NCRA – TIFR Press Note English – 28th March 2023

GMRT Observations Question Decades-Long Understanding of Gamma Ray Bursts

On Sunday, Oct. 9, 2022, a pulse of intense gamma-ray radiation swept through our solar system, saturating detectors on numerous spacecraft, and sending astronomers across the world scurrying to train the fastest and most powerful telescopes on it. The new source, dubbed GRB 221009A, turned out to be the brightest gamma-ray burst (GRB) ever observed. In a new study that appears in the Astrophysical Journal Letters, radio observations of this exceptional event with GMRT have questioned our decades-long understanding of how these events explode into their multi-coloured fireworks.

The gamma-ray emission from GRB221009A lasted over 300 seconds and was the brightest ever observed for a GRB, marking this as an exceptional and exciting new event. Astronomers think that such "long-duration" GRBs are the birth cry of a black hole, formed as the core of a massive 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 known so far, a real mystery lay in what would come after the initial burst of gamma-rays. "As the jets slam into the gas surrounding the dying star, a bright ‘afterglow’ of light is produced across the entire spectrum," said Tanmoy Laskar, Assistant Professor of Physics and Astronomy at the University of Utah, and lead author of the study. "The afterglows of GRBs fade quite rapidly, which means we had to be quick and nimble in capturing the light before it disappeared, taking its secrets with it."

Laskar and his colleagues quickly triggered observing programs on the Giant Metrewave Radio Telescope (GMRT), as well as a slew of other facilities, including the MeerKAT Array in South Africa, the US National Science Foundation's Karl G. Jansky Very Large Array (VLA) in New Mexico (USA), the Atacama Large Millimeter Array (ALMA) in Chile, and the Submillimeter Array (SMA) in Hawai'i. The radio observations collected by the researchers now comprise one of the most detailed such data sets for a GRB afterglow date.

On analyzing and combining the data from all these telescopes, the astronomers were flummoxed: the radio measurements were brighter than expected based on the X-ray and visible light of this afterglow. "At first we were very excited because we thought we might have captured the fleeting signature of a `reverse shock' - a shock wave going backwards through the jet and lighting it up in the radio," said Kate Alexander, Assistant Professor of Astronomy at the University of Arizona and co-author of the study. While such a signature has been predicted to show up at radio frequencies, its presence has only been confirmed in a few cases. Catching one now in the brightest GRB ever could have helped the researchers pin down the composition of the GRB's jets, a puzzle that remains poorly understood to this day.

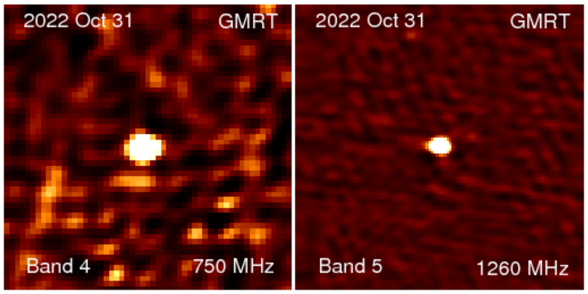
"What we found in the radio looks a bit like a reverse shock in the sense that there is extra emission at radio frequencies," said Laskar. "But we also have models for how a reverse shock spectrum should evolve with time, and the radio spectrum of GRB 221009A faded much too slowly. So either we don't understand reverse shocks, or we've found a completely new emission component."

"Our GMRT observations were essential for this study", said Alexander, "because, when combined with the rest of the data, they were key in pinning down the peak frequency and peak brightness of this emission component. From that, we were able to calculate that the outflow producing this light must consist of a small amount of mass moving at about 99.4% of the speed of light."

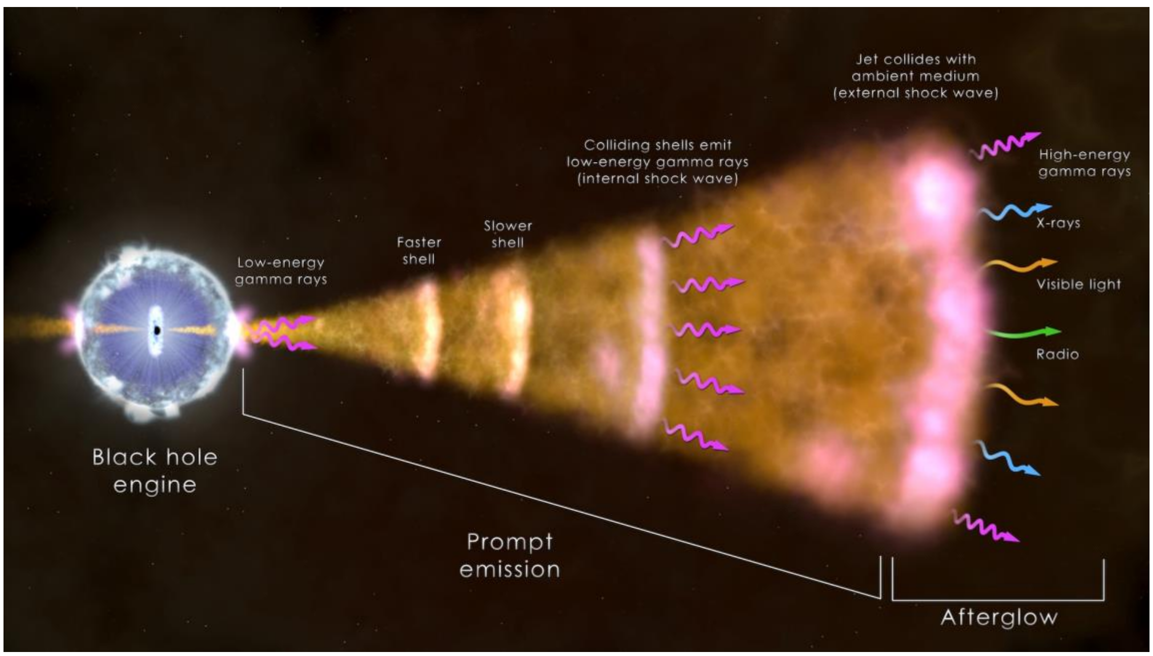
While that's fast even for most astrophysical objects, it's actually much slower than other GRB jets. "We think that there is still a very fast-moving jet that is generating the X-ray and visible light in this afterglow," said Raffaella Margutti, Associate Professor of Astronomy and Physics at the University of California, Berkeley, and co-author of the study. "But our modeling suggests that something else entirely is creating the radio light." Either that, or astronomers' understanding of how GRB jets produce light is about to be overturned. In both cases, these GMRT observations imply that a decades-old theory of GRB jets needs to be revisited.

"We still don't know what is producing the radio emission, but we are still collecting data, and it's possible that some more theoretical investigations and numerical simulations together could help us in deriving a better understanding," added Margutti. "But for now it's still a bit of a mystery."

"Without GMRT, we would still be grasping in the dark with many levels of uncertainty in this new emission component," Laskar concluded. "While we may have to go back to the drawing board to hash out what is going on, thanks to GMRT, we have an excellent starting point from a fantastic set of measurements."



The radio afterglow of GRB 221009A observed with GMRT in Band 4 (750 MHz; left image) and Band 5 (1260 MHz; right image) on 31 Oct 2022, 22 days after the burst. The afterglow is clearly seen as a point-like source at the center in both images. Tracking the brightness of this afterglow with time allowed the researchers to discover a new component in the radio emission of this energetic stellar explosion.
Credit: T. Laskar, K. Alexander, NCRA/GMRT.



Caption: This illustration shows the ingredients of the most common type of gamma-ray burst. 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 near 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

More visualation material available at https://svs.gsfc.nasa.gov/14227

Youtube animation available at https://www.youtube.com/watch?v=nwZSO6ULI2o

Additional Information

"The Radio to GeV Afterglow of GRB 221009A," Laskar et al (2023), The Astrophysical Journal Letters, (https://iopscience.iop.org/journal/2041-8205/acbfad)

GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research, India under the Department of Atomic Energy.

The MeerKAT telescope is operated by the South African Radio Astronomy Observatory, which is a facility of the National Research Foundation, an agency of the Department of Science and Innovation.

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada), MOST and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ.

The Submillimeter Array is a joint project between the Smithsonian Astrophysical Observatory and the Academia Sinica Institute of Astronomy and Astrophysics and is funded by the Smithsonian Institution and the Academia Sinica. We recognize that Maunakea is a culturally important site for the indigenous Hawaiian people; we are privileged to study the cosmos from its summit.

This work made use of data from the NuSTAR mission, a project led by the California Institute of Technology, managed by the Jet Propulsion Laboratory, and funded by the National Aeronautics and Space Administration.

Contacts:

Tanmoy Laskar, University of Utah (tanmoy.laskar@utah.edu)
Kate D. Alexander, University of Arizona (kdalexander@arizona.edu)
Yashwant Gupta (ygupta@ncra.tifr.res.in); Phone: 020-25719242
Nissim Kanekar (nkanekar@ncra.tifr.res.in); Phone: 020-25719246,
CH. Ishwara-Chandra (ishwar@ncra.tifr.res.in); Phone: 020-25719228
J. K. Solanki (solanki@ncra.tifr.res.in); Mobile: 9890447888
Anil Raut (anil@gmrt.ncra.tifr.res.in); Mobile: 8605525945