

Stellar demolition derby births powerful gamma-ray burst

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Artistic illustration of a gamma-ray burst. Credit: International Gemini Observatory/NOIRLab/NSF/AURA/M. Garlick/M. Zamani

While searching for the origins of a powerful gamma-ray burst (GRB), an international team of astrophysicists may have stumbled upon a new way to destroy a star.

Although most GRBs originate from exploding massive stars or neutron-

star mergers, the researchers concluded that GRB 191019A instead came from the collision of stars or stellar remnants in the jam-packed environment surrounding a supermassive black hole at the core of an ancient galaxy. The demolition derby-like environment points to a long-hypothesized—but never-before-seen—way to demolish a star and generate a GRB.

The study was published in the journal *Nature Astronomy*. Led by Radboud University in the Netherlands, the research team included astronomers from Northwestern University.

"For every hundred events that fit into the traditional classification scheme of gamma-ray bursts, there is at least one oddball that throws us for a loop," said Northwestern astrophysicist and study co-author Wen-fai Fong, "However, it is these oddballs that tell us the most about the spectacular diversity of explosions that the universe is capable of."

"The discovery of these extraordinary phenomena within dense stellar systems, especially those encircling [supermassive black holes](#) at the cores of galaxies, is undeniably exciting," said Northwestern astrophysicist and study co-author Giacomo Fragione. "This remarkable discovery grants us a tantalizing glimpse into the intricate dynamics at work within these cosmic environments, establishing them as factories of events that would otherwise be deemed impossible."

Fong is an assistant professor of physics and astronomy at Northwestern's Weinberg College of Arts and Sciences and a member of the Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA). Fragione is a research assistant professor in CIERA. Other Northwestern co-authors include Anya Nugent and Jillian Rastinejad—both Ph.D. students in astronomy and members of Fong's research group.

Most stars die, according to their mass, in one of three predictable ways. When relatively low-mass stars like our sun reach old age, they shed their outer layers, eventually fading to become white dwarf stars. More massive stars, on the other hand, burn brighter and explode faster in cataclysmic supernovae explosions, creating ultra-dense objects like neutron stars and black holes. The third scenario occurs when two such stellar remnants form a binary system and eventually collide.

But the new study finds there might be a fourth option.

"Our results show that stars can meet their demise in some of the densest regions of the universe, where they can be driven to collide," said lead author Andrew Levan, an astronomer with Radboud University. "This is exciting for understanding how stars die and for answering other questions, such as what unexpected sources might create [gravitational waves](#) that we could detect on Earth."

Long past their star-forming prime, ancient galaxies have few, if any, remaining [massive stars](#). Their cores, however, teem with stars and a menagerie of ultra-dense stellar remnants, such as white dwarfs, neutron stars and black holes. Astronomers have long suspected that in the turbulent beehive of activity surrounding a supermassive black hole, it only would be a matter of time before two stellar objects collided to produce a GRB. But evidence for that type of merger has remained elusive.

On Oct. 19, 2019, astronomers glimpsed the first hints of such an event when NASA's Neil Gehrels Swift Observatory detected a bright flash of gamma rays that lasted a little over one minute. Any GRB lasting longer than two seconds is considered "long." Such bursts typically come from the collapse of stars at least 10 times the mass of our sun.

The researchers then used the Gemini South telescope in Chile—part of

the International Gemini Observatory operated by the National Science Foundation's NOIRLab—to make long-term observations of the GRB's fading afterglow.

These observations enabled the astronomers to pinpoint the location of the GRB to a region less than 100 light-years from the nucleus of an ancient galaxy—very near the galaxy's supermassive black hole. Curiously, the researchers also found no evidence of a corresponding supernova, which would leave its imprint on the light captured by Gemini South.

"The lack of a supernova accompanying the long GRB 191019A tells us that this burst is not a typical massive star collapse," said Rastinejad, who performed calculations to ensure a supernova was not hiding within the data. "The location of GRB 191019A, embedded in the nucleus of the host galaxy, teases a predicted but not yet evidenced theory for how gravitational-wave emitting sources might form."

In typical galactic environments, the production of long GRBs from colliding stellar remnants, such as neutron stars and black holes, is incredibly rare. The cores of ancient galaxies, however, are anything but typical, and there may be a million or more stars crammed into a region just a few light-years across.

Such extreme population density may be great enough that occasional stellar collisions can occur, especially under the titanic gravitational influence of a [supermassive black hole](#), which would perturb the motions of stars and send them careening in random directions. Eventually, these wayward stars would intersect and merge, triggering a titanic explosion that could be observed from vast cosmic distances.

"This event confounds almost every expectation we have for the environments of short and long GRBs," said Nugent, who performed

crucial modeling of the host galaxy.

"While long GRBs are never found in galaxies as old and dead as GRB 191019A's host, short GRBs, with their merger origins, have not been observed to be so connected to their hosts' nuclei. The discovery of this event in the core of its old, quiescent galaxy opens the door to promising new avenues for the formation of binary systems that have rarely been observed before."

It is possible that such events occur routinely in similarly crowded regions across the universe but have gone unnoticed until this point. A possible reason for their obscurity is that galactic centers are brimming with dust and gas, which could obscure both the initial flash of the GRB and the resulting afterglow. GRB 191019A may be a rare exception, allowing astronomers to detect the burst and study its aftereffects.

"While this event is the first of its kind to be discovered, it's possible there are more out there that are hidden by the large amounts of dust close to their galaxies," Fong said. "Indeed, if this long-duration event came from merging compact objects, it contributes to the growing population of GRBs that defies our traditional classifications."

By working to discover more of these events, the researchers hope to match a GRB detection with a corresponding gravitational-wave detection, which would reveal more about their true nature and confirm their origins—even in the murkiest of environments. The Vera C. Rubin Observatory, when it comes online in 2025, will be invaluable in this kind of research.

The study, "A long-duration gamma-ray burst of dynamical origin from the nucleus of an ancient galaxy," is published in *Nature Astronomy*.

More information: Levan, A.J., et al. A long-duration gamma-ray

burst of dynamical origin from the nucleus of an ancient galaxy. *Nature Astronomy* (2023). DOI: [10.1038/s41550-023-01998-8](https://doi.org/10.1038/s41550-023-01998-8).
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