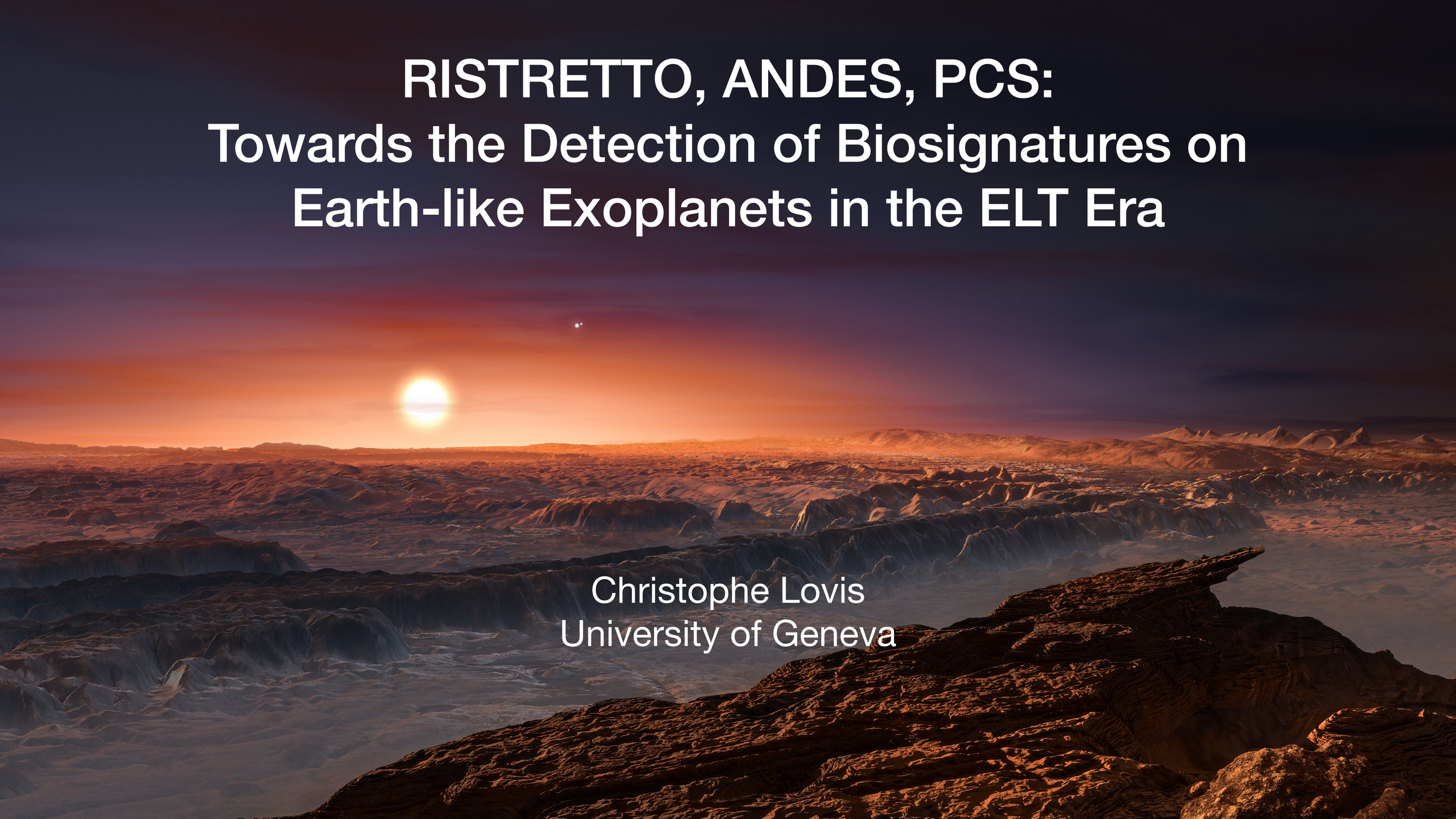
RISTRETTO, ANDES, PCS: Towards the Detection of Biosignatures on Earth-like Exoplanets in the ELT Era



Christophe Lovis
University of Geneva

How to characterize the atmospheres of ***temperate rocky exoplanets***?

Timeline	Space	Ground
2022 2025	Transit spectroscopy with the James Webb Space Telescope	
2030		Mid-IR imaging with ELT-METIS?
2035		Transit spectroscopy and high-contrast spectroscopy in the visible/near-IR with ELT-ANDES
>2040	Large space mission for high-contrast spectroscopy in the visible/near-IR (Habitable Worlds Observatory) Large space mission for mid-IR interferometry (LIFE)	High-contrast spectroscopy in the visible/near-IR with ELT-PCS

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Towards the atmospheric characterization of Earth-like exoplanets in reflected light

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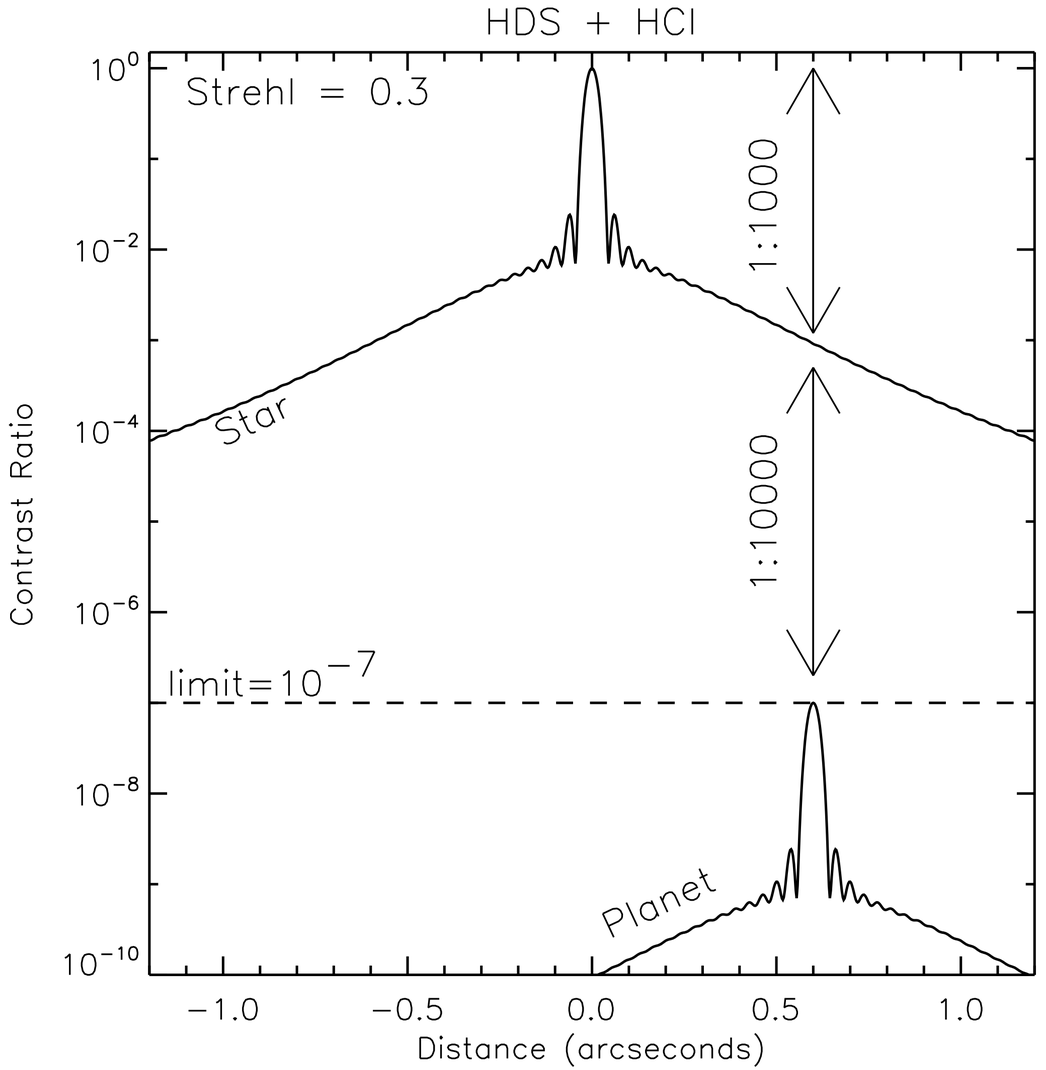
Combining high contrast and high spectral resolution

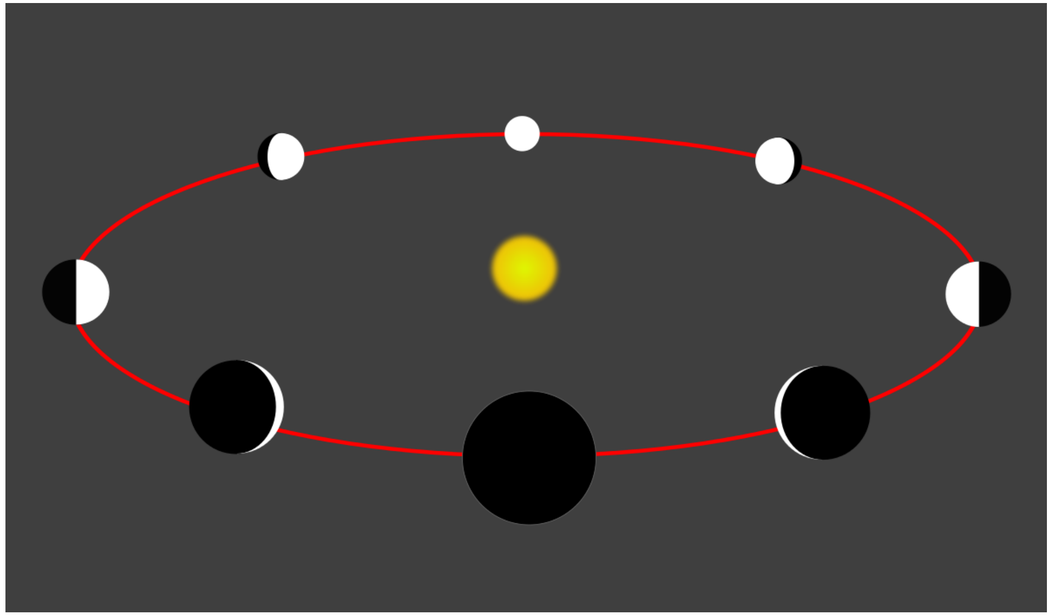
- Atmospheric turbulence degrades ground-based images down to typically 1 arcsec angular resolution
- Adaptive optics (AO) systems are needed to obtain diffraction-limited, high-contrast images
- Planet/star contrast levels achievable in ground-based images will not be enough to reach temperate rocky planets directly (contrasts of 10^{-7} to 10^{-10})
- **Idea: boost high-contrast systems by coupling them to a high-resolution spectrograph**
- The planet light does not need to be fully separated from the stellar light by the AO system
- It will be **spectrally separated** by the high-resolution spectrograph, based on its **distinct spectral content and Doppler shift**

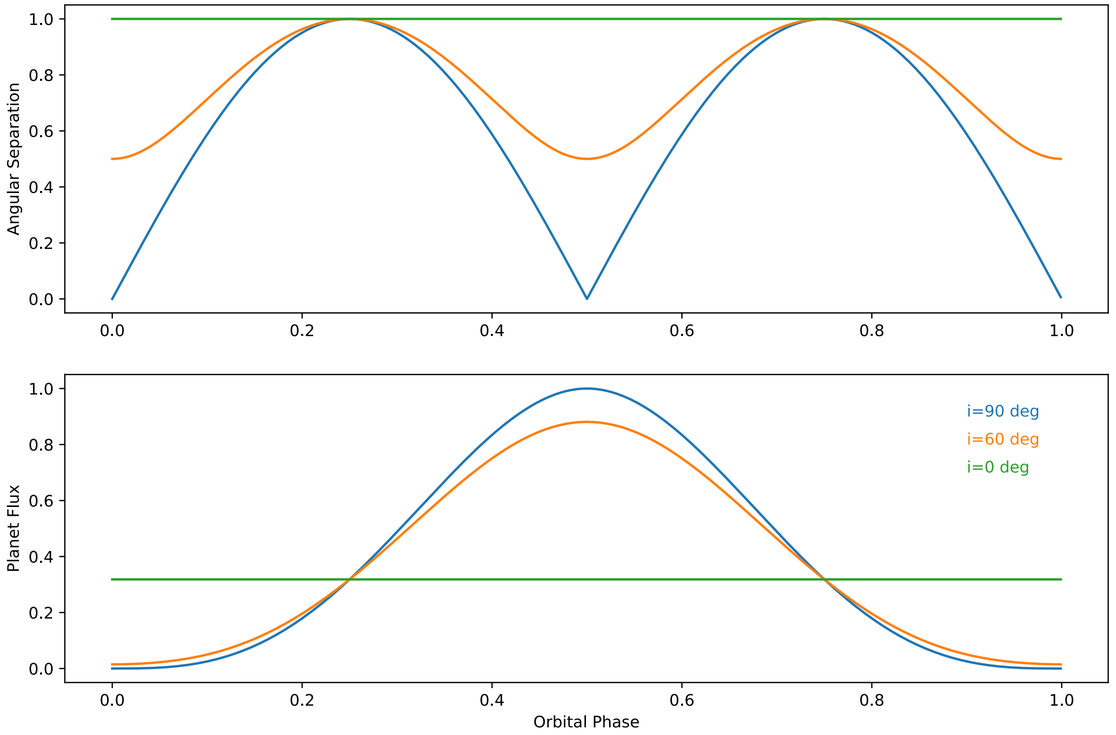


Snellen et al. 2015

Reflected-light spectroscopy

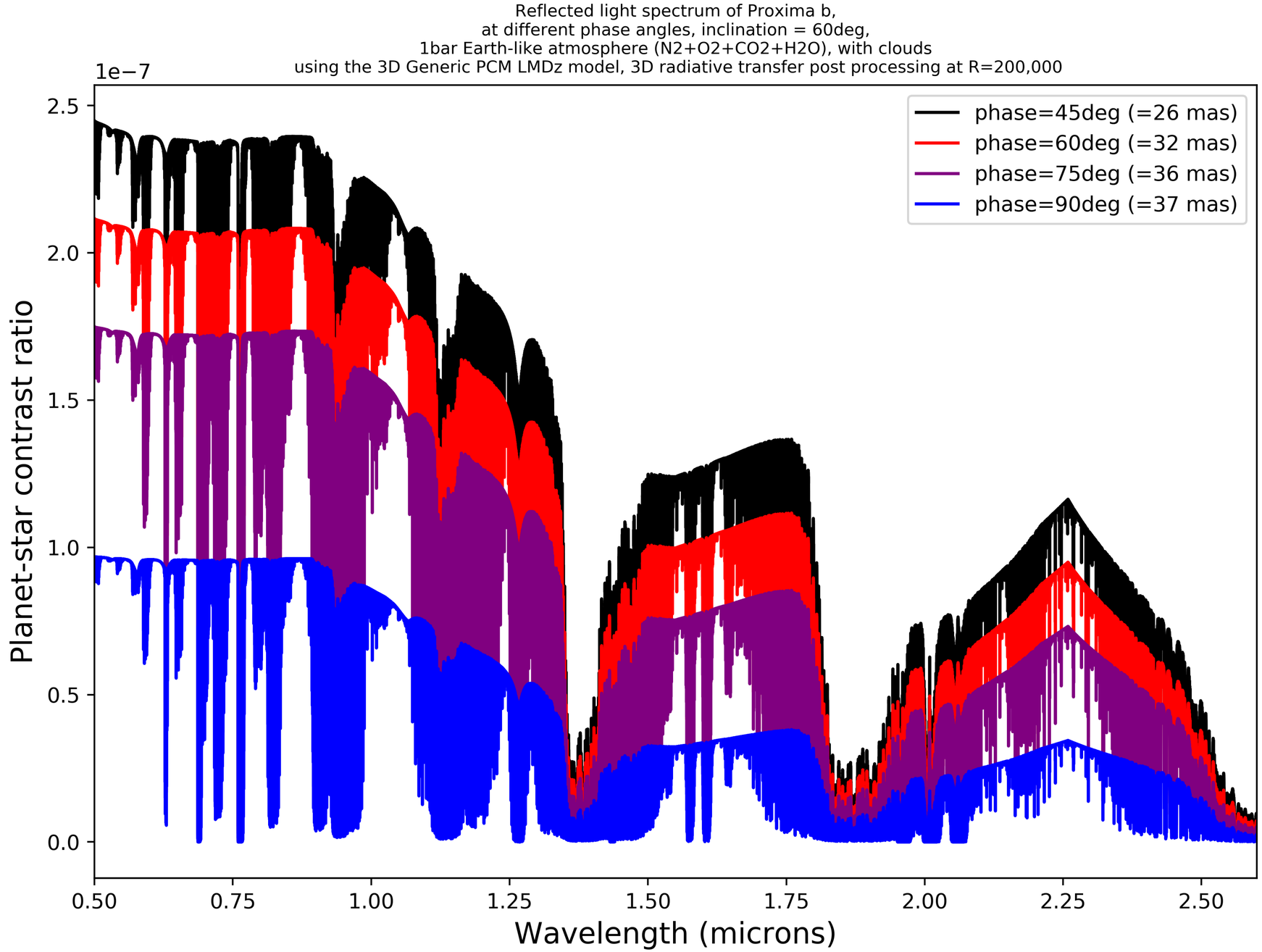
- Unique access to the population of nearby exoplanets, i.e. **our immediate neighbours**
- The vast majority of those are not transiting
- **Easier access to the habitable zone** (e.g. Proxima b)
- Diverse sample in terms of mass and irradiation
- Reflected-light geometry **probes deeper atmospheric layers** than transit geometry; it can even probe the **planetary surface** if atmosphere allows





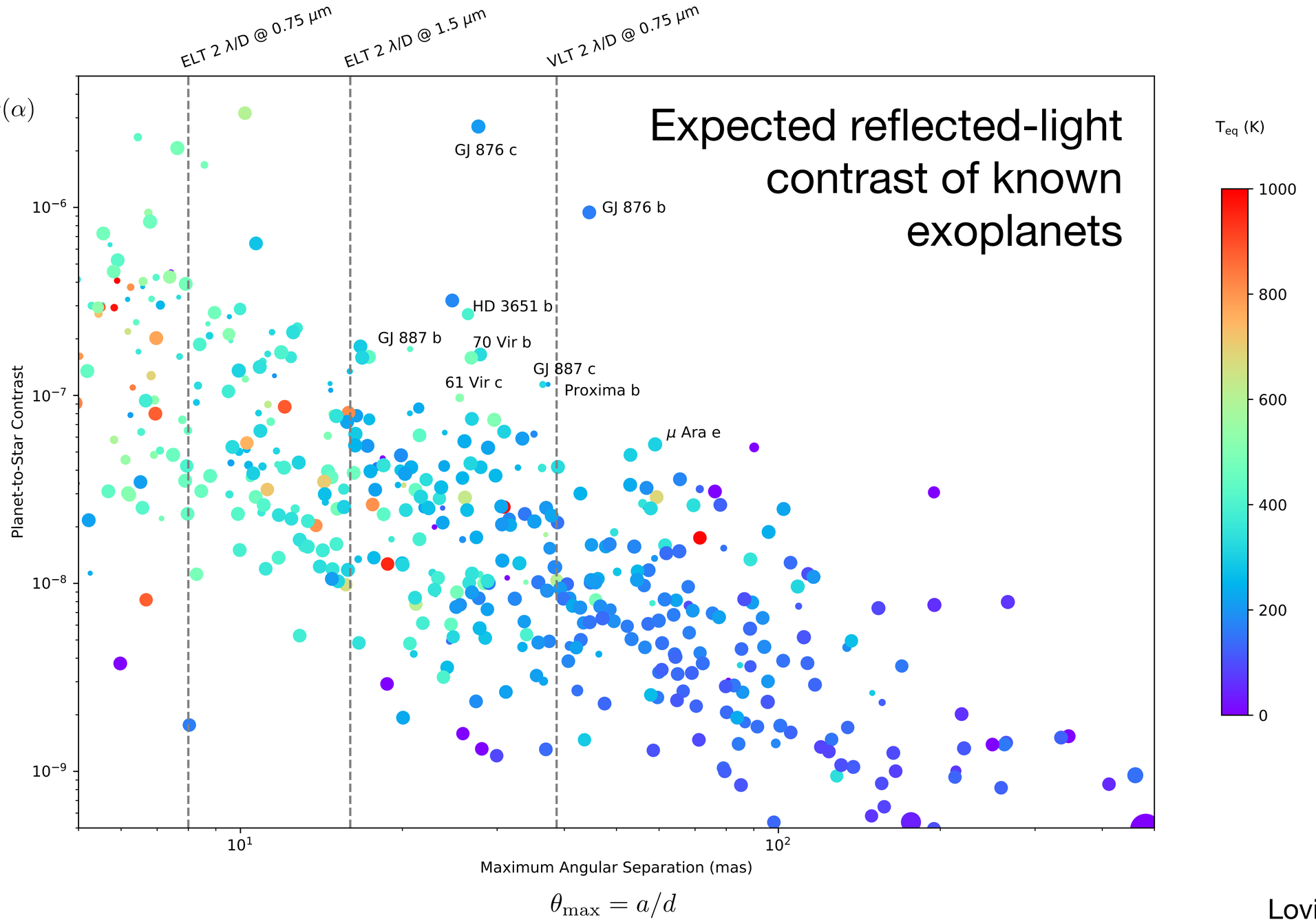
- These exoplanets were discovered by RV surveys and **have a known RV orbit**
- Known from RV orbit: **epochs of maximum elongation, value of maximum elongation**
- Unknown: position angle of the planet on the sky, orbital inclination
- Detection of the planetary signal will immediately determine its RV and thus inclination and **true mass**

Reflected-light spectroscopy



Credit: M. Turbet

$$C = \left(\frac{R_p}{a}\right)^2 A_g(\lambda)\, g(\alpha)$$

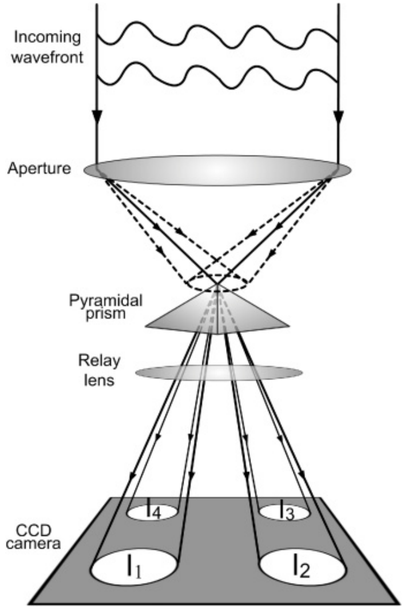


$$\theta_{\max} = a/d$$

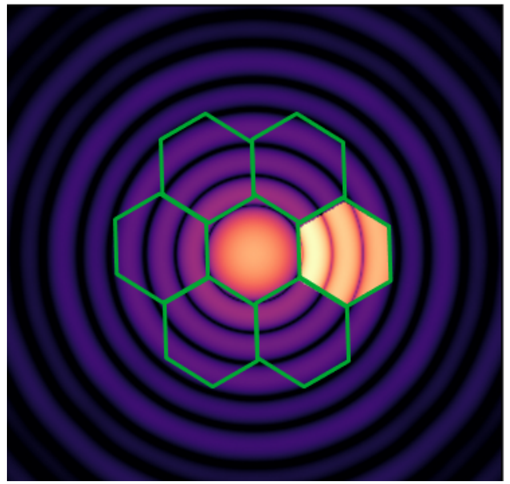
Lovis et al. 2017

The RISTRETTO project:
A pathfinder instrument for reflected-light spectroscopy at the VLT

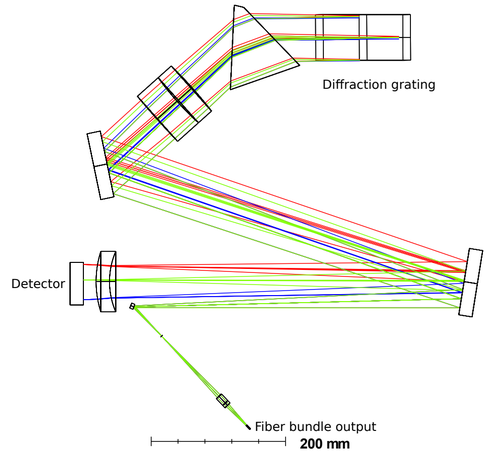
VLT-UTx
8-m primary mirror



Fast XAO system based on near-IR
Pyramid wavefront sensor

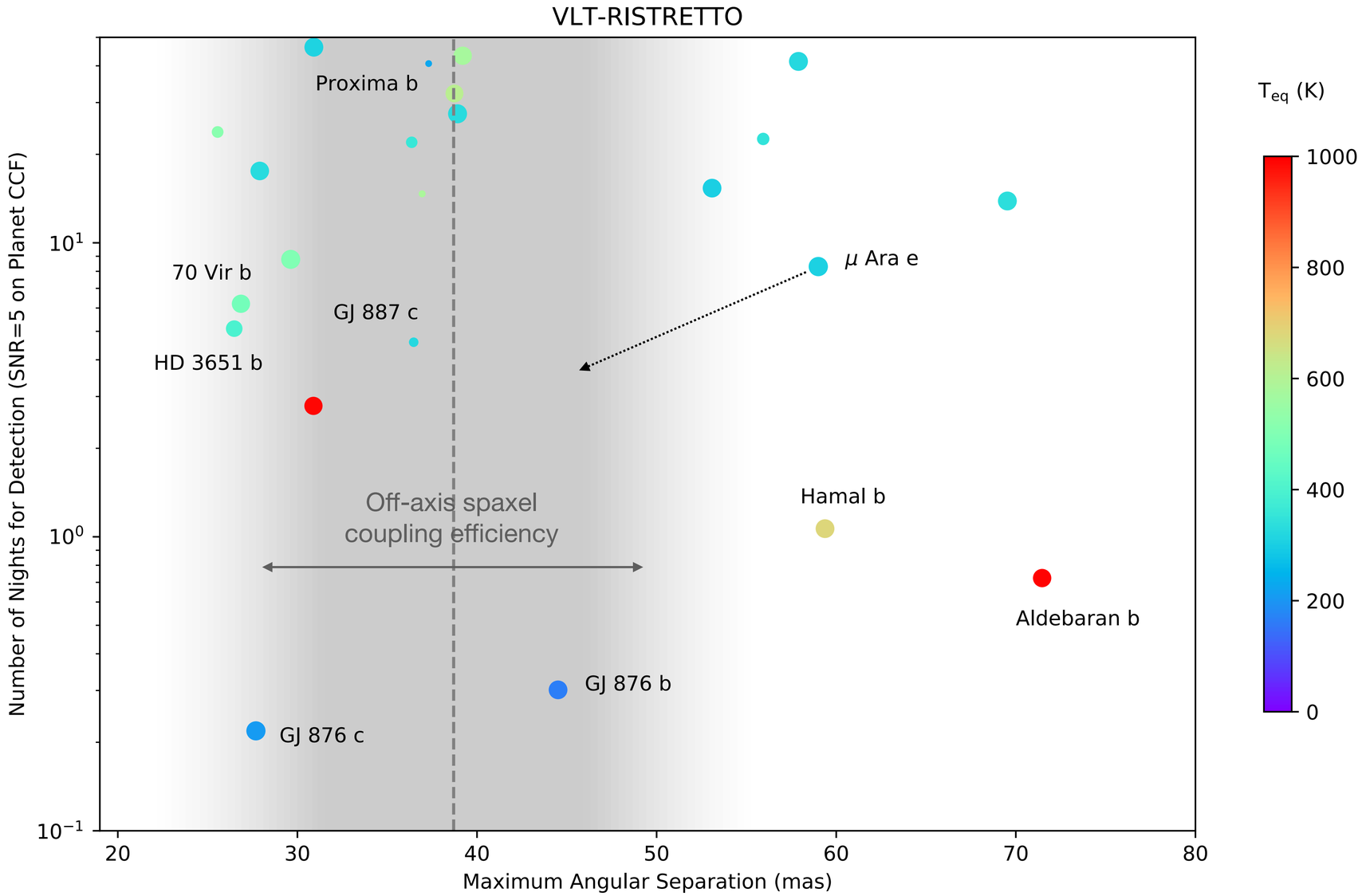


7-spaxel coronagraphic
integral-field unit feeding
single-mode fibers



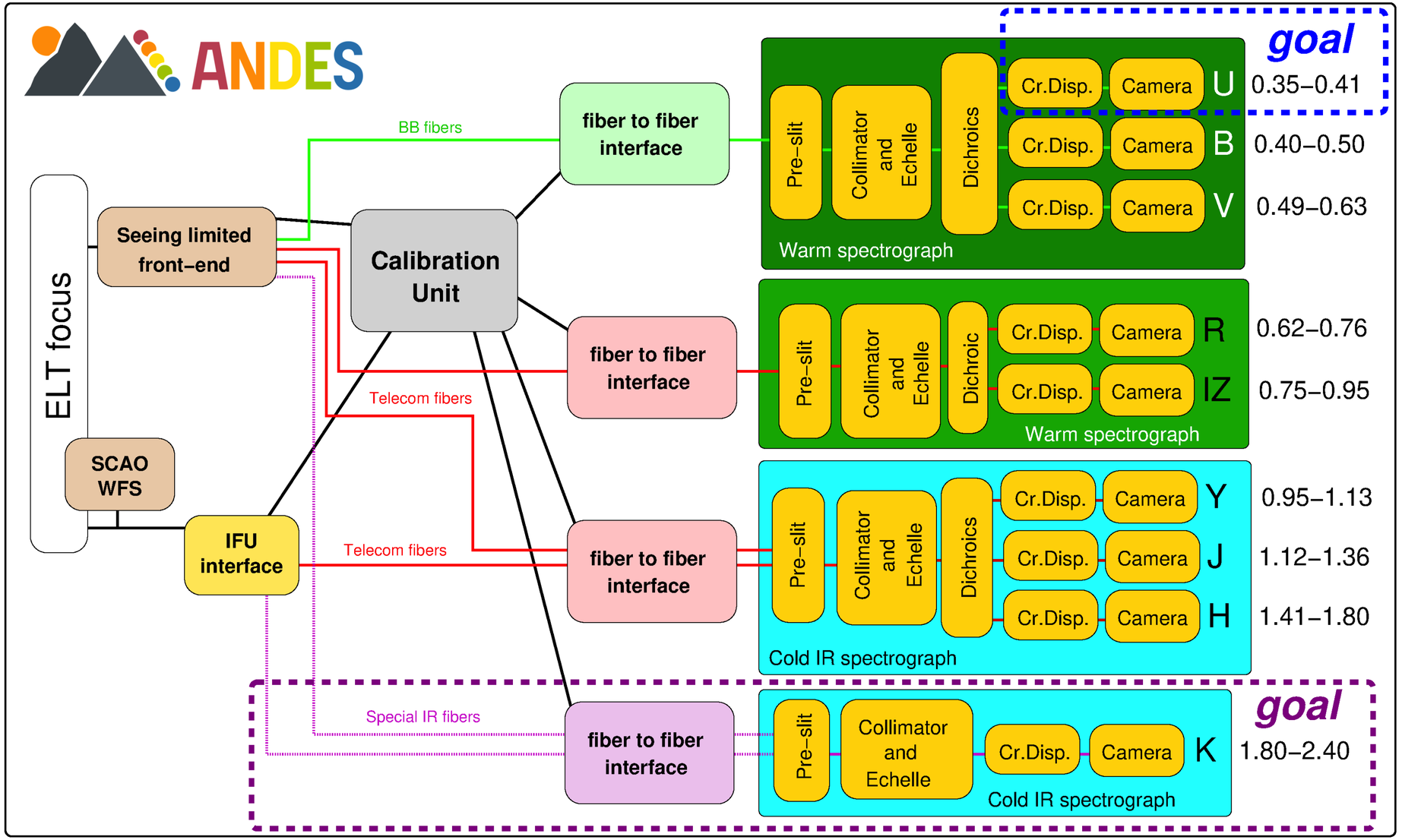
Visible high-resolution
spectrograph

RISTRETTO: Target list

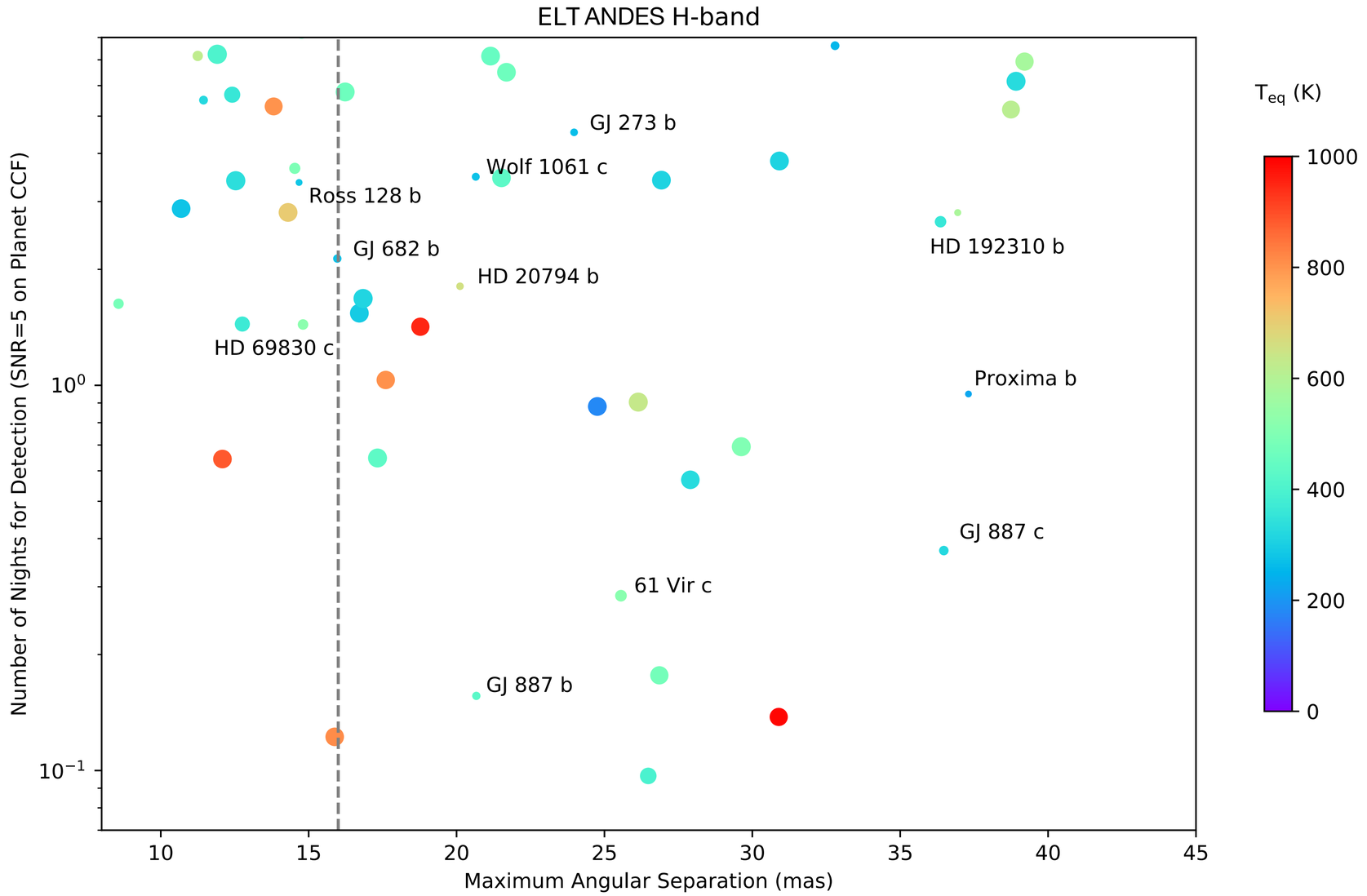


ANDES: the visible/near-IR high-resolution spectrograph for the ELT

ELT-ANDES instrument architecture



High-contrast, high-resolution spectroscopy with ANDES: exploring the population of nearby habitable exoplanets



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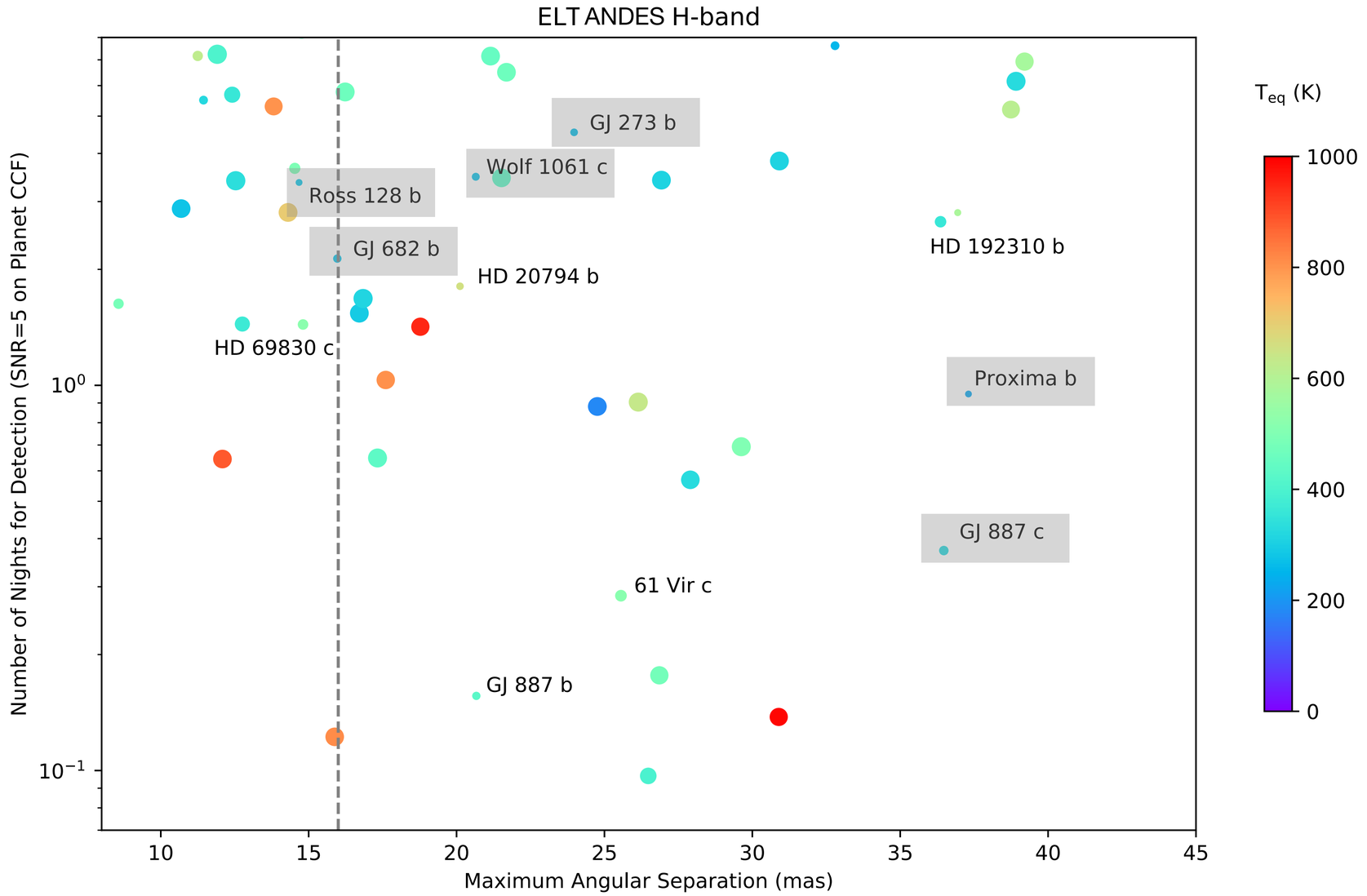


High-contrast, high-resolution spectroscopy with ANDES: exploring the population of nearby habitable exoplanets

Name	*d*	*V*	*P*	*msini*	R_p	T_{eq}	θ_{max}	*C*	H_p	T_{exp}
Proxima Cen b	1.30	11.11	11.19	1.3	1.08	229	37.3	1.15e-07	22.1	0.95
Ross 128 b	3.38	11.15	9.87	1.4	1.11	283	14.7	1.16e-07	23.3	3.36
GJ 273 b	3.80	9.87	18.65	2.9	1.51	266	24.0	6.34e-08	23.1	4.54
Wolf 1061 c	4.31	10.03	17.87	3.4	1.66	275	20.6	8.03e-08	23.1	3.48
GJ 682 b	5.01	10.97	17.48	4.4	1.93	275	16.0	1.34e-07	23.1	2.13

Table 1: *Sample of 5 known potentially habitable exoplanets that could be studied with ANDES in less than 15 nights of observations. d: distance to the star (pc), V: V-band magnitude of the star, P: planet orbital period (days), msini: planet minimum mass (Earth masses), R_p: estimated planet radius (Earth radii), T_{eq}: planet equilibrium temperature (K), θ_{max}: maximum angular separation (mas), C: estimated planet-to-star contrast, H_p: H-band magnitude of the planet, T_{exp}: integration time to reach SNR=5 on the planet reflected spectrum (nights).*

More to come from ongoing RV surveys with ESPRESSO, NIRPS, CARMENES, etc.

ELT-PCS: XAO-fed planetary camera and (high-resolution!) spectrograph

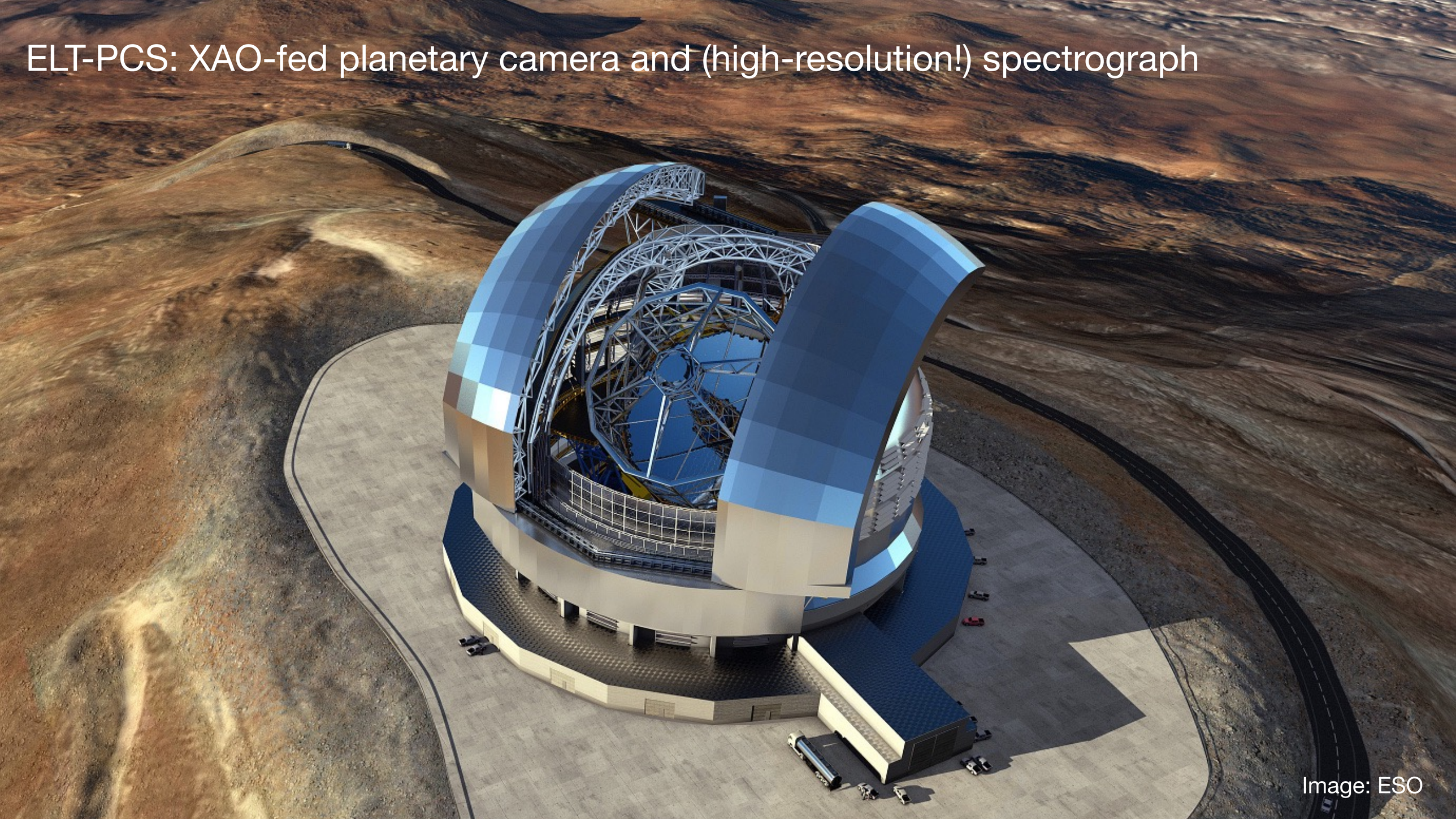
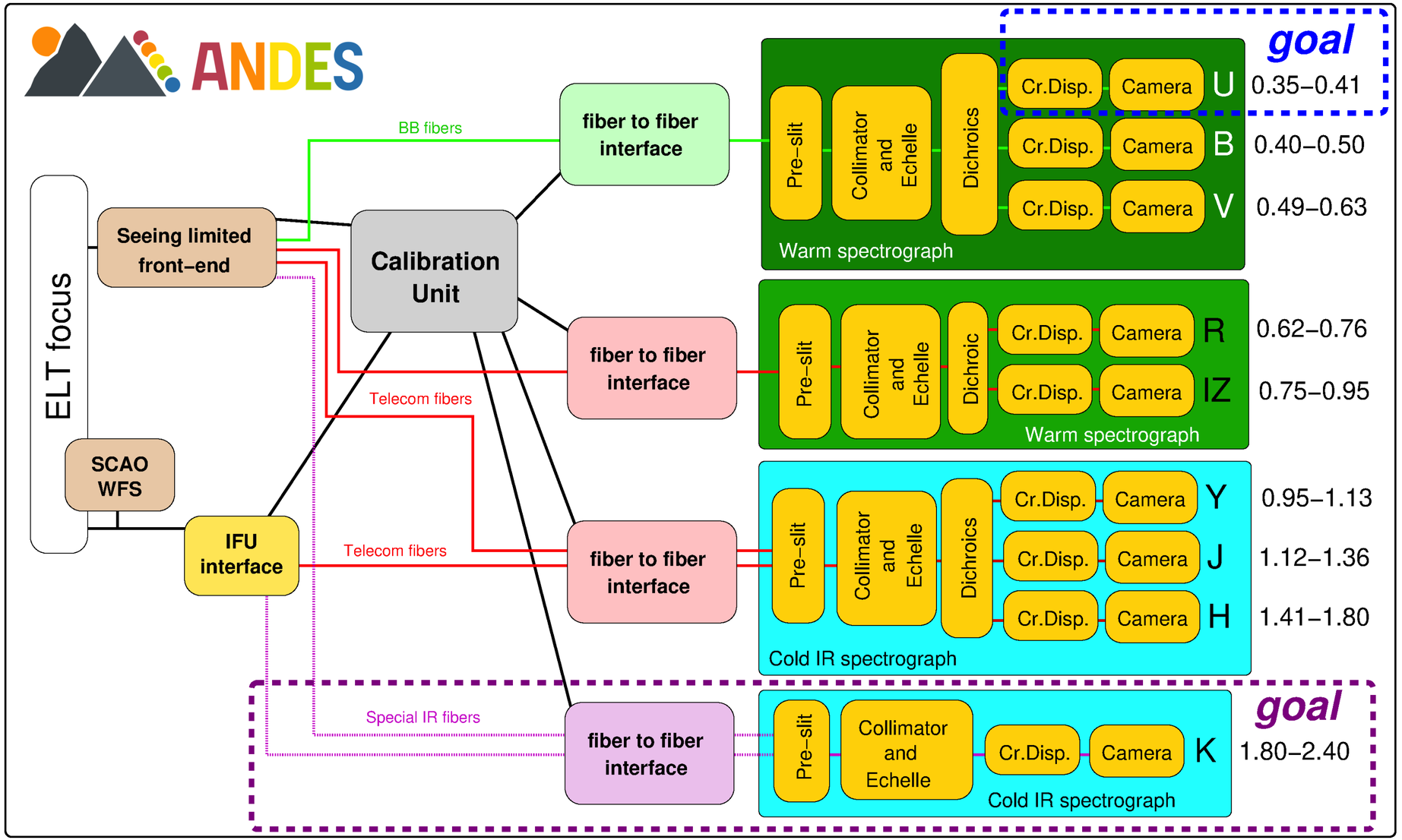


Image: ESO

From ANDES to PCS: towards an XAO front-end, IFU and fiber link feeding the ANDES RIZ and YJH spectrographs?



RIZ and YJH spectrographs installed in the Coudé room below the ELT

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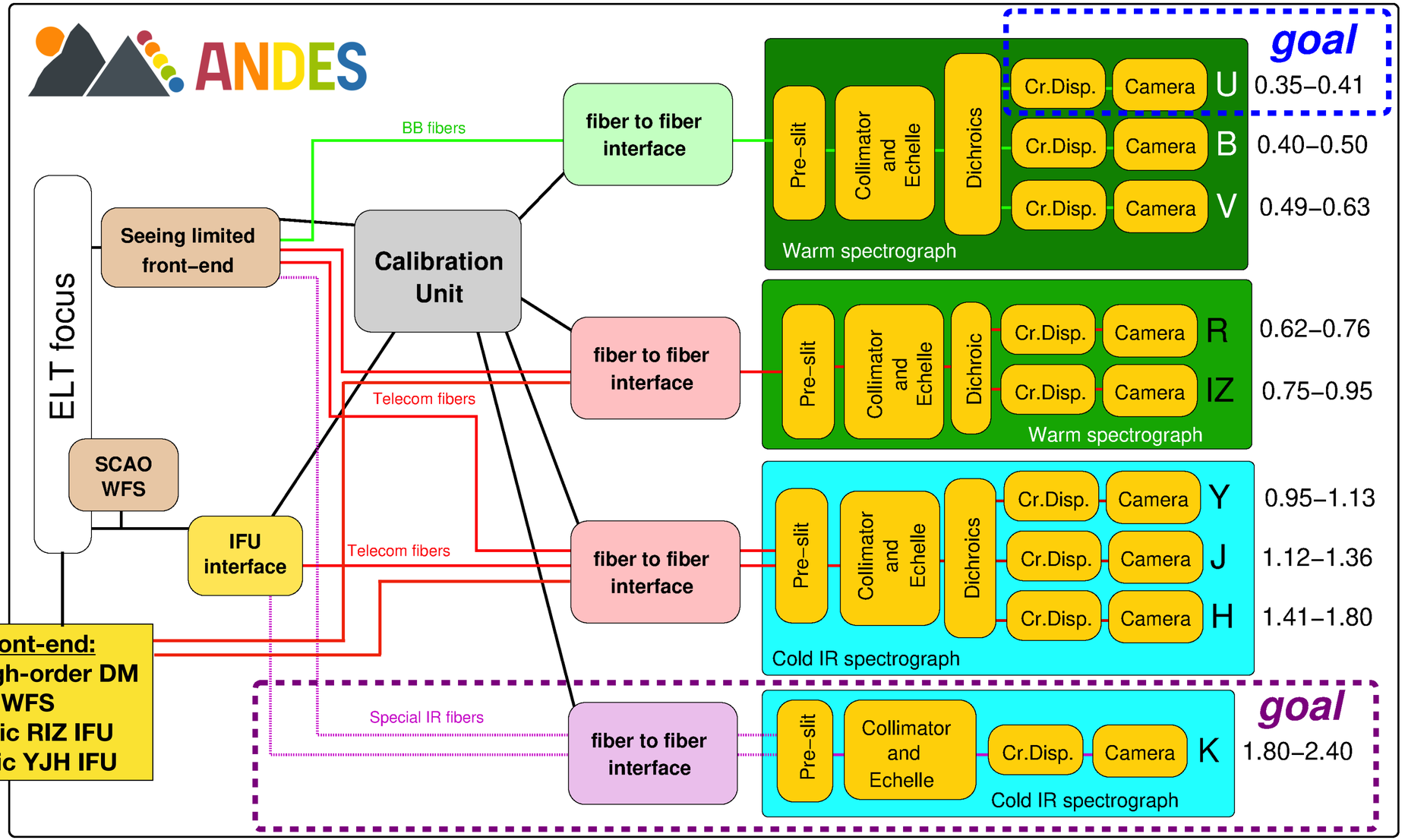

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