White Dwarf Exoplanets: 3-D Chemistry-Climate Modeling in Synchronous Rapid Rotation Regime

C. T. Whyte[1], H. Chen[1], L. H. Quiroga-Nuñez[1]
[1] Florida Institute of Technology, Melbourne, FL, USA

Habitable Zone

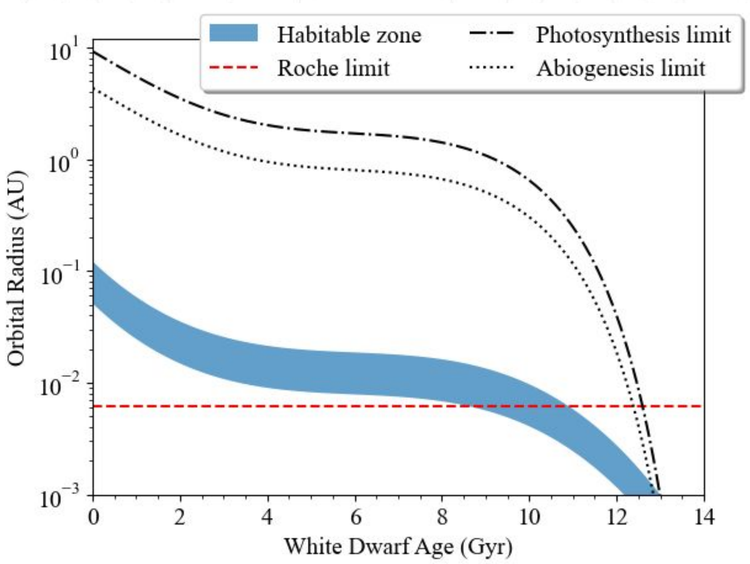
- A time-varying habitable zone (HZ) is found based on a typical white dwarf cooling function.

$$a_{WD} = \frac{64818}{T_p^2} \times \left(\frac{L_{WD}}{L_\odot}\right)^{1/2},$$

Here the relationship between orbital radius (a_{WD} [AU]) and the planet's effective temperature (T_p [K]) is used to model the inner and outer edges of the HZ as the white dwarf's luminosity (L_{WD} [$L_\odot$]) decreases (Whyte et al. 2024).

- A planet with a constant orbital radius of ~0.012 AU can remain habitable for at least 7 Gyr.
- This is the constant circular orbit corresponding to the maximum habitable lifetime (HL) of the planet.

PAR and UV-C Flux



Plot from Figure 3 of Whyte et al. 2024 shows the impact of white dwarf cooling on the habitable zone and biologically relevant photon fluxes for the formation and maintenance of life.

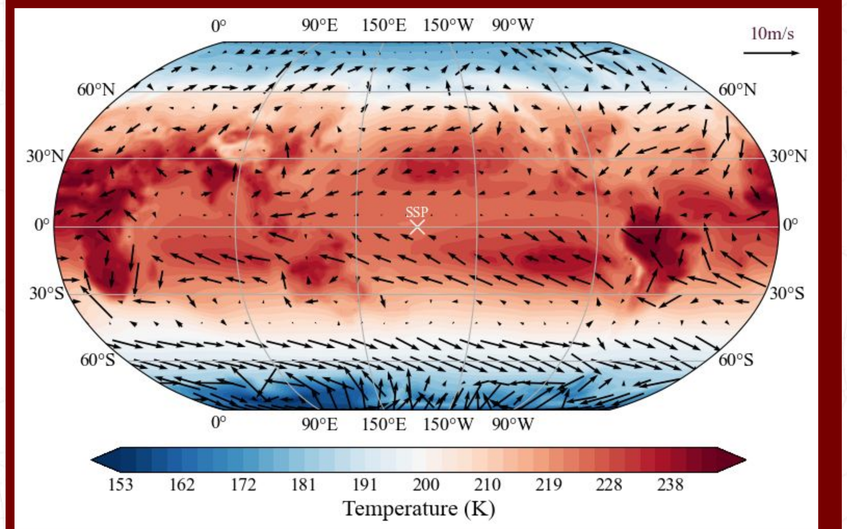
- Range of 400-750 nm corresponds to the photosynthetically active region (PAR), and 200-280 nm corresponds to the UV region used to drive prebiotic chemical reactions (Lingam & Loeb, 2021).
- Any orbit within the HZ will also receive a high enough PAR and UV-C flux to support abiogenesis and photosynthetic life throughout its habitable lifetime.
  - The critical photon fluxes for PAR and UV-C are 1.2×10^{16} m^{-2} s^{-1} and 5.44×10^{16} m^{-2} s^{-1} respectively (Lingam & Loeb, 2021).
- Overlap of PAR zone, abiogenesis zone, and HZ is very promising, and only seen for stars with an effective temperature greater than ~4500 K (Lingam & Loeb, 2021).

Climate Model Configuration

In order to better constrain the HZ and estimate surface conditions, WACCM6 (a component of CESM2) is being used to simulate the atmospheric chemistry and climate dynamics of an Earth-like planet orbiting a typical white dwarf.

- Habitable orbit requires a period of about 15 hours with tidal forces quickly leading to synchronization
- Unique rotation regime will impact the planet's habitability and the observed spectral features

5000 K White Dwarf WACCM Model



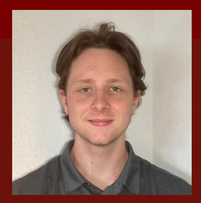
Plot of surface temperature and surface winds reveals the signature atmospheric dynamics of bat rotation (Zhan et al, 2024). Model run for 130 years with stellar irradiation from 5000K white dwarf.

References

Danabasoglu et al., 2020, JAMES, 12, e2019MS001916.
Fujii, et al., 2018, Astrobio., 18, 739–778.
Lingam & Loeb, 2021, *Life in the Cosmos*, HUP.
Whyte et al., 2024, ApJL, 977, L38.
Zhan et al., 2024, ApJ, 971:125, 18pp.

Contact Info

Caldon Whyte
cwhyte2021@my.fit.edu

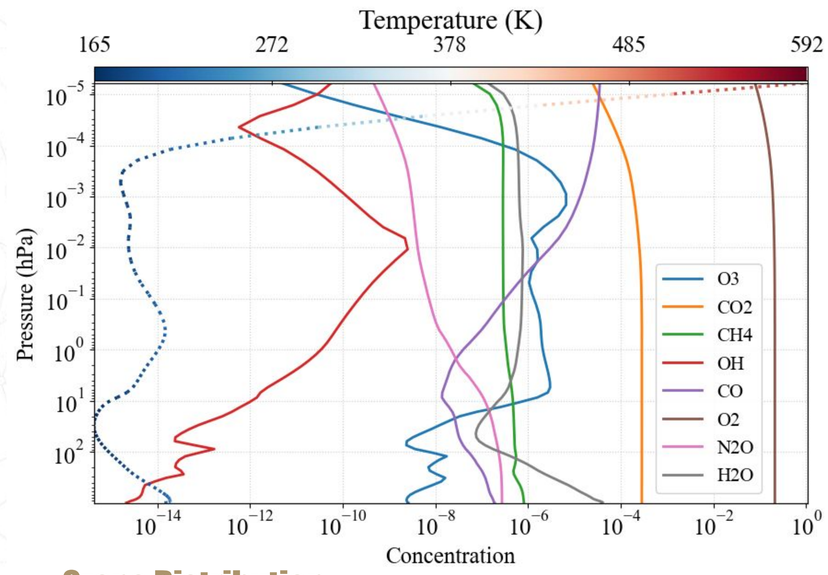


Website:

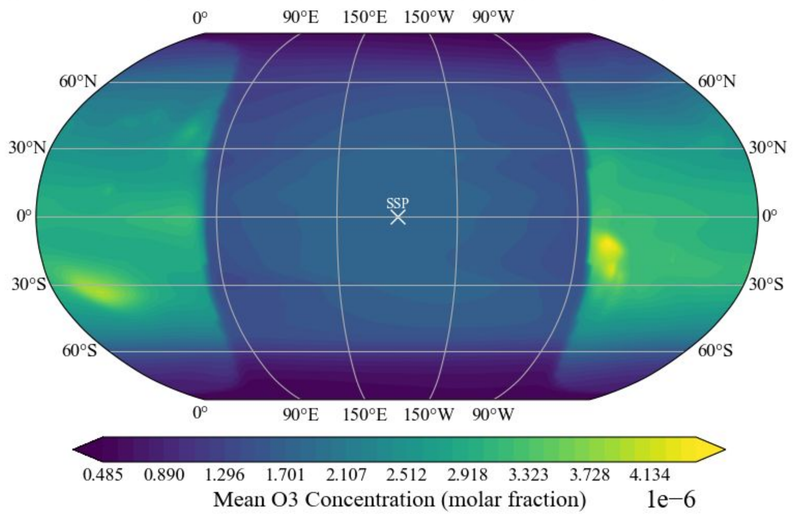
Acknowledgments:

C.W. acknowledges high-performance computing support from the Derecho system (doi:10.5065/qx9a-pg09) provided by the NSF National Center for Atmospheric Research (NCAR), sponsored by the National Science Foundation, and the support from the Ortega Observatory to complete this research.

Vertical Profiles

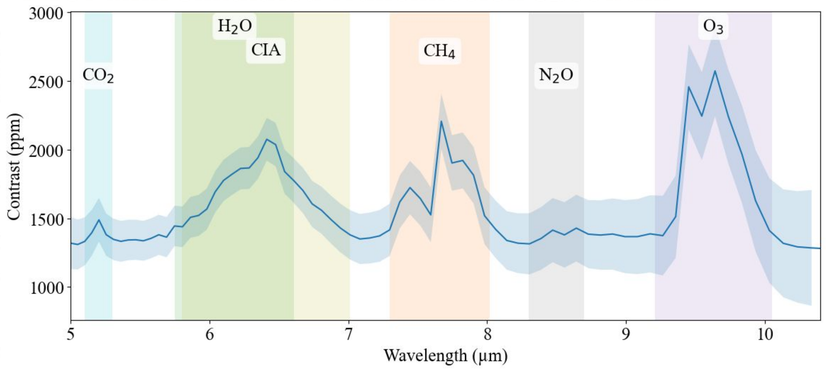


Ozone Distribution



Observational Features

JWST-MIRI Simulated Transmission Spectrum



Transmission spectra generated from NASA's PSG based on WACCM simulation results of 5000K white dwarf.

- Using JWST, it is possible to obtain a signal-to-noise ratio of at least 5 with an integration time of less than one hour (based on the scaling relations from Fuji et al., 2018).