White Dwarf Exoplanets: Habitability & Detection

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Habitable Zone

With improvement in the ability to detect exoplanets and their features, it is important to evaluate the type of planetary system that creates the best environment for life.

Recent observations (e.g., Vanderburg et al. 2020) have confirmed the existence of exoplanets around white dwarfs, leading to an exciting opportunity in the search for life.

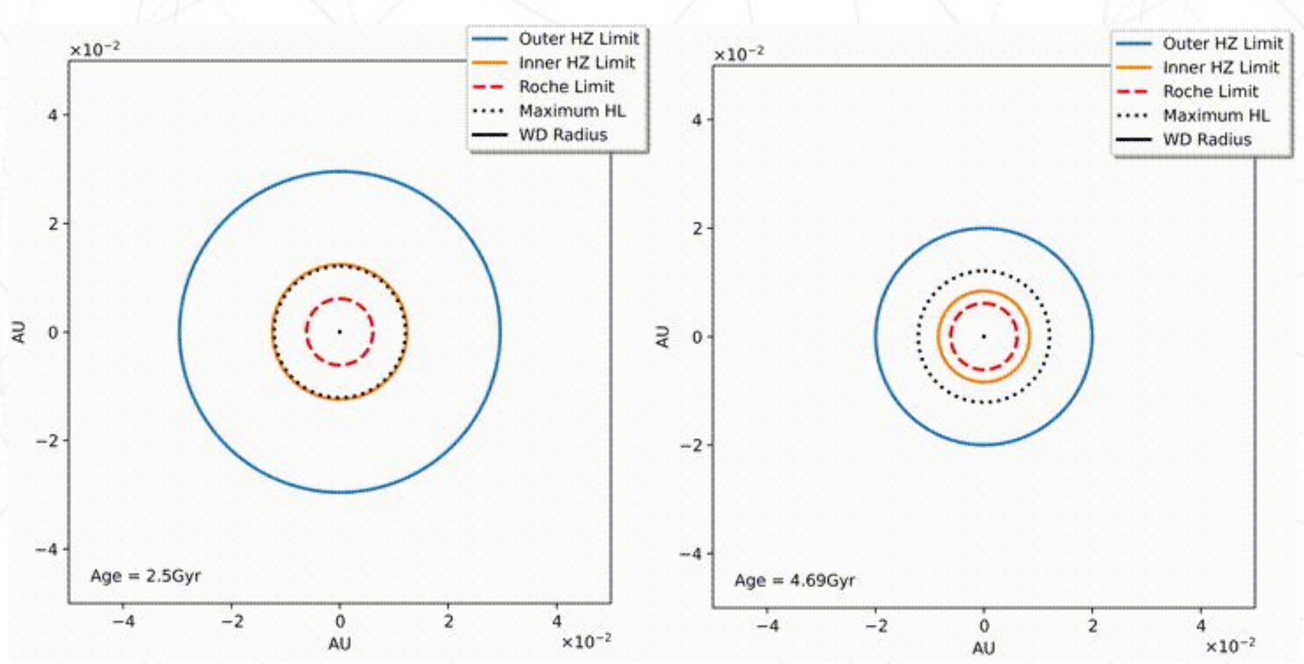
- A time-varying habitable zone (HZ) is found based on a typical white dwarf cooling function.

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

Here the relationship between orbital radius (a_{WD} [AU]) and the planet's effective temperature (T_p [K]) is shown. This 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.

Time-evolving habitable zone



The inward motion of the HZ is shown with the orbital distances of the inner and outer edges decreasing as the white dwarf cools. The figure on the left indicates the time at which the maximum HL orbit first enters the HZ. The figure on the right shows the size of the HZ during the period its size remains most stable.

References

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Lingam & Loeb, 2021, *Life in the Cosmos*, HUP.
Tremblay et al., 2015, ApJ, 809, 148.
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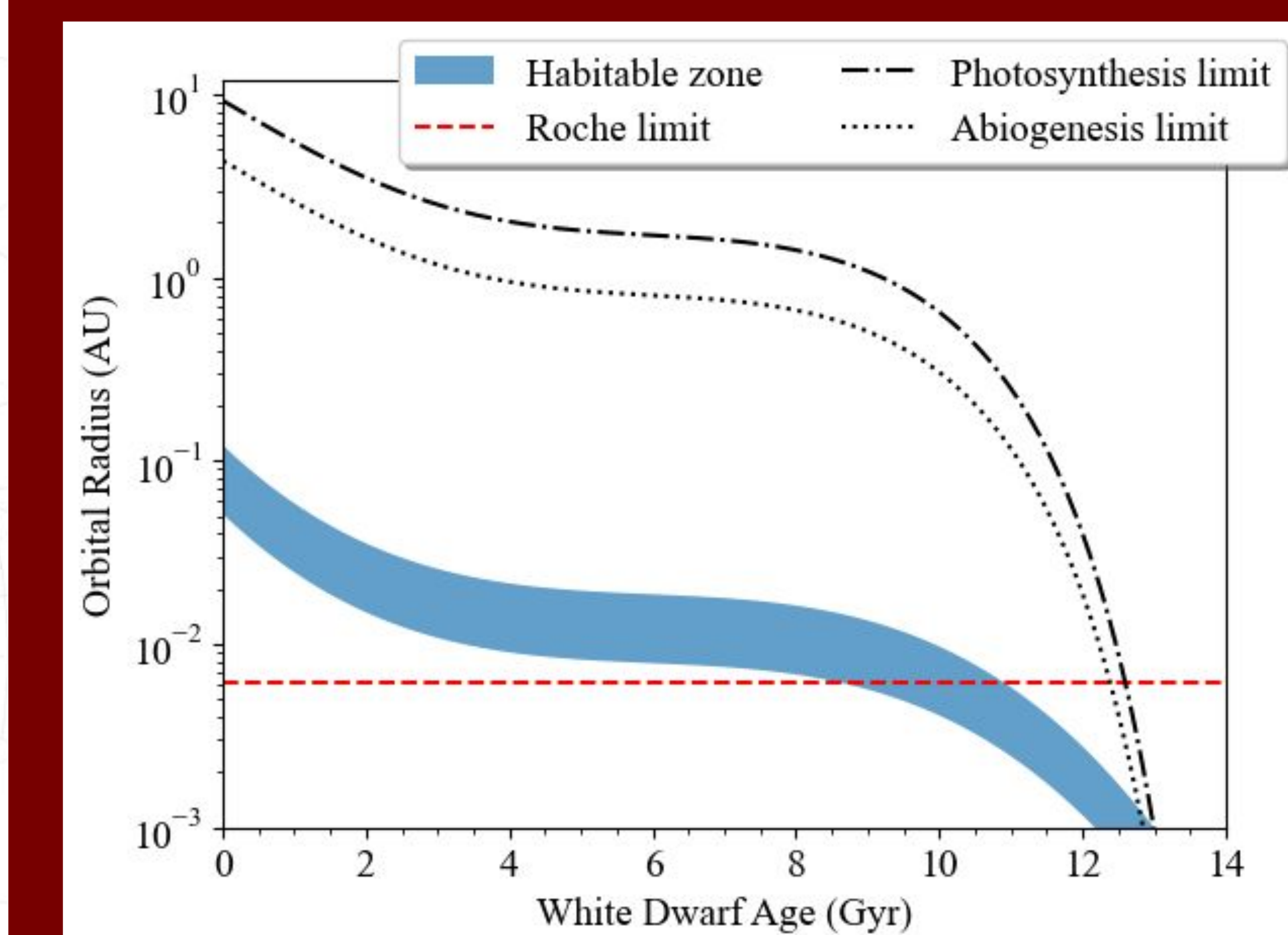
Energy to Support Life

Integrating the blackbody function over a wavelength range of interest can be used to estimate the flux of radiation necessary to create and support 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 the formation and existence of life throughout its habitable lifetime.
- 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).

PAR and UV-C Flux:



The radius at which the flux of photosynthetically active photons and UV radiation reaches their critical flux of 1.2×10^{16} $m^{-2}\,s^{-1}$ and 5.44×10^{16} $m^{-2}\,s^{-1}$ respectively (Lingam & Loeb, 2021). Any orbital distance below this limit will receive the appropriate flux to support photosynthetic life or abiogenesis. Taken from Figure 3 of Whyte et al. 2024.

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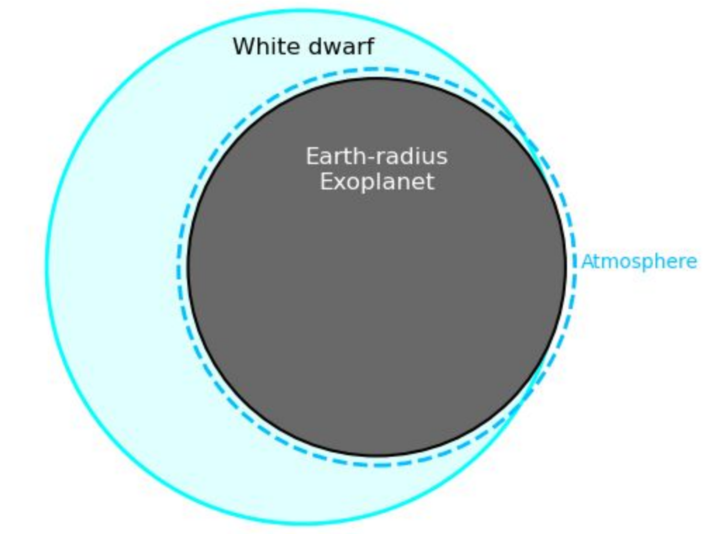
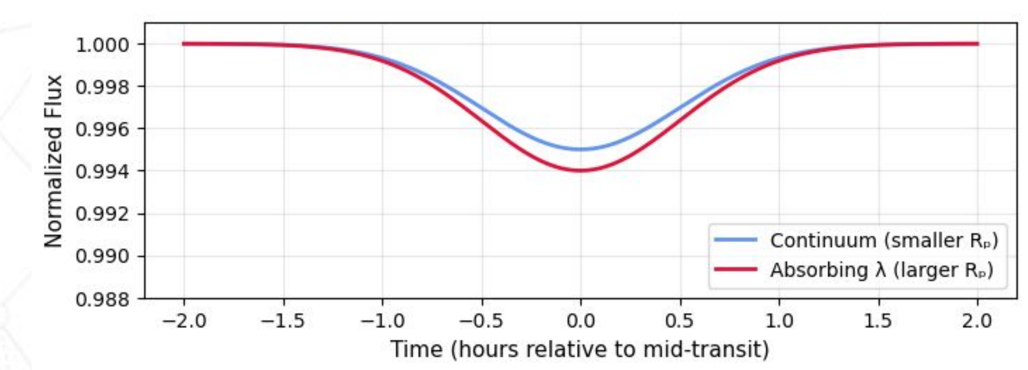
Detection Potential

Once the observation of an Earth-like planet around a white dwarf is made, transmission spectroscopy would be one of the ideal methods to search for biosignatures.

- 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).
- Smaller radius of a white dwarf would make the transit probability lower, it would also allow for more noticeable spectral features.

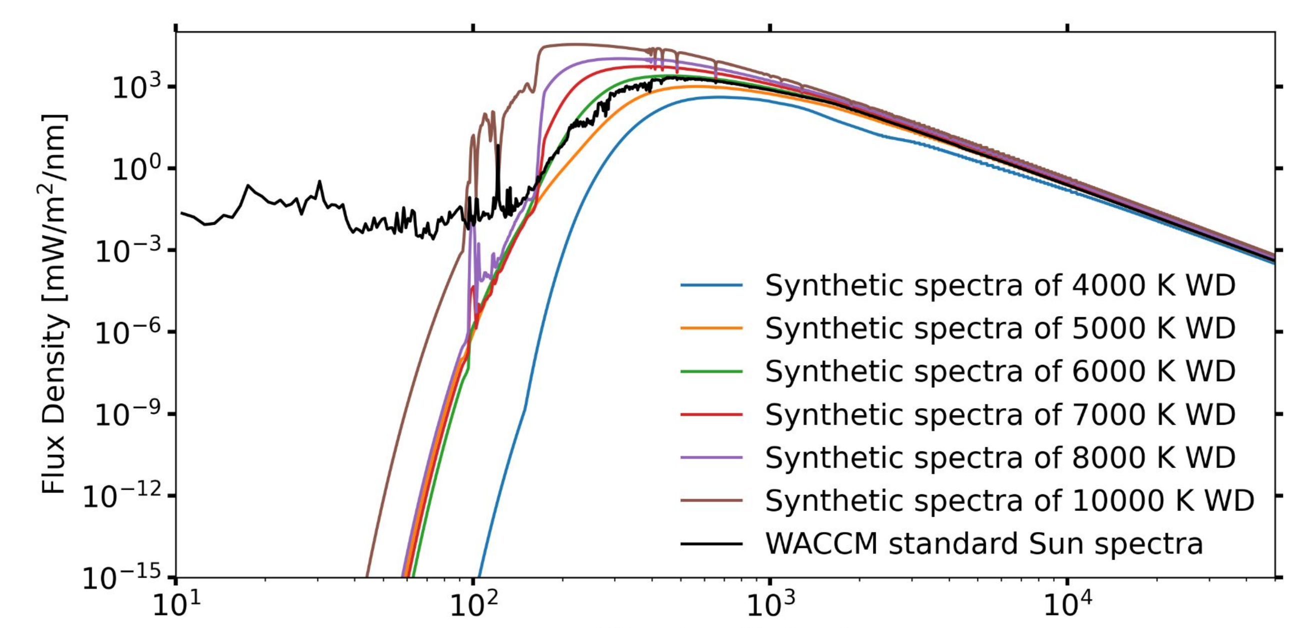




Above figure shows size comparison of a typical 0.6 M white dwarf and an Earth-sized exoplanet, and how transmission spectroscopy could help detect atmospheric signals.

Climate Modeling

Temperature Dependent Stellar Irradiation



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 at different effective temperatures that correspond to the previously studied HZ. The above figure displays the stellar spectra used as input which are based on synthetic 3D pure-hydrogen LTE spectra from Tremblay et al. 2015.