A Search for Life Around Dead Stars

Thematic Areas (Check all that apply):

☒ (Theme A) Key science themes that should be prioritized for future JWST and HST observations
☐ (Theme B) Advice on optimal timing for substantive follow-up observations and mechanisms for enabling exoplanet science with HST and/or JWST
☐ (Theme C) The appropriate scale of resources likely required to support exoplanet science with HST and/or JWST
☒ (Theme D) A specific concept for a large-scale (∼500 hours) Director's Discretionary exoplanet program to start implementation by JWST Cycle 3.

Summary: JWST has the remarkable ability to detect biosignatures on nearby white dwarf (WD) exoplanets in ∼25 hours, a task no other observatory, existing or planned, can accomplish. Our advocacy focuses on exploring **habitable worlds surrounding WDs**. WD exoplanets, particularly those within the habitable zone (HZ), have been identified as prime targets for detecting life with JWST [1, 2, 3]. Utilizing **phase curve monitoring via MIRI 15 μm broadband or MRS time-series observations (TSOs)**, JWST can detect terrestrial planets orbiting WDs [4]. JWST's sensitivity enables the detection of HZ worlds around the nearest ∼20 WDs (Fig. 1, left). To capture complete phase curves, which typically correspond to a day-long orbital period for WD HZ worlds (Fig. 1, right), amounts to ∼480 hours of JWST observations. Optimal observations should involve MRS long/C sub-band or MIRI imaging TSO for phase curve monitoring of each WD within 10 pc. Additionally, MIRI imaging at 21 & 25 μm should be included to mitigate false positives. Exposure times depend on (1) achieving the necessary SNR for detecting Earth-analogs and eliminating false positives, and (2) considering the orbital period of the exoplanet in the HZ.The constructed phase curves from the MRS channels facilitate exoplanet detection (Fig. 2). Moreover, if the observations are performed in close succession to mitigate the MRS throughput issue [5], it would be possible to detect spectral features in the combined WD+planet spectral energy distribution (SEDs) indicative of exoplanet atmospheres (Fig. 3). Detecting atmospheres requires a precision of ∼1 ppt for using relative measurements between WD systems. H_2O, CO_2, and potentially CH_4 can be probed with observations in the long/C sub-band; O_3 can be detected through follow-up observations in the MRS medium sub-band (Fig. 3) or with LRS.

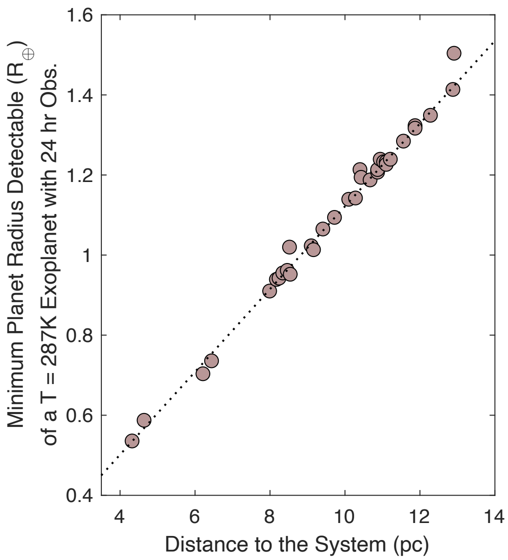
Anticipated Science Objectives: The objectives of this program would be to detect and place the first occurrence rate constraints on (1) terrestrial worlds, as small as Mars, orbiting WDs, (2) WD exoplanets in the habitable-zone, (3) biosignatures in the atmospheres of WD exoplanets. This program has the potential to detect life outside our Solar System. The current Decadal Survey ranked the search for life as the premier science goal for the 2020s [6]. While NASA plans to construct the HWO for a similar search and characterization targeting HZ worlds around main sequence stars, it's important to note that only JWST can perform this task for WDs. Finding life outside the solar system would likely be the most significant scientific discovery ever, with far-reaching impacts on the entire global community. *Ancillary stellar science:* Additionally, this data will help refine the currently uncertain collision-induced absorption opacities in white dwarfs, enhancing the accuracy of their atmospheric parameters and age estimates. The data will also test predictions of evolution models in white dwarfs.

Urgency: MRS and the MIRI imager are crucial for detecting WD terrestrial worlds. However, their throughput has decreased over time and may continue to degrade. To identify and study terrestrial planets orbiting WDs, it is imperative to implement this program promptly. This may be our sole chance to understand the existence of nearby WD HZ worlds. No future missions are capable of detecting or characterizing nearby non-transiting (i.e. $>99\%$ of) terrestrial worlds around WDs. The program should be conducted now to allow ample time for detection, follow-up and characterization before MRS and the MIRI imager becomes obsolete. This could be the best opportunity for JWST to detect life.

Risk/Feasibility: *Risks*: (1) The occurrence rate of terrestrial worlds in the HZ of WDs is unknown. (2) We don't know if life exist around WDs, but: multiple authors have demonstrated that life on WD exoplanets is feasible as there is a stable HZ for several billion years [7, 8, 9, 10, 11, 12, 13] . *Feasibility:* The observations are well within the realm of JWST's capabilities; WD HZ exoplanets can be detected and characterized with tens of hours of MIRI observations.

Timeliness: Astro2020 defined the search for life as the primary science goal for the 2020s [6].

Cannot be accomplished in the normal GO cycle: TACs typically hesitate to approve high-risk, high-reward projects that have the potential to make significant breakthroughs, so this program is well-suited for the director's program. Despite the inherent risks, observing nearby WDs offers the potential to detect terrestrial worlds and conduct biosignature searches.



Name	D (pc)	Period (hrs)*
Wolf 28	4.3	15.2
GJ 440	4.6	39.1
GJ 1221	6.2	8.6
WD 0552-041	6.4	6.9
V1201 Ori	8.0	11.9
LAWD 26	8.2	15.8
Wolf 489	8.2	11.5
LAWD 96	8.3	29.6
WD J2151+5917	8.5	10.4
CD-32 5613	8.5	99.5
GJ 1276	8.5	6.1
GJ 2012	9.1	13.5
GJ 283	9.2	35.5
GJ 3306	9.4	23.0
GJ 3112	9.7	23.8

*Orbital period of an exoplanet that receives the same bolometric radiation as earth

Figure 1: **Left:** Minimum detectable radius of a habitable-zone exoplanet ($T_{\rm eq} = 287\,$K) for each WD in our sample with 24 hours of observation. For systems within 10 pc, MRS is sensitive to HZ planets with radii ranging from $0.5R_\oplus$ to $1.1R_\oplus$. **Right:** List of isolated WDs in 10pc and the orbital period for a HZ planet.

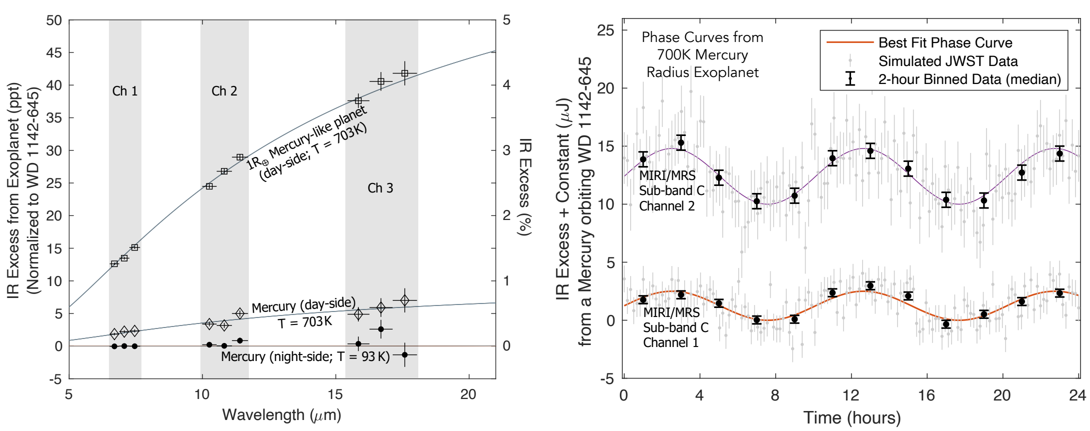


Figure 2: IR excess (left) and phase curves (right) from a planet with Mercury's temperature range around WD 1142-645 in two of the MRS long/C Sub-band.

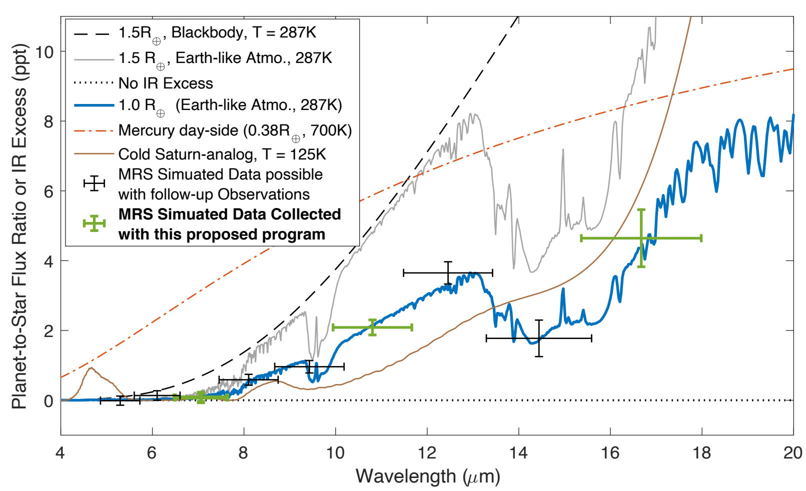


Figure 3: Planet-to-star flux ratio (IR excess), in ppt, from a 1 $R_\oplus$ Earth-analog (blue line) and other planets (see legend) orbiting Wolf 28. The simulated JWST MRS data (errorbars) are 10 hrs per sub-band. Data points are binned measurements in each MRS channel. Note that the Saturn-analog (brown line) is detectable with MIRI 21/25μm imaging (not shown here), allowing for elimination of false-positives.

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