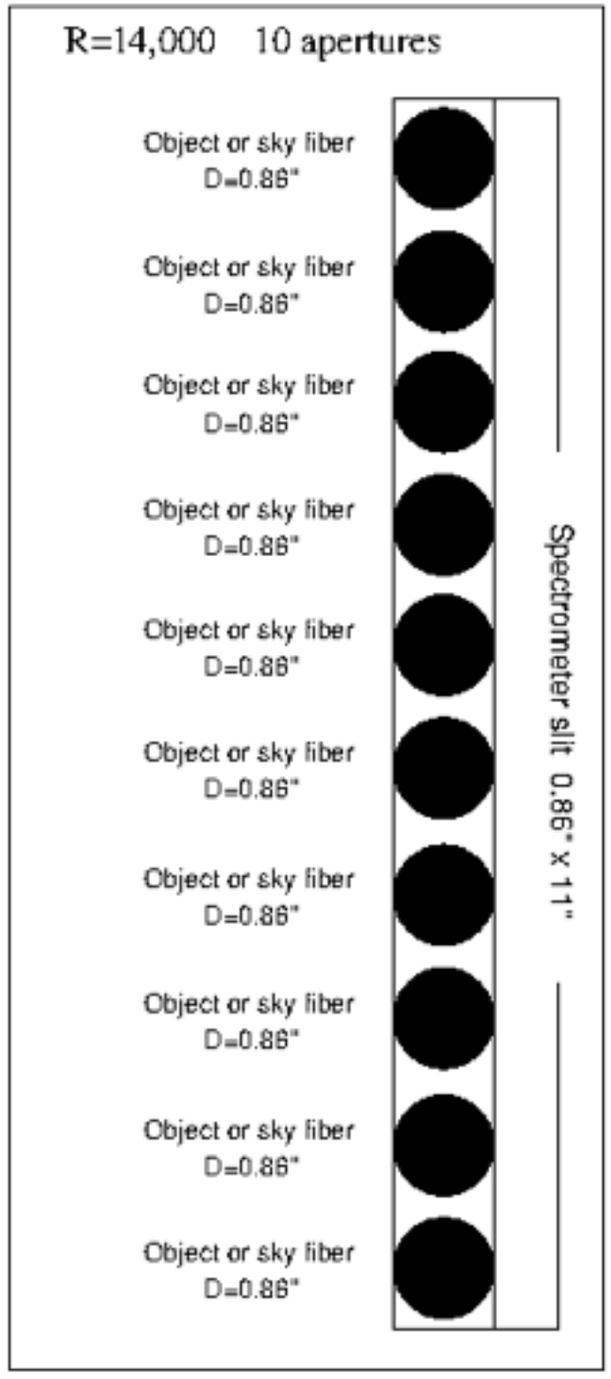
UHR mode



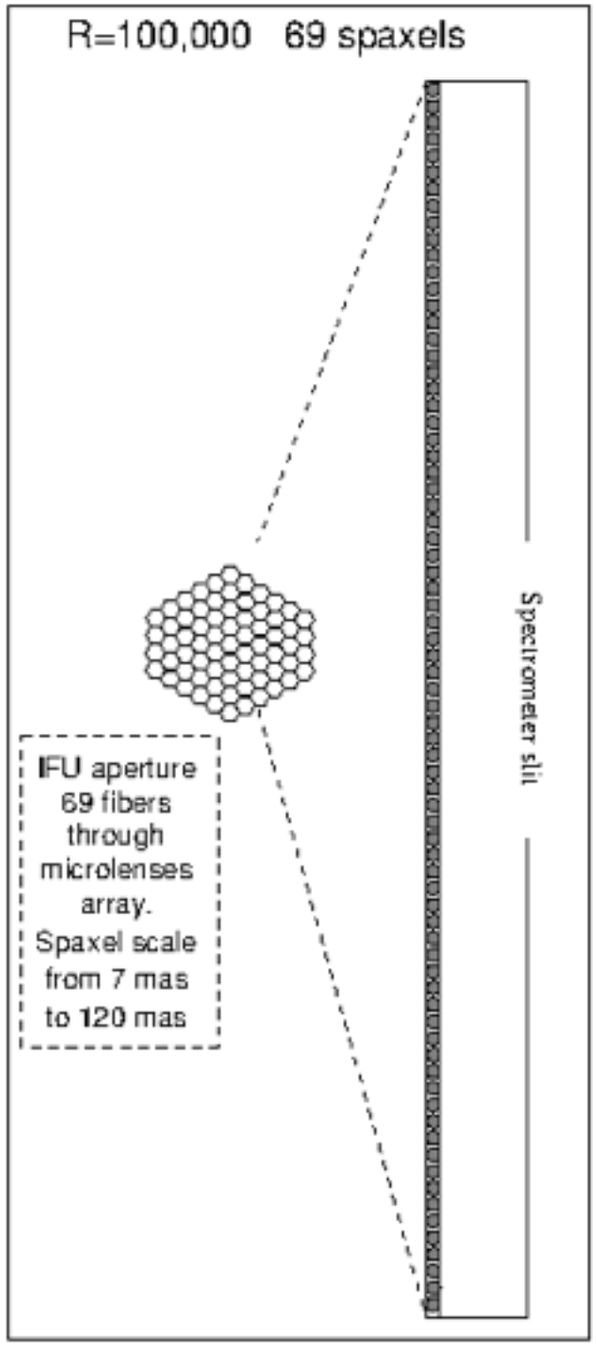
HR mode



MR mode

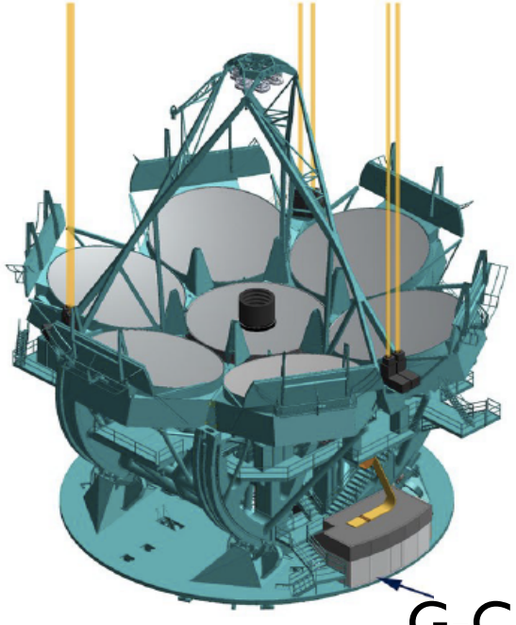


HR^2 IFU mode



Credits M. Riva, E. Oliva

High resolution spectrographs for GMT and TMT



G-CLEF

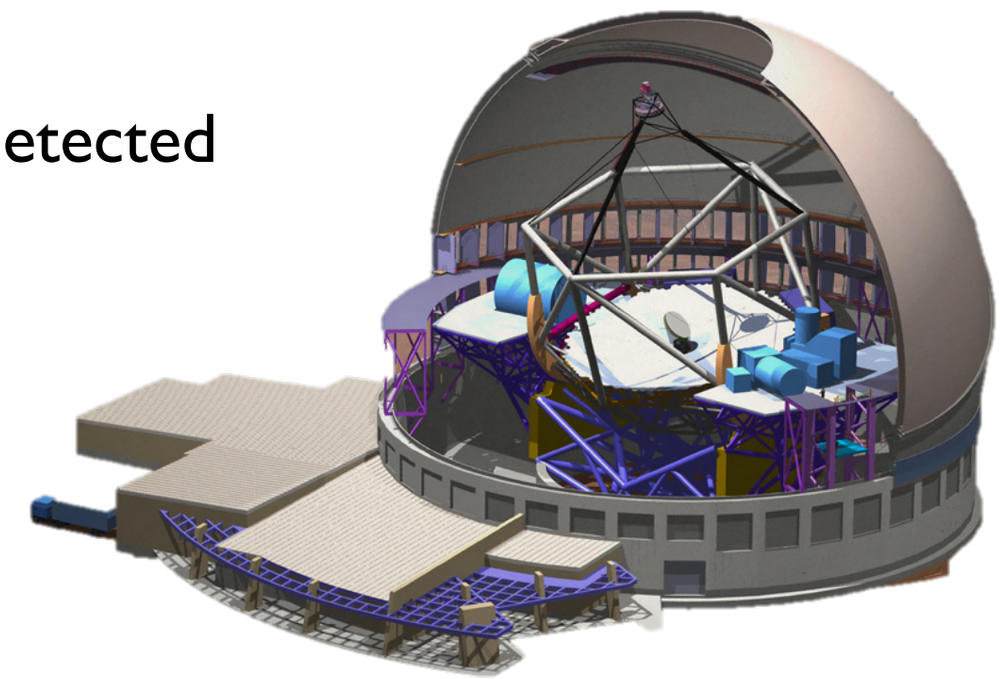
GMT-Consortium Large Earth Finder (G-CLEF)

First light instrument
Optimized for the blue (350-900 nm)
Starting operations in 2022

Mode	PRV	NS-PRV	MR	HT	MOS
Resolution	108,000	110,000	35,000	19,000	35,000

HROS@TMT

Wavelength range: 0.31-1.1 μm
Spectral resolution: R=50K & >95K
Throughput >20% from telescope focal plane to detected photons.



NIRES@TMT

Wavelength range: 1-5 μm
Spectral resolution: 20k<R<100k
Slit spectrometer ➔ goal of high throughput

Starting operations in 2029

Summary

Next Future: ESPRESSO@VLT (2017)

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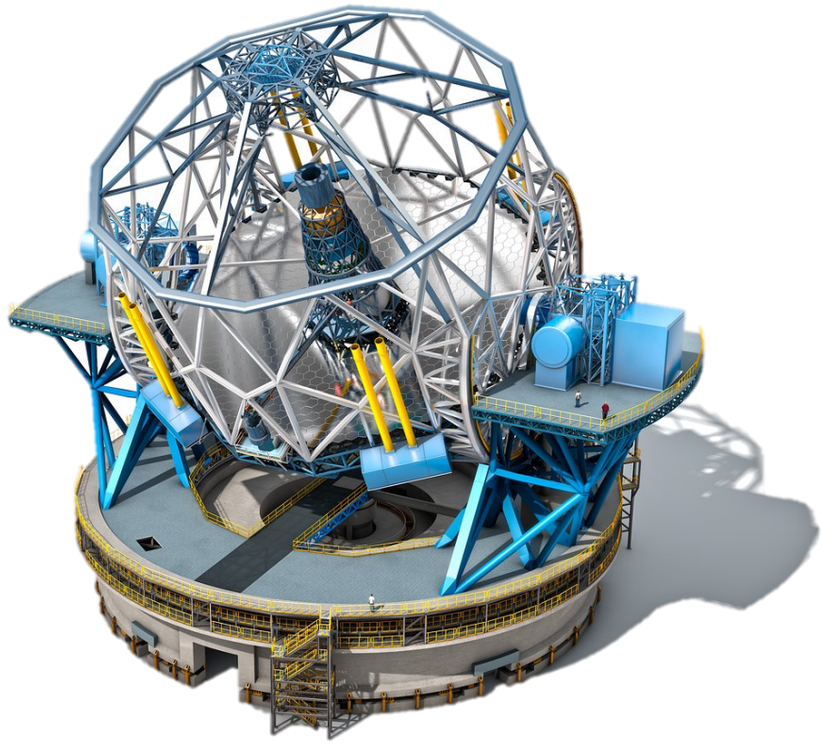
Total efficiency	11%	11%	5%
Instrumental RV precision	< 10 cm s^{-1}	~ 1 m s^{-1}	< 10 cm s^{-1}

Far away future: spectrographs at ELTs (in ~10 years)

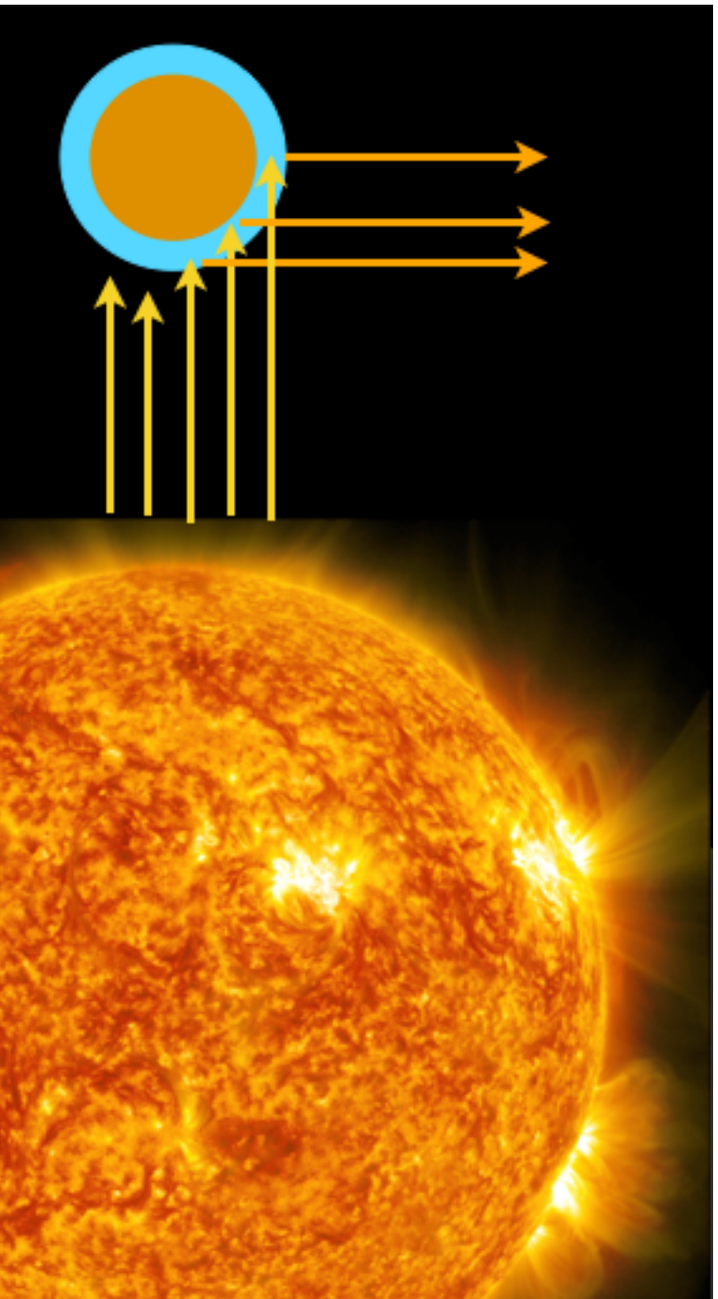
HIRES@E-ELT Phase A study, Italian PIship
Not a first light instrument (?)
Missing blue extension (?)



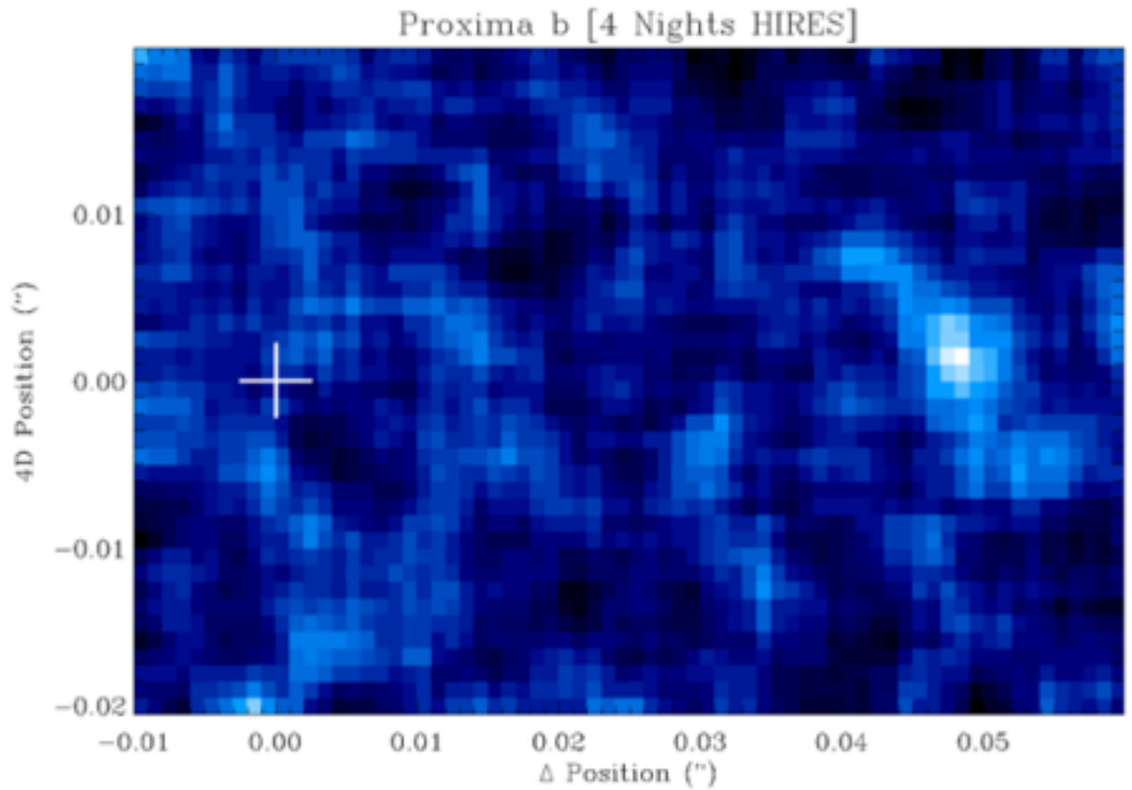
THANK YOU!

Exoplanet atmospheres in emission

- Enhance the planet-to-star contrast at the planet location with AO
- Use high-resolution spectroscopy to disentangle the planetary and stellar spectra by comparing the combined spectrum to a star-only reference spectrum aided by the radial velocity offset (e.g. Snellen+15)

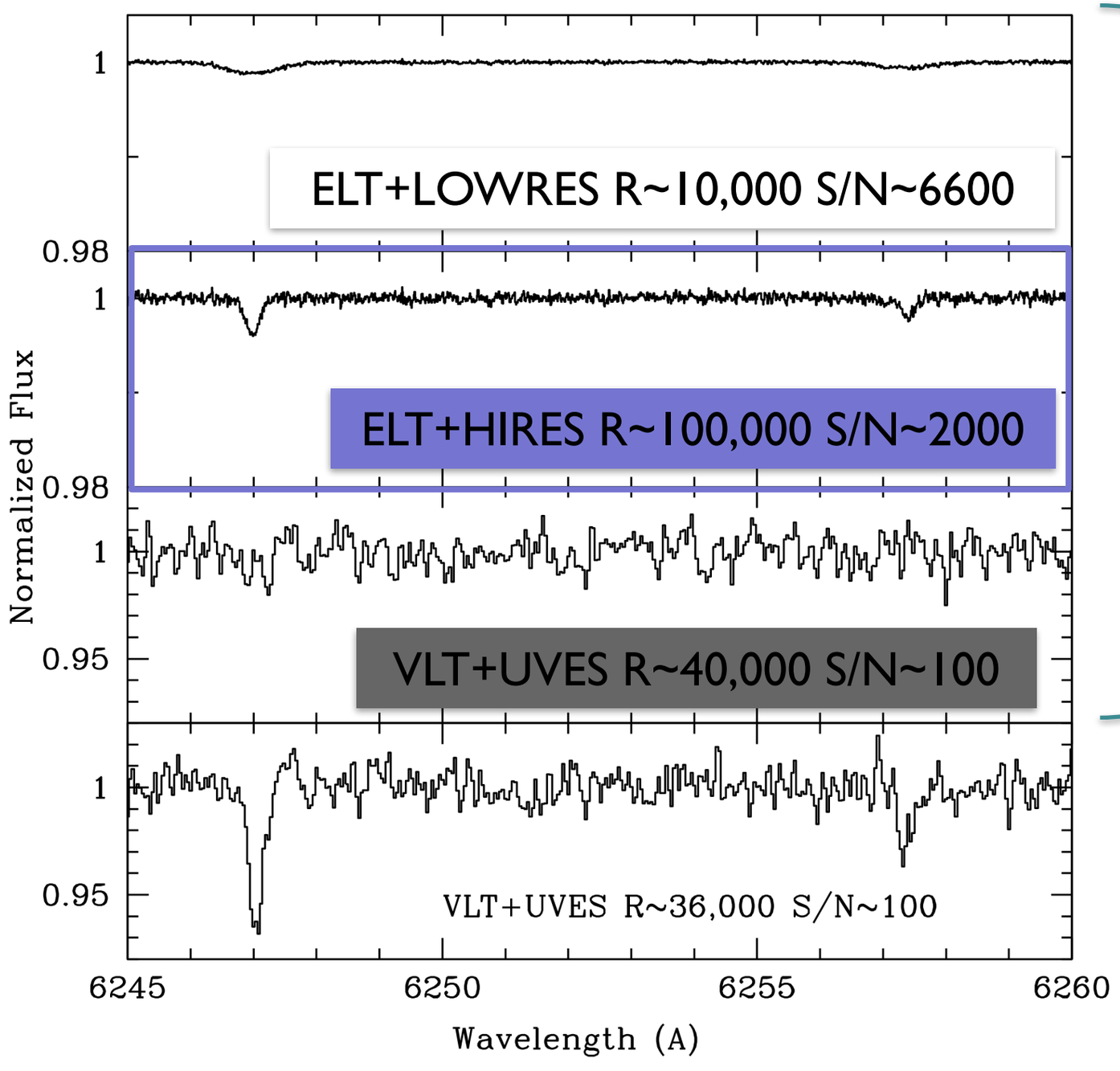


Example: Proxima b
HIRES can detect planet in 7 nights at 8 sigma level (simulation by WG1)



Metal enrichment of the IGM

Metal enrichment of the low density IGM at z~2-4 and signatures of the 1st generation of stars in very metal poor DLAs



T_{exp}~20 h
for an R~16 QSO at z~3

Scaled to the mean density:
log N(CIV) ~ 11

Limit of present observations:
log N(CIV) = 12 δ ~ 5-10

Detection and investigationof near pristine gas

Chemical enrichment imprint of primordial supernovae: PopIII signature