PROXIMA CENTAURI B: ENVIRONMENTAL STATES AND OBSERVATIONAL DISCRIMINANTS.

V. S. Meadows[1,2], G. N. Arney[1,2,3], E. W. Schwieterman[1,2,4], J. Lustig-Yaeger[1,2], A. P. Lincowski[1,2], T. D. Robinson[2,5], S. D. Domagal-Goldman[2,3], R. K. Barnes[1,2], D. P. Fleming[1,2], R. Deitrick[1,2], R. Luger[1,2], P. E. Driscoll[2,6], T. R. Quinn[1,2] and D. Crisp[2,7], [1]University of Washington (vsm@astro.washington.edu), [2]NASA Astrobiology - Institute Virtual Planetary Laboratory, [3]NASA Goddard Space Flight Center, [4] NASA Astrobiology Institute Postdoctoral Fellow at the University of California – Riverside, [5]NASA Sagan Postdoctoral Fellow at the University of California – Santa Cruz, [6]Carnegie Institution for Science, Washington, [7]Jet Propulsion Laboratory/California Institute of Technology.

Introduction: The recent discovery of Proxima Centauri b, a $1.3M_{Earth}$ minimum mass planet in the habitable zone of the Sun's nearest stellar neighbor [1] provides an unprecedented opportunity to understand the evolution and nature of terrestrial planets orbiting late-type M dwarfs. M dwarfs are the most common type of star in the Galaxy, and likely harbor the majority of habitable zone terrestrial planets. However, M dwarfs undergo significant luminosity evolution when young, and may trigger ocean loss and generate massive O_2 atmospheres [2] for planets that form in what will become the main sequence habitable zone. These planets may also form with dense H_2 atmospheres [3] or migrate in from further out in the planetary system [4] Consequently, although Proxima Cen b currently orbits within its star's habitable zone, there are multiple plausible evolutionary paths that could have generated different planetary environments [3].

Methods: To explore some of the possible current environmental states of Proxima Centauri b, and to determine if they are habitable, we used 1D coupled climate-photochemical models to generate self-consistent atmospheres for several evolutionary scenarios. These included high-O_2, high-CO_2, and more Earth-like atmospheres, with either oxidizing or reducing compositions (Table 1). We then used radiative transfer models to generate synthetic spectra and thermal phase curves for these simulated environments, and instrument models to identify observations that could discriminate between possible planetary states.

Results: We find that these modeled environments can be habitable or uninhabitable at Proxima Cen b's position in the habitable zone (Table 1). In some of the uninhabitable cases a habitable surface temperature is obtained, but the planet is desiccated. These results are applicable not only to Proxima Cen b, but to other terrestrial planets orbiting M dwarfs. We show that thermal phase curves may provide the first constraint on the existence of an atmosphere, and JWST observations longward of 7 μm could characterize atmospheric heat transport and molecular composition. Detection of ocean glint is unlikely with JWST, but may be observable with 10m-class, or larger, telescopes. Direct imaging spectra can potentially probe the volatile-rich lower atmosphere and surface, and may detect O_4 absorption, a diagnostic of massive water loss and O_2 retention – rather than a photosynthetic biosphere. Similarly, space and ground-based observations of strong CO_2 and CO bands at wavelengths shortward of 2.5μm would indicate a CO_2-dominated atmosphere. If Proxima Centauri b is terrestrial, a microbial biosphere could be sought by looking for CH_4 in conjunction with either photosynthetically produced O_2 or a hydrocarbon haze, and by searching for and excluding signs of possible abiotic planetary processes that could mimic the impact of a biosphere.

References: [1] Anglada-Escudé et al. (2016) *Nature*, *536(7617)*, 437-440. [2] Luger & Barnes (2015) *Astrobiology 15*, 119-43. [3] Barnes et al., (2016), arXiv:1608.06919. [4] Luger et al. (2015) *Astrobiology*, *15(1)*, 57-88. [5] Meadows et al. (2016) arXiv: 1608.08620.

Case	Tsurf	H_2O?	Notes	Hab?
N_2/O_2-rich, Modern Earth-like, 1 bar, H_2O cloud.	283K	✔	5% CO_2, self-consistent w/ star, HEC or orbital evolution	✔
$N_2/CO_2/CH_4$ Archean Earth-like, haze,1 bar	289K 285K	✔	5% CO_2, 1% CH_4 - 3% CH_4 for haze, HEC or orbital evolution	✔
O_2-rich, H_2O-remains, 10 bar	320K	✔	0.5% CO_2, incomplete ocean loss. O_2 may hamper life's origin	✔?
$CO_2/CO/O_2$, no-H_2O 1 bar	298K	✗	Stable mix if H < 1ppm. CO_2 recombination if H_2O/ catalysts.	✗
O_2-rich, H_2O lost 10 bar	257K	✗	0.5% CO_2, ocean loss, some O_2 sequestration	✗
O_2/CO_2-rich, H_2O lost 10 and 90 bar	342K 383K	✗	Ocean loss, outgassing of CO_2, some O_2 sequestration	✗
CO_2-rich,20 ppm H_2O 10 and 90 bar	428K 567K	✗	Ocean loss, outgassed CO_2, all O_2 sequestered, Venus-like	✗

Table 1: Coupled climate-photochemical model results for several evolutionary scenarios and resulting atmospheric compositions for Proxima Centauri b [5]. Even though Proxima Cen b orbits in the habitable zone of its parent star, it may or may not be habitable, depending on the planetary end state of different formation and evolution scenarios.