Brightest gamma-ray burst ever observed reveals new mysteries of cosmic explosions

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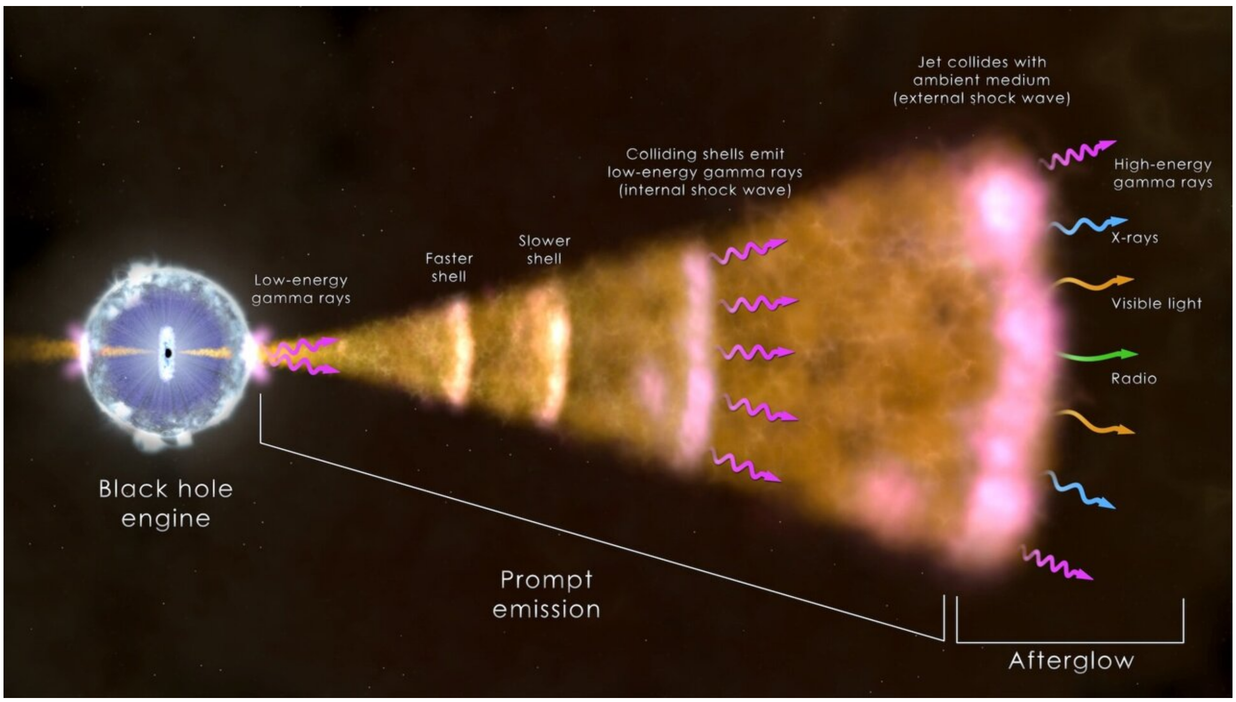

This illustration shows the ingredients of a long gamma-ray burst, the most common type. The core of a massive star (left) has collapsed, forming a black hole that sends a jet of particles moving through the collapsing star and out into space at nearly the speed of light. Radiation across the spectrum arises from hot ionized gas (plasma) in the vicinity of the newborn black hole, collisions among shells of fast-moving gas within the jet (internal shock waves), and from the leading edge of the jet as it sweeps up and interacts with its surroundings (external shock). Credit: NASA's Goddard Space Flight Center

On October 9, 2022, an intense pulse of gamma-ray radiation swept through our solar system, overwhelming gamma-ray detectors on numerous orbiting satellites, and sending astronomers on a chase to study the event using the most powerful telescopes in the world.

The new source, dubbed GRB 221009A for its discovery date, turned out to be the brightest gamma-ray burst (GRB) ever recorded.

In a new study that appears today in *Astrophysical Journal Letters*, observations of GRB 221009A spanning from radio waves to gamma-rays, including critical millimeter-wave observations with the Center for Astrophysics | Harvard & Smithsonian's Submillimeter Array (SMA) in Hawaii, shed new light on the decades-long quest to understand the origin of these extreme cosmic explosions. This study is part of a series of discoveries that are to be published as a collection in *Astrophysical Journal Letters*.

The gamma-ray emission from GRB 221009A lasted over 300 seconds. Astronomers think that such "long-duration" GRBs are the birth cry of a black hole, formed as the core of a massive and rapidly spinning star collapses under its own weight. The newborn black hole launches powerful jets of plasma at near the speed of light, which pierce through the collapsing star and shine in gamma-rays.

With GRB 221009A being the brightest burst ever recorded, a real mystery lay in what would come after the initial burst of gamma-rays. "As the jets slam into gas surrounding the dying star, they produce a bright 'afterglow' of light across the entire spectrum," says Tanmoy Laskar, assistant professor of physics and astronomy at the University of Utah, and lead author of the study. "The afterglow fades quite rapidly, which means we have to be quick and nimble in capturing the light before it disappears, taking its secrets with it."

As part of a campaign to use the world's best radio and millimeter telescopes to study the afterglow of GRB 221009A, astronomers Edo Berger and Yvette Cendes of the Center for Astrophysics (CfA) rapidly gathered data with the SMA.

"This burst, being so bright, provided a unique opportunity to explore the detailed behavior and evolution of an afterglow with unprecedented detail—we did not want to miss it," says Edo Berger, professor of astronomy at Harvard University and the CfA. "I have been studying these events for more than twenty years, and this one was as exciting as the first GRB I ever observed."

"Thanks to its rapid-response capability, we were able to quickly turn the SMA to the location of GRB 221009A," says SMA project scientist and CfA researcher Garrett Keating. "The team was excited to see just how bright the afterglow of this GRB was, which we were able to continue to monitor for more than 10 days as it faded."

After analyzing and combining the data from the SMA and other telescopes all over the world, the astronomers were flummoxed: The millimeter and radio wave measurements were much brighter than expected based on the visible and X-ray light.

"This is one of the most detailed datasets we have ever collected, and it is clear that the millimeter and radio data just don't behave as expected," says CfA research associate Yvette Cendes. "A few GRBs in the past have shown a brief excess of millimeter and radio emission that is thought to be the signature of a shockwave in the jet itself, but in GRB 221009A the excess emission behaves quite differently than in these past cases."

She adds, "It is likely that we have discovered a completely new mechanism to produce excess millimeter and radio waves."

One possibility, says Cendes, is that the powerful jet produced by GRB 221009A is more complex than in most GRBs. "It is possible that the visible and X-ray light are produced by one portion of the jet, while the early millimeter and radio waves are produced by a different component."

"Luckily, this afterglow is so bright that we will continue to study its radio emission for months and maybe years to come," adds Berger. "With this much longer time span, we hope to decipher the mysterious origin of the early excess emission."

Independent of the exact details of this particular GRB, the ability to respond rapidly to GRBs and similar events with millimeter-wave telescopes is an essential new capability for astronomers.

"A key lesson from this GRB is that without fast-acting radio and millimeter telescopes, such as the SMA, we would miss out on potential discoveries about the most extreme explosions in the universe," says Berger. "We never know in advance when such events will occur, so we have to be as responsive as possible if we're going to take advantage of these gifts from the cosmos."

More information: Maia A. Williams et al, GRB 221009A: Discovery of an Exceptionally Rare Nearby and Energetic Gamma-Ray Burst, *Astrophysical Journal Letters* (2023). DOI: 10.3847/2041-8213/acbcd1. iopscience.iop.org/article/10. … 847/2041-8213/acbcd1

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