Biosignature Detection Simulations with ANDES on the Extremely Large Telescope

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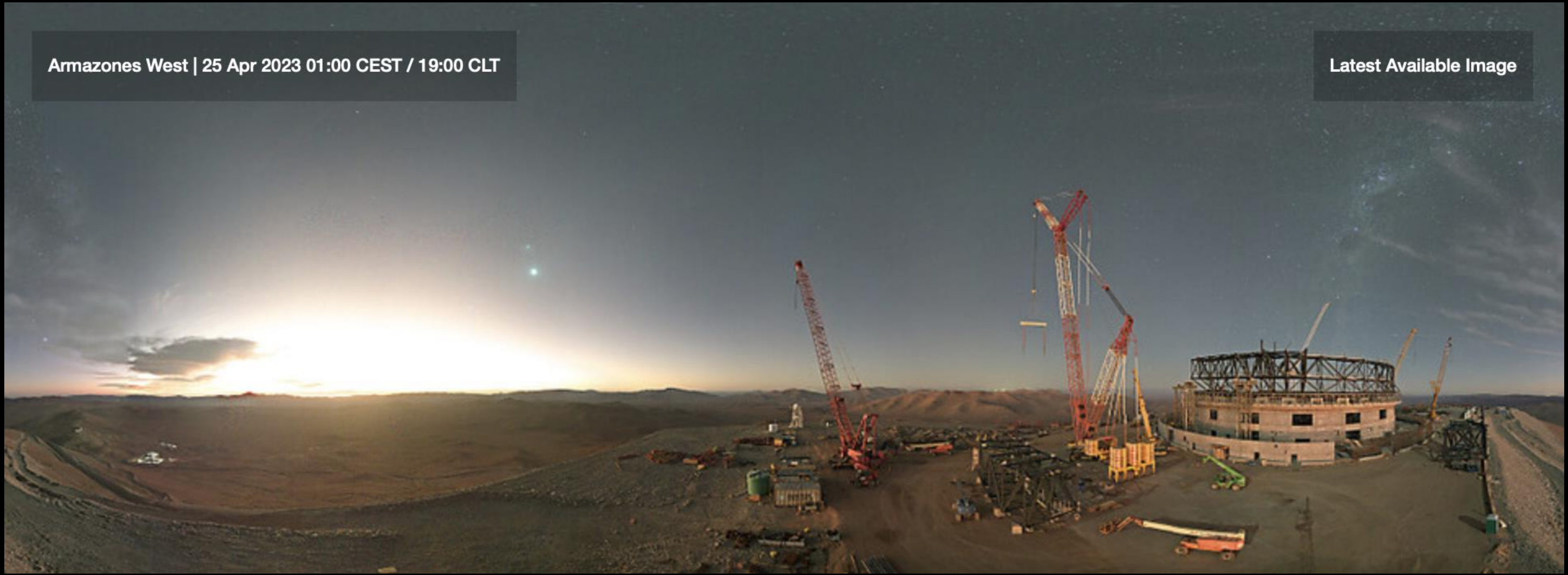
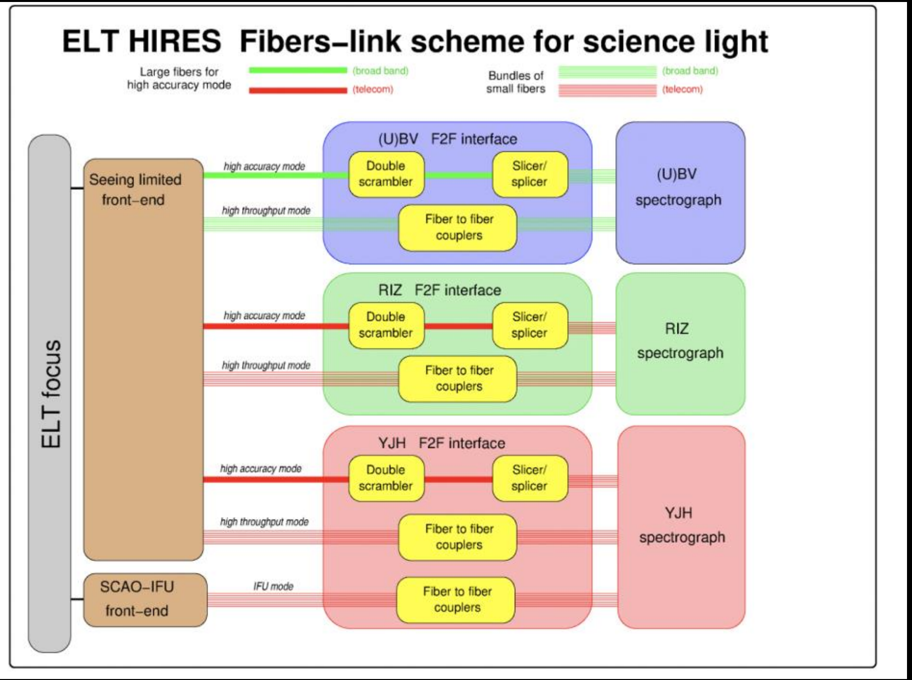
ELT Status

- 39 m under construction
- 2027: Technical First Light
- 2028: Science verification

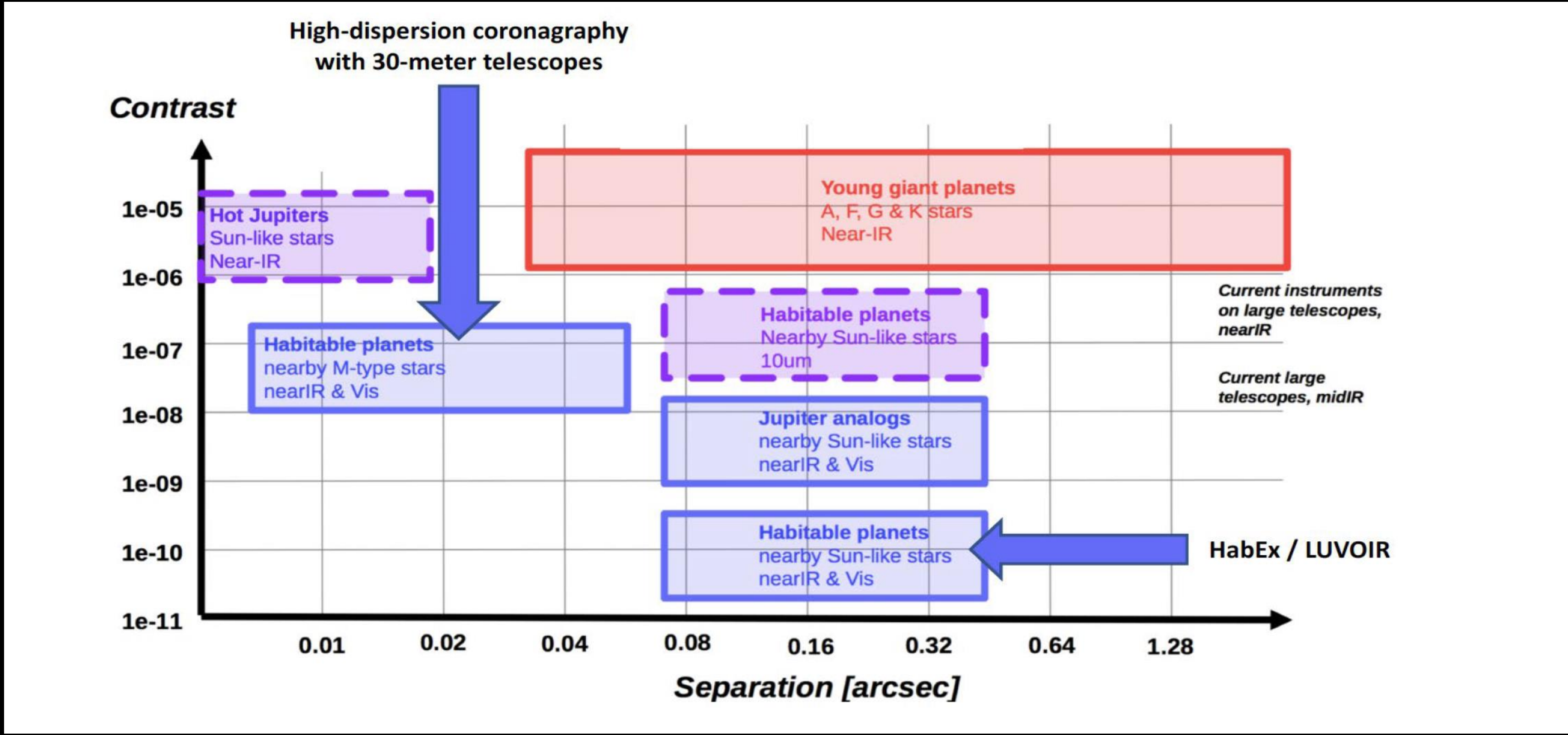


ANDES Overview

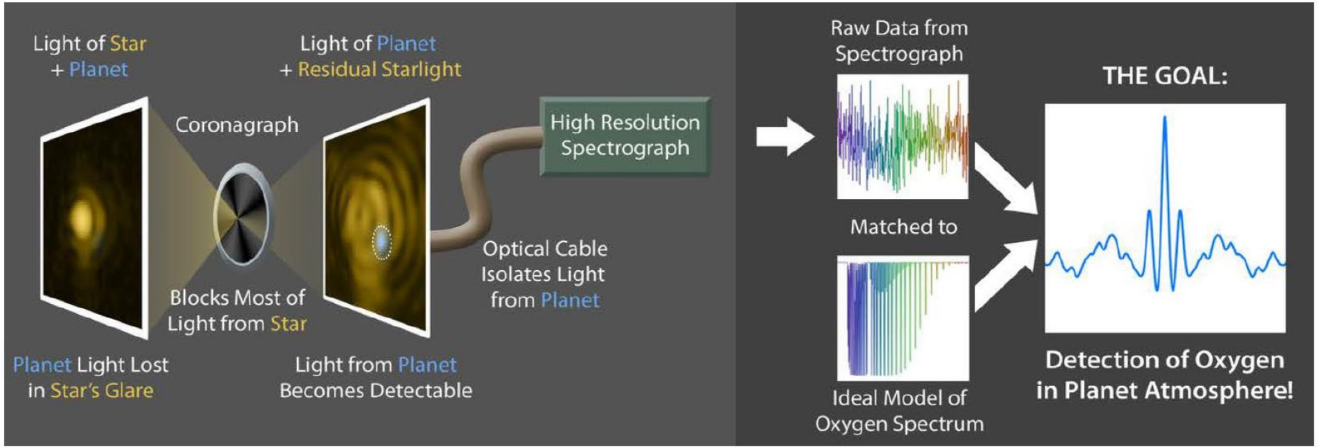
- ANDES: *ArmazoNes high Dispersion Echelle Spectrograph*
- Simultaneous wavelength coverage: 0.4-1.8 (2.4 um goal)
- Spectral resolution: 100K
- Fiber-fed
- No moving parts
- IFU capabilities
- Seeing-limited + AO mode (YJH)
- Strong heritage from HARPS, ESPRESSO & NIRPS

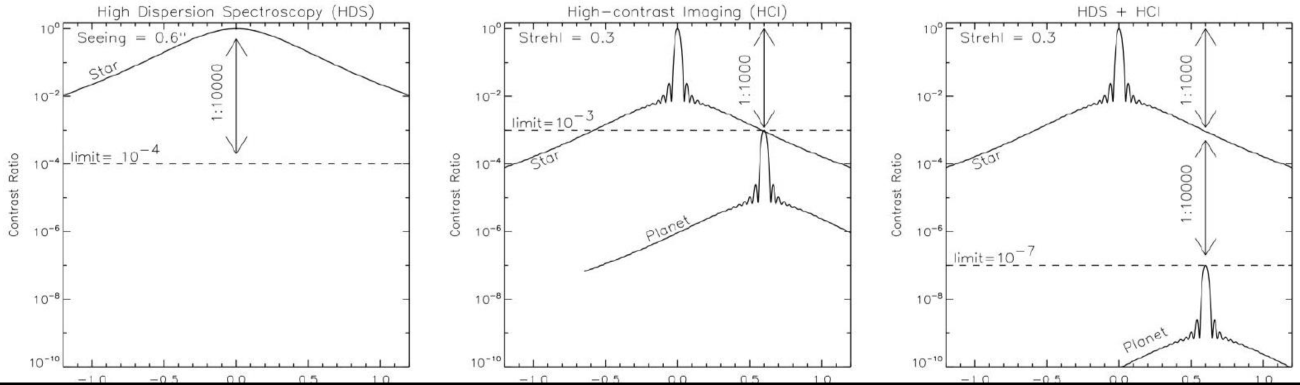


Shortcut to study Habitable Exoplanets on Giant Telescopes



Exoplanet Atmosphere Detection through High-Contrast Imaging and High-Dispersion Spectroscopy





Biosignature Detection with ANDES
Proxima b test case

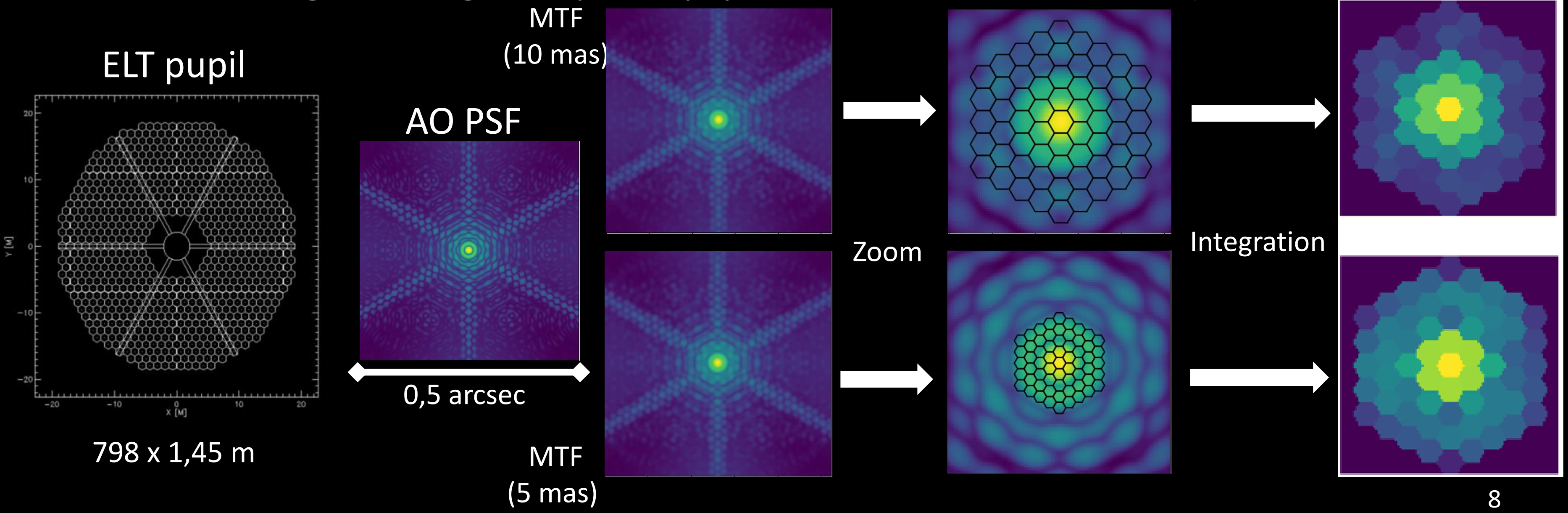
Exposition time needed to detect an atmosphere

- t: Exposition time
- *SNR:* Signal-to-noise ratio
- *R:* Resolving power
- C_p: Exoplanet contrast
- F_ν: Stellar flux density
- *A*: Collecting Area
- *K:* Contrast gain with AO
- N_{lines}: Number of spectral lines in a given band

$$t = \left(\frac{SNR}{C_p}\right)^2 \frac{Rh}{F_\nu A K N_{lines} \tau}$$

From Pupil to IFU

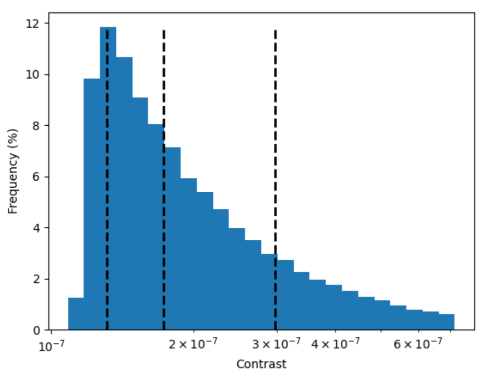
- PSFs calculated using PAOLA package for IDL, using ELT Pupil
- PSFs convolved with the instrument’s MTF (hexagonal spaxels 5 or 10 mas side-to-side)
- The signal is integrated spaxel-by-spaxel for two different IFU sizes (5 & 10 mas)

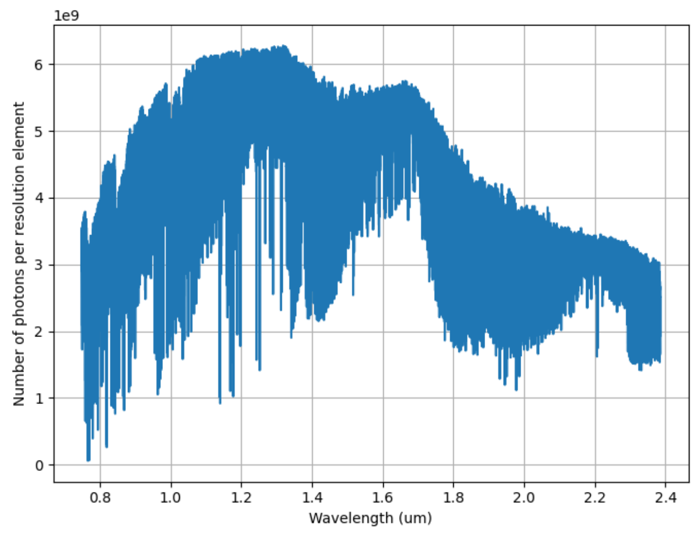


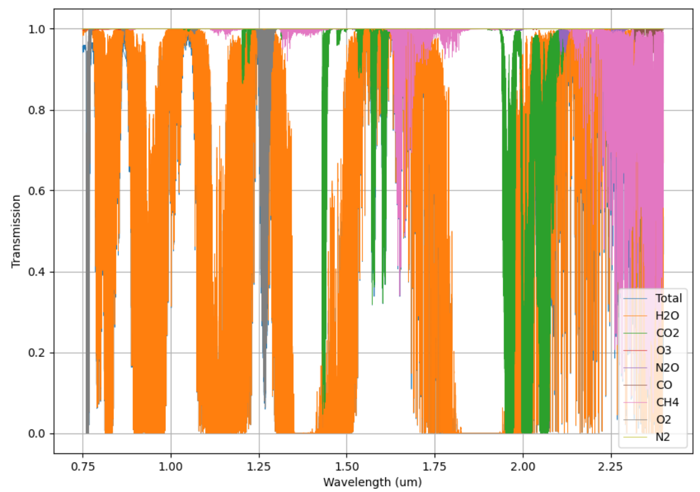
Target: Proxima b

- Bright M dwarf (I=7.4; J=5.3)
- Closest exoplanet (1.3 parsecs)
- Semi-major axis: 0.0485 AU, within the habitable zone
- Orbital period: 11.2 days
- $M \sim 1.3\ M_{\oplus};\ R \sim 1.1\ R_{\oplus}$
- Planet contrast: $\mathbf{1,31^{+1,6}_{-0,1} \times 10^{-7}}$
- Star spectrum: PHOENIX database(T=3000 K, log(g) = 5,0)
- Earth-like atmosphere: NASA planetary spectrum generator

$$cr = A_b \left(\frac{R_{pl}}{d_{pl}}\right)^2 P(\alpha)$$







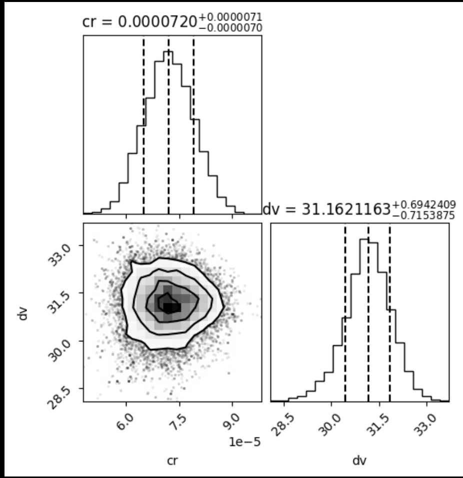
Spectral detection methodology

- First step is to construct a reference spectrum from all spaxels.
- Exoplanet spectrum extracted through Monte Carlo Markov Chain (MCMC): Maximize Bayesian Likelihood
- Two parameters: contrast cr and radial velocity dv.
- Corner plots generated show the most likely parameters
- Example here: detection of a full Earth-like spectrum

$$\ln(\mathcal{L}) = -\sum_{\lambda}\left(\ln(2\pi(\sigma_f)^2) + \frac{(m(cr,dv)-d)^2}{2(\sigma_f)^2}\right)$$

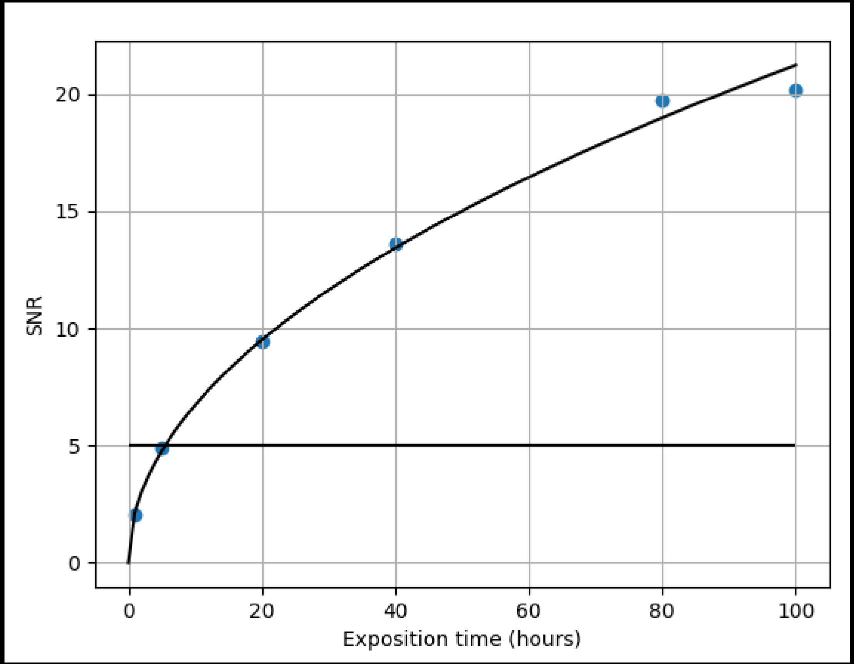
$$\sigma_f = \sqrt{(\sigma_m)^2 + (\sigma_d)^2}$$

Earth-like spectrum (H_2O dominated) recovered in 20 hours (SNR = 9.5)

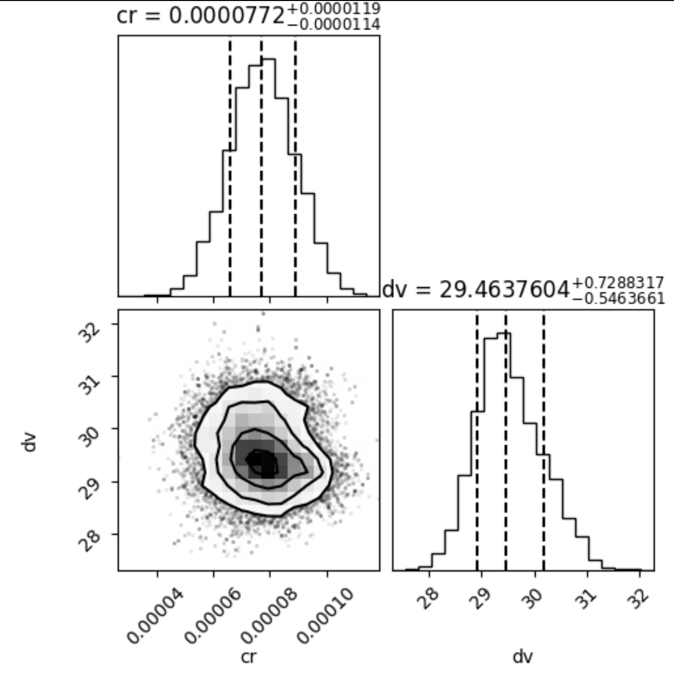


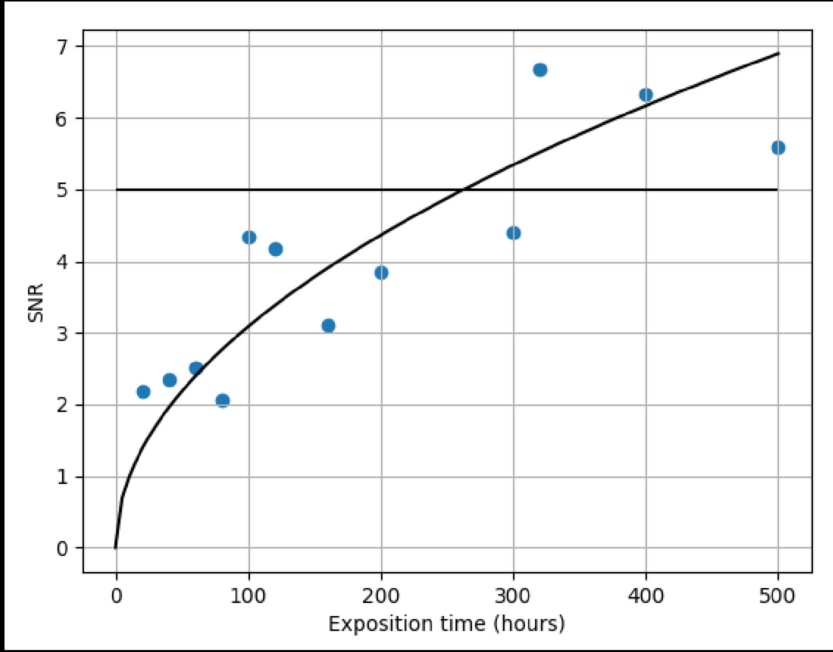
SNR and exposition time – Full spectrum (H_2O dominated)

- In a photon-noise limited regime, one expects SNR $\propto \sqrt{t}$
- By running the simulations at different exposition times, one can calculate the time needed to reach a SNR of 5
- 6 hours is needed to detect the atmosphere



O_2 Detection (250-300 hrs @ SNR=5)





SNR @ 320 hours: 6.7

Takeaways

- ANDES will be able to detect and study an atmosphere on Proxima b (reflection spectroscopy)
- Full AO+HDS simulations improve on past work (Snellen et al. (2015), Hawker & Parry (2019))
- Earth-like atmosphere: <10 hours
- O_2: ~250-300 hours