JWST Directly Images Giant Planet Candidates Around Two Metal-polluted White Dwarf Stars

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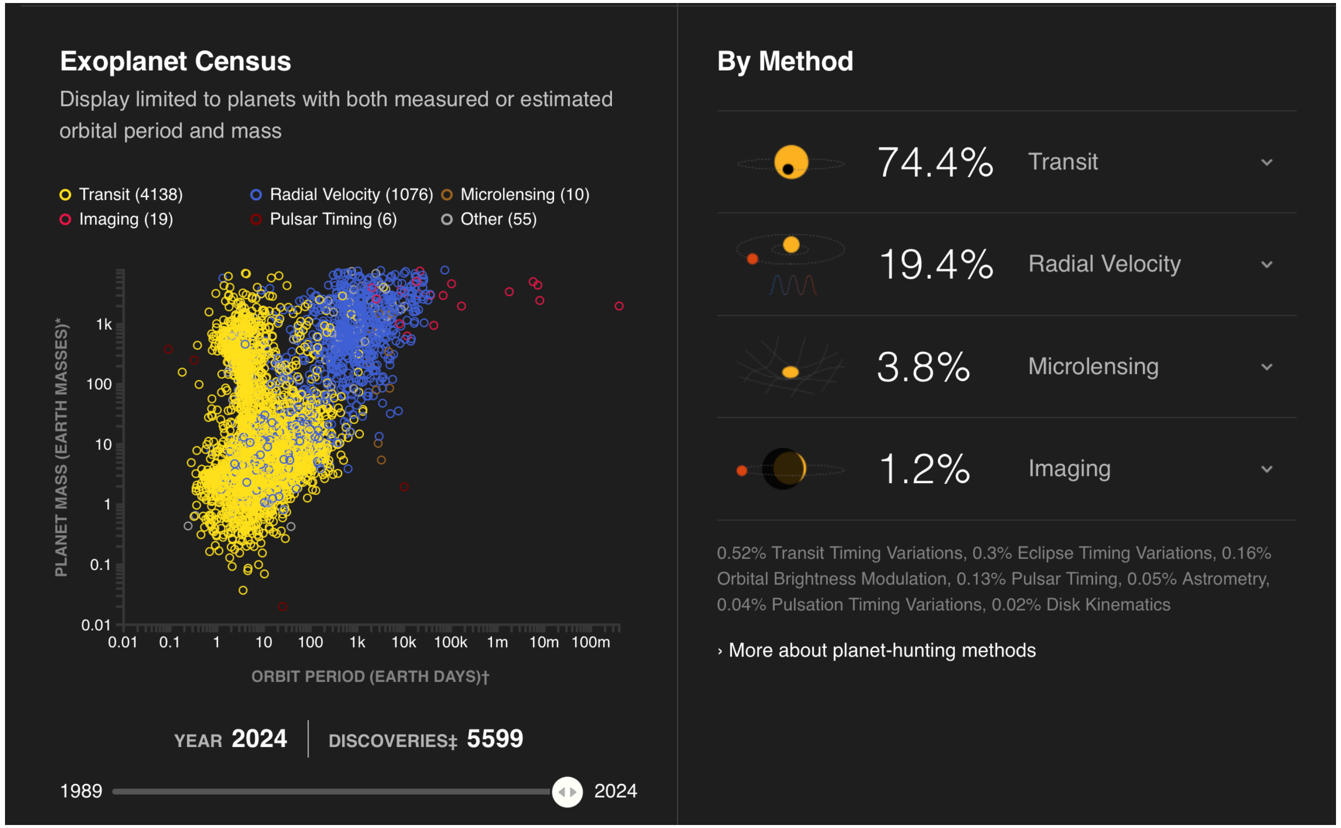
1 Background

<u>Exoplanets</u>

- Only a small fraction of the more than 5000 confirmed exoplanets are known to orbit non-main-sequence stars.
- Few observational constraints on what happens to planetary systems in the late stages of stellar evolution.
- Theory suggests that exoplanets should exist around WDs.
- Finding exoplanets around these remnants can teach us about the fate of the planets in our own solar system.
- Only a few planetary mass objects have been found orbiting WDs.

Recent examples of giant planets found orbiting single WDs include one found via microlensing (MOA-2010-BLG-477Lb; Blackman et al. 2021) and another found transiting with a short orbital period (WD 1856+534 b; Vanderburg et al. 2020).



1 Background

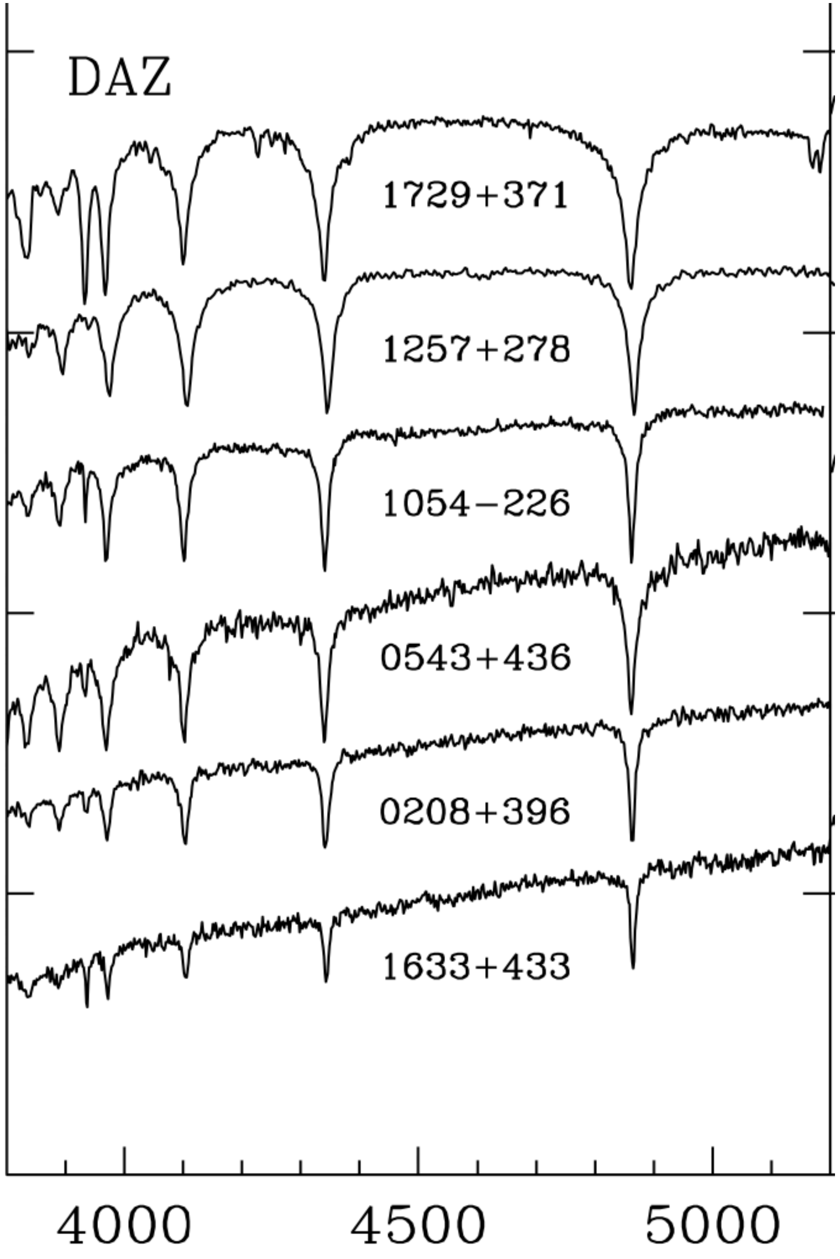
DAZ white dwarfs

Having metals in their atmosphere.

Actively accreting since the strong gravitational field pulls heavier elements out of the atmosphere on timescales as short as a few days (Koester 2009).

Relic planetary systems are the favored theory for the source of the accreted material (Alcock et al. 1986; Jura 2003).

Planets that survive the red giant phase occasionally perturb the orbits of asteroids and comets (Debes et al. 2012), which then fall in toward the WD. When these bodies pass inside the Roche limit of the star, they disintegrate into a cloud of dust and gas, which then accretes onto the star.



Gianninas et al. 2011

1 Background

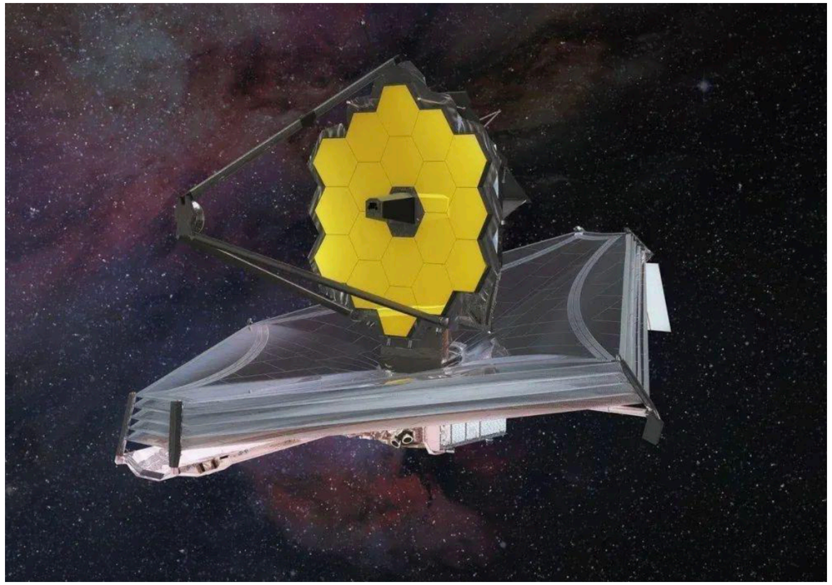
The infrared capabilities of James Webb Space Telescope (JWST; Rigby et al. 2023; Wright et al. 2023)

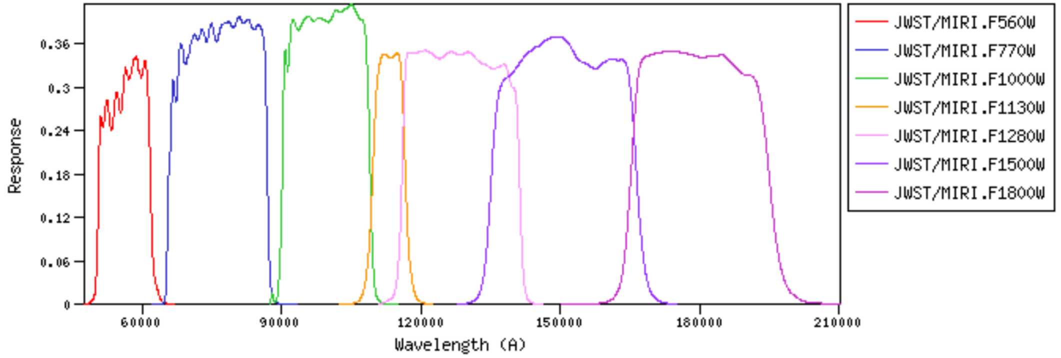
JWST is a large (6.6 m), cold (<50 K), infrared-optimized observatory with a segmented mirror design, that was launched on 2021 December 25 and is now in science operations.

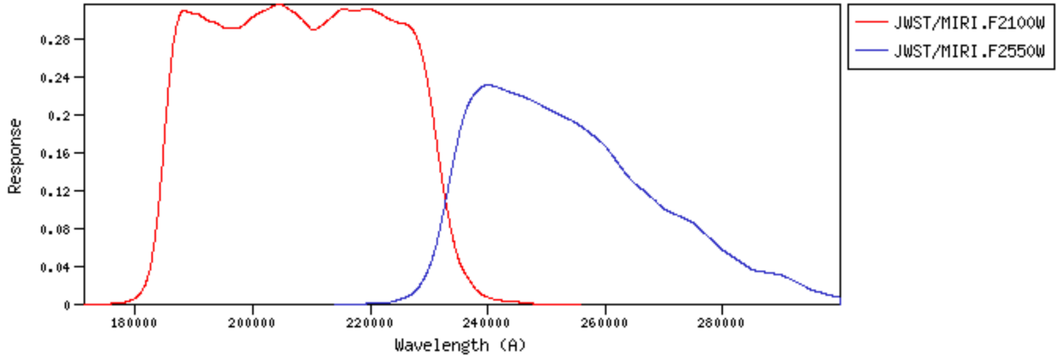
- The primary mirror segments have cooled to temperatures of 35–55 K.
- The secondary mirror has cooled to 29.3 K.
- The Mid-Infrared Instrument (MIRI) has cooled to 6.4 K.

  A 1024 × 1024 pixel detector array; a FOV of 74" × 113"; eight broadband filters.

  The image scale is 0.11" per pixel.







2 White dwarf star properties

WD 1202–232 (LP 852-7), WD 2105–82 (GJ820.1), WD 1620-391 and WD2149+02

Isolated, having metals in their atmospheres; either young (younger stars will have warmer, brighter planets in the mid-infrared) or nearby WDs (to improve MIRI' s sensitivity to giant exoplanets).

The total age is made up of the cooling age plus the main-sequence age/

The wdwarfdate (Kiman 2022) software;

The cooling models of Bedard et al. (2020);

The initial-to-final mass relation of Cummings et al. (2018);

The stellar evolutionary models of Choi et al. (2016).

Table 1
Atmospheric Parameters for WD 1202−232 and WD 2105−82

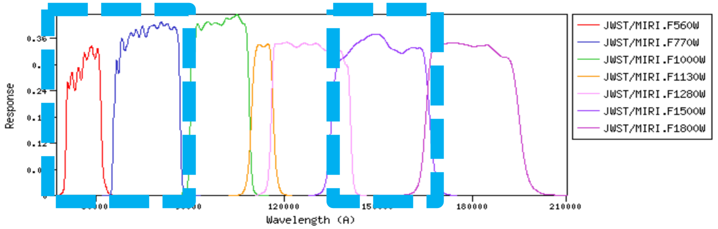
Name	K_{mag} (Vega)	T_{eff} (K)	log g (cgs)	Dist. (pc)	M_{WD} ($M_\odot$)	M_{MS} ($M_\odot$)	Total Age (Gyr)
WD 1202−232	12.3	8760 ± 130	8.01 ± 0.05	10.43	$0.60^{+0.03}_{-0.02}$	$1.3^{+0.4}_{-0.3}$	$5.3^{+5.0}_{-2.5}$
WD 2105−82	13.5	9890 ± 170	8.22 ± 0.08	16.18	$0.70^{+0.06}_{-0.05}$	$2.5^{+0.6}_{-0.7}$	$1.6^{+0.8}_{-0.2}$

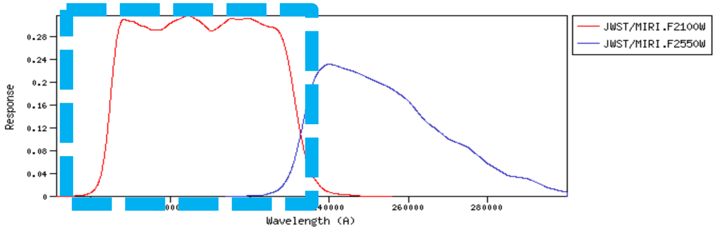
Note. Ages and masses inferred using wdwarfdate (Kiman 2022); distances from Gaia Collaboration et al. (2023). Atmospheric parameters for WD 1202−232 are based on the optical spectroscopy of Gianninas et al. (2011) with the 3D corrections of Tremblay et al. (2013), and for WD 2105−82 are based on the radiative-atmosphere, optical spectroscopic fits of Gentile Fusillo et al. (2018).

3 Observation, source detection and photometry

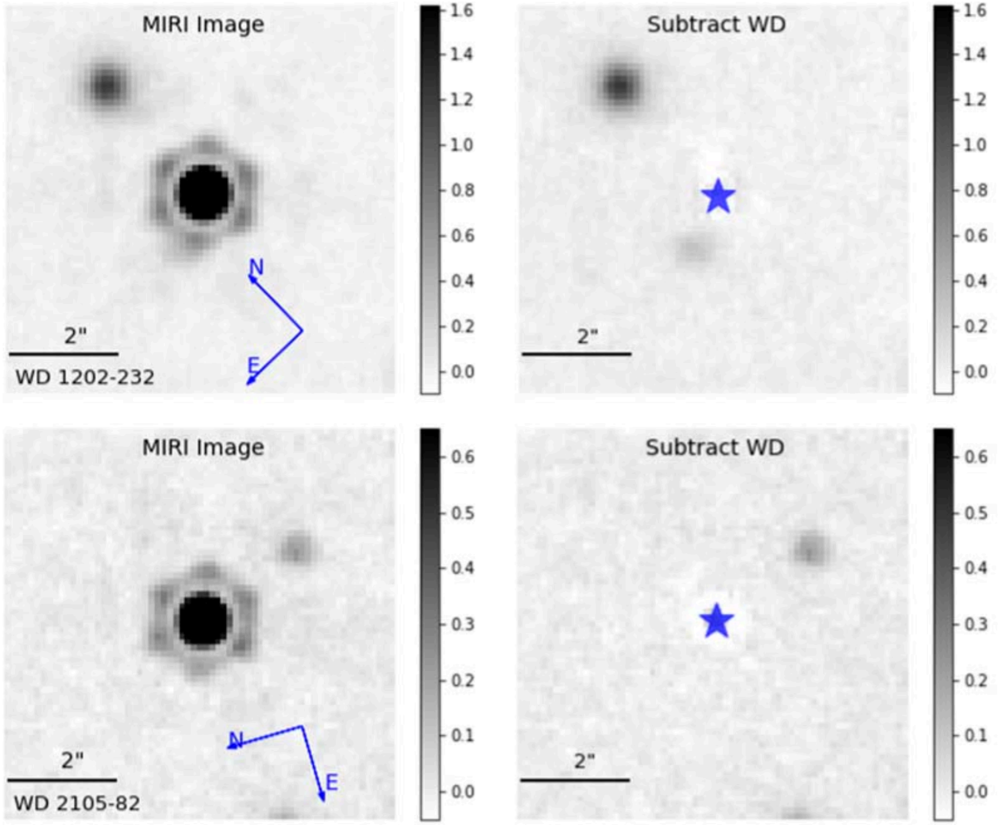
■ The mid-infrared instrument (MIRI) in imaging mode

	F560W	F770W	F1500W	F2100W
WD 1202−232	255.3 s	277.5 s	8413.9 s	1309.8 s
WD 2105−82	233.1 s	233.1 s	12088.1 s	6016.3 s





■ PSF subtraction to detect the candidates



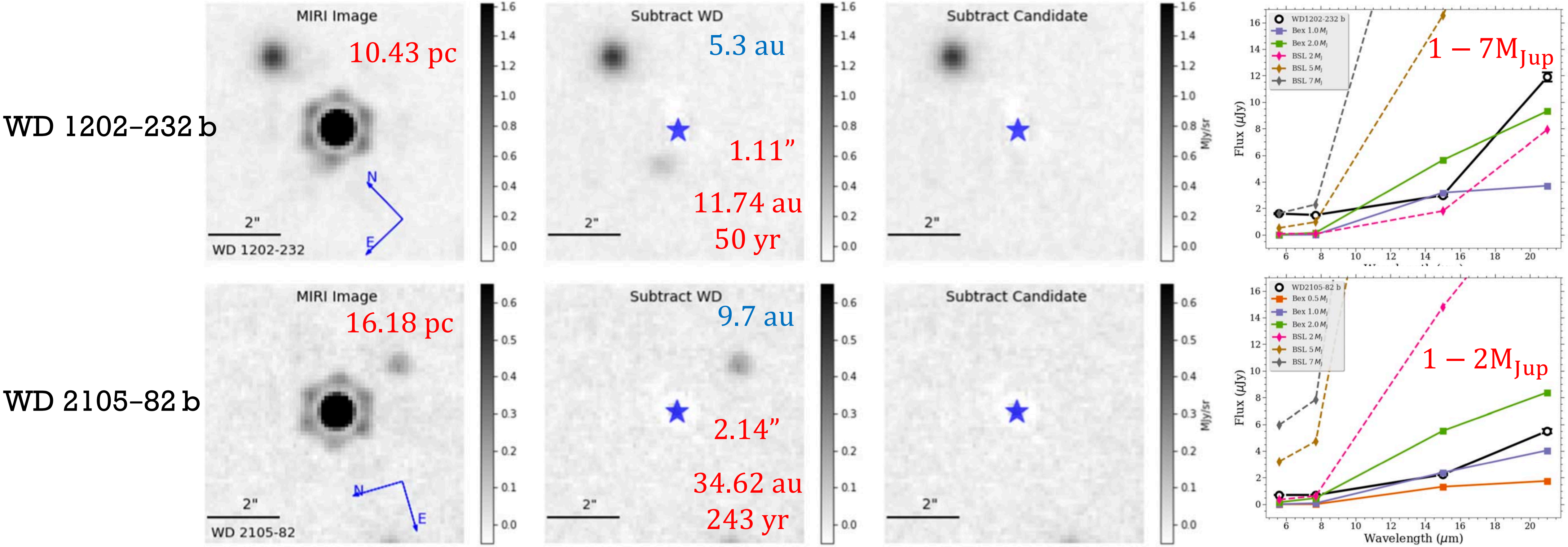
■ Aperture photometry

Table 2
Photometric Measurements in the Four JWST Bands of the WDs and the Candidate Companion to the WDs

Object	F560W (μJy)	F770W (μJy)	F1500W (μJy)	F2100W (μJy)
WD 1202−232	1208 ± 36	699 ± 21	181 ± 5	105 ± 3
WD 1202−232 b	1.6 ± 0.1	1.5 ± 0.1	3.0 ± 0.1	11.9 ± 0.6
WD 2105−82	428 ± 13	229 ± 7	68 ± 2	35 ± 1
WD 2105−82 b	0.7 ± 0.2	0.7 ± 0.2	2.2 ± 0.1	5.5 ± 0.3

4 Results

- This study is aim to identify candidate substellar companions to the WDs and expects them to appear as point sources and be brighter at longer wavelengths.
- Compare the four band SEDs with planet models and constrain the mass of the planet assuming the observed sources lie at the distance of the star and have an age matching that of the WD.



5 Discussion

Potential False Positives

✗ A typical main-sequence or evolved red giant star

- Even the coolest of these stars (~2000 K) would be brighter at 5 μm than at 15 μm (Husser et al. 2013) unless enshrouded in dust.

✗ A brown dwarf

- The flux of our candidates would place it farther away and unbound to the WD

✗ Objects with the appropriate size out of the Neptune

- Likely moving by several pixels during the exposures
- Both WDs lie at modest-to-high ecliptic latitudes (−21° and −60°) where the density of such objects is low.

✗ A distant galaxy (a variety of colors and can appear as a point source if sufficiently small or far away)

- Following the same procedures outlined in Poulsen et al. (2023), they performed aperture photometry using the recommended aperture radii and background apertures across the entire field of view.
- The core of each source was fit with a Gaussian to determine if its shape was consistent with a point source.
- They counted red sources whose F1500W/F770W and F2100W/F1500W flux ratios are both greater than 1
- They limited the search to sources whose flux in the F1500W filter is less than 100 μJy.
- The probability of both candidates being false positives due to red background sources is approximately 1 in 3000.

5 Discussion

- The significance of confirmation these candidates to be planets

✓The planet–pollution connection

While all invoke the destruction of some kind of minor planet (a comet or asteroid) as a direct explanation of the pollution, models differ in how to transport those minor planets from beyond 3 au to the Roche limit where they are disrupted (Veras 2021).

The standard model of Debes & Sigurdsson (2002), Frewen & Hansen (2014) invoke changes in the orbit of a large planet to drive orbital instability in the minor planets.

✓Wide-orbit giant planets are ubiquitous

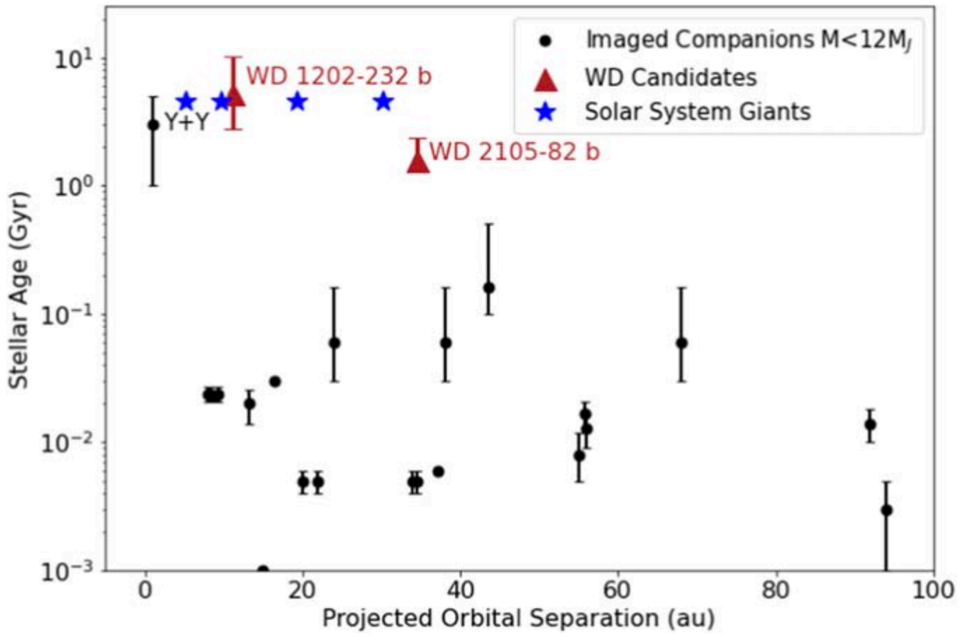
Outer giant planets like Jupiter survive the evolution of low-mass stars.

✓The indirect evidence that 25%–50% of WDs host large planets.

✓Give the insight into what happens to planetary systems in the late stages of stellar evolution.

6 Summary

- Two directly imaged, giant planet candidates orbiting the metal-rich, hydrogen atmosphere white dwarfs WD 1202–232 and WD 2105–82.
- Assuming the planets formed at the same time as their host stars, with total ages of 5.3 and 1.6 Gyr, the MIRI photometry is consistent with giant planets with masses $\approx 1 - 7\mathrm{M_{Jup}}$.
- If confirmed using common proper motion method, these giant planets demonstrate that widely separated giant planets like Jupiter survive stellar evolution and provide evidence that directly links giant planets to metal pollution in white dwarf stars.
- The first directly imaged planets that are similar in both age and separation to the giant planets in our own solar system.



THANKS