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JWST Glimpses Dazzling Stellar Spirals

A new image of a star surrounded by strange swirls reveals a hidden chapter in the story of the cosmos

By Phil Plait

One of the more poetic aspects of the universe is that frighteningly powerful and raging forces can sculpt objects of graceful symmetry and beauty. And, as an added bonus, such forces may also lend a hand in our own existence.

WR 140 is a binary-star system, meaning two stars orbiting each other, some 5,400 light-years from Earth. Both stars are absolute beasts, blasting out fierce amounts of light, but across that astronomical distance their brilliance is diminished to naked-eye invisibility.

The James Webb Space Telescope (JWST), however, has far keener eyesight than we mere humans, plus it peers at the cosmos in infrared wavelengths far beyond what our eyes can see. Astronomers recently pointed JWST at the twin stars in WR 140, and what it witnessed was absolutely spectacular.

Astronomers have long wondered if grains of cosmic dust can form in and escape from the harsh inner regions of violent stellar systems. These JWST observations of WR 140 reveal that the answer is yes. This entire structure is at least two light-years (or 20 trillion kilometers) in diameter—and probably even more because there are likely fainter arms farther out that lie beyond the reach of these JWST observations. Just accounting for the visible arms, this structure surrounding WR 140 is the largest of its kind ever seen, four times the width of the next bigger known one.

The rippling spiral almost looks like a defect in the telescope itself, some strange optical phenomenon affecting the observations. But it's very real, despite what its gossamer appearance suggests: As described in a paper published in November 2022 in the journal *Nature Astronomy,* this eye-catching construct emerges from the clash of immense forces flinging vast amounts of matter into space at soul-crushing speeds, powered by stars that make our own sun look like a flashlight with dying batteries. And you can set your watch by it. Or at least your calendar.

Each star in the WR 140 binary system is far more massive than the sun. One lies at the upper range of what can be called a normal star—that is, one that shines by fusing hydrogen into helium in its core, just as our own star does. At 30 times the sun's mass, it's a monster and monstrously luminous, radiating energy at a rate a million times that of our sun. Replace the sun with this star in the center of our solar system, and Earth would get cooked.

The other component of WR 140 gives the binary system part of its name; it's in a special class of stars called Wolf-Rayet (WR). It probably started its life with 20 or more solar masses but eventually ran out of usable hydrogen in its core and is now instead furiously fusing helium into carbon. Fusing helium rather than hydrogen liberates much more energy, which disrupts the star's delicate equilibrium between its gravity trying to collapse it and its infernal heat trying to make it explode. This causes it to blow material out into space at a truly fantastic rate. The resulting windy maelstrom has carried off fully half the star's original mass—we're talking something like *20 octillion tons* here, a nearly unfathomable amount—leaving the star with only (*only*) 10 times the sun's bulk. It's roughly half as luminous as its companion, which still makes it a radiation powerhouse.

In fact, the other star is also expelling a wind of particles, though at a substantially lower rate than its Wolf-Rayet companion. These two winds slam into each other as they expand away from their respective stars, and it's this cosmic collision that forms the spiral pattern in the JWST image.

Researchers have spied this kind of structure before in Wolf-Rayet binaries, but WR 140 is different because its two stars are on a highly elongated elliptical orbit. Their separation ranges from about four billion kilometers to only 200 million kilometers apart—about the distance of Neptune and Mars from the sun, respectively.

When the stars are at their most distant from each other, their winds expand relatively freely, but every 7.93 years they come so close together in their orbit that the winds begin to interact strongly. Mind you, these winds blow at nine million kilometers per hour. Their collision at that speed generates powerful shock waves, which act a bit like a hammer pounding the material within.

Observers studying WR 140 with ground-based telescopes had already shown that the Wolf-Rayet star's wind is heavily laced with carbon dredged up from the stellar core. When the collisional shock wave sweeps over that carbon, the atoms rearrange themselves into complicated molecules called polycyclic aromatic hydrocarbons, or PAHs. Astronomers generically call this material dust.

The expansion of the winds plus the orbital motion of the stars makes their interaction geometrically complex. Using computer models to simulate the physics of the situation, the astronomers in the new work have reproduced in remarkable detail the structures seen in the JWST image.

What they found is that the collision stirs up most of the dust just before and after the stars' closest approach to each other but not during that closest approach, when the cumulative effects of stellar winds and radiation overpower dust formation. This leads to two pulses of dust creation and ejection, which we see as long streamers flying away from the point of contact much like plumes of sand flung off a sharply turning dump truck.

Moreover, this process repeats like clockwork every orbit, each time spewing twin sprays of expanding material as the stars approach each other. Every set of sprays has nearly eight

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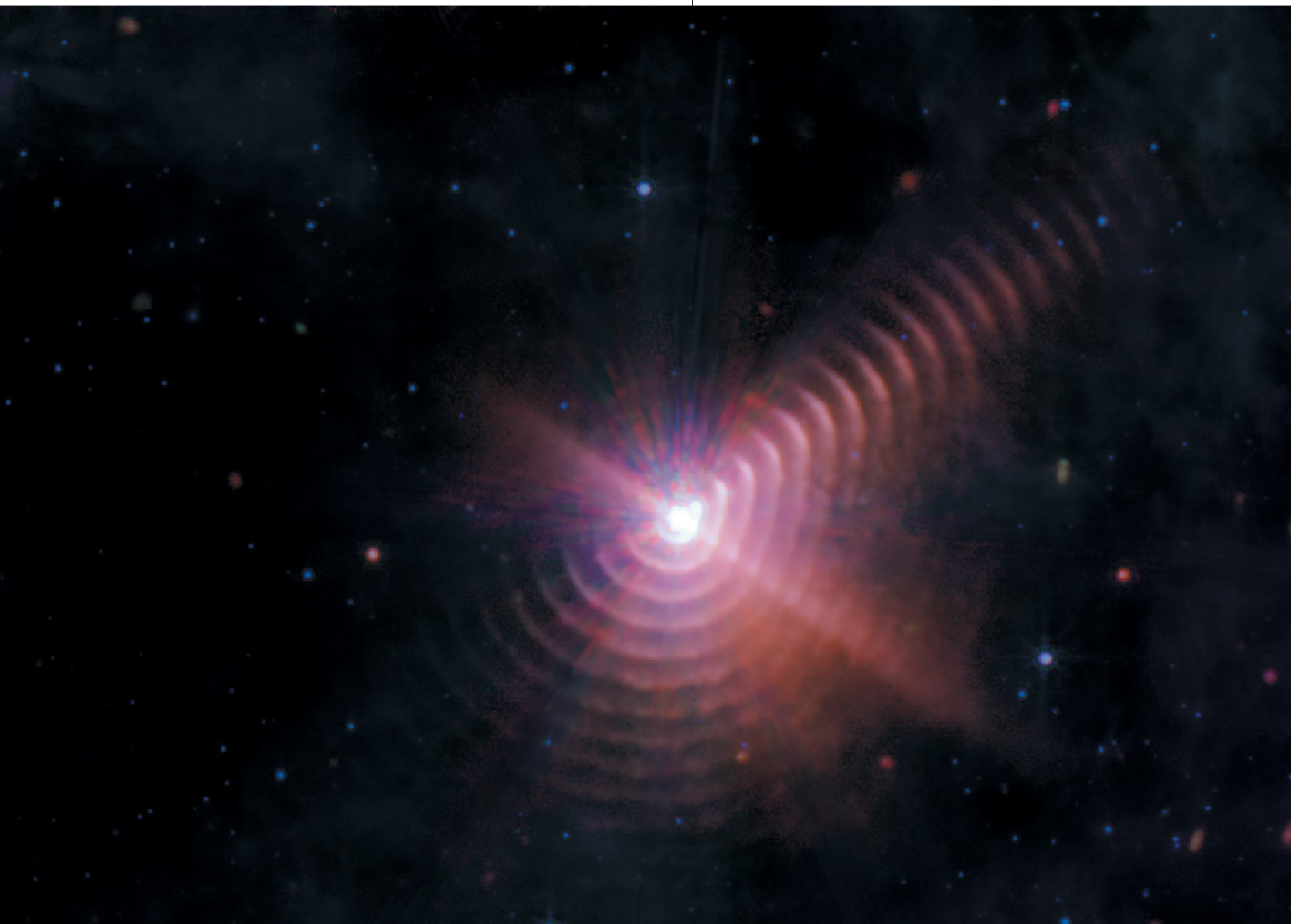

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Infrared JWST observations of the WR 140 system show a huge and complex spiral structure of gas flowing away from the stars in the center.

years to fly away at high speed, moving well over 600 million kilometers before another set emerges, creating a rippling pattern of dusty arms and rarefied gaps. Shortly after its formation, this dust is warm, making it visible to JWST's infrared instruments, which see the thermal glow of its heat. But as the arms expand away, they cool and fade, which is why the outer arms look dimmer. Close inspection reveals 17 such spiral arms in the JWST image, with incomplete arcs marking older, colder and more distant ejecta.

The breadth of the repeated spiral patterns—starting practically on top of the stars and stretching so far away from them—indicates this dust originates near the stars and then travels to the depths of interstellar space, something astronomers weren't sure could occur in such a system. And that means similar binary stars can account for a large fraction of the dust we observe in our galaxy.

Much of that dust is located in enormous clouds of gas that can eventually collapse to give birth to vast numbers of stars. These star-forming factories are all over the Milky Way, making it likely the sun was born in one as well. In fact, some prior research suggests that the winds from a nearby Wolf-Rayet star can actually trigger such a cloud's collapse and may have done so in the case of the sun.

The brutal fury of a system like WR 140 is undeniable, from the incredible luminosities of its stars to the cosmic tsunami of dusty winds they blast away. But there is order in that chaos: the laws of physics sculpting a pattern vast and lovely, a glowing pinwheel we can see across the interstellar abyss that may have a connection to our own cosmic origin.

That dust will mix with older material floating in space and may one day cause and be a part of the creation of new stars, some of which may very well start the pattern again. Poetry indeed. SA

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