What made the brightest cosmic explosion of all time so exceptional?

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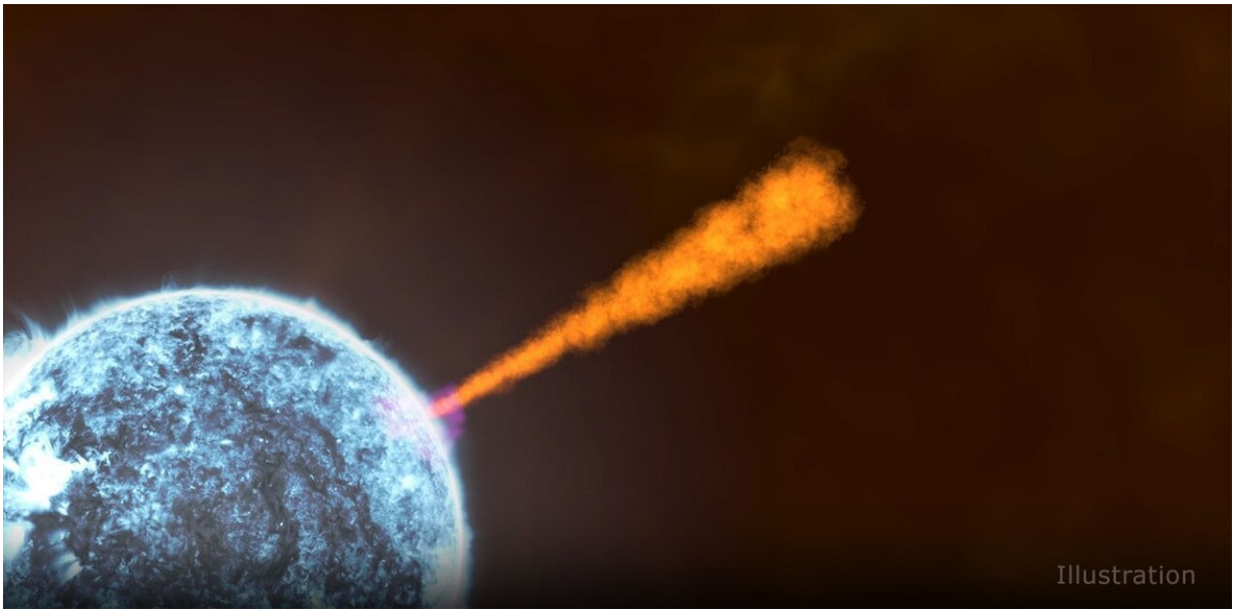

A jet of particles pierces a star as it collapses into a black hole during a typical gamma-ray burst, as depicted in this artist's concept. The jet created by gamma-ray burst 221009A had some unique features. Credit: NASA's Goddard Space Flight Center

Few cosmic explosions have attracted as much attention from space scientists as the one recorded on October 22 last year and aptly named the Brightest of All Time (BOAT). The event, produced by the collapse of a highly massive star and the subsequent birth of a black hole, was witnessed as an immensely bright flash of gamma rays followed by a

slow-fading afterglow of light across frequencies.

Since picking up the BOAT signal simultaneously on their giant telescopes, astrophysicists the world over have been scrambling to account for the brightness of the gamma-ray burst (GRB) and the curiously slow fade of its afterglow.

Now an international team that includes Dr. Hendrik Van Eerten from the Department of Physics at the University of Bath in the U.K. has formulated an explanation: the initial burst (known as GRB 221009A) was angled directly at Earth and it also dragged along an unusually large amount of stellar material in its wake.

The team's findings are published June 7 in the journal *Science Advances*. Dr. Brendan O'Connor, a newly graduated doctoral student at the University of Maryland and George Washington University in Washington, DC, is the study's lead author.

Dr. Van Eerten, who co-led the theoretical analysis of the afterglow, said, "Other researchers working on this puzzle have also come to the conclusion that the jet was pointed directly at us—much like a garden hose angled to spray straight at you—and this definitely goes some way to explain why it was seen so brightly."

But what remained a puzzle was that the edges of the jet could not be seen at all.

"The slow fade of the afterglow is not characteristic of a narrow jet of gas, and knowing this made us suspect there was an additional reason for the intensity of the explosion, and our mathematical models have borne this out.

"Our work clearly shows that the GRB had a unique structure, with

observations gradually revealing a narrow jet embedded within a wider gas outflow where an isolated jet would normally be expected."

So what made this GRB wider than normal? The researchers have a theory. As Dr. Van Eerten explained, "GRB jets need to go through the collapsing star in which they are formed, and what we think made the difference in this case was the amount of mixing that happened between the stellar material and the jet, such that shock-heated gas kept appearing in our line of sight all the way up to the point that any characteristic jet signature would have been lost in the overall emission from the afterglow."

He added, "Our model helps not just to understand the BOAT, but also previous brightness record holders that had astronomers mystified about their lack of jet signature. These GRBs, like other GRBs, must be directed straight towards us when they happen, as it would be unphysical for that much energy to be expelled in all directions at once.

The Hubble Space Telescope captured the infrared afterglow (circled) of the gamma-ray burst known as GRB 221009A and its host galaxy. This composite incorporates images taken Nov. 8 and Dec. 4, 2022, about one and two months after the eruption. The afterglow may remain detectable for several years. Credit: NASA

"An exceptional class of events appears to exist that are both extreme and manage to mask the directed nature of their gas flow. Future study into the magnetic fields that launch the jet and into the massive stars that host them should help reveal why these GRBs are so rare."

Dr. O'Connor said, "The exceptionally long GRB 221009A is the brightest GRB ever recorded and its afterglow is smashing all records at all wavelengths. Because this burst is so bright and also nearby (cosmically speaking: it occurred at the minor distance of 2.4 billion light years from Earth), we think this is a once-in-a-thousand-year opportunity to address some of the most fundamental questions regarding these explosions, from the formation of black holes to tests of dark matter models."

More information: Brendan O'Connor et al, A structured jet explains the extreme GRB 221009A, *Science Advances* (2023). DOI: 10.1126/sciadv.adi1405. www.science.org/doi/10.1126/sciadv.adi1405

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