Carbon-rich Dust Injected into the Interstellar Medium by Galactic Wolf-Rayet Binaries Survives for Hundreds of Years

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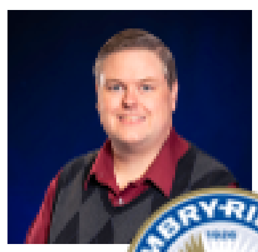


Some carbon-rich Wolf–Rayet (WC) stars show an infrared excess from dust emission (WCd stars). Dust forms in the collision of the WC wind with a companion star's wind. As this dust is carried toward the interstellar medium (ISM) at close to the WCd wind speed (v_∞~1000-3000 km/s) and the binary continues through its orbit, a spiral structure forms around the system. The shape depends on the orbital eccentricity and period, as well as stellar parameters like mass-loss rates and terminal wind speeds. Imaging of the WCd binary WR 140 with JWST/MIRI revealed 17 concentric dust shells surrounding the binary. We present new JWST imaging of five additional WCd systems (WR 48a, WR 112, WR 125, WR 137, and Apep) that were imaged in 2024. In this analysis, we show that the dust is long-lived, detected with an age of at least 130 yr, but more than 300 yr in some systems. Longer-duration measurements are limited by sensitivity. Regular spacing of dust features confirms the periodic nature of dust formation, consistent with a connection to binary motion. We use these images to estimate the proper motion of the dust, finding the dust to propagate out to the ISM with motion comparable to the wind speed of the WC stars. In addition to these results, we observe unusual structures around WR 48a, which could represent dusty clumps shaped by photoevaporation and wind ablation like young proplyd objects. These results demonstrate that WC dust is indeed long-lived and should be accounted for in galactic dust budgets.

What is a *Wolf-Rayet* star?

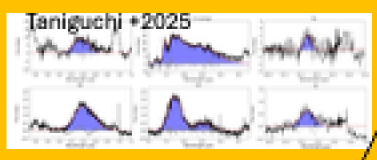
Classical Wolf-Rayet stars are evolved, massive stars that are helium burning and have lost their hydrogen envelopes. They can be nitrogen-, carbon-, or oxygen-rich. Some carbon-rich WRs (WC) in binary systems experience wind collisions with their neighbors. As the shocked gas propagates to the ISM, it can cool and form carbonaceous dust in these systems. In this poster, we show some results on six such binaries imaged with JWST and MIRI.

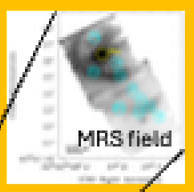
Image credit: Gemini Observatory

WR 140

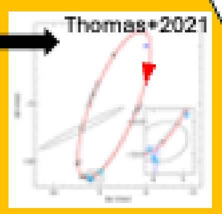
(WC7+O5.5I, P=7.93 yr, e=0.8997)

This binary is often considered the prototype of the dust-producing Wolf-Rayet binaries. It has a well-established visual and spectroscopic orbit, and its episodic dust production was linked to the periastron passages. It was an Early-Release Science target for JWST, with two epochs of imaging now performed with MIRI. MRS spectroscopy reveals that there is evidence of PAHs in the outflows (Taniguchi+2025).

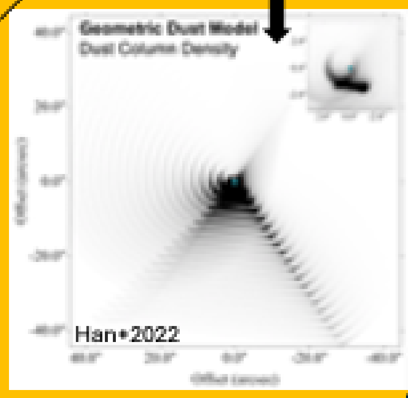




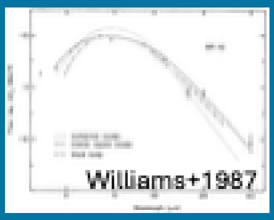
Observed visual (and spectroscopic) orbit and dust creation at phases near periastron leads to geometric model and understanding of dust survival



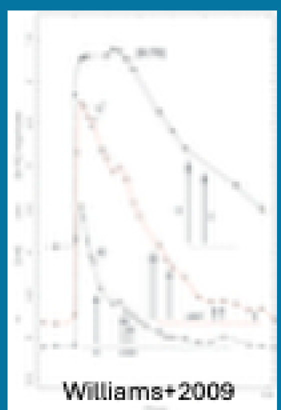
See more in the poster by Emma Lieb



Evidence of Dust Around Carbon-rich Wolf-Rayet Binaries



Infrared excess (above) and time-variable infrared photometry (right)

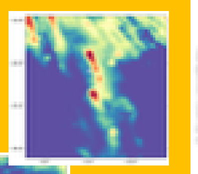


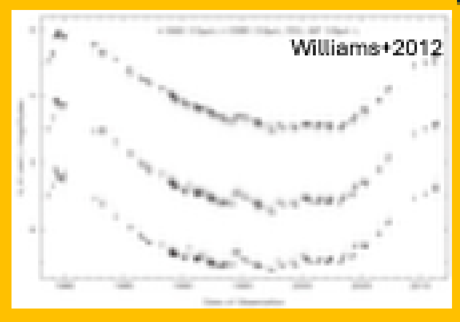
Dust around WC stars was first indicated by strong, often sudden variable infrared flux observed around several WC stars by Allen+1972. WR137 and WR140 were seen to be variable in the infrared by Hackwell+ 1976, and following further observations, interpreted as the rapid formation of dust by Williams+1977,1978,1979. The presence of dust around late-type WC stars is now indicated by a suffix of "d" being added to these stars' spectral type (WCd stars), which in turn relies both on spectral features and a spectral energy distribution.

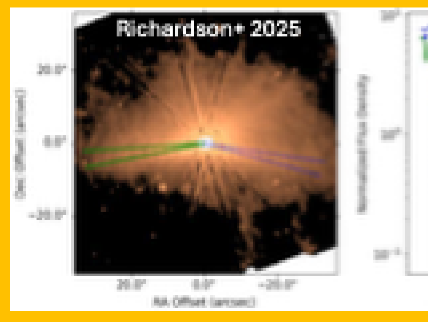
WR 48a

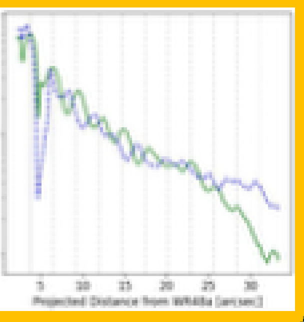
(WC8+Oe, P=32 yr)

WR 48a shows evidence for a ~32 yr timescale for the dust production, with some minor episodes of dust creation superimposed on the long-term trends (Williams+2012). The JWST imaging shows multiple shells of dust that indicate persistent dust production, although there seem to be phases of stronger dust production. Interestingly, there are some clumpy structures that are reminiscent of proplyds in Orion (center below).





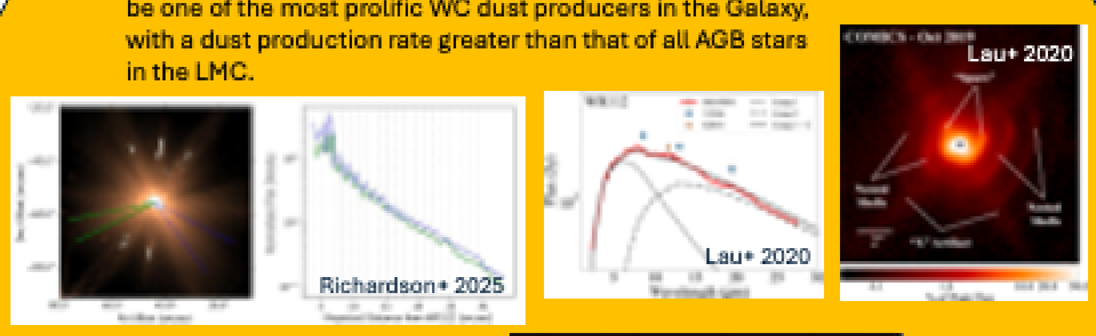


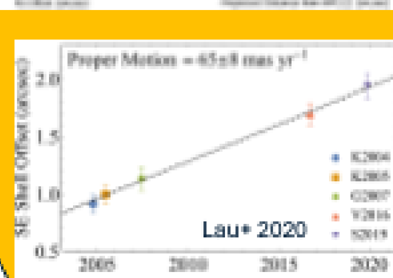


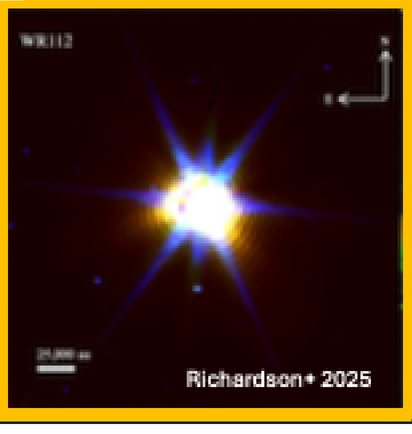
WR 112

(WC8+OB, P=20 yr, e=0)

WR 112 is a long-period system with an orbit expected to be nearly face-on. The dust geometry was modeled and examined by Lau et al. (2020), who also examined the proper motion of various features, deriving a value of 65±8 mas/yr, whereas our JWST images suggest a similar value of 71 mas/yr. WR 112 showed several shells from the ground-based imaging while JWST revealed at least 18 shells. Lau+2020 find this star to be one of the most prolific WC dust producers in the Galaxy, with a dust production rate greater than that of all AGB stars in the LMC.







Take Away Messages

1. All six systems imaged with JWST and MIRI show evidence for hundreds of years of dust that survives to the ISM
2. The geometry of the dust surrounding the systems is imprinted with information about the orbits of the stars.
3. WR 140 shows evidence that the dust is formed with PAHs.
4. We have only probed dust around WC7 and WC8 type WRs, we have yet to observe how dust survives around hotter/cooler systems.

Download our first paper to learn more!

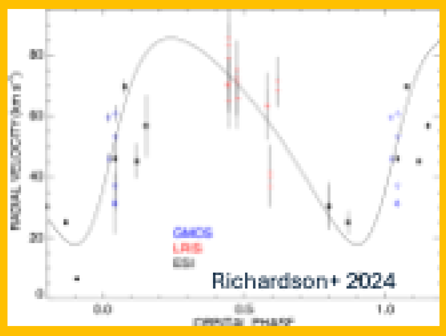
Coming soon:

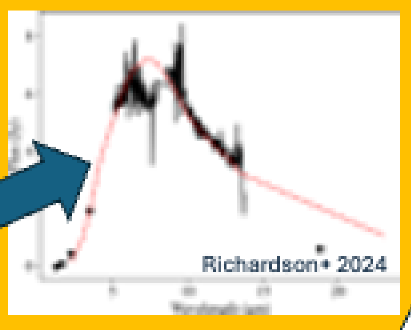
Geometric Models of WR 48a, 112,125, and 137 (led by Corey Jones)
Temperature Maps of the dust (led by Maze Herr)

WR 125

(WC7+O9III, P=28.12 yr, e=0.29)

WR 125 is a near twin to WR 140 spectroscopically. The similarities led Williams+1992 to monitor the system with IR photometry, finally discovering an outburst in 1990. The next outburst happened in 2018 when the IR brightening was discovered with NEOWISE (Williams 2019). The orbit was examined with archival and new spectroscopy by Richardson+2024, who also reported on SOFIA/FORCAST spectroscopy during the outburst.





WR 137

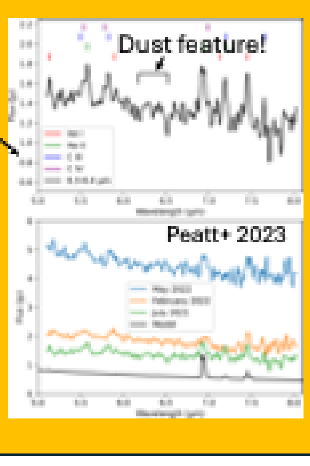
(WC7+O9Ve, P=13.105 yr, e=0.316)

WR 137 was one of the first WRs discovered with *visual* spectroscopy. Its dusty outbursts are not quite as repeatable as those of WR 140, but the orbit is also well-established with both spectroscopic and interferometric techniques. The orbital parameters work well to explain the dust geometry with JWST and both NIRISS and MIRI.

Infrared light curve showing dust creation near periastron.

JWST/NIRISS image reconstruction and first geometric model

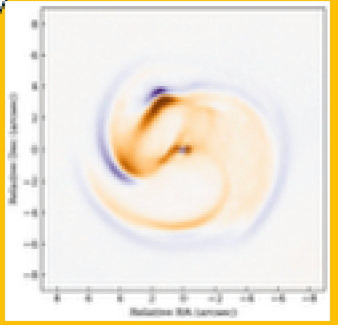
SOFIA/FORCAST spectroscopy of WR 137 during the recent periastron



Apep

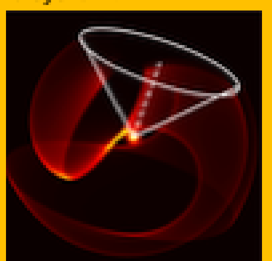
(WC8+WN, P=193 yr, e=0.82)

Apep is an unusual system with a WC+WN binary, having a likely period of about two centuries. Ground-based imaging showed that this system was a striking dust plume, with proper motion seen between 2016 and 2024 with VLT/VISIR. Many unusual features are seen that are modeled with inclusion of a third body north of the central binary destroying a cone of dust in the system.

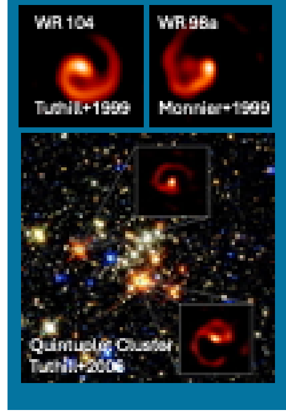


Left: Proper motion between 2016 and 2024 from VLT+VISIR (Han+2025)

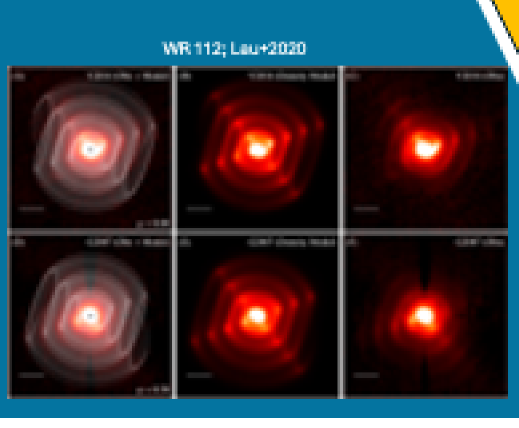
Right: Illustration of the cavity carved in the dust by a third body in the system (White+2025)



Pre-JWST Ground-based Imaging of WC Dust



Prior to JWST, the inner dust spirals had ben resolved for some systems. Aperture-masking at Keck revealed the spirals around WR 104, WR 98a, and IR-bright sources in the Quintuplet Cluster. A variety of AO-assisted images of WR 112 were also collected, with a first model of the geometric changes analyzed.



Dust Production Rates

The classical WC+O star binaries have had dust production rates measured via various studies (Lau+2022a,b). Comparisons to their IR luminosities show a strong correlation between dust production and luminosity. Note that WR 112 produces more dust than all AGB stars combined in the LMC.