THE SCIENTIFIC PROMISE OF HIRES: A HIGH RESOLUTION SPECTROGRAPH FOR THE ESO ELT

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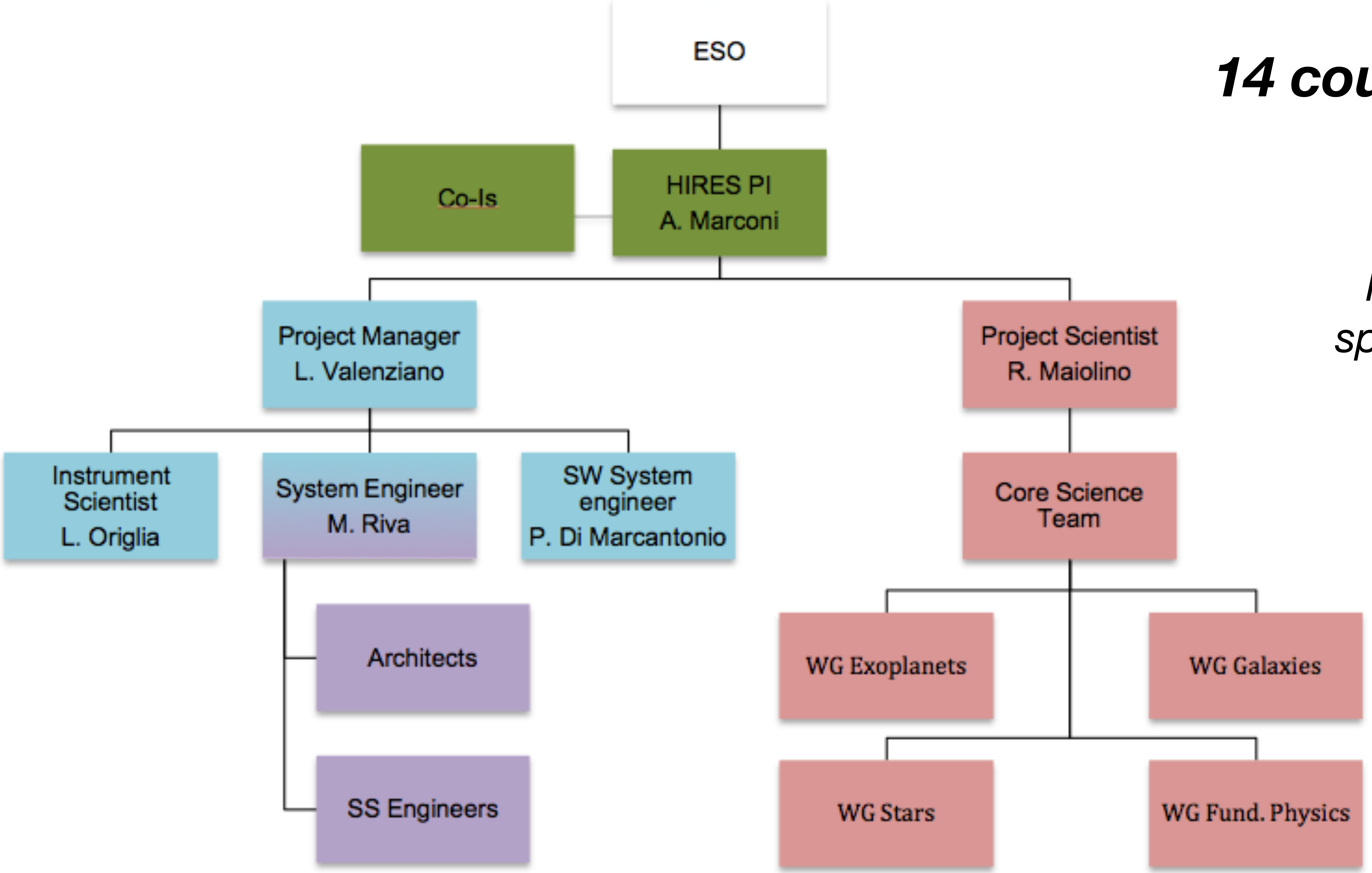
on behalf of

The HIRES Consortium

Broad Context

- European Extremely Large Telescope (ELT) will be the largest ground-based telescope at visible and infrared wavelengths
    - Flagship science cases: the detection of life signatures in Earth-like exoplanets and the direct detection of the cosmic expansion re-acceleration (both require high resolution spectroscopy)
- High resolution spectroscopy (HRS)
    - Interdisciplinary (from Exoplanets to Cosmology and Fundamental Physics)
    - Successful ESO tradition (UVES, FLAMES, CRIRES, X-shooter, HARPS; ESPRESSO)
    - More than 30% of ESO publications can be attributed to its high-resolution spectrographs.
- HRS At 8m-class telescope entered into photon starved regime
- **Merging of CODEX and SIMPLE concepts into HIRES spectrograph R~100.000 in 0.37-2.4 μm**
- **HIRES Phase A study started March 2016, completed March 2018**

The HIRES Consortium



14 countries

~200 people

Majority of high resolution spectroscopy experts in ESO member states

The HIRES Consortium

Principal Investigator (PI): A. Marconi

Executive Board & Institutes

- **Brazil: J. Renan de Medeiros**
  Federal Univ. of Rio Grande do Norte, Mauá Institute of Technology
- **Canada: R. Doyon (new partner for Phase B)**
  Univ. De Montreal
  (leading consortium of Canadian Universities)
- **Chile: L. Vanzi**
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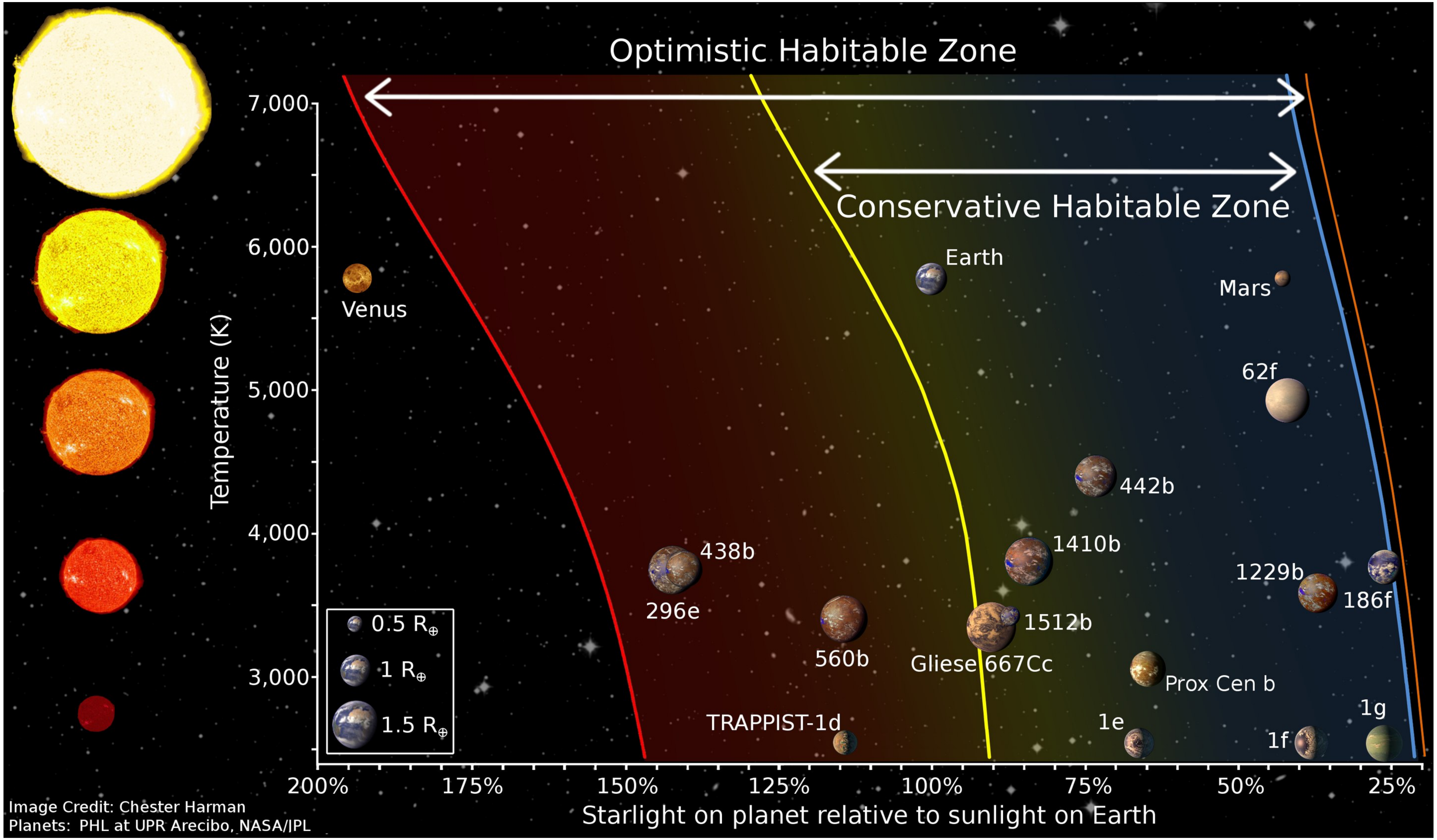
- **Germany: K. Strassmeier**
  Astrophysics Institute Potsdam, Univ. Göttingen, Landessternwarte Heidelberg, Thüringer Landesternwarte Tautenburg, Univ. Hamburg
- **Italy: A. Marconi**
  INAF Istituto Nazionale di AstroFisica (Lead)
- **Poland: A. Niedzielski**
  Nicolaus Copernicus Univ. in Toruń
- **Portugal: N. Santos**
  Inst. Astrofísica e Ciências do Espaço
- **Spain: R. Rebolo**
  Inst. Astrofísica de Canarias, Inst. Astrofísica de Andalucía
- **Sweden: N. Piskunov**
  Uppsala Univ.
- **Switzerland: C. Lovis**
  Univ. de Genève, Univ. Bern
- **United Kingdom: M. Haehnelt**
  Univ. of Cambridge, UK Astronomy Technology Centre, Durham Univ., Heriot-Watt Univ.
- **USA: T. Bergin (new partner for Phase B)**
  Univ. of Michigan

A subset of HIRES Science Cases

- **Exoplanets** (characterisation of Exoplanets Atmospheres: detection of signatures of life)
- **Protoplanetary Disks** (dynamics, chemistry and physical conditions of the inner regions)
- **Stellar Astrophysics** (abundances of solar type and cooler dwarfs in galactic disk bulge, halo and nearby dwarfs: tracing chemical enrichment of Pop III stars in nearby universe)
- **Stellar Populations** (metal enrichment and dynamics of extragalactic star clusters and resolved stellar populations)
- **Intergalactic Medium** (Signatures of reionization and early enrichment of ISM & IGM observed in high-z quasar spectra)
- **Galaxy Evolution** (massive early type galaxies during epochs of formation and assembly)
- **Supermassive Black Holes** (the low mass end)
- **Fundamental Physics** (variation of fundamental constants - α, m_p/m_e Sandage Test)

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

Exoplanet atmospheres in habitable zone

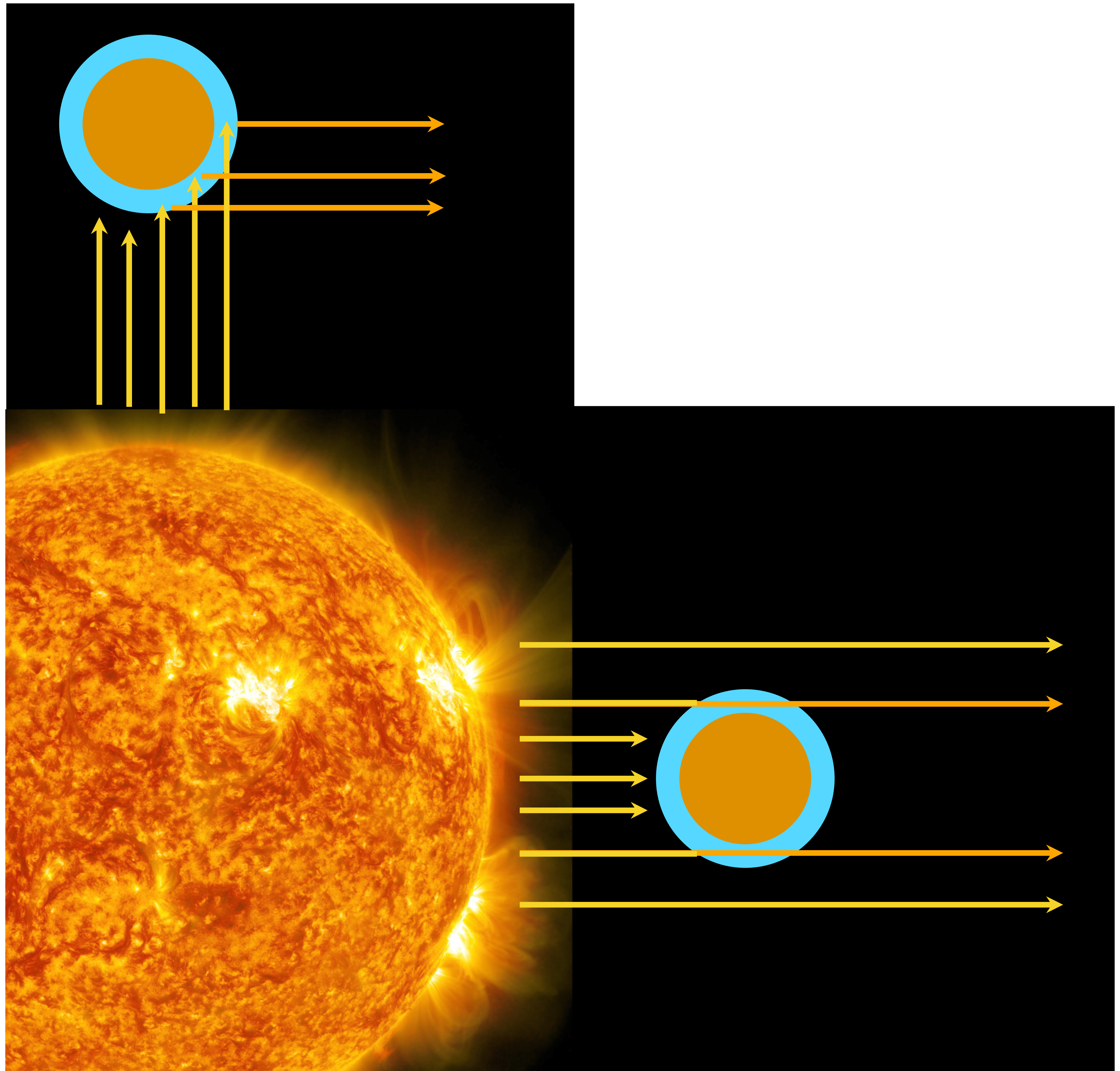


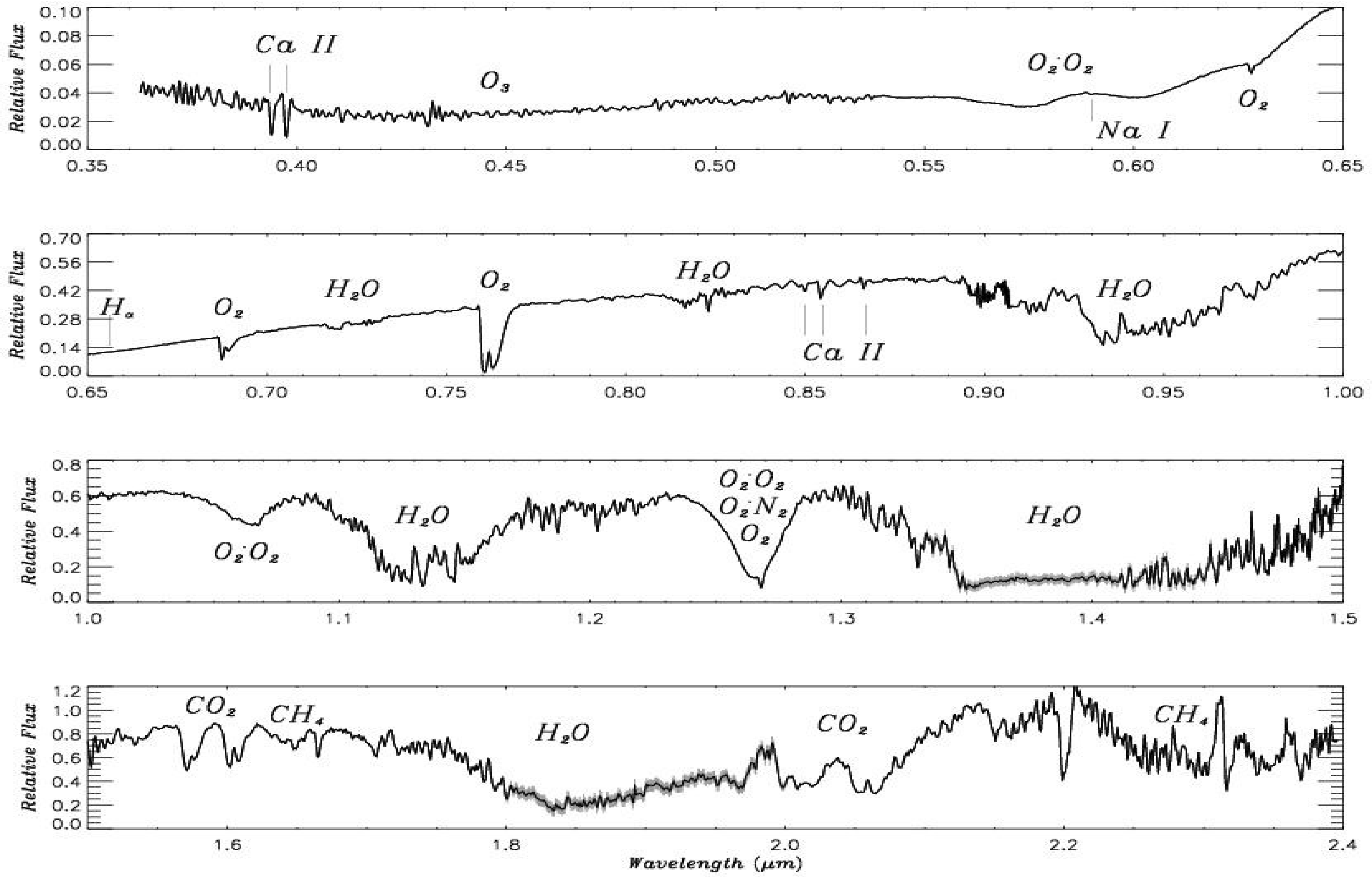
Relative flux
Wavelength (µm)
1.0
0.8
0.6
0.4
0.2
0.0
0.5
1.0
1.5
2.0
2.5
O_3
O_2
H_2O
H_2O
O_2
H_2O
CH_4
CO_2
H_2O
CO_2
CH_4
molecular oxygen
water
carbon dioxide
methane
Exo-Earths Atmospheres
Detecting signatures of life

Exoplanet Atmospheres

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)

☆ In reflected light





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

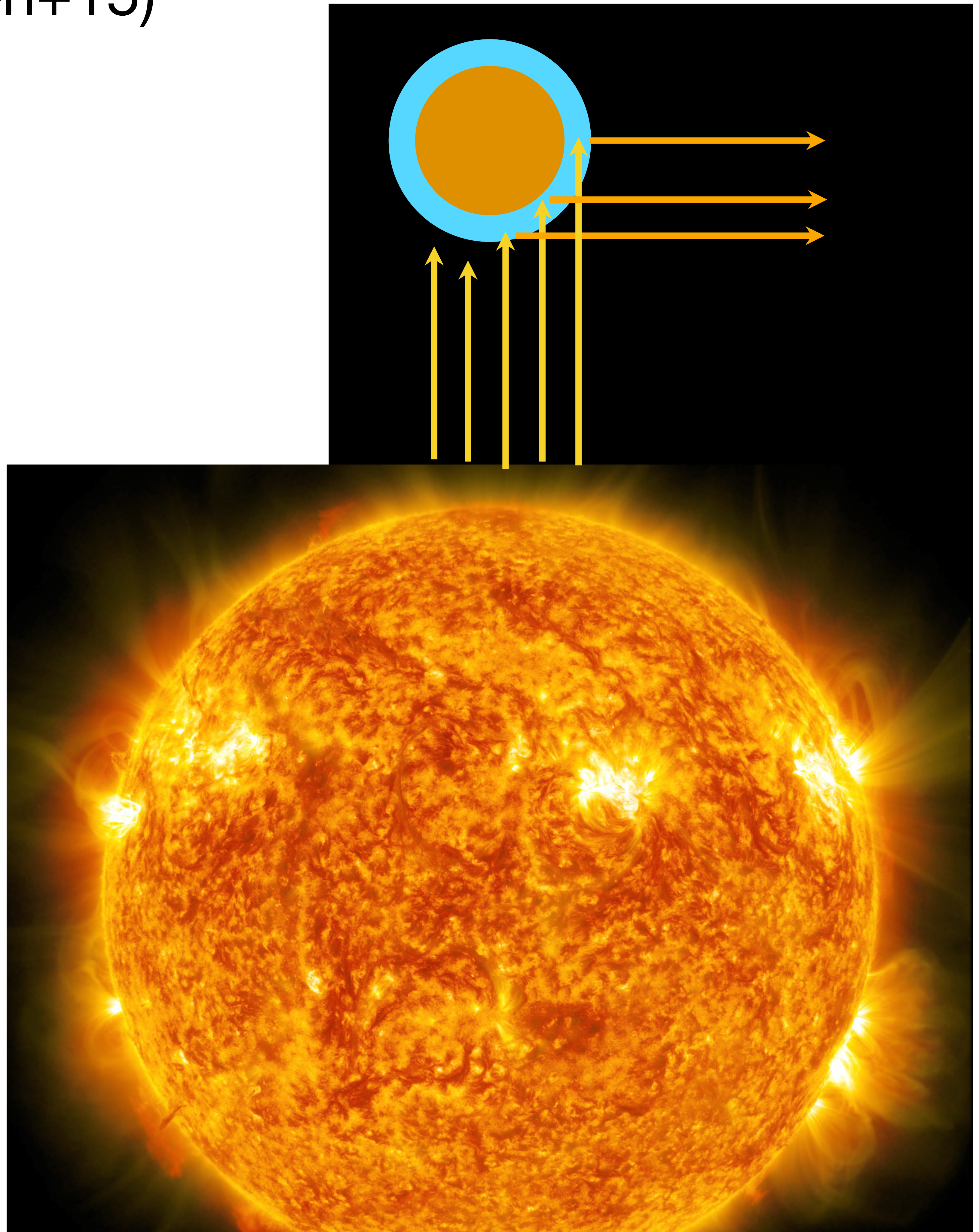
☆ In transmitted light

Example: Trappist 1 & 2 HIRES cat 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

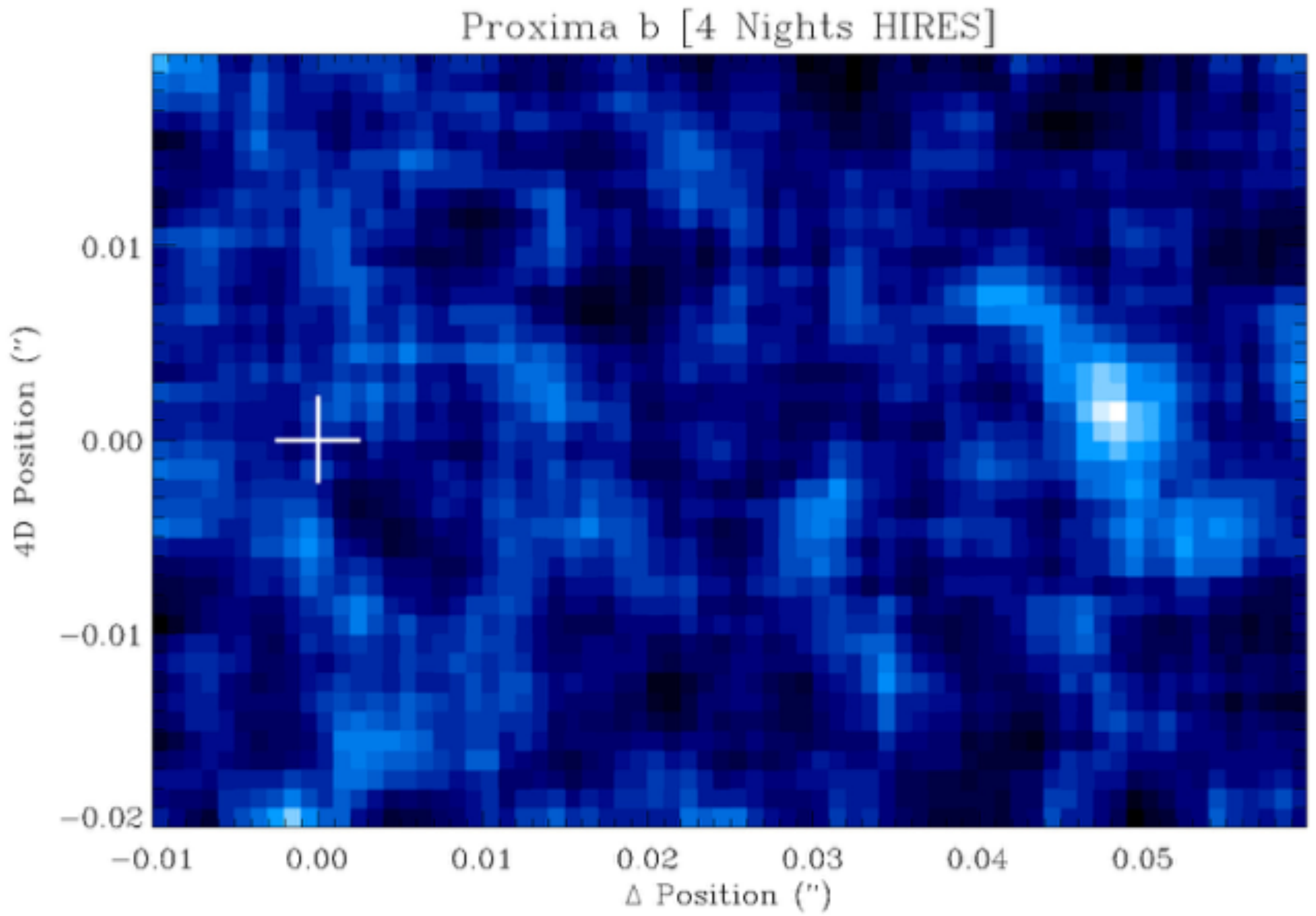
Hi-cont./Hi-res. spectroscopy in reflected light

- Enhance the planet-to-star contrast at the planet location with AO – *IFU required*
- 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)

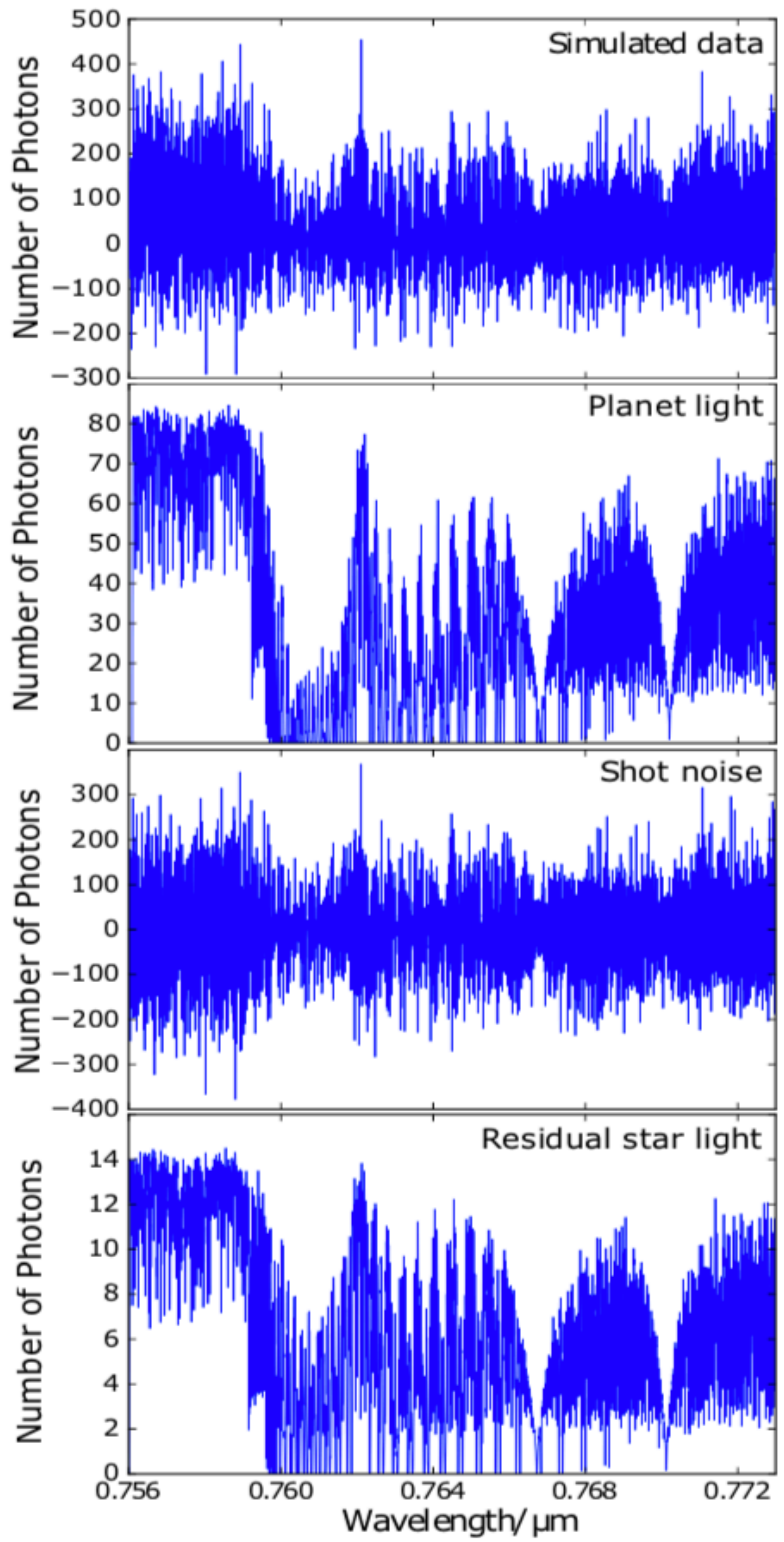


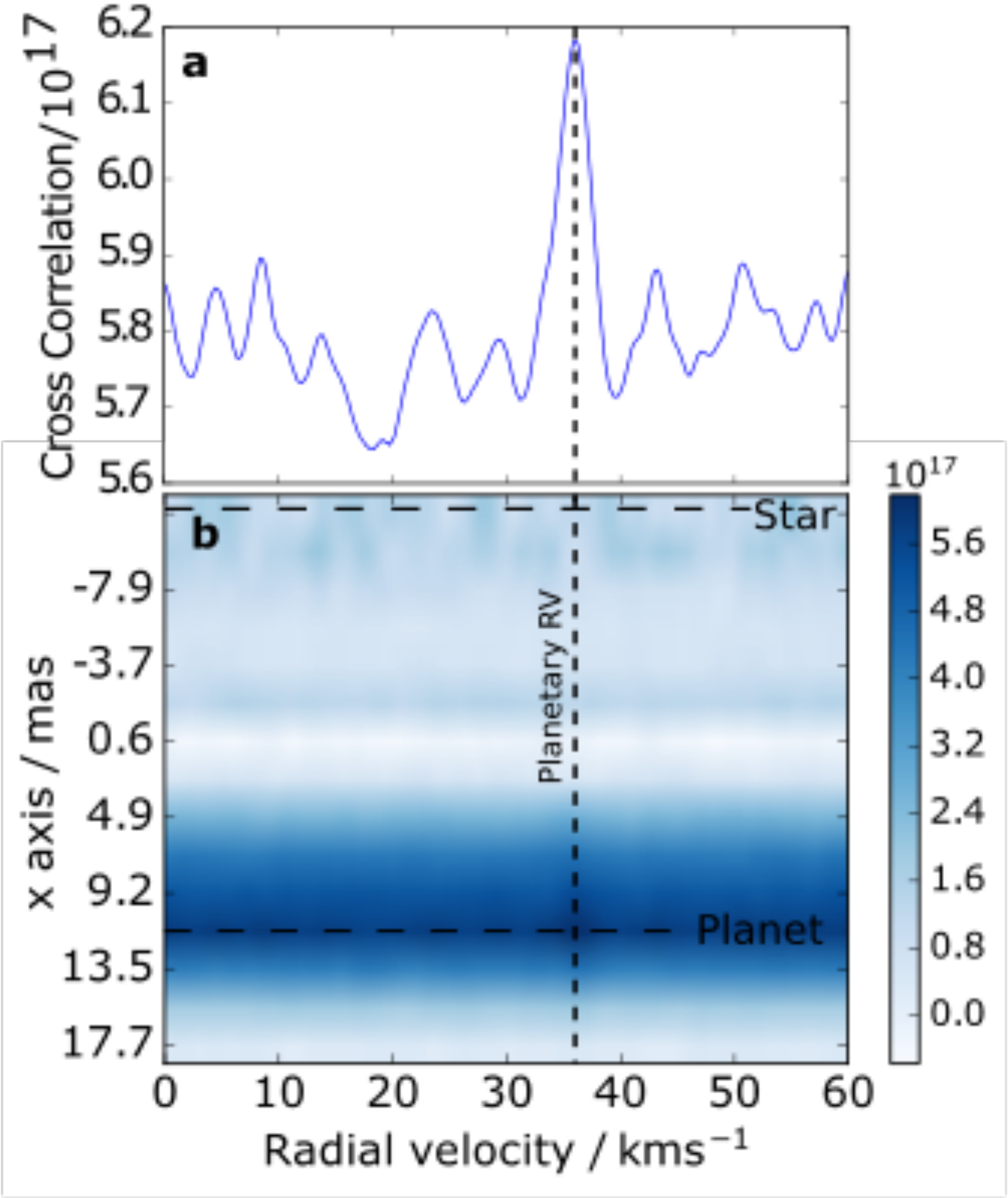
- Example: Proxima b
  HIRES cat detect planet in 7 nights
  at 8 sigma level

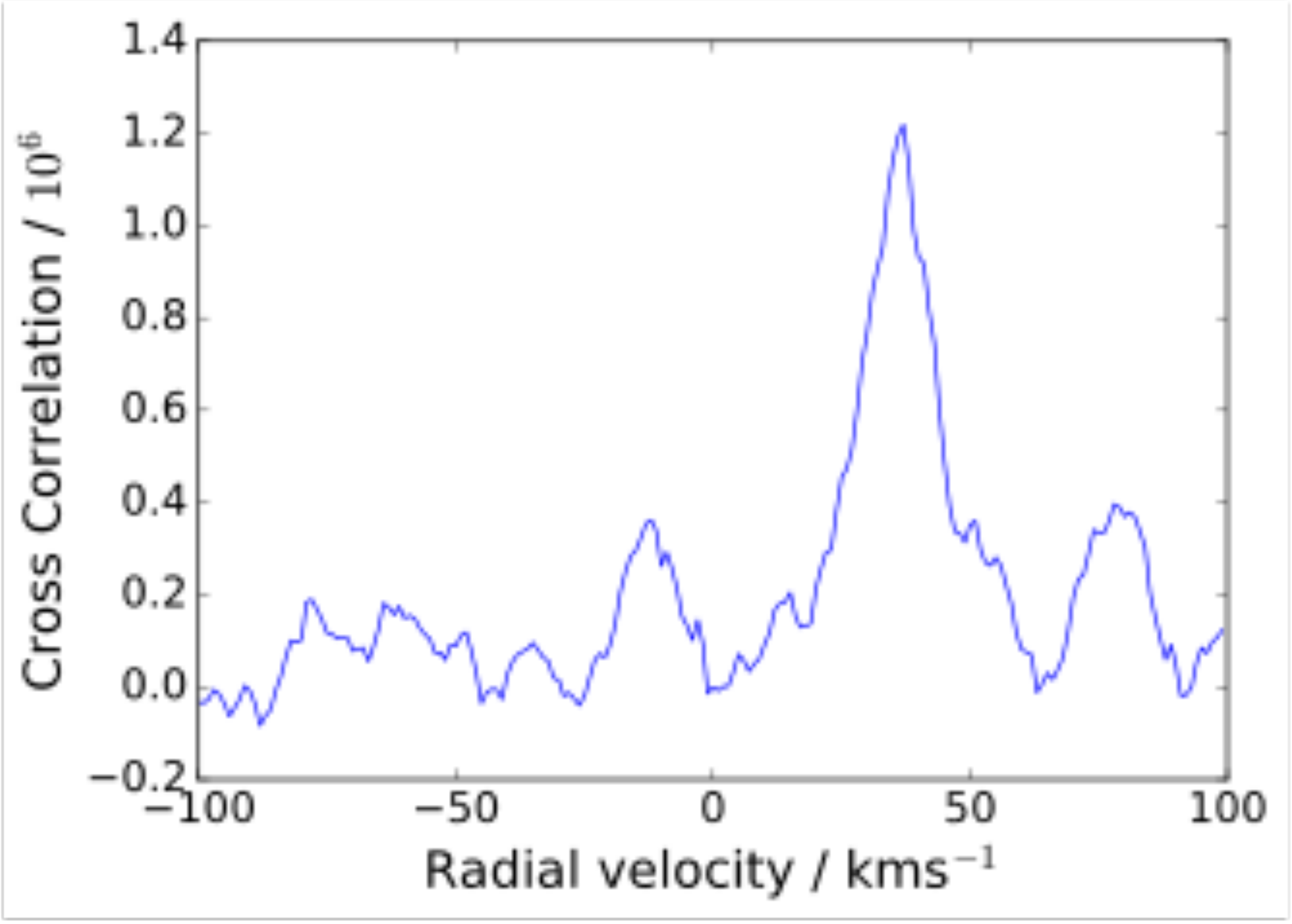
  Work by HIRES Science WG 1



Hi-cont./Hi-res. spectroscopy in reflected light





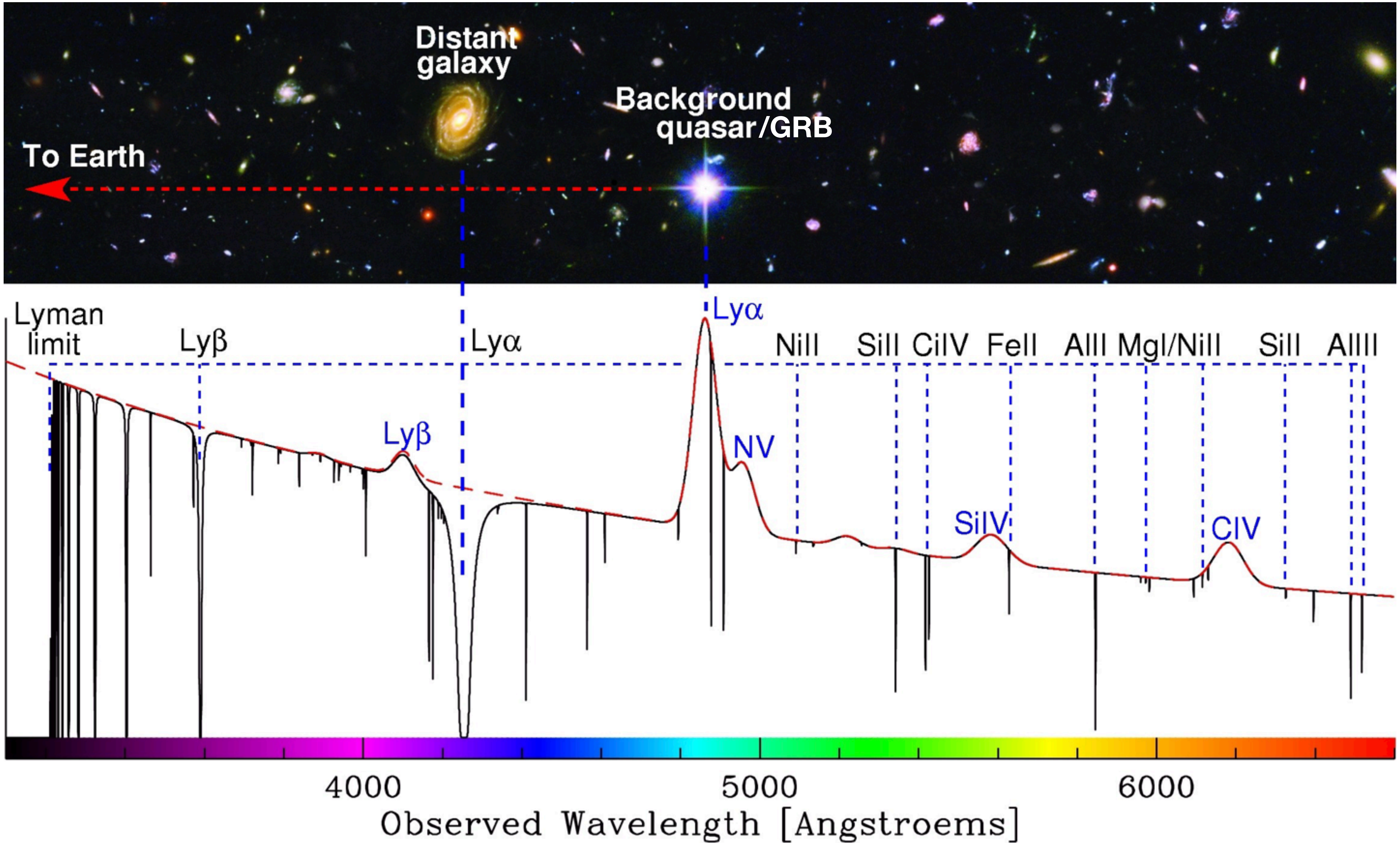


CCF with the detection of Proxima b in O_2 in 70h (Hawker & Parry 19)

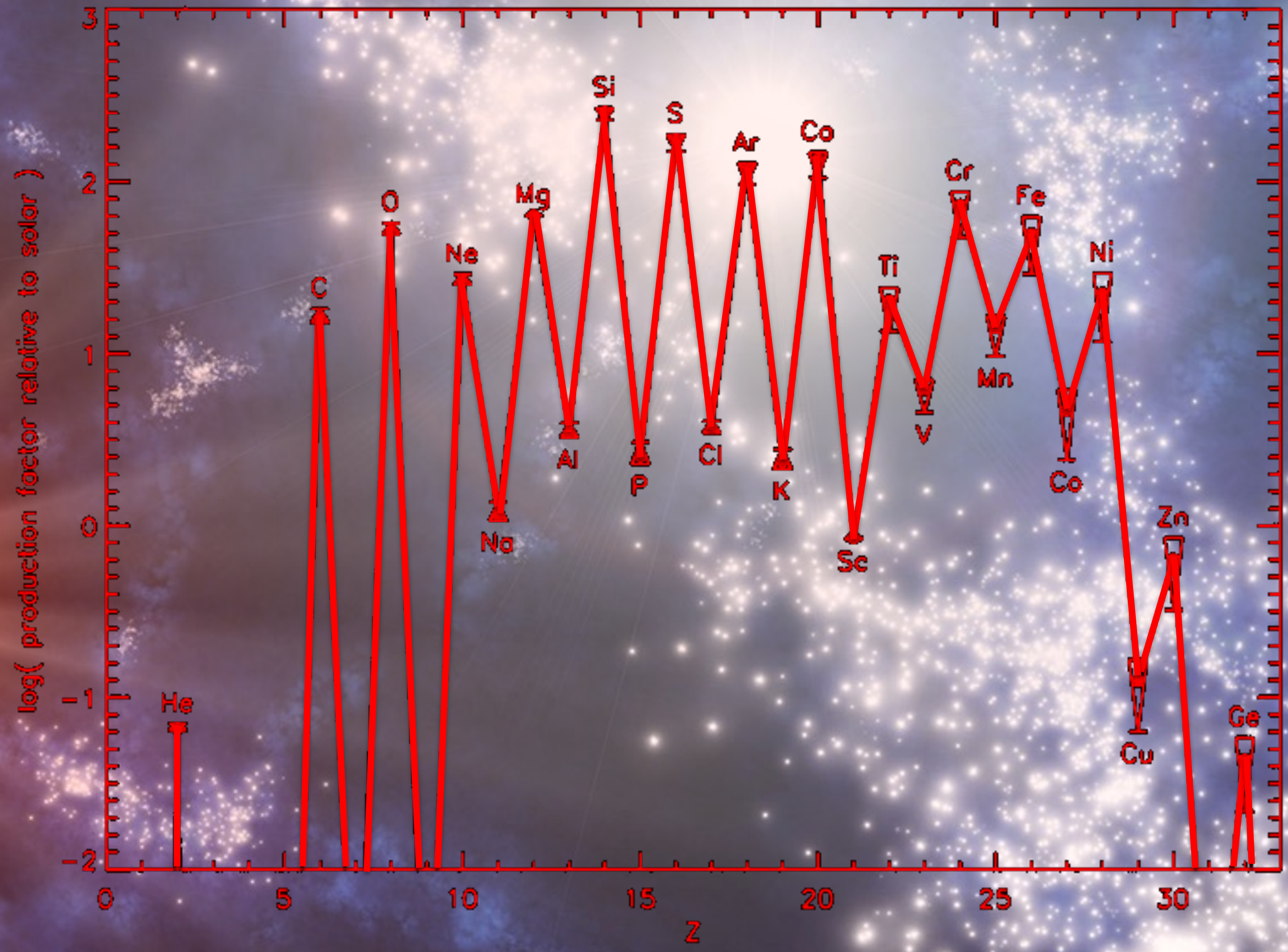
CCF with the detection of Proxima b in stellar reflected light in 10h (Hawker & Parry 19)

The Inter-Galactic Medium: tracing the chemical enrichment of the universe (e.g. Pop III SNe)

High spectral resolution (R>50-100x10^3) and broad spec. cov. (opt+NIR)



Chemical enrichment
imprint of primordial supernovae: PopIII signature



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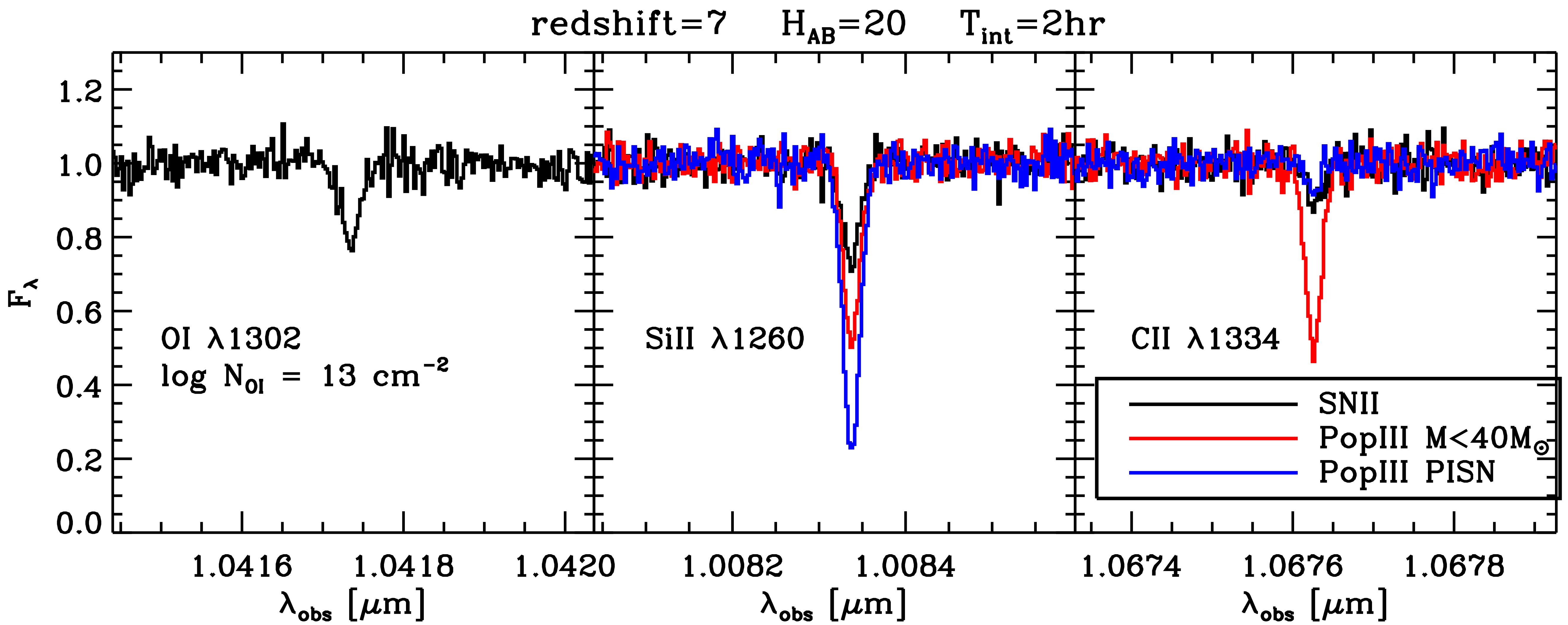
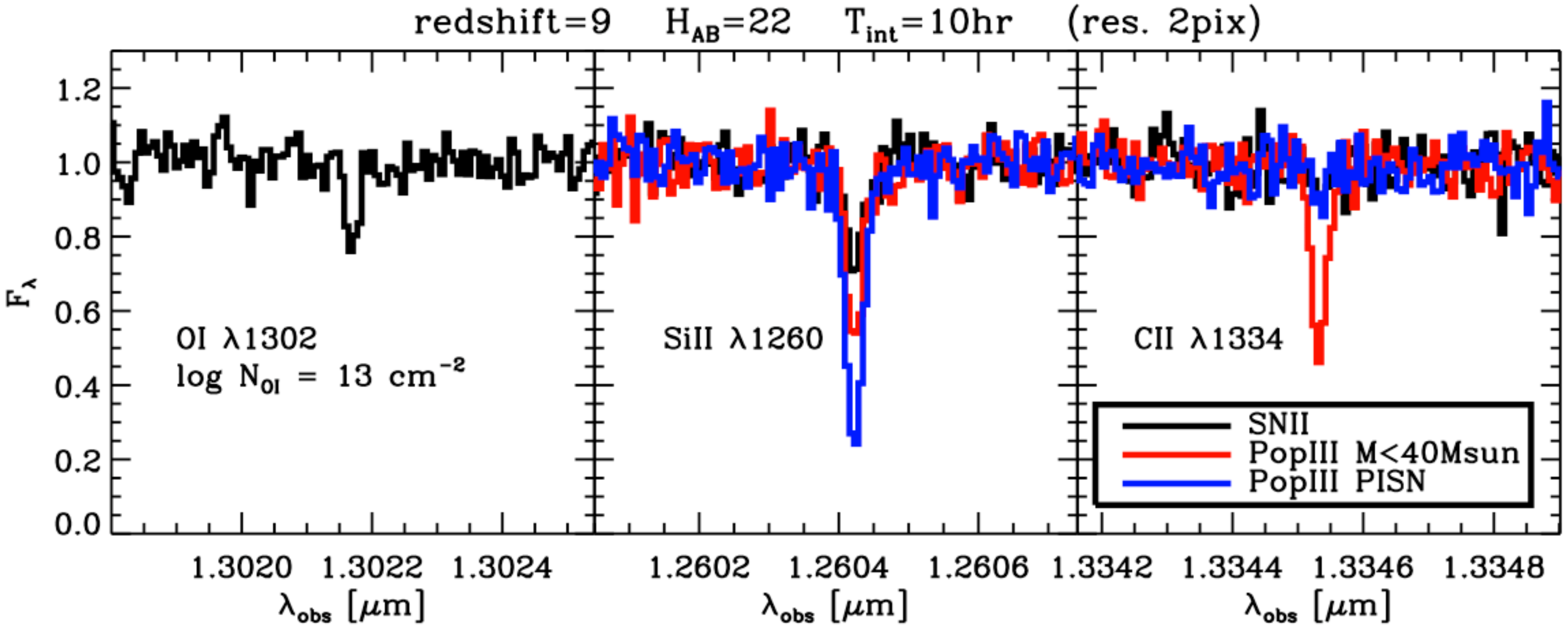
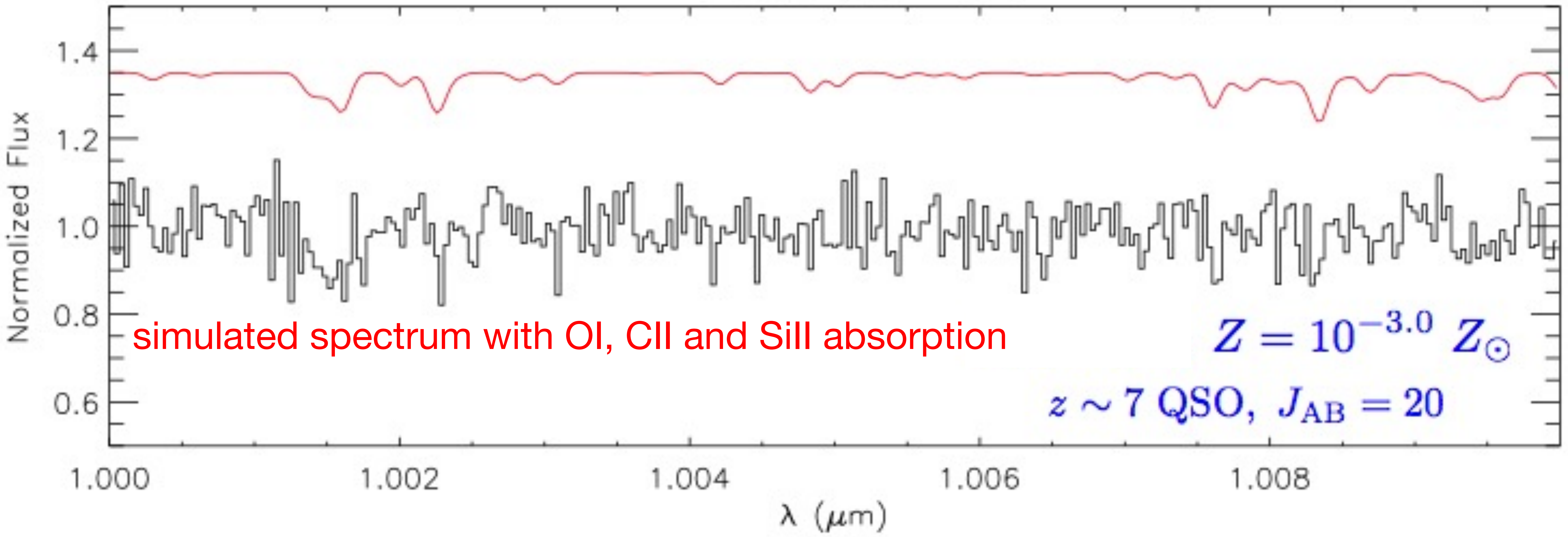


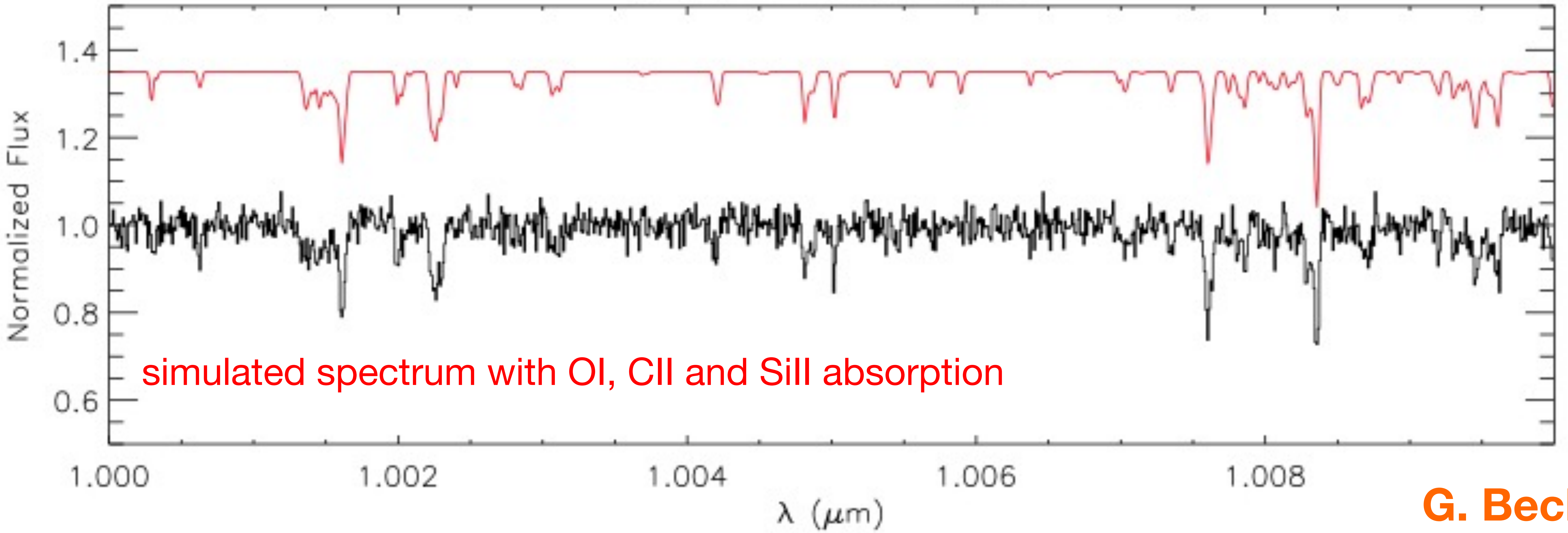


Probing the early chemical enrichment

VLT X-shooter 25 hours

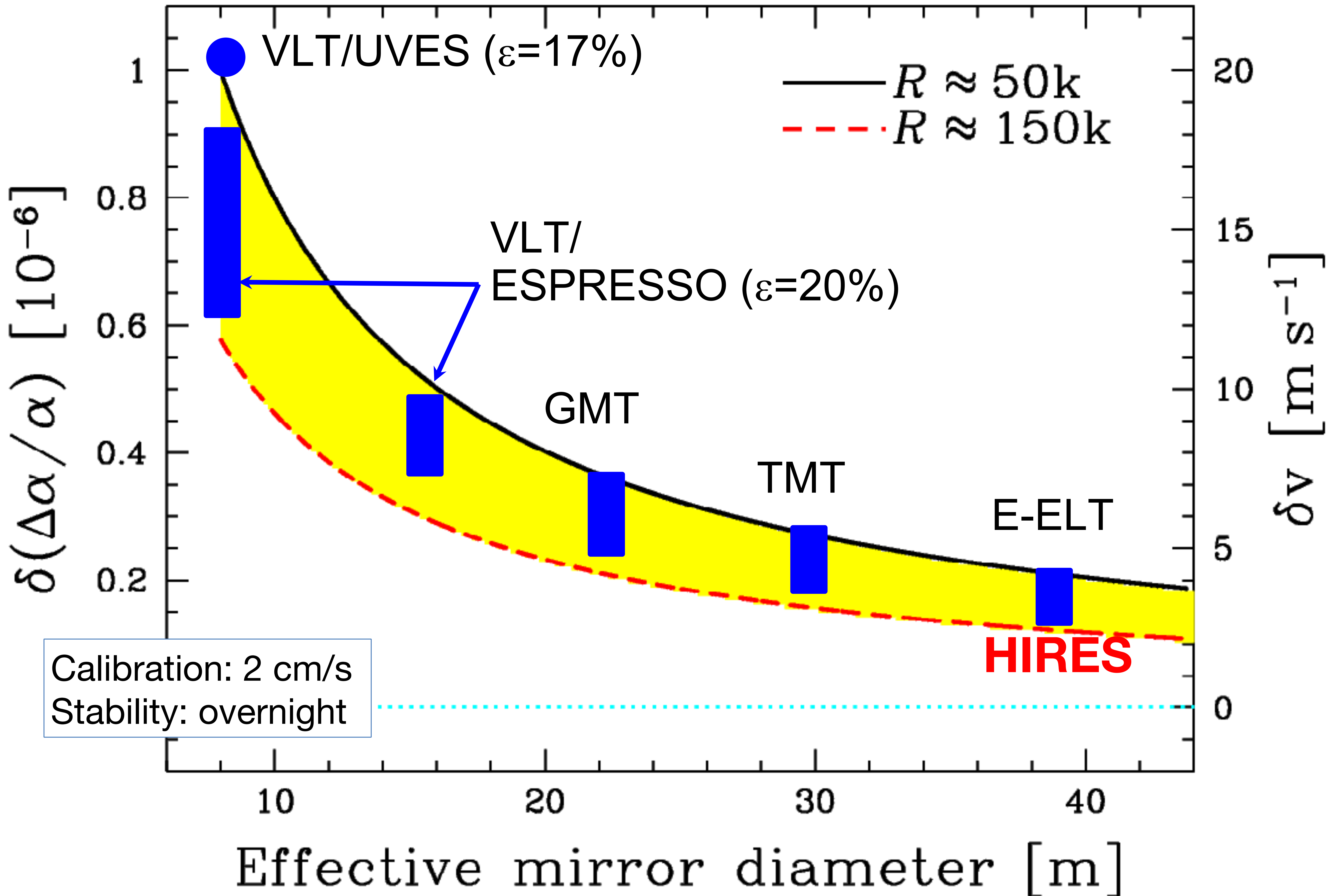


ELT HIRES 5 hours



G. Becker

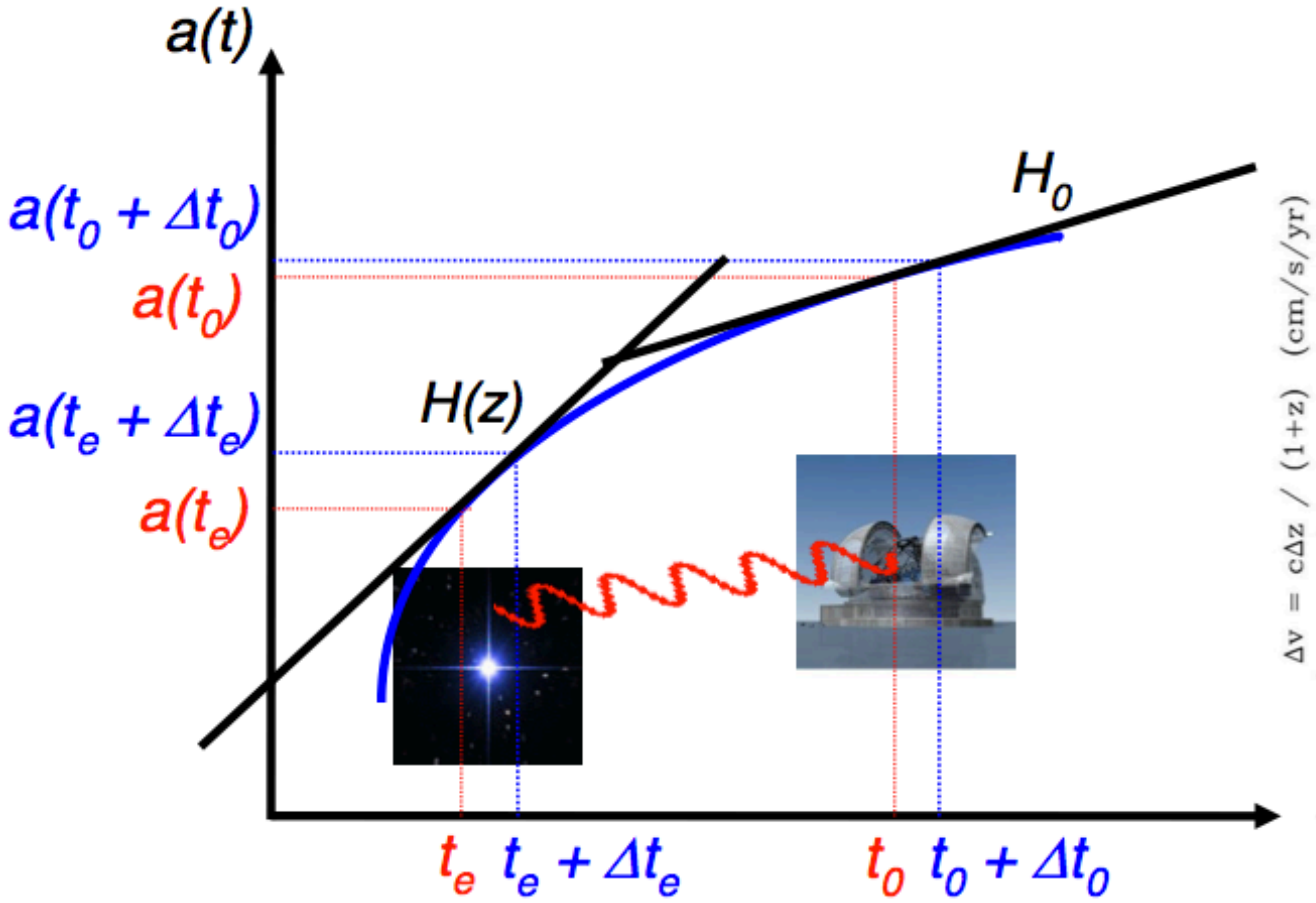
Fundamental Physics: variation of the fundamental constants

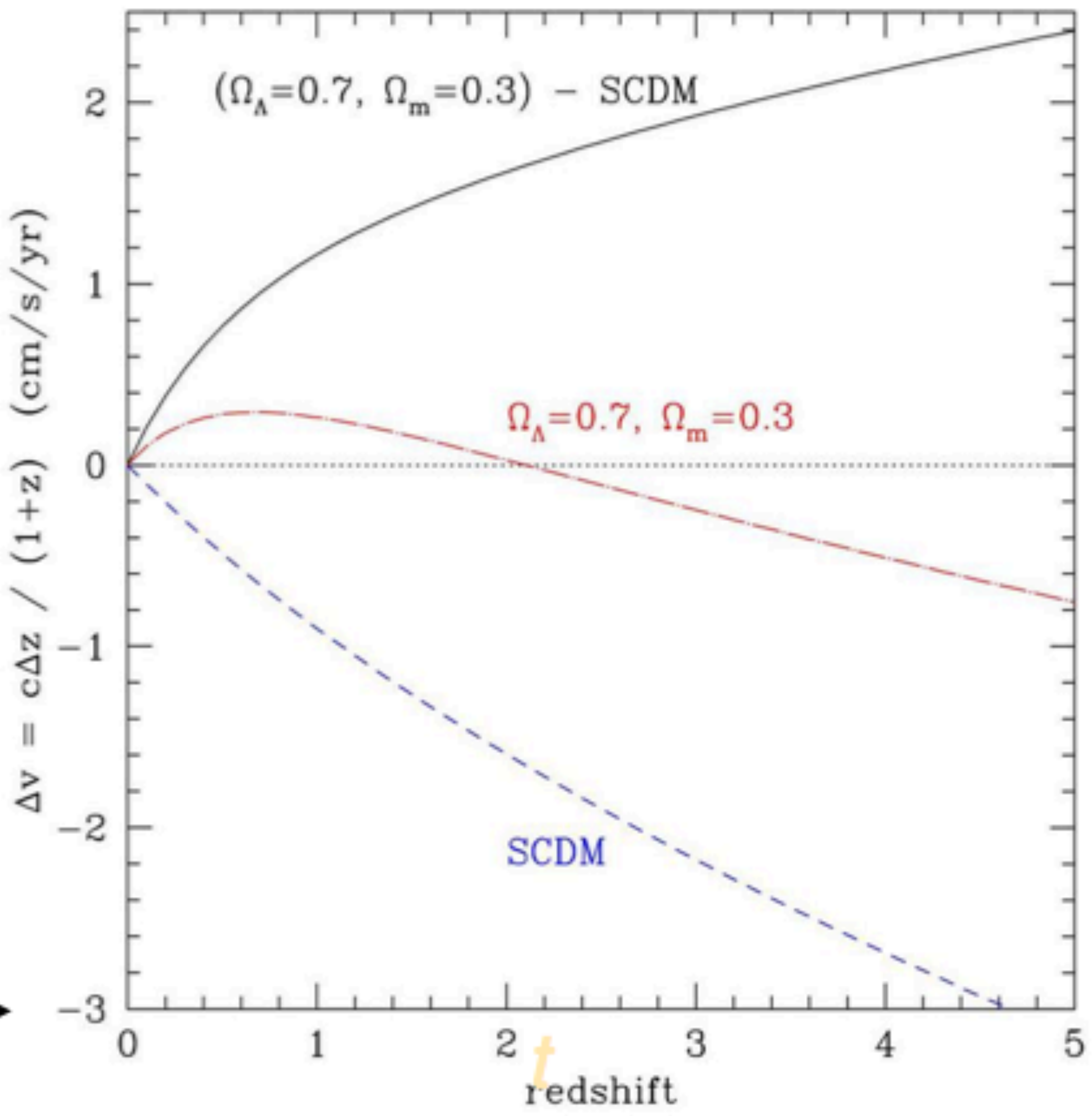


Redshift drifts ("Sandage test"):

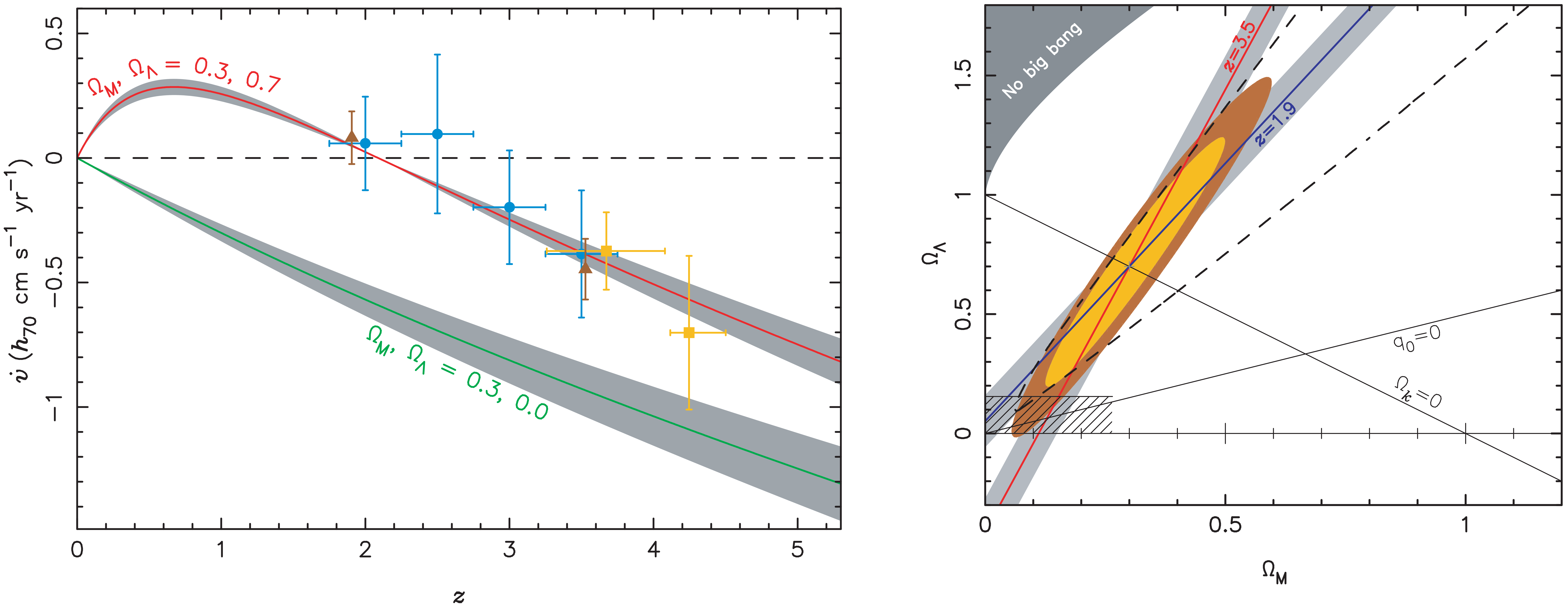
Direct non-geometric (model-independent) measurement of the expansion history of the Universe

- ➔ **alternative to all other geometrical methods**
- ➔ **exploring potential new physics**





Redshift drifts ("Sandage test"):



$\Delta t \sim 20$ yr, $T_{exp} \sim 4000$hr

N=20

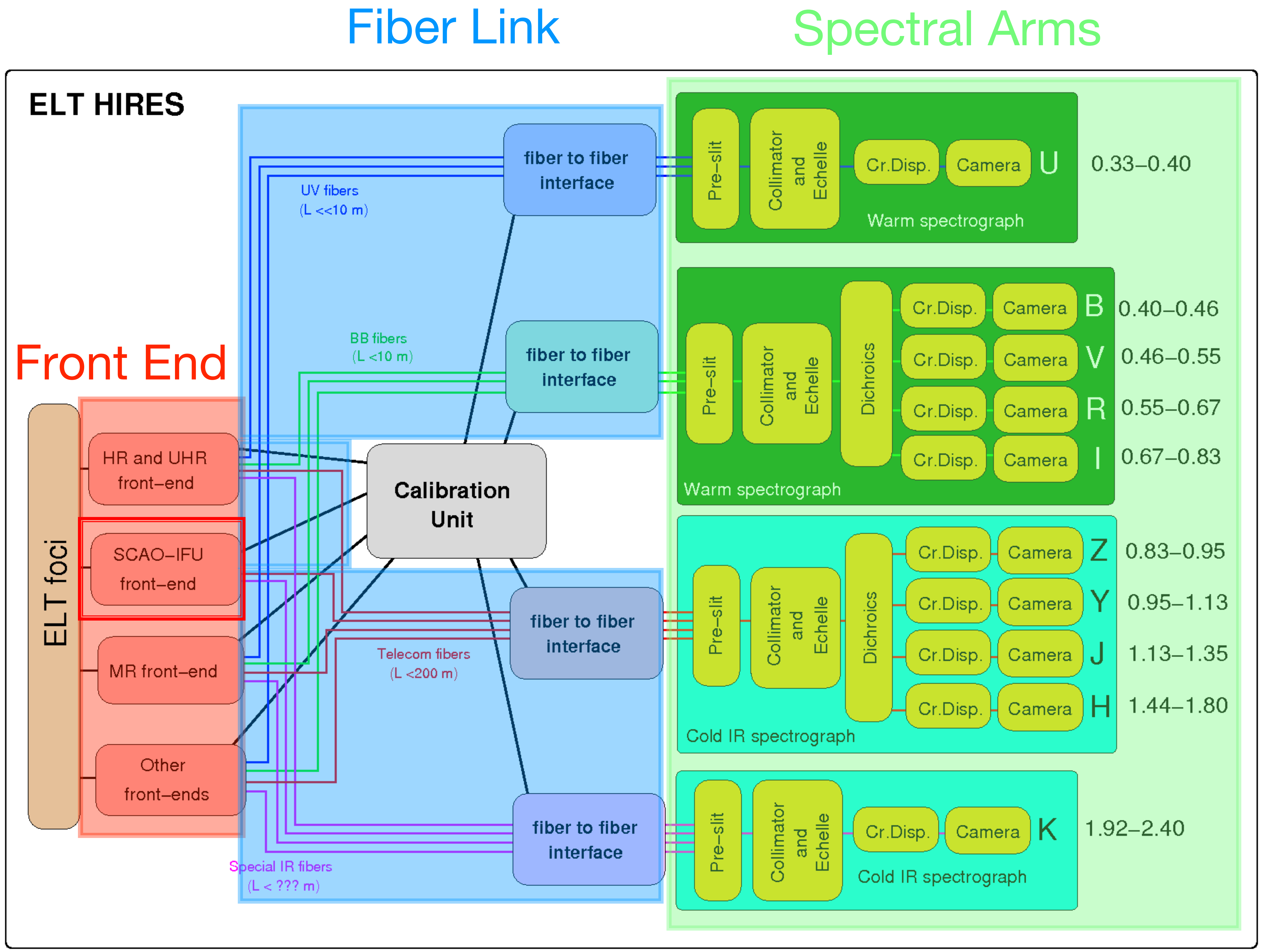
N=10

N=2

Liske et al. 2008

Science Prioritisation

- Combination of science cases requires:
  R~100,000, 0.33< λ<2.4 μm and many different observing modes
- Achievable with a fibre-fed modular system



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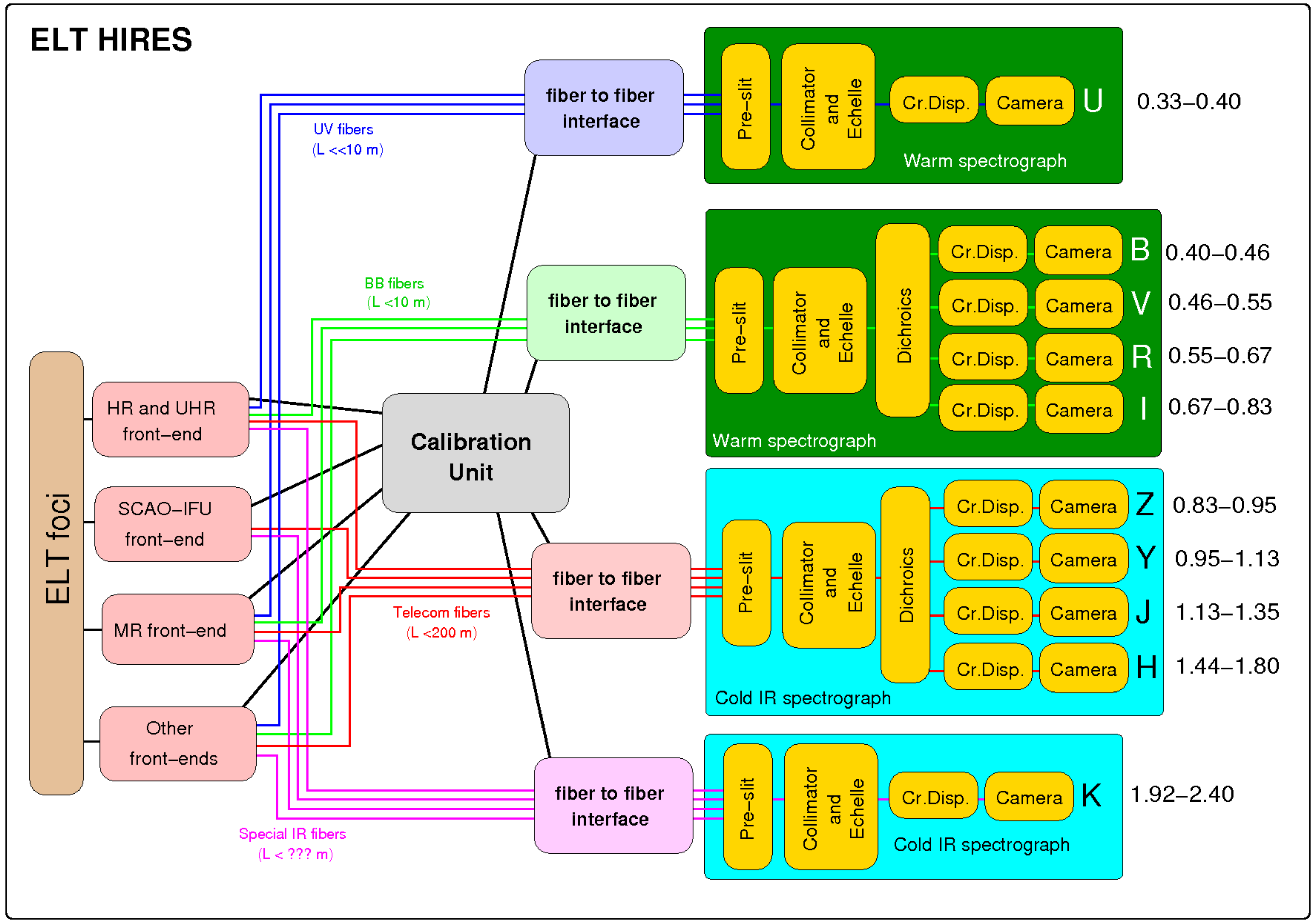
- >40 MEUR *modular* instrument (hardware only): *prioritisation of science requirements mandatory*



Science Priorities

- **Priority 1: Exoplanet atmospheres via transmission spectroscopy (potential detection of bio-signatures)**
  - **TLR 1: R > 100,000, 0.5-1.8 μm, *et alia*;** drive the HIRES baseline design
  - Enables: reionization of Universe; characterization of Cool stars
  - Doable: detection and investigation of near pristine gas; 3D reconstruction of the CGM; Extragalactic transients
- **Priority 2: Variation of the fundamental constants of Physics**
  - **TLR 2: blue extension to 0.37 μm**
  - Enables: Cosmic variation of the CMB temperature, Determination of the deuterium abundance; investigation and characterization of primitive stars
- **Priority 3: Exoplanet atmospheres via reflection spectroscopy (potential detection of bio-signatures)**
  - **TLR 3: SCAO+IFU**
  - Enables: Planet formation in protoplanetary disks; characterization of stellar atmospheres; Search of low mass Black Holes
  - Doable: characterization of the physics of protoplanetary disks
- **Priority 4: Redshift drift (Sandage test)**
  - **TLR 4: λ accuracy 2 cm/s, stability 2 cm/s**
  - Enables: Mass determination of exoplanets (Earth-like objects)
  - Doable: Radial velocity search for exoplanets around M-dwarf stars

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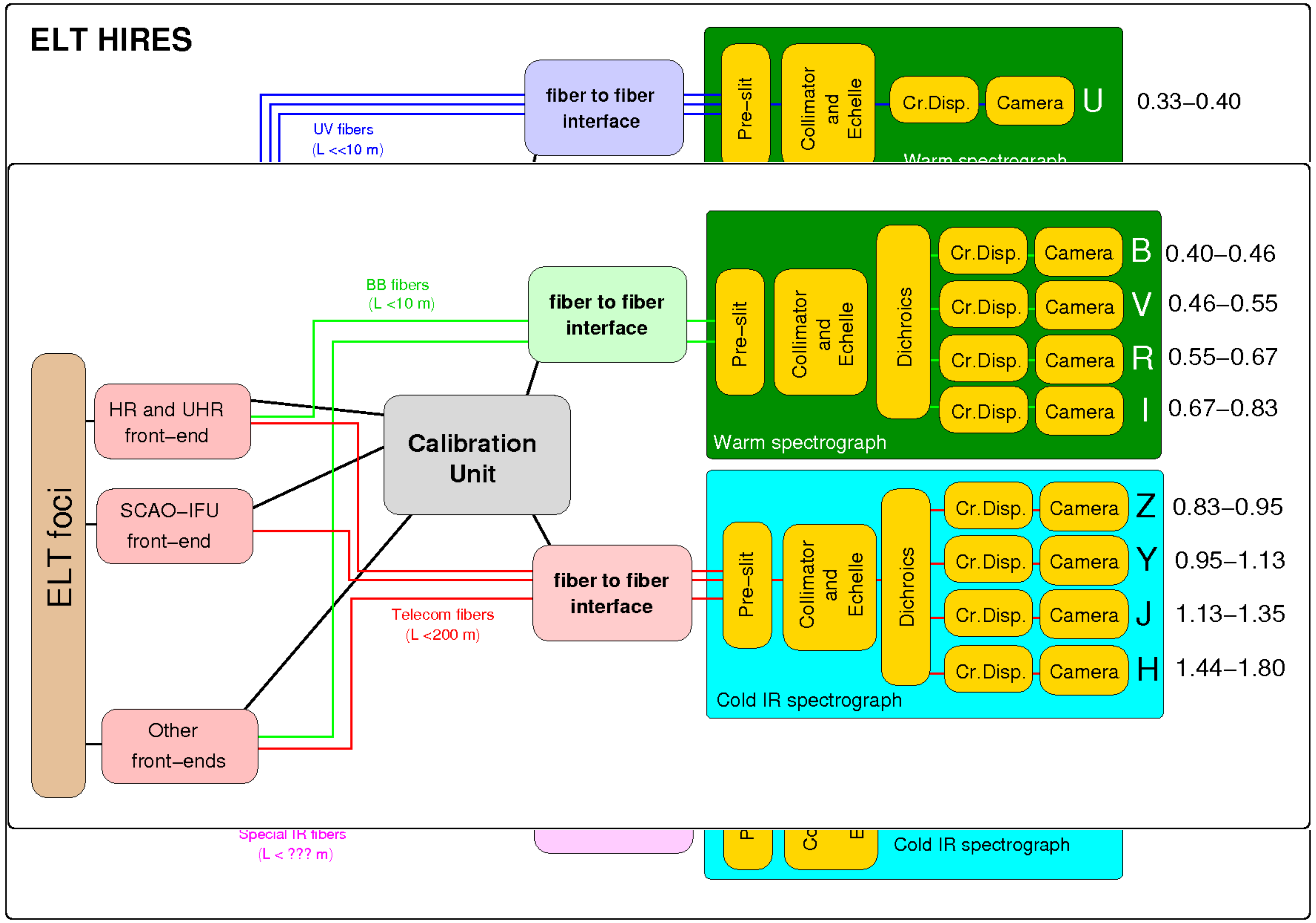
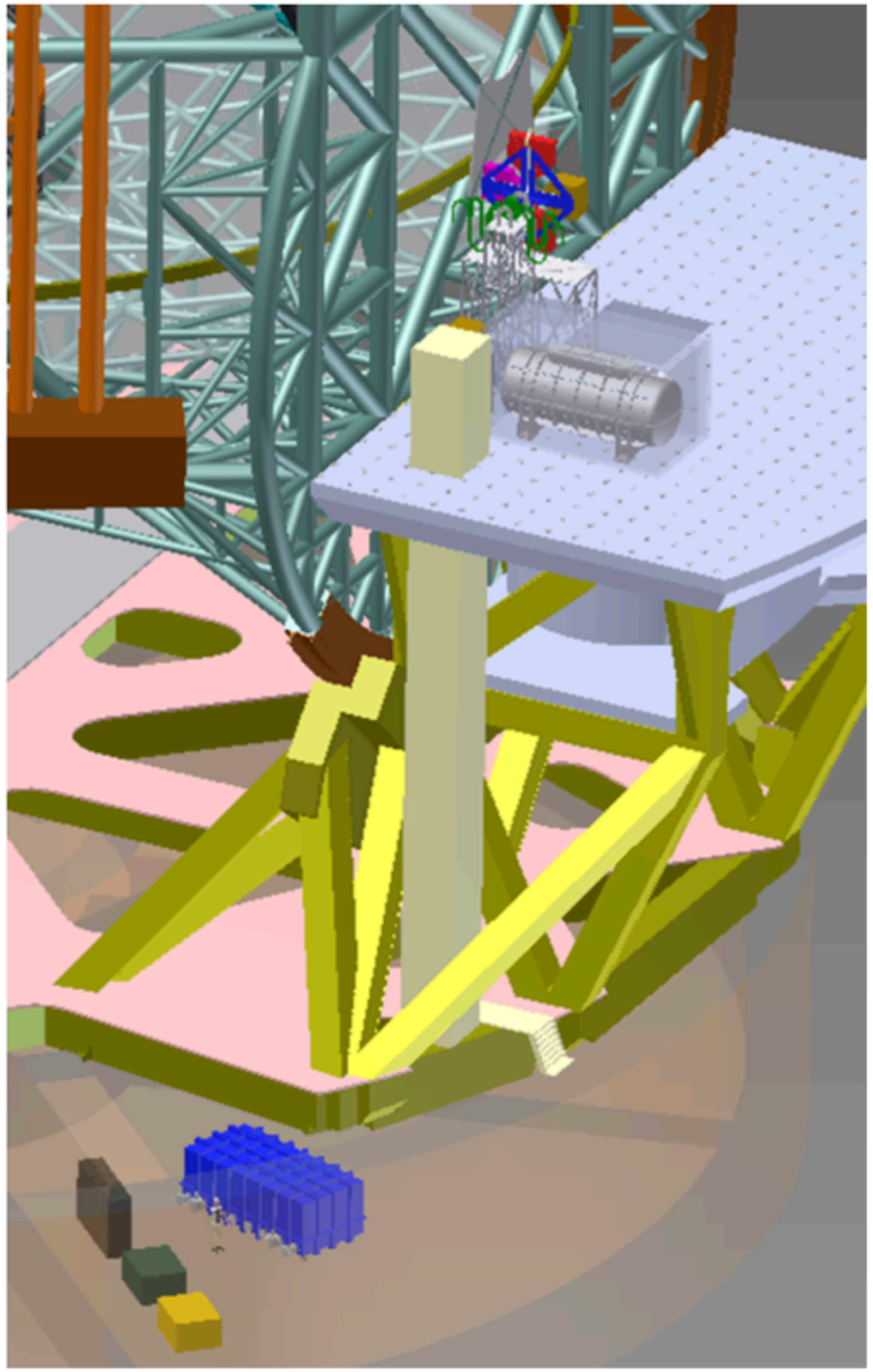
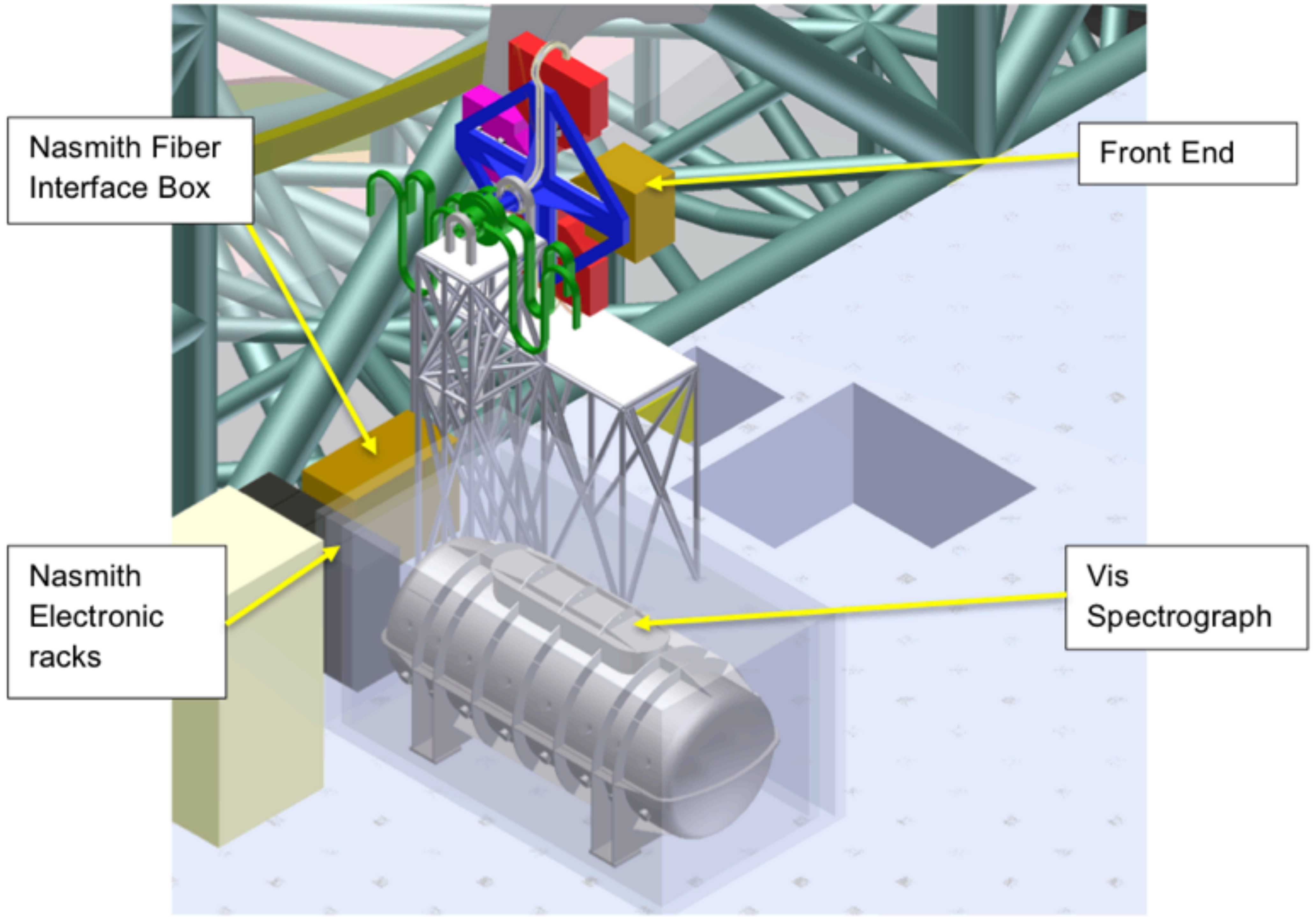
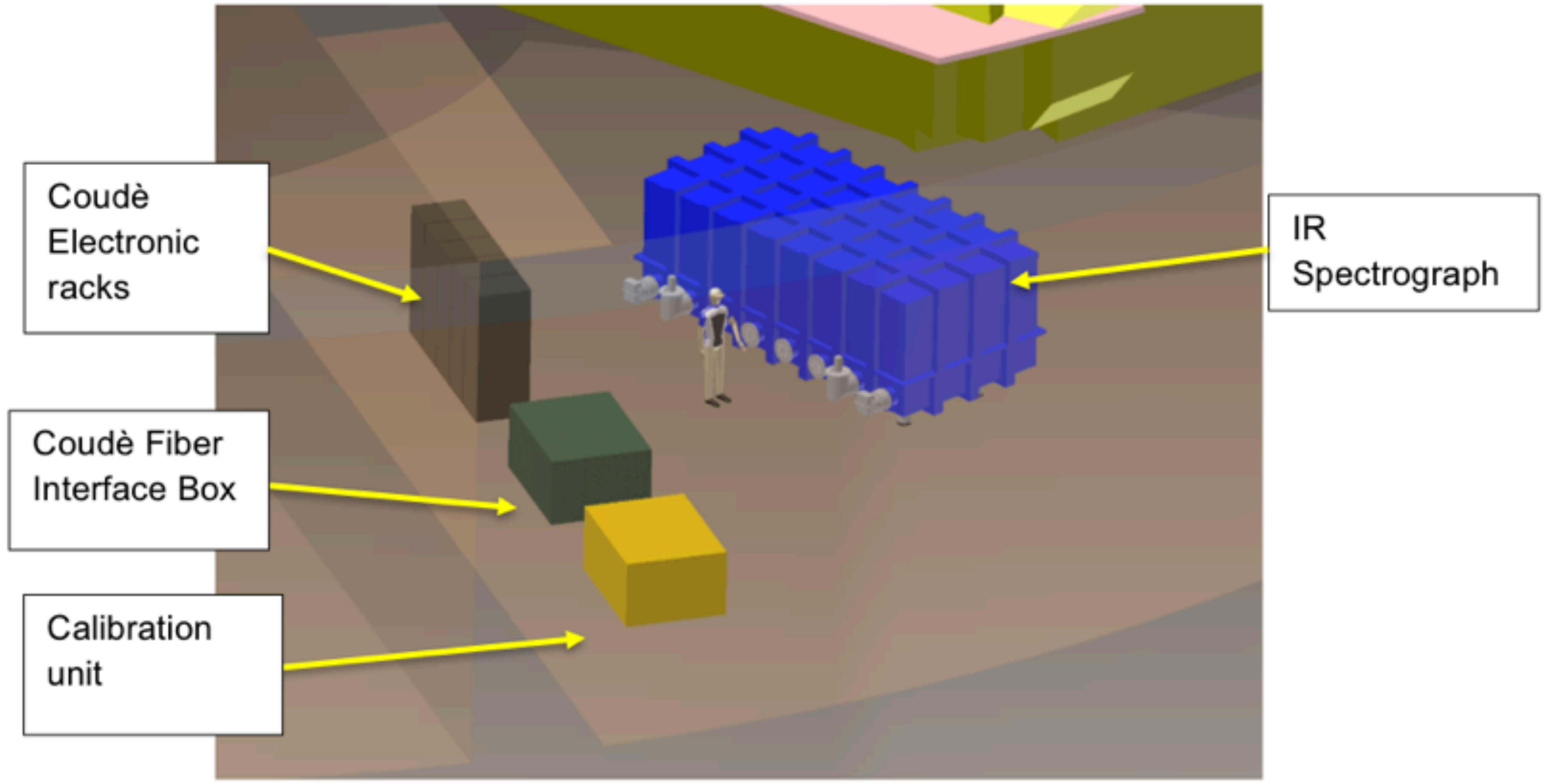


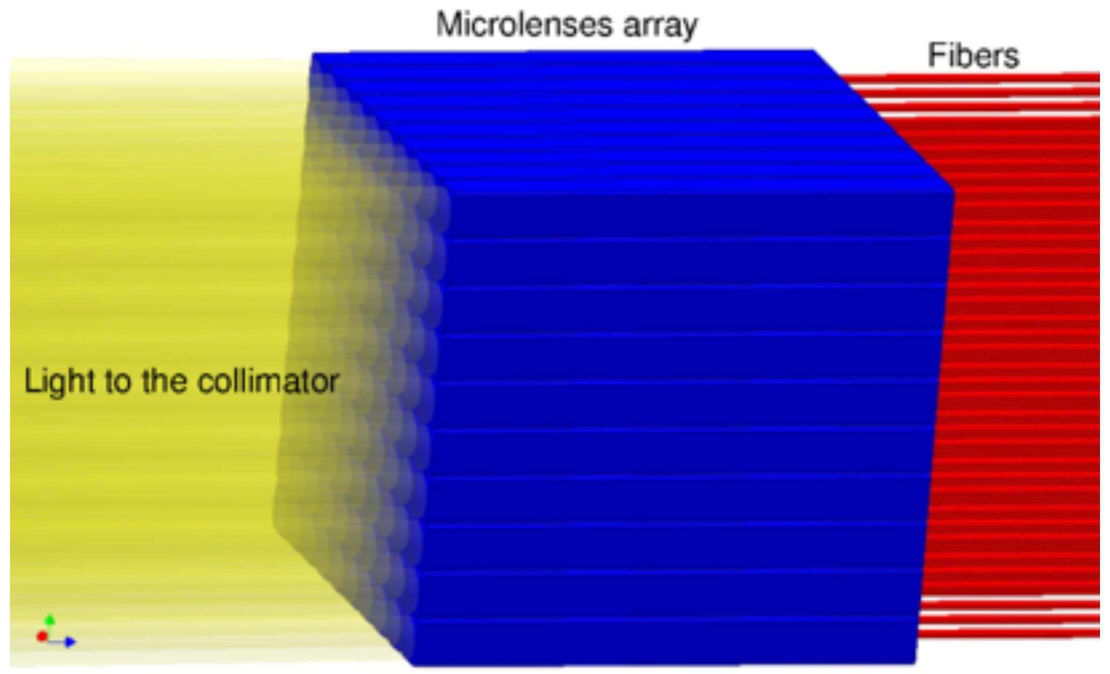
HIRES at ELT

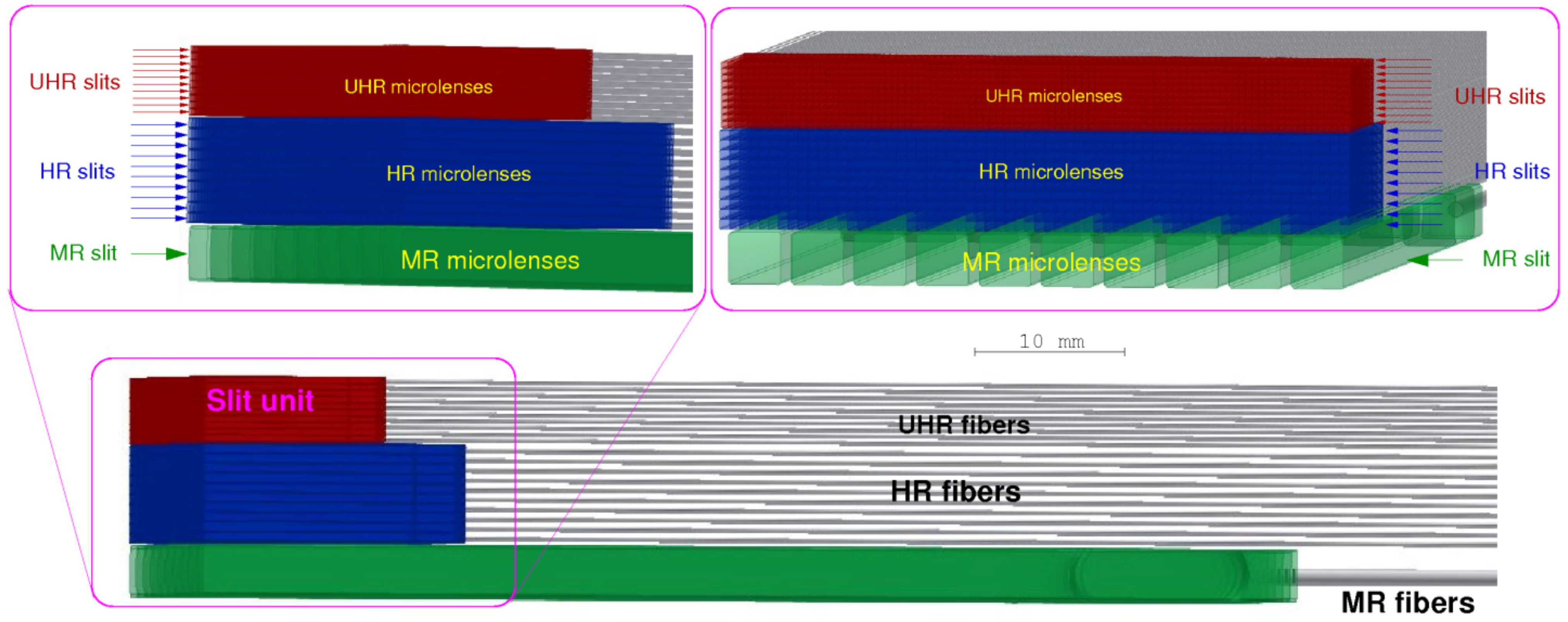


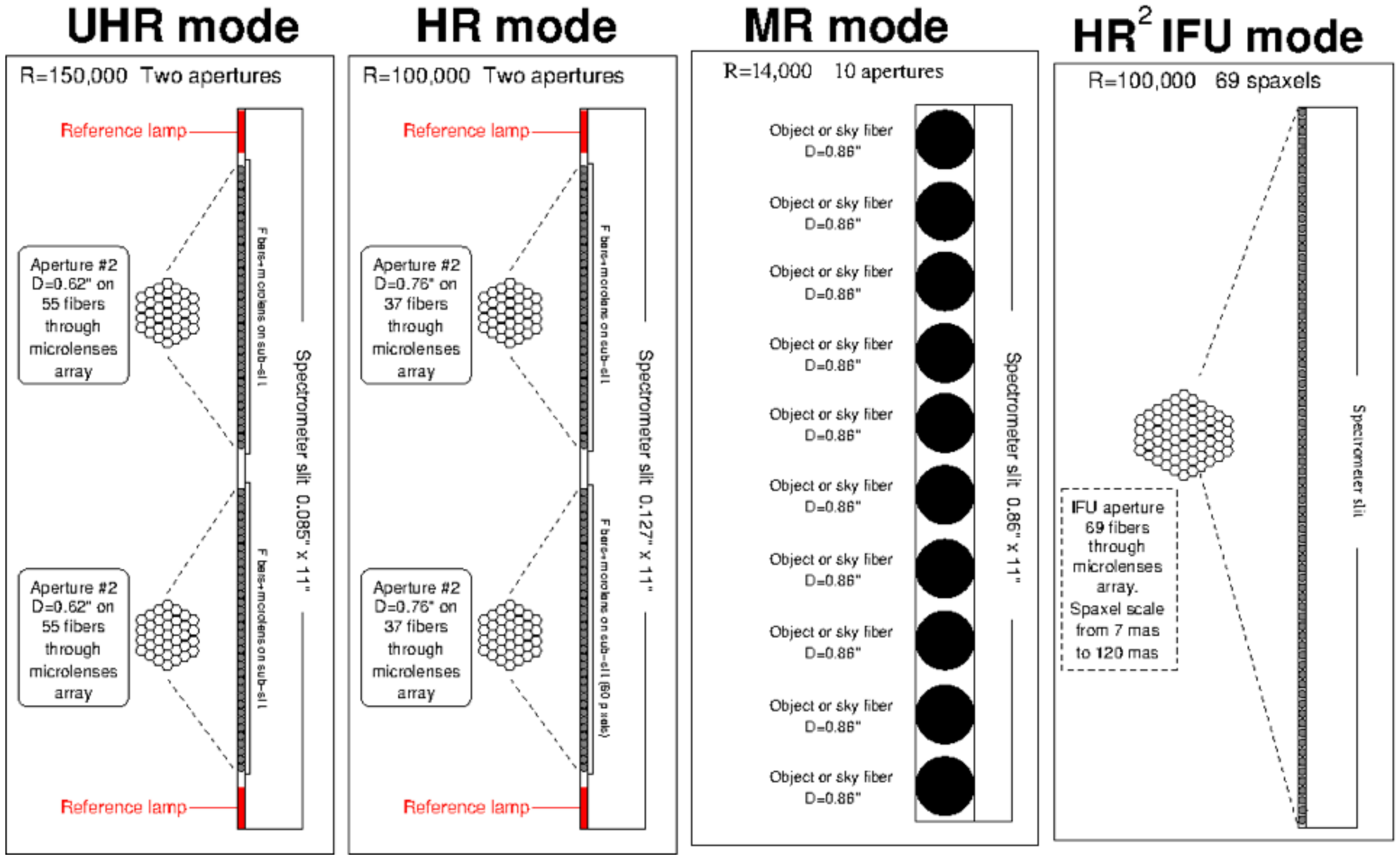

Nasmith Fiber Interface Box
Front End
Nasmith Electronic racks
Vis Spectrograph


Coudè Electronic racks
IR Spectrograph
Coudè Fiber Interface Box
Calibration unit

Fibre feeding & observing modes







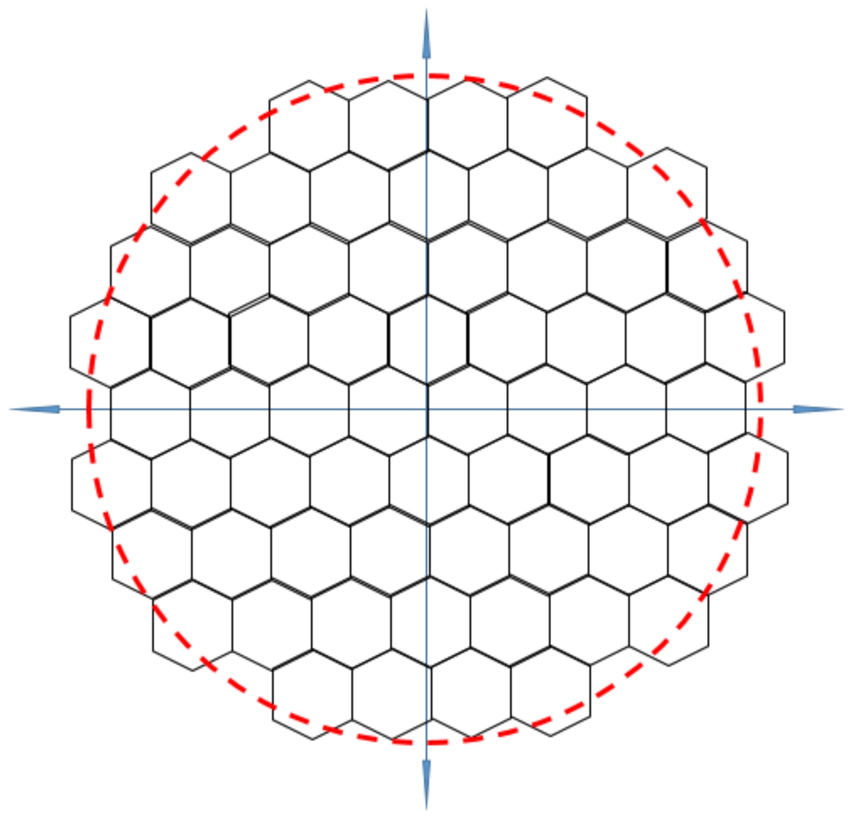
Integral Field Unit

64 spaxels

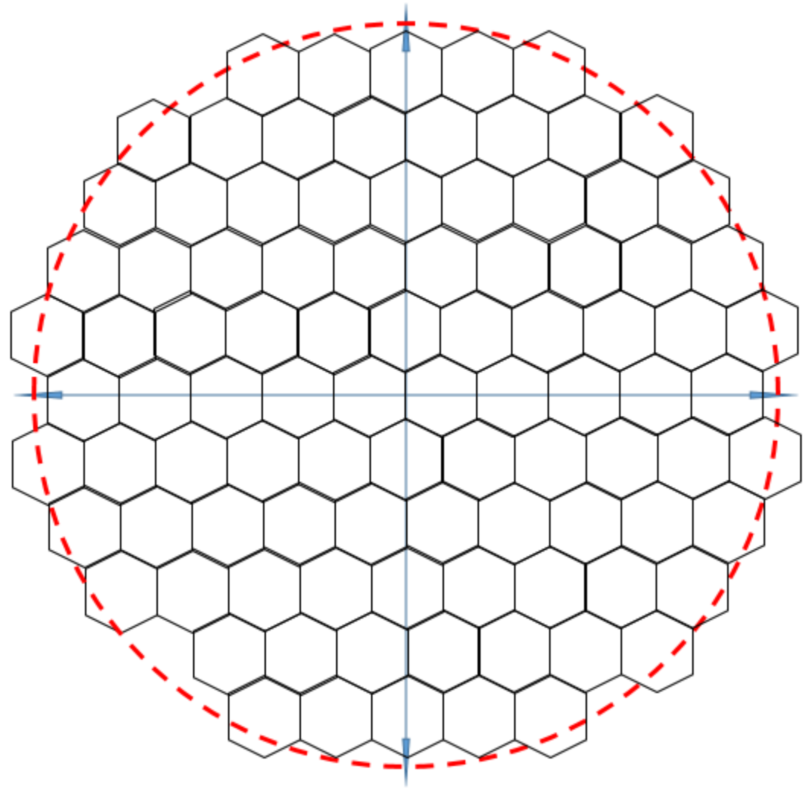
- 10 mas to 100 mas spaxel scale
- FOV 0.07″×0.07″ — 0.7″×0.7″
- R = 100,000

96 spaxels

- 10 mas to 100 mas spaxel scale
- FOV 0.09″×0.09″ — 0.9″×0.9″
- R = 150,000
- **0.9 - 1.8 micron simultaneous coverage**



*Bundle of 64 fibres (Diameter ~ 8*lens diameter)*



*Bundle of 96 fibres (Diameter ~ 10*lens diameter)*

- **Unique IFU capability!**

Many science cases:

- Exoplanets in reflection
- Protostellar disks and Jets
- Stellar Astrophysics
- Stellar populations in nearby Galaxies.
- Small supermassive Black Holes ($<10^5$ $M_\odot$)

Summary of ELT HIRES project (after Phase A)

- International consortium: **32+ institutes, 14 countries, >200 people**
- Successful Phase A study 03/2016 - 03/2018
- **Aggressive schedule: Start Phase B ~2021, @ELT in 2028-2029**
- **Science priorities (plus many other great science cases ..**
  1. biomarkers from exoplanet atmospheres in transmission
  2. variation of fundamental constants of Physics
  3. biomarkers from exoplanet atmospheres in reflection
  4. direct detection of Cosmic acceleration through Sandage effe
- **Modular fiber-fed cross dispersed echelle spectrograph**
- **Simultaneous range 0.4-1.8 μm (ultrastable VIS+NIR)**
  Resolution ~100,000 & 150,000
- Several interchangeable, observing modes:
  Seeing limited & SCAO+IFU
- **Total estimated cost of baseline is 25.9 MEUR, + 500 FTEs**
  - technically “simple”
  - almost pupil independent
  - great science cases (fulfills top 4 priorities)
  - modular, staged deployment possible