Deep-space discovery: Oddball gamma-ray burst forces revision of theoretical framework

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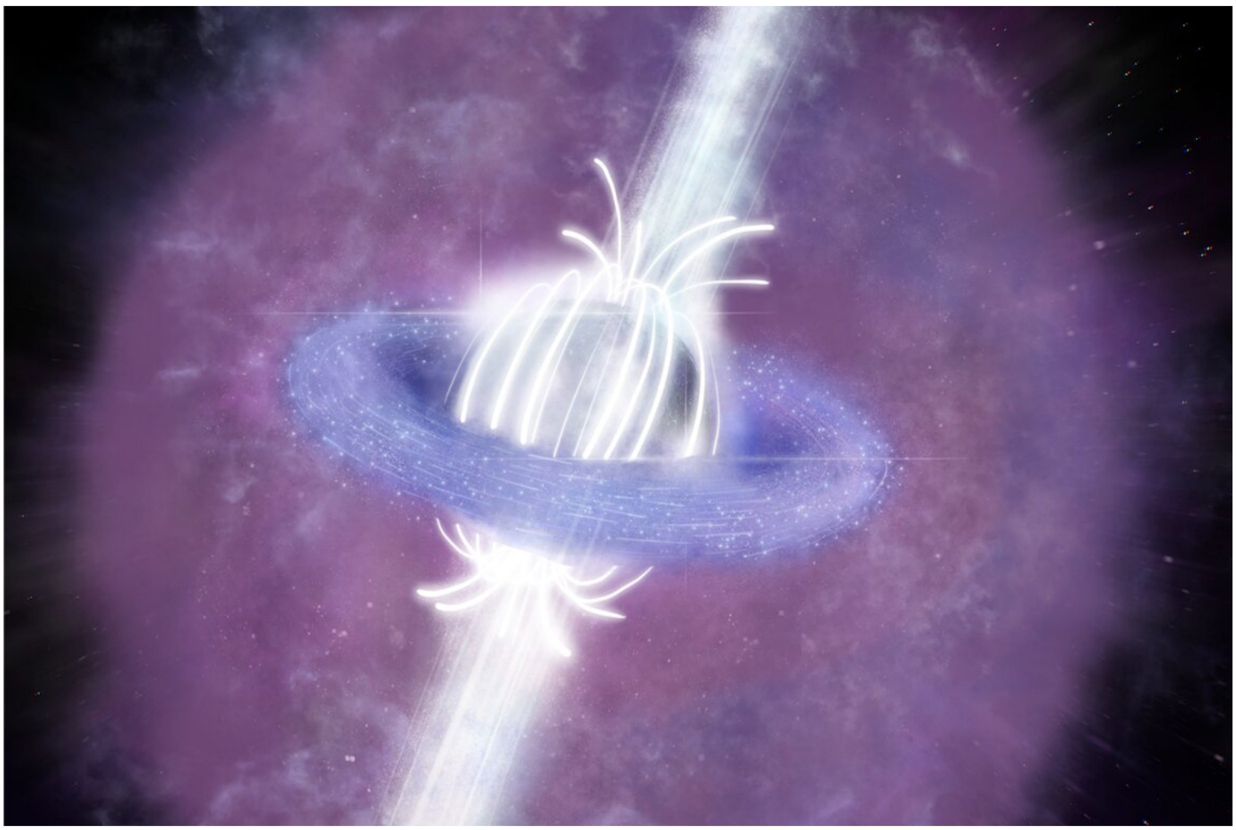

Artist rendering. Credit: Anyu Lei and Jing Chen, Nanjing University School of Arts

The mysteries of the cosmos continue to amaze astronomers, and with each new observation comes a chance to deepen—or upend—our understanding of the universe.

In the Dec. 7 issue of the journal *Nature*, an international team of astrophysicists report the discovery of a unique cosmological gamma-ray burst (GRB) that defies prevailing theories of how the violent cosmic explosions form. This "oddball" burst led the team to propose a new model, or source, for certain types of GRBs.

Gamma-ray bursts are the most luminous and violent explosions in the universe. They signify the deaths of stars or collisions of stellar remnants. Observed GRBs are typically placed into two categories: short- or long-duration GRBs. Long GRBs originate from the deaths of massive stars, and are typically associated with bright optical transients named supernovae. Short GRBs have a duration of less than two seconds and originate from the collisions of two neutron stars or a neutron star and a black hole, and are typically associated with more faint optical transients known as kilonovae.

For decades, GRBs nestled nicely into these cozy categories. Until now.

On Dec.11, 2021, a GRB triggered several gamma-ray detectors in space, including NASA's Fermi Gamma-ray Telescope and the Neil Gehrels Swift Observatory. This burst, with a duration of nearly 70 seconds, would typically be regarded as a normal long GRB. That is, until multiple teams from the U.S. and Europe performed follow-up observations and discovered a surprising signature.

"This GRB includes two parts: a 13-second long hard spike and a 55-second softer extended emission," said UNLV alumnus and study corresponding author Bin-Bin Zhang, who's currently with China's Nanjing University. "The duration of the 13-second hard spike should have completely excluded this burst from the short GRB category."

In other words, instead of showing a much brighter supernova, as expected, the observation was consistent with a kilonova that is more typically associated with a short GRB.

"Such a peculiar GRB was the first of its kind ever detected," said UNLV astrophysics professor Bing Zhang, co-corresponding-author of the *Nature* paper. "This discovery not only challenged our understanding of GRB origins, it also requires us to consider a new model for how some GRBs form."

The research team believes that this unique GRB, known as GRB 211211A, likely formed through collision between a neutron star and a white dwarf, what's known as a WD-NS merger.

White dwarfs are earth-sized objects that form from the death of low-mass stars—those with a mass smaller than that of about eight of our Suns. Neutron stars form when more massive stars, those with a mass of between about eight and 20 Suns, die off. When even larger stars die, they form black holes directly.

Massive, low-density stars make long-duration GRBs whereas high-density stars, including neutron stars, make short duration GRBs. According to UNLV's Zhang, white dwarfs have intermediate densities, which make them ideal origins for the type of GRB discovered in 2021 as it displays an intermediately long duration without involving a massive star.

"Despite the relatively large number of GRBs observed each year, the unique signature of GRB 211211A pushed the envelope of our current categorial systems and required a new way of thinking," said Zhang. "After careful review, the only merger scenario that made sense was that of a white dwarf and neutron star."

UNLV doctoral student Shunke Ai and a student from Nanjing University collaborated to develop a detailed model to interpret the peculiar kilonova signature observed by GRB 211211A. Ai found that if a WD-NS merger leaves behind a rapidly spinning neutron star, known as a magnetar, the additional energy injection from the magnetar combined with the nuclear reaction energy from the material thrown during the burst can account for the kilonova emission observed for GRB 211211A.

The study, "A long-duration gamma-ray burst with a peculiar origin", appeared Dec. 7 in the journal *Nature*. The paper includes 10 co-authors from 4 institutions, with UNLV and Nanjing University being the lead institutions. Published in the same issue are three parallel papers that report the detection of the kilonova. This paper focuses on the peculiar gamma-ray emission itself and proposes the WD-NS merger model to interpret the data.

More information: Jun Yang et al, A long-duration gamma-ray burst with a peculiar origin, *Nature* (2022). DOI: 10.1038/s41586-022-05403-8

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