Astrophysics research advances understanding of how gamma-ray bursts produce light

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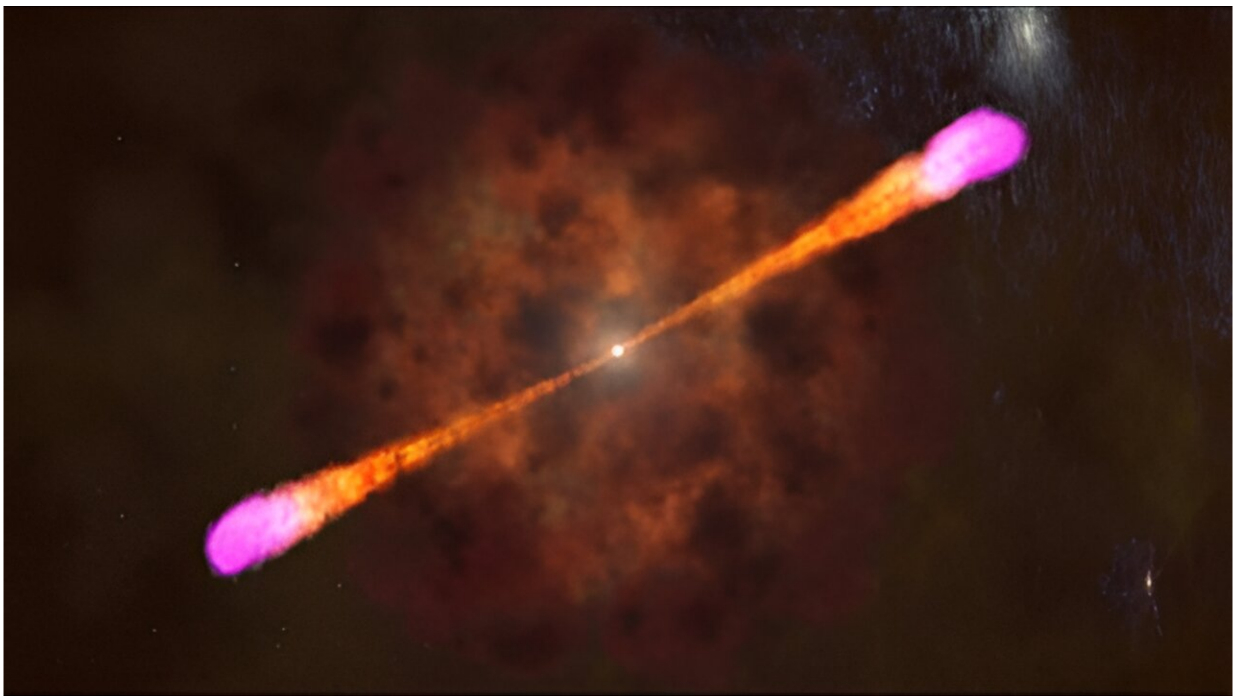

Artist concept of a jet of particles piercing a star as it collapses into a black hole during a typical gamma-ray burst (GRB). GRBs are the most energetic and luminous electromagnetic events since the Big Bang. Credit: NASA

Gamma-ray bursts (GRBs) are intense bursts of gamma radiation, typically generating more energy in a few seconds than the sun will produce over its ten-billion-year lifetime. These transient phenomena present one of the most challenging puzzles in astrophysics, dating back to their accidental discovery in 1967 by a nuclear surveillance satellite.

Dr. Jon Hakkila, a researcher from The University of Alabama in Huntsville (UAH), a part of the University of Alabama System, is lead author on a paper in *The Astrophysical Journal* that promises to shed light on the behavior of these mysterious cosmic powerhouses by focusing on the motion of the jets where these forces originate. The paper is co-authored by UAH alumnus Dr. Timothy Giblin, Dr. Robert Preece and Dr. Geoffrey Pendleton of deciBel Research, Inc.

"Despite being studied for over fifty years, the mechanisms by which GRBs produce light are still unknown, a great mystery of modern astrophysics," Hakkila explains. "Understanding GRBs helps us understand some of the most rapid and powerful light-producing mechanisms that Nature employs. GRBs are so bright, they can be seen over the breadth of the universe, and—because light travels at a finite velocity—they allow us to see back to the earliest times that stars existed."

One reason for the mystery is the inability of theoretical models to provide consistent explanations of GRB characteristics for their light-curve behaviors. In astronomy, a light curve is a graph of the light intensity of a celestial object as a function of time. Studying light curves can yield significant information about the physical processes that produce them, as well as help define the theories about them. No two GRB light curves are identical, and the duration of emission can vary from milliseconds to tens of minutes as a series of energetic pulses.

"Pulses are the basic units of GRB emission," Hakkila says. "They indicate times when a GRB brightens and subsequently fades away. During the time a GRB pulse emits, it undergoes brightness variations that can sometimes occur on very short timescales. The strange thing about these variations is that they are reversible in the same way words like 'rotator' or 'kayak' (palindromes) are reversible.

"It is very hard to understand how this can happen, since time moves in only one direction. The mechanism that produces light in a GRB pulse somehow produces a brightness pattern, then subsequently generates this same pattern in reverse order. That is pretty weird, and it makes GRBs unique."

GRB emission is generally assumed to occur within relativistic jets —powerful streams of radiation and particles—launched from newly-formed black holes.

"In these models, the core of a dying massive star collapses to form a black hole, and material falling into the black hole is torn apart and redirected outward along two opposing beams, or jets," Hakkila notes. "The jet material pointing in our direction is ejected outward at nearly the speed of light. Since the GRB is relatively short-lived, it has always been assumed that the jet remains pointing at us throughout the event. But the time-reversed pulse characteristics have been very hard to explain if they originate from within a nonmoving jet."

To help demystify these characteristics, the paper proposes adding motion to the jet.

"The idea of a laterally-moving jet provides a simple solution by which time-reversed GRB pulse structure can be explained," the researcher says. "As the jet crosses the line-of-sight, an observer will see light produced first by one side of the jet, then the jet center, and finally the other side of the jet. The jet will brighten and then get fainter as the jet center crosses the line-of-sight, and radially-symmetric structure around the jet's core will be seen in reverse order as the jet gets fainter."

The rapid expansion of gamma-ray burst jets, coupled with the motion of the jet's "nozzle" relative to an observer, works to help illuminate the structure of GRB jets.

"Jets must spray material similar to the way a fire hose sprays water," Hakkila says. "The jet behaves more like a fluid than a solid object, and an observer who could see the entire jet would see it as being curved rather than straight. The motion of the nozzle causes light from different parts of the jet to reach us at different times, and this can be used to better understand the mechanism by which the jet produces light, as well as a laboratory for studying the effects of special relativity."

More information: Jon Hakkila et al, Gamma-Ray Burst Pulses and Lateral Jet Motion, *The Astrophysical Journal* (2024). DOI: 10.3847/1538-4357/ad2f26

Provided by University of Alabama in Huntsville

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