Characterizing exoplanetary atmospheres with a mid-infrared nulling spectrograph

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Overview

The discovery of an increasing number of terrestrial planets around nearby stars marks the dawn of a new era in the exoplanet field: the characterization and understanding of their atmospheres. To make significant progress, it becomes clear that a large number of exoplanetary atmospheres have to be studied at various wavelengths. This is particularly relevant for identifying possible bio-signatures. In this poster, we present a concept of a space-based mid-infrared nulling spectrograph **that can characterize a large number of exoplanetary atmospheres** and provide key information **on their size, surface temperature, and the presence of key molecules such as CO_2, H_2O, CH_4 and O_3.** The proposed mission concept would be particularly suited to characterize Proxima Cen b.

Why the mid-infrared regime?

- Favorable planet/star contrast (10^{-7} vs 10^{-10} in the visible, see Fig. 1);

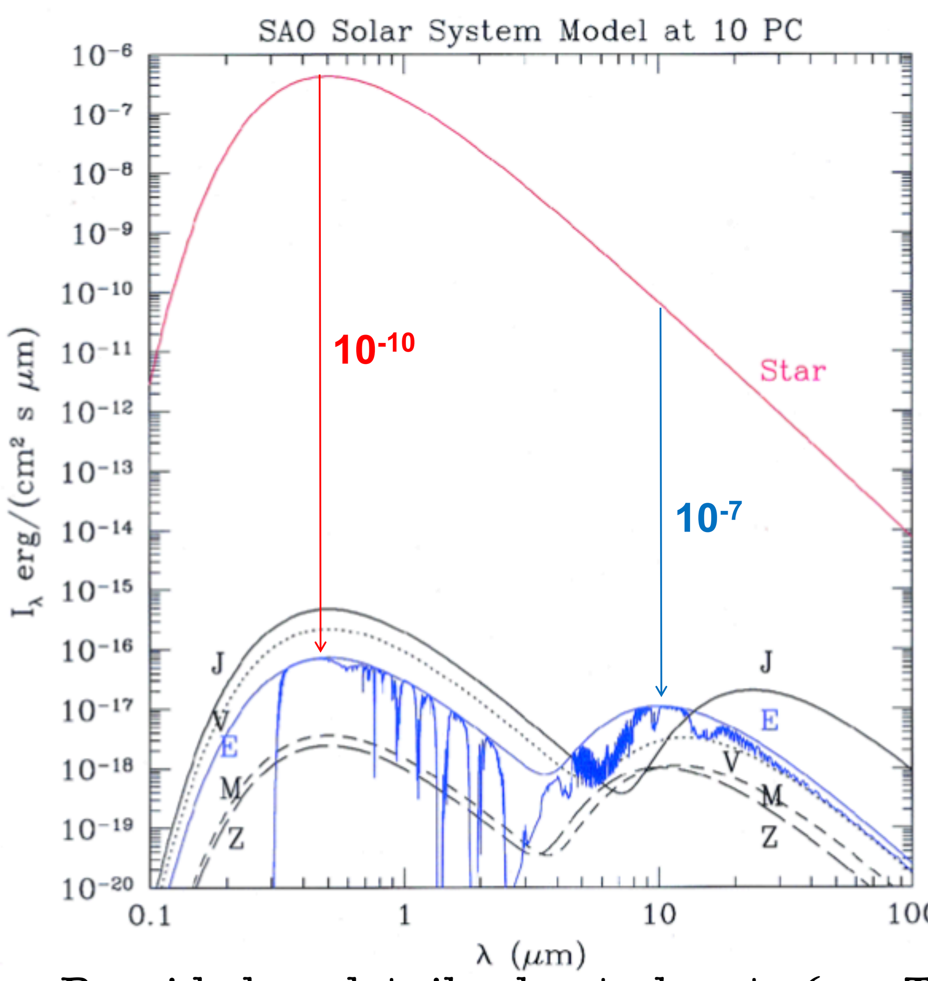


Fig.1: Model spectrum of the sun and planets as seen from a distance comparable to that of a nearby star (10 pc), shown in physical units. Simple blackbody Planck emission and wavelength-independent albedo reflectance components are shown. For Earth, a pure molecular absorption spectrum is superimposed for reference.

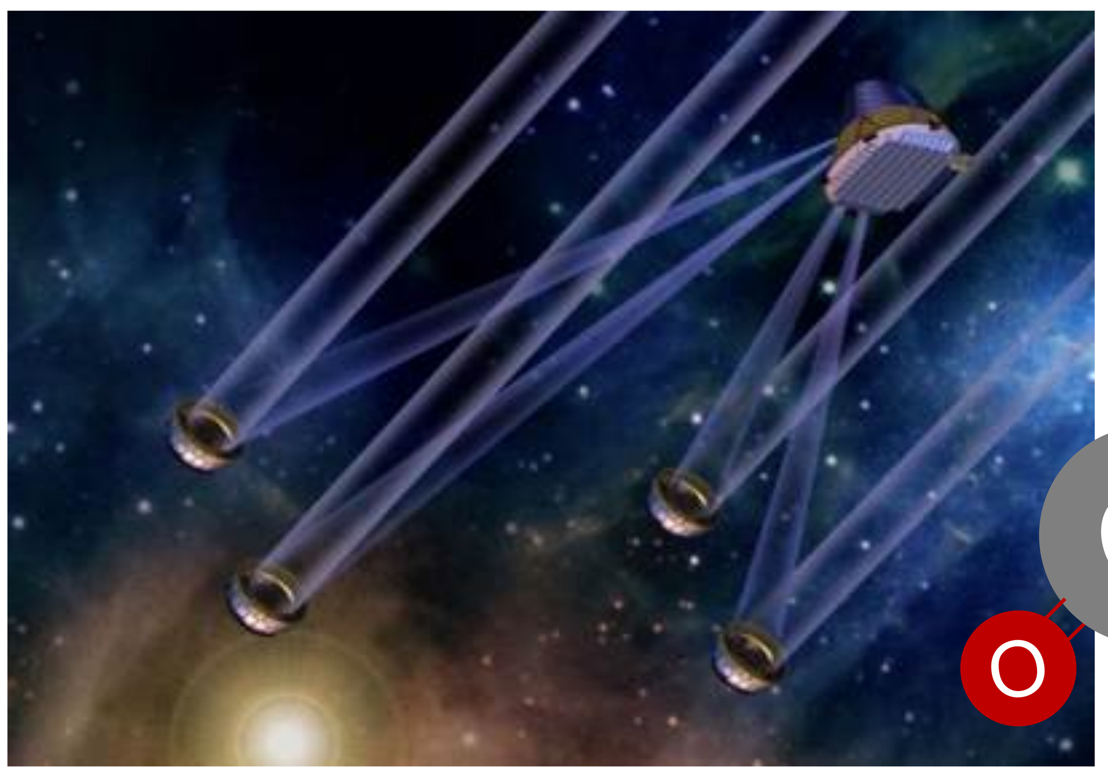
- Provide key details about planets (see Table below, R = required spectral resolution):

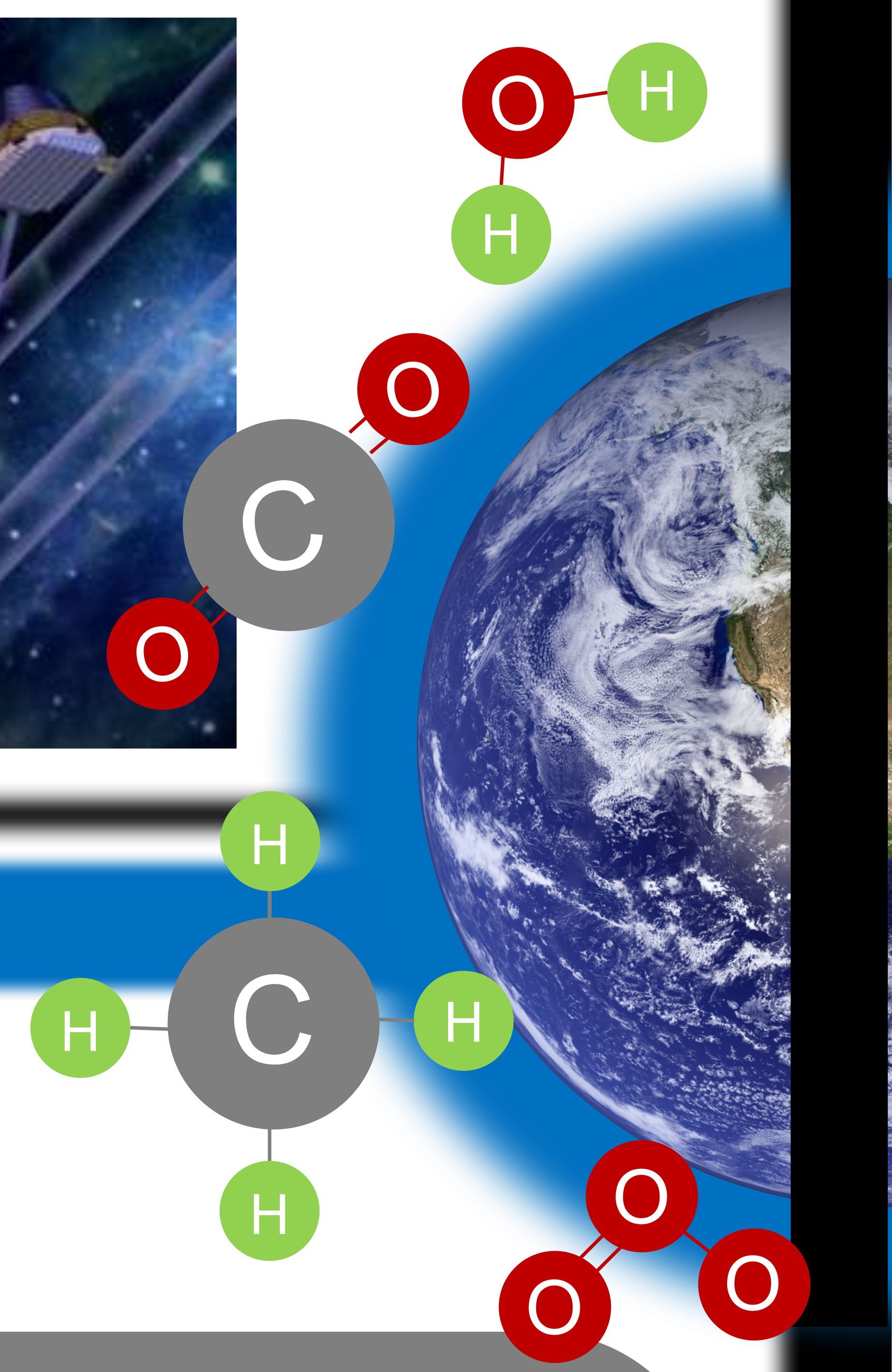
	Information on planet	Species	λ_{MIN} [μm]	λ_{MAX} [μm]	λ_{AVG} [μm]	R
1	Orbit characteristics	Cont. 1	6.00	20.0	13.0	1
2	Combination of temperature,	Cont. 2	10.1	12.4	11.2	5
	radius, and albedo	Cont. 3	8.16	9.24	8.67	8
3	Existence of atmosphere	Cont. 1	6.00	20.0	13.0	1
		CO_2	9.07	9.56	9.31	19
			10.1	10.7	10.4	16
			13.3	17.0	15.0	4
4	Presence of water	H_2O	6.67	7.37	7.00	10
			17.4	25.0	20.5	3
5	Suggestion of life	CH_4	7.37	7.96	7.65	13
			7.37	8.70	7.98	6
		O_3	9.37	9.95	9.65	17

Why a nulling interferometer?

1. Can observe non transiting exo-planets and build up S/N more quickly.
2. Extremely good inner working angle (a few mas).
3. No need to launch very large apertures (i.e., >20m, required to observe the HZ of nearby main-sequence stars at 10 μm).
4. Stellar photon noise mitigated by nulling interferometry.
5. Can be used in constructive mode for general astrophysics programs

Fig. 2: Artist impression of the Darwin/TPF space interferometer in its "Emma X-array'" baseline configuration. It consists of four free-flying telescopes and a beam combiner spacecraft, deployed and observing at the Sun-Earth Lagrange point L2. The array configuration can be tuned to observe very compact systems around nearby M-type stars (e.g., Proxima Cen b).





OBSERVING PROXIMA CEN B

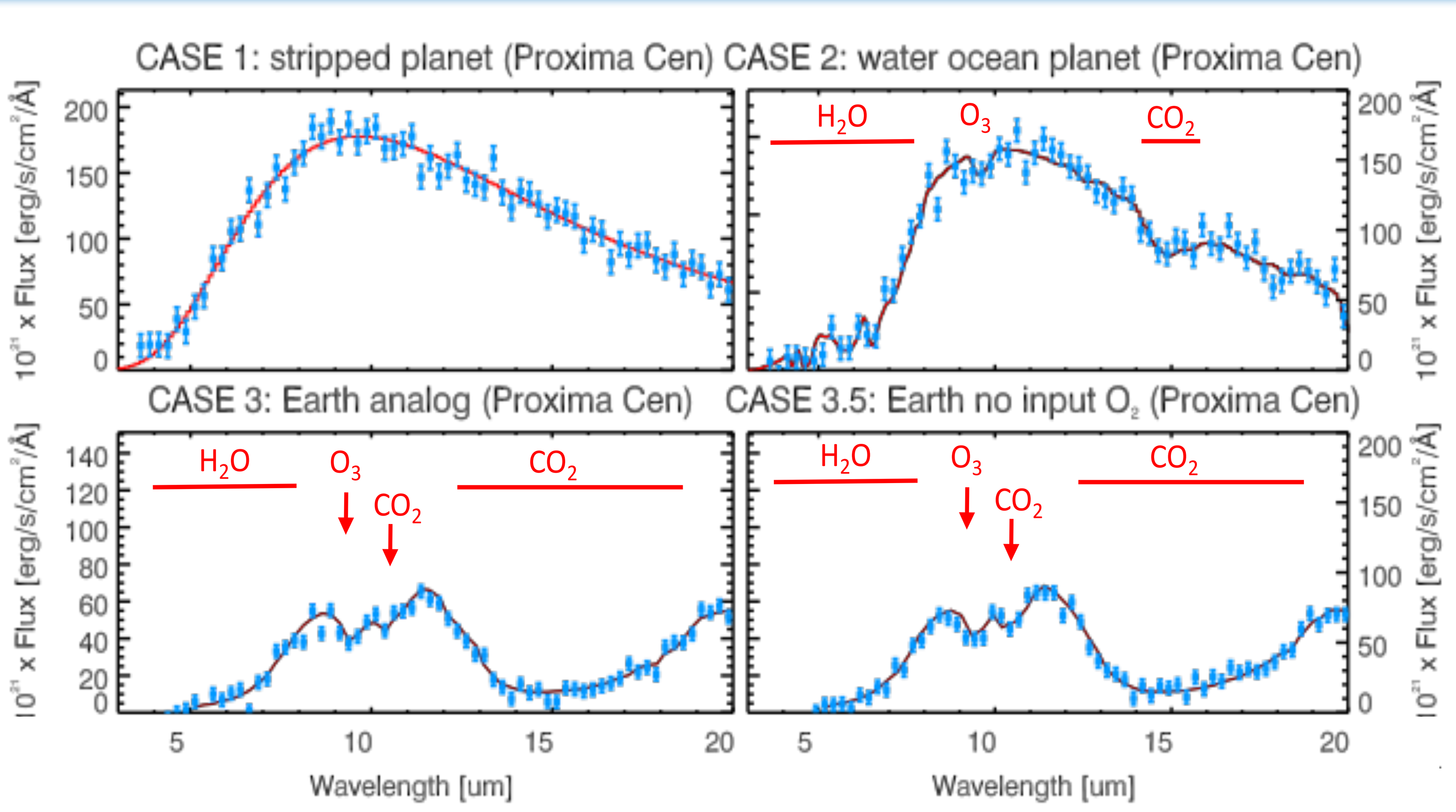


Fig. 3: Simulated mid-infrared spectra of planets with various atmospheric properties that can be studied by remote sensing (red line). The synthetic spectra are computed by coupled climate chemistry models (Rauer et al. 2011 and Tian et al. 2014) for Proxima Cen b. Overplotted in blue are simulated observations (R=40), imposing a S/N of 20 on continuum detection at 10 μm. Besides O_3 in the atmosphere of the water ocean planet around Proxima Cen (Case 2), all spectral features can be retrieved in a single visit with these requirements (R=40 and S/N=20). Detecting O_3 in Case 2 would require a higher S/N or follow-up observations.

EXOPLANETARY ATMOSPHERE YIELD IN 3-YEAR

Configuration	Tel. diameter	Pl. radius	M	K	G	F	Total
Emma X-array (4T)	0.75 m	1.0 $R_\oplus$	8	3	1	0	12
		1.5 $R_\oplus$	18	6	2	1	27
	2.0 m	1.0 $R_\oplus$	16	8	6	2	32
		1.5 $R_\oplus$	40	16	12	3	71

Table 2: Number of rocky planet atmospheres that can be studied over a 3-year mission by an Emma X-array nulling interferometer (four apertures), assuming that each nearby main-sequence star has a HZ exoplanet (with an equilibrium temperature of 300K and imposing a S/N of 20 with a spectral resolution of 40). Additional mission lifetime could be spent on follow up observations to study in more details the most interesting planets and/or a detection phase if the planets are not known in advance. Note that a Bracewell configuration (two apertures) is another possible option for a mission focused on M and K stars.