Scientists investigate the origins of the Crab Nebula with James Webb Space Telescope

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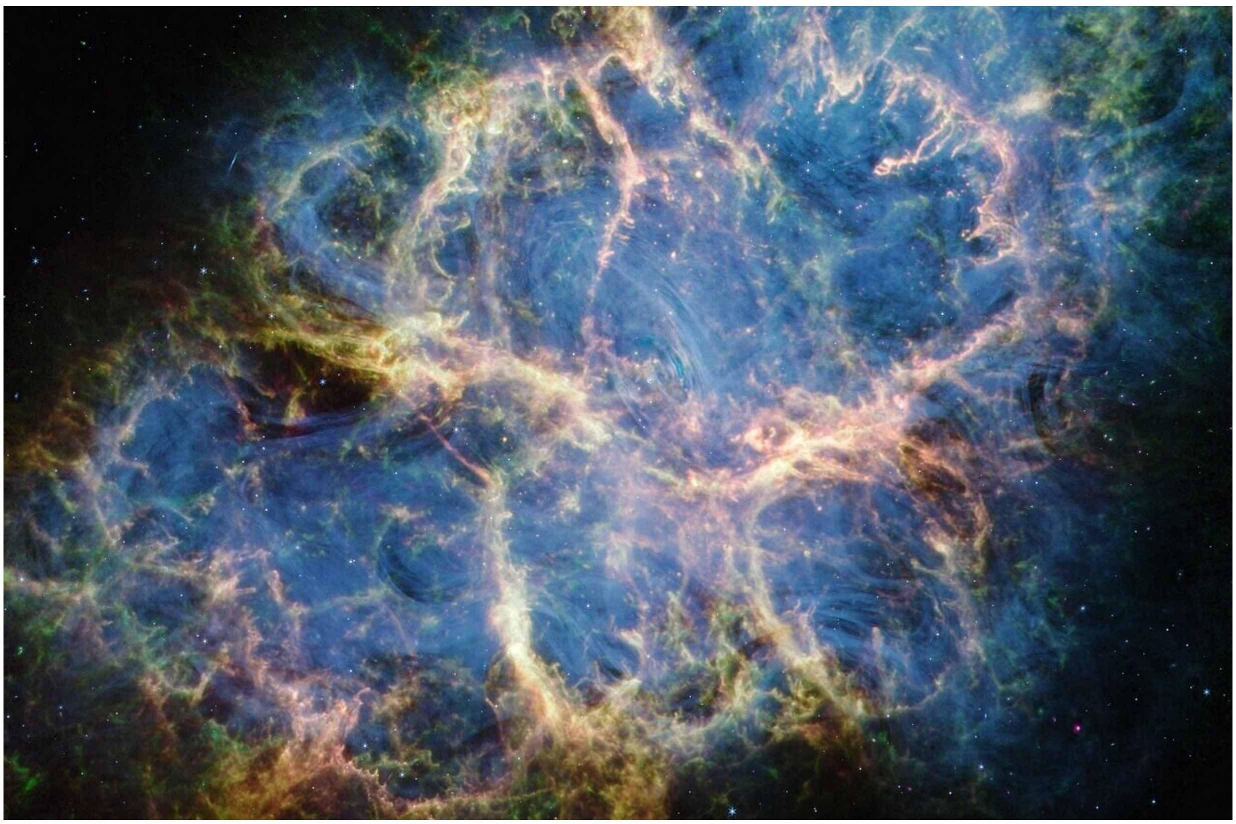

Crab Nebula (MIRI and NIRCam image). Credit: ESA/Hubble Information Centre

A team of scientists used the NASA/ESA/CSA James Webb Space Telescope to parse the composition of the Crab Nebula, a supernova remnant located 6,500 light-years away in the constellation Taurus. With the telescope's MIRI (Mid-Infared Instrument) and NIRCam (Near-Infrared Camera), the team gathered data that are helping to clarify the Crab Nebula's history.

The Crab Nebula is the result of a core-collapse supernova that was the death of a massive star. The supernova explosion itself was seen on Earth in 1054 CE and was bright enough to view during the daytime. The much fainter remnant observed today is an expanding shell of gas and dust, and an outflowing wind powered by a pulsar, a rapidly spinning and highly magnetized neutron star.

The Crab Nebula is also highly unusual. Its atypical composition and very low explosion energy have previously led astronomers to think it was an electron-capture supernova—a rare type of explosion that arises from a star with a less-evolved core made of oxygen, neon, and magnesium, rather than a more typical iron core.

Past research efforts have calculated the total kinetic energy of the explosion based on the quantity and velocities of the present-day ejecta. Astronomers deduced that the nature of the explosion was one of relatively low energy (less than one-tenth that of a normal supernova), and the progenitor star's mass was in the range of eight to 10 solar masses—teetering on the thin line between stars that experience a violent supernova death and those that do not.

However, inconsistencies exist between the electron-capture supernova theory and observations of the Crab, particularly the observed rapid motion of the pulsar. In recent years, astronomers have also improved their understanding of iron-core-collapse supernovae and now think that this type can also produce low-energy explosions, providing the stellar mass is adequately low.

To lower the level of uncertainty about the Crab's progenitor star and the nature of the explosion, the science team used Webb's spectroscopic capabilities to home in on two areas located within the Crab's inner filaments.

Theories predict that because of the different chemical composition of the core in an electron-capture supernova, the nickel to iron (Ni/Fe) abundance ratio should be much higher than the ratio measured in our sun (which contains these elements from previous generations of stars). Studies in the late 1980s and early 1990s measured the Ni/Fe ratio within the Crab using optical and near-infrared data and noted a high Ni/Fe abundance ratio that seemed to favor the electron-capture supernova scenario.

The Webb telescope, with its sensitive infrared capabilities, is now advancing Crab Nebula research. The team used MIRI's spectroscopic abilities to measure the nickel and iron emission lines, resulting in a more reliable estimate of the Ni/Fe abundance ratio. They found that the ratio was still elevated compared to the sun, but only modestly so and much lower in comparison to earlier estimates.

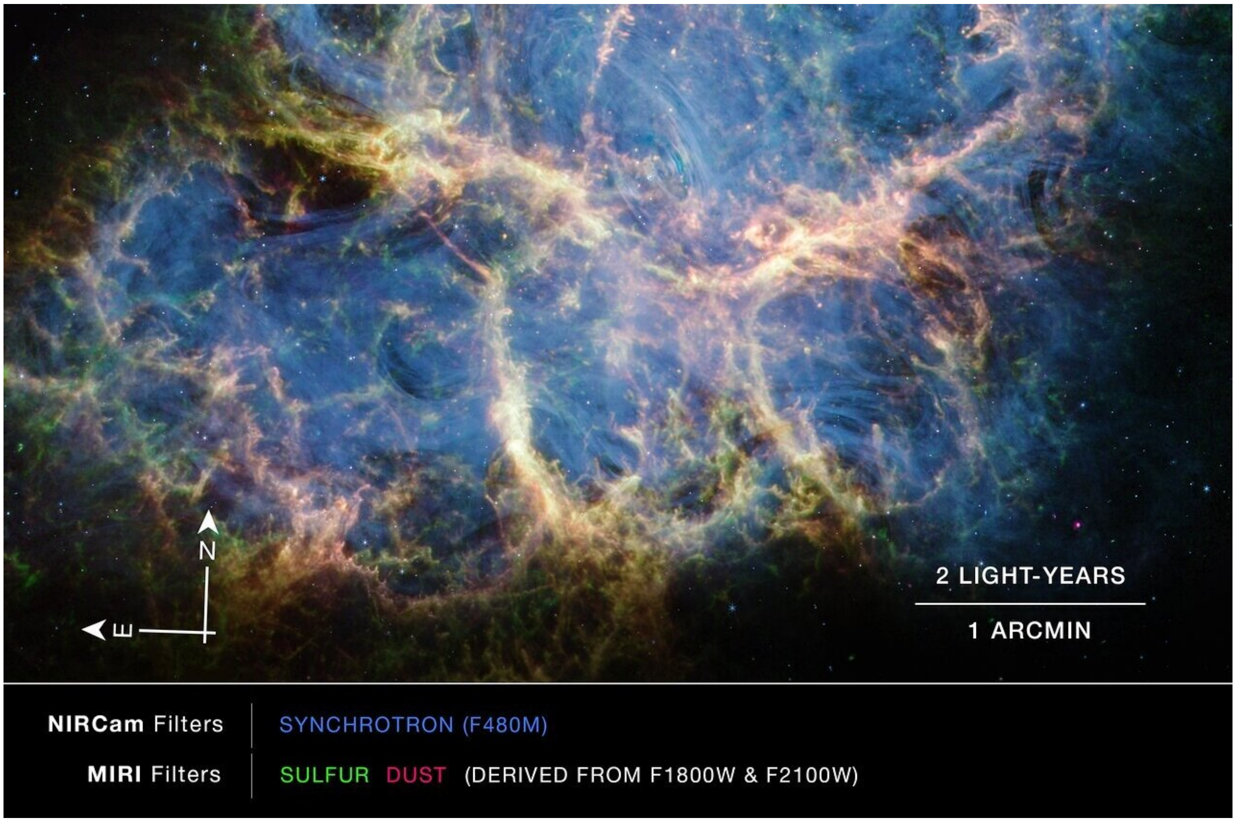

Image of the Crab Nebula captured by Webb's NIRCam and MIRI, with compass arrows, scale bar, and color key for reference. Credit: NASA, ESA, CSA, STScI, T. Temim (Princeton University)

The revised values are consistent with electron-capture, but do not rule out an iron-core-collapse explosion from a similarly low-mass star. (Higher-energy explosions from higher-mass stars are expected to produce Ni/Fe ratios closer to solar abundances.) Further observational and theoretical work will be needed to distinguish between these two possibilities.

Besides pulling spectral data from two small regions of the Crab Nebula's interior to measure the abundance ratio, the telescope also observed the remnant's broader environment to understand details of the synchrotron emission and the dust distribution.

The images and data collected by MIRI enabled the team to isolate the dust emission within the Crab and map it in high resolution for the first time. By mapping the warm dust emission with Webb, and even combining it with the Herschel Space Observatory's data on cooler dust grains, the team created a well-rounded picture of the dust distribution: the outermost filaments contain relatively warmer dust, while cooler grains are prevalent near the center.

The work is published in *The Astrophysical Journal Letters*.

More information: Tea Temim et al, Dissecting the Crab Nebula with JWST: Pulsar Wind, Dusty Filaments, and Ni/Fe Abundance Constraints on the Explosion Mechanism, *The Astrophysical Journal Letters* (2024). DOI: 10.3847/2041-8213/ad50d1

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