Potential for an Earth-like planet orbiting a white dwarf to host life

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Research question

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. This research looks to determine if white dwarfs could be hosts for habitable Earth-like exoplanets. The following topics are examined to evaluate this.

- The time-varying habitable zone is found based on a typical white dwarf cooling function.
- The flux of biologically relevant stellar radiation is calculated to verify that such a planet in the habitable zone can host life.
- The integration time needed to collect reliable biosignature data using transmission spectroscopy is determined.

Why white dwarfs?

- Stable luminosity on timescales needed to form life
- Expected to be common as a majority of stars will become white dwarfs
- Proven observationally that white dwarfs can host exoplanets (Vanderburg et al. 2020).
- Up to half of white dwarfs show evidence of circumstellar debris accretion (Koestar et al., 2014)
- Relatively small size could make clear detection of atmospheric biosignatures using transmission spectroscopy more likely.

Biosignature detection

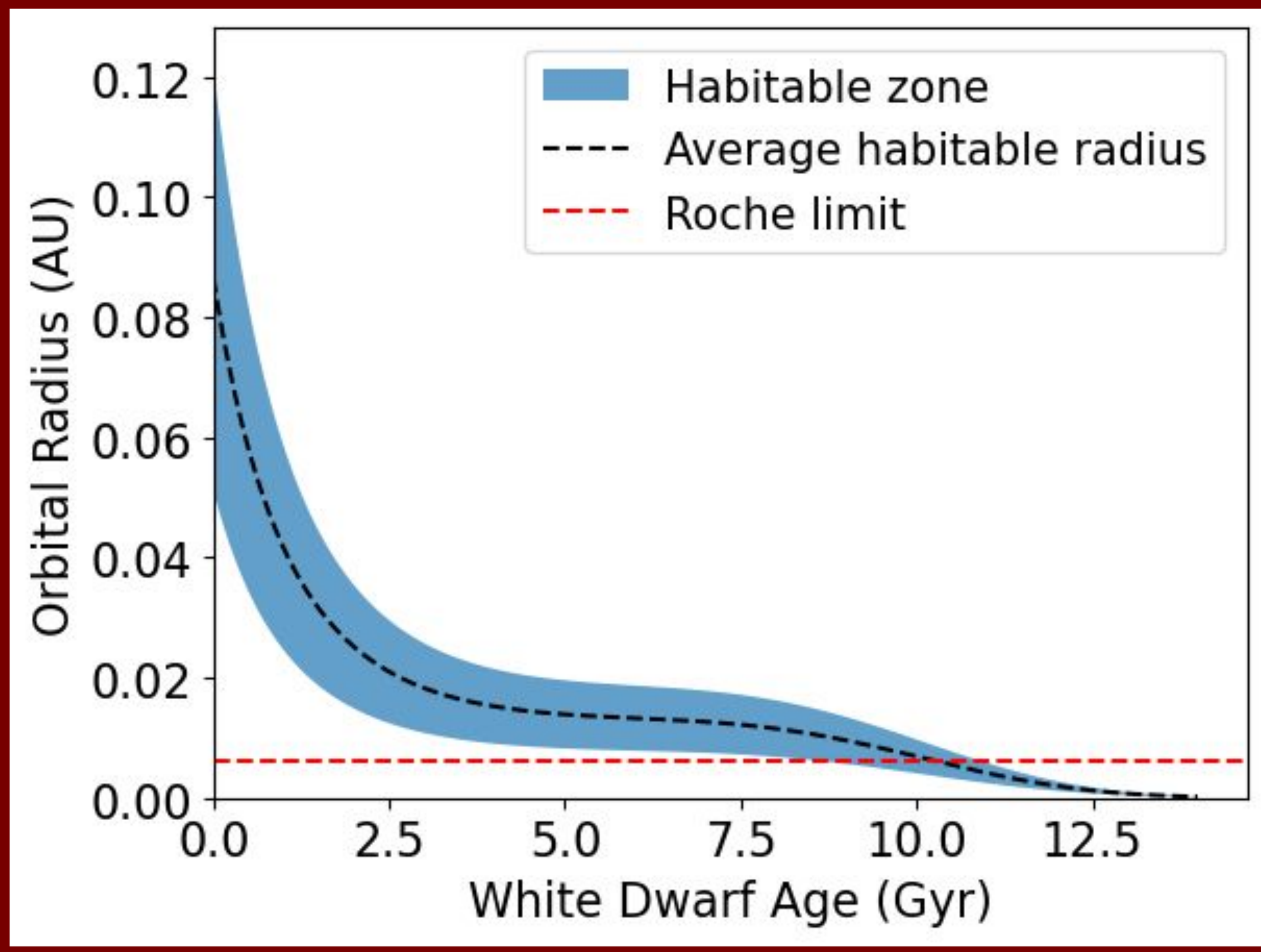
Once the observation of an Earth-like planet around a white dwarf is made, transmission spectroscopy would be one of the ideal methods to search for biosignatures.

- 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.
- Spectroscopy of white dwarf atmosphere could reveal that a once-habitable planet has since been accreted

References

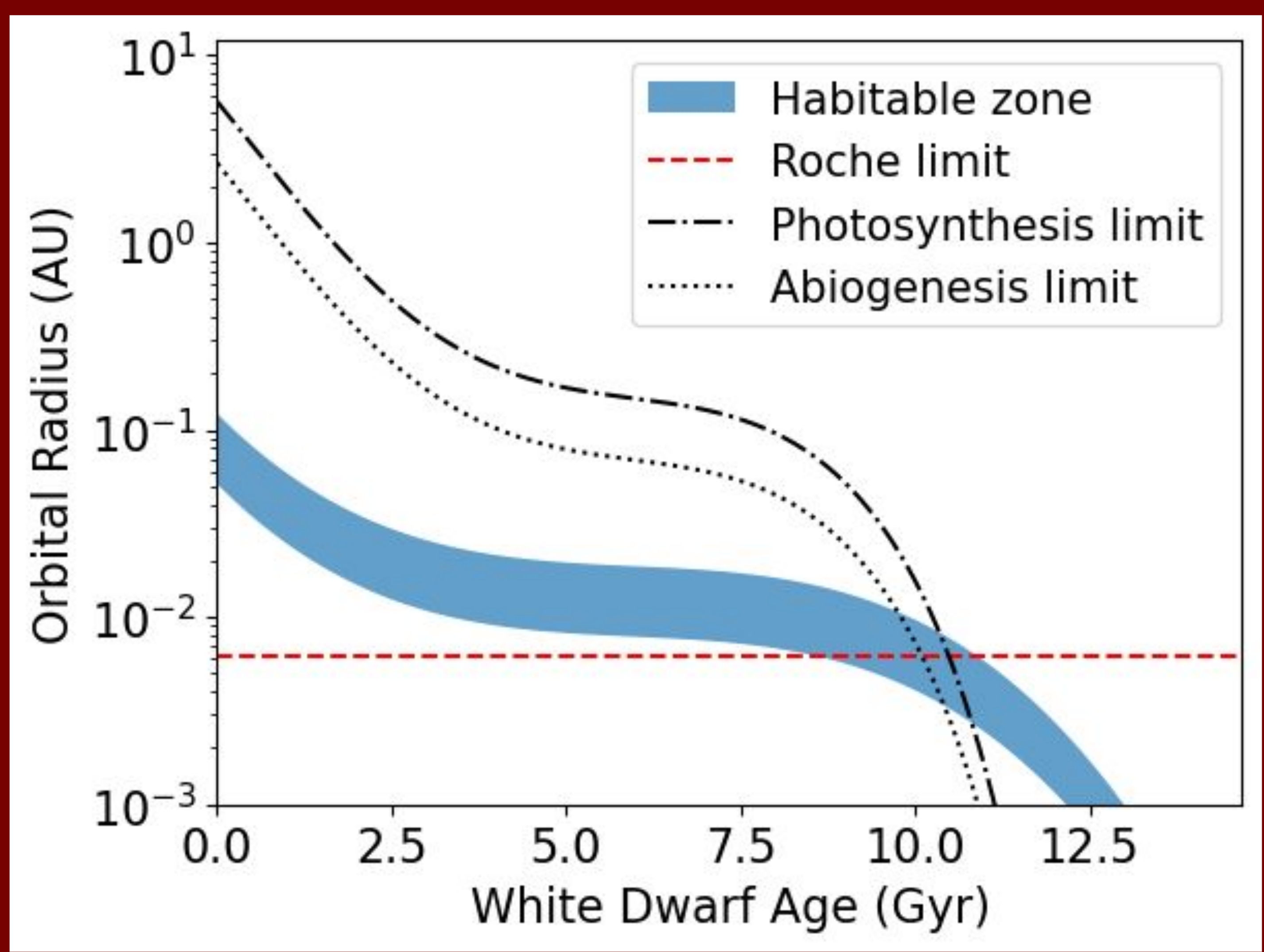
Agol, 2011, ApJL, 731, 31.
Barnes & Heller, 2013, Astrobio., 13, 279–291.
Becker, et al., 2023, ApJL, 945, 24.
Fujii, et al., 2018, Astrobio., 18, 739–778.
Kaltenegger & Sasselov, 2011, ApJL, 736, 25.
Koestar, et al., 2014, A&A, 566, 34.
Lingam & Loeb, 2021, *Life in the Cosmos*, HUP.

Habitable Zone:



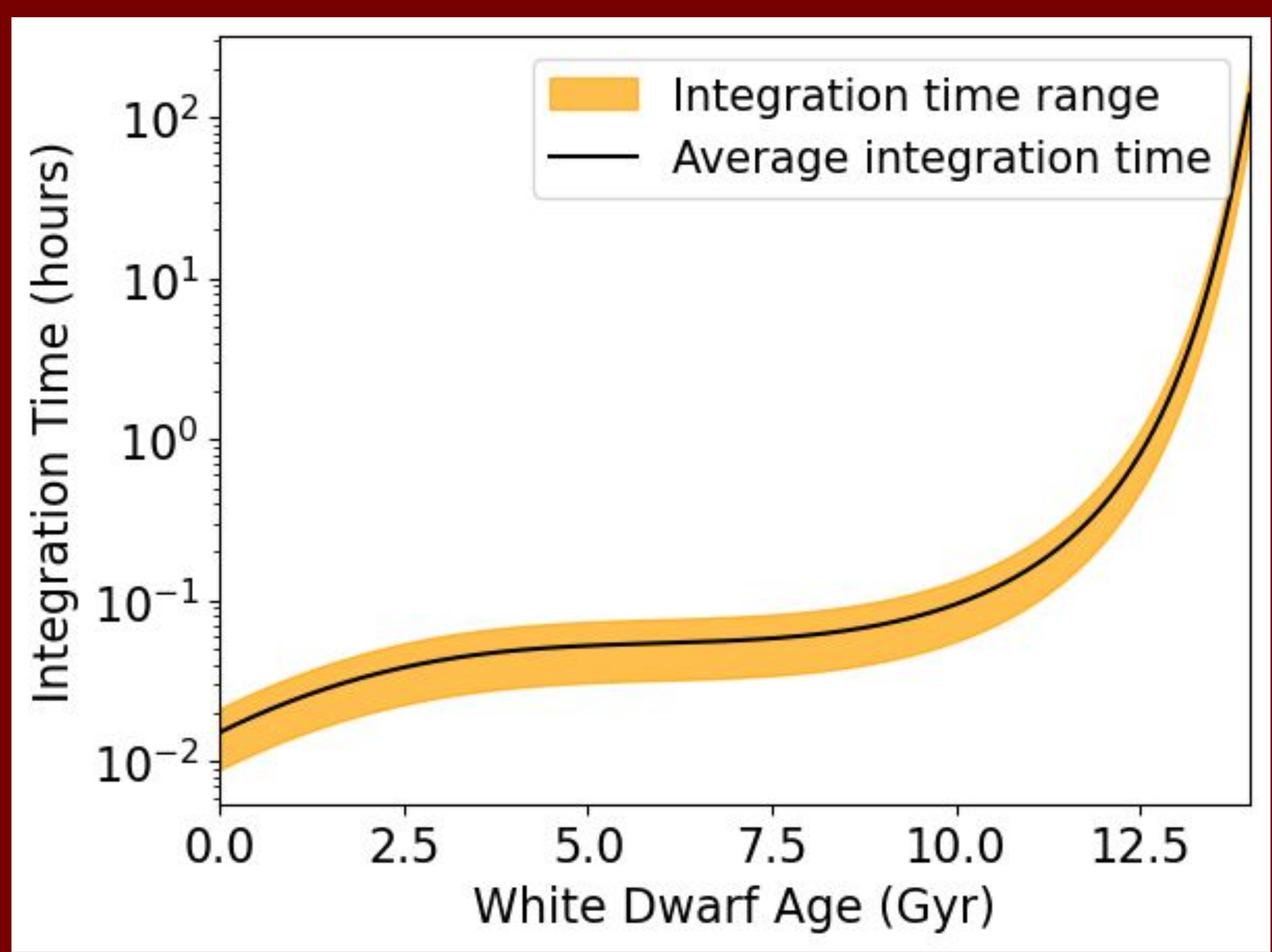
Habitable zone based on the cooling function of a typical 0.6 $M_\odot$ white dwarf (Barnes & Heller, 2013). The inner and outer limits are based on an effective planetary temperature of 270 K and 175 K, respectively (Kaltenegger & Sasselov, 2011).

PAR and UV 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 $\times 10^{16}$ 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.

Integration time:



The JWST integration time needed to achieve a S/N of 5 using transmission spectroscopy to observe biosignatures present in an atmosphere, with d = 10 pc and λ = 3 μm. This was calculated using the expression from Fujii et al., 2018.

Habitable zone model

The habitable zone used here was generated based on the cooling function from Barnes & Heller 2013, and solving for the orbital radius (a_{WD} [AU]) at which an Earth-like planet would have an effective temperature (T_p [K]) giving:

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

where L_{WD} is the luminosity of the white dwarf in solar luminosities.

- This is used to find how the orbital radius of the edges of the habitable zone change as the white dwarf ages
- A planet with a constant orbital radius of 0.01 AU can remain habitable for ~8 Gyr

This ideal distance of ~0.01 AU agrees with previous studies such as Agol 2011, Barnes & Heller 2013, and Becker, et al. 2023.

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 habitable zone will also receive a high enough PAR and UV flux to support the formation and existence of life throughout its habitable lifetime.
- Wien's Law and the white dwarf's temperature as a function of time can be used to find that the peak wavelength is around 600 nm throughout the habitable lifetime (similar to the Sun).

Conclusions

- White dwarf exoplanets could remain in the habitable zone for timescales larger than the current age of Earth.
- Overlap of PAR zone, abiogenesis zone, and habitable zone is very promising, and only seen for stars with an effective temperature greater than ~4500 K (Lingam & Loeb, 2021).
- Nearly instant integration times makes the search for atmospheric biosignatures efficient.

Limitations:

- Model only considers a constant circular orbit.
- Atmospheric conditions could impact the PAR and UV flux.

Contact Information

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