Searching for Jovian Analogs Around White Dwarf 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: The ultimate fate of the planets in the Solar System after the death of the Sun is largely unknown. JWST has the opportunity to solve this mystery by searching for planets around nearby white dwarf stars (WDs). Theory suggests that the outer planets (Jupiter and beyond) should survive the AGB phase unscathed [1], however no prior surveys have been sensitive enough to directly image sub-Jovian mass planets around other stars. A MIRI imaging survey in the mid-infrared is *the best technique* to both measure the frequency of nearby outer solar-system analogs, and find the first cool, giant planets (similar in age and temperature to those in our own solar system) whose atmospheres can be further characterized. WDs are the ideal places to look for cool giant planets because of the favorable contrast ratio (1:100 in the mid-IR) and the expectation that these planets will move outward during the AGB mass loss stage, making them easier to find with direct imaging. A deep MIRI imaging survey of ≈100 nearby WDs (≈500 hours with JWST) will accomplish the following:

- Potentially detect and confirm 40-170 old (>1Gyr), giant planets (0.5-10 $M_{\rm J}$ and 10-100 au) orbiting WDs [2],
- Provide a sample of directly imaged, old, cool Jupiter analogs whose atmospheres and orbits can be characterized with follow-up observations, placing our own solar system into context.
- Provide the first measurements of low-mass, outer planetary systems orbiting dead stars and investigate whether planets like those in our own solar system will survive the death of their host star [1, 3, 4, 5],

Anticipated Science Objectives: The detection of Jupiter analogs (loosely defined here as 0.1 – 10 $M_{\rm J}$, $\sim$3 – 40 au, and $>$1 Gyr) is difficult with current technology. See Figure 1 for a comparison to other planet hunting techniques. While micro-lensing surveys will statistically determine the occurrence of jovian analogs, none of those planets can be followed-up to constrain orbits or planetary atmospheres. WDs are intrinsically faint and similar in age to the Solar System, giving us a unique opportunity to find nearby solar-system analogs. For nearby WDs, planetary companions as close as 5 au have projected separations of 0.5 arc seconds, and are detectable with MIRI as resolved companions without coronagraphic imaging (Figure 2). While little is known about post-MS planet evolution [5], we expect giant planets to survive the red giant stage [6], so one estimate of the survey's yield comes from extrapolating the occurrence of planets orbiting young A/F stars [2, 7]. MIRI can detect the more common low mass giant planets for most of the nearby WDs and so a survey of $\approx$100 WDs will yield $\approx$40-170 $>$1 $M_{\rm J}$ planets beyond 10 au [2, 8, 9]. The recent result that two candidates have been found after a 4 WD pilot survey (GO 1911) are in line with these estimates.

An imaging survey of $\approx$100 nearby WDs would require about 5 hours per target, split between 2 filters (e.g. 7 and 15μm) to determine a candidate's color, followed by a repeat observation a year later to verify common proper motion pairs of any red, point-source candidates.

The survey could be designed to confirm only those cool, giant planets that can be followed-up with multi-color photometry and spectroscopy, providing new insights into planetary atmospheres in mass and surface temperature regimes inaccessible to transit spectroscopy or current direct imaging approaches. The same observations will identify unresolved, cool disks and planets from infrared excess measurements. Finally, the entire MIRI detector is read-out, so the same images can be used for additional science, such as archival studies of red, dusty galaxies.

Urgency: The survey depth depends on the decreasing throughput of the MIRI detector. Only JWST can follow-up and further characterize these new planets.

Risk/Feasibility: GO 1911 in cycle 1 has shown that JWST is capable of reaching sub-Jovian mass limits (Poulsen 2023, in prep) for a large population of WDs.

Timeliness: This survey will provide a population of cool solar system analogs that can be followed-up placing our solar system in context prior to HWO.

Cannot be accomplished in the normal GO cycle: This survey does not fit into the large TAC; a compelling science case cannot be justified with a small subset of the targets. Planet confirmation requires a second TAC 1-2 years later.

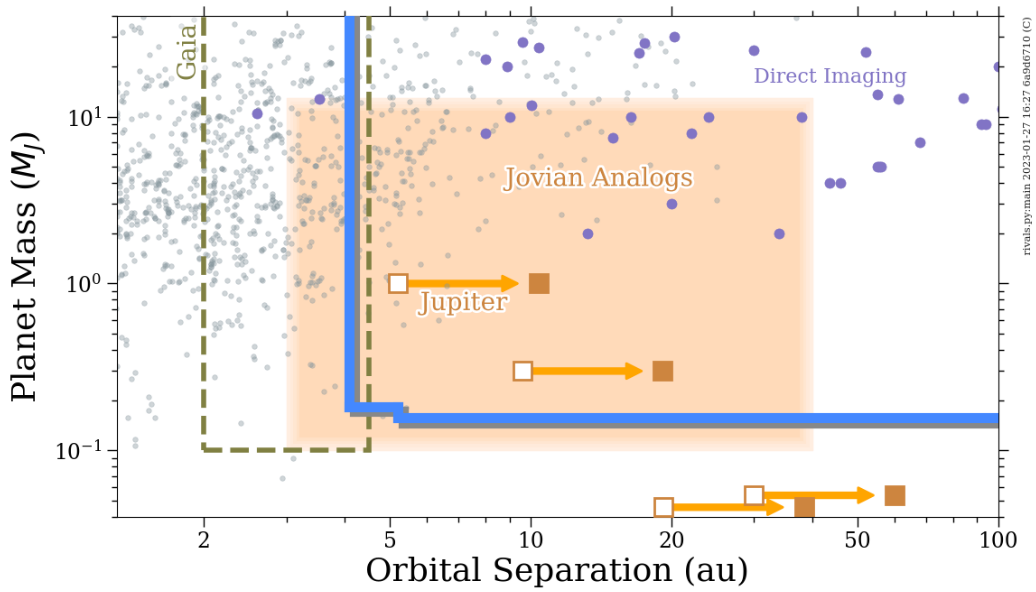

Figure 1: A potential survey of nearby WDs (thick blue line) is sensitive to directly imaged Jovian analogs (large orange rectangle), a region of parameter space largely unexplored by radial velocity (grey circles), direct imaging (purple circles), or GAIA [dashed line, 10]. This is especially true for low-mass, middle-aged ($>$1 Gyr) giant planets at wide orbital separations. The white squares show the location of gas- and ice-giants in our solar system. The filled brown squares show the projected location of the planet after the Sun evolves to become a WD.

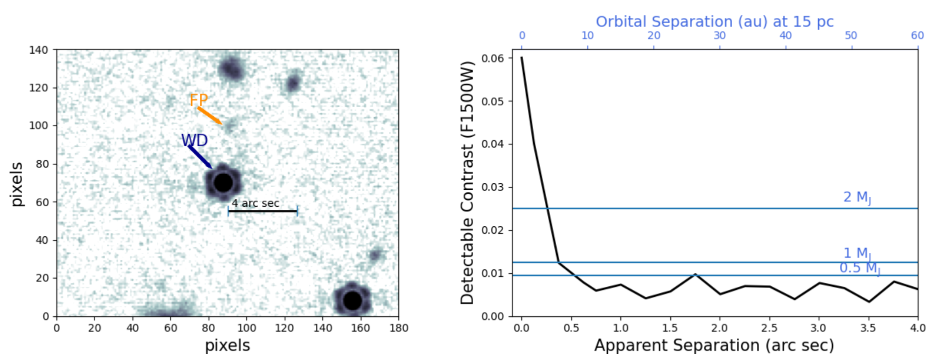

Figure 2: Left: MIRI image of WD 2149+02 (Poulsen 2023, in prep) with the WD labeled as 'WD' and a 0.9 μJy (just above the background limit) false positive labeled as 'FP'. The signal was identified as a false positive using morphology and the F770W filter, but otherwise is similar in brightness to a 0.5 M_J companion. Right: The MIRI F1500W detection curve shown as the star-planet contrast ratio observed for WD 2149+02 using PSF subtraction and KPI [11]. In blue is the expected contrast ratio for different mass planets when scaling the contrast curve to a star at 15 pc and 4 Gyr old (the median distance and age of the nearby WDs).

References

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