Space scientists solve a decades-long gamma-ray burst puzzle

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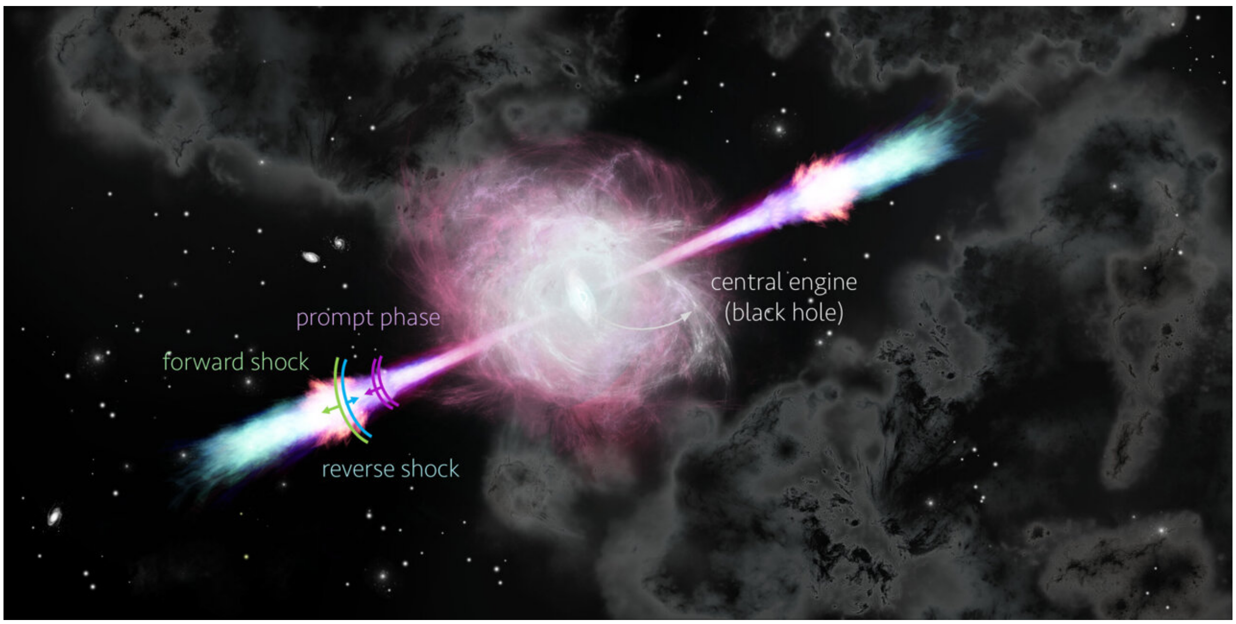

Impression of a GRB outflow showing the prompt phase (gamma-ray flash), reverse shock and forward shock. Credit: Nuria Jordana-Mitjans

An international team of scientists, led by astrophysicists from the University of Bath in the UK, has measured the magnetic field in a far-off Gamma-Ray Burst, confirming for the first time a decades-long theoretical prediction—that the magnetic field in these blast waves becomes scrambled after the ejected material crashes into, and shocks, the surrounding medium.

Black holes are formed when massive stars (at least 40 times larger than our Sun) die in a catastrophic explosion that powers a blast wave. These extremely energetic events drive out material at velocities close to the speed of light, and power bright, short-lived gamma-ray flashes that can be detected by satellites orbiting the Earth—hence their name, Gamma-Ray Bursts (GRBs).

Magnetic fields may be threaded through the ejected material and, as the spinning black hole forms, these magnetic fields twist into corkscrew shapes that are thought to focus and accelerate the ejected material.

The magnetic fields can't be seen directly, but their signature is encoded in the light produced by charged particles (electrons) that whiz around the magnetic field lines. Earth-bound telescopes capture this light, which has travelled for millions of years across the Universe.

Head of Astrophysics at Bath and gamma-ray expert Professor Carole Mundell, said: "We measured a special property of the light—polarisation—to directly probe the physical properties of the magnetic field powering the explosion. This is a great result and solves a long-standing puzzle of these extreme cosmic blasts—a puzzle I've been studying for a long time."

Capturing the light early

The challenge is to capture the light as soon as possible after a burst and decode the physics of the blast, the prediction being that any primordial magnetics fields will ultimately be destroyed as the expanding shock front collides with the surrounding stellar debris.

This model predicts light with high levels of polarisation (>10%) soon after the burst when the large-scale primordial field is still intact and driving the outflow. Later, the light should be mostly unpolarised as the field is scrambled in the collision.

Mundell's team was first to discover highly polarised light minutes after the burst that confirmed the presence of primordial fields with large-scale structure. But the picture for expanding forward shocks has proved more controversial.

Teams who observed GRBs in slower time—hours to a day after a burst—found low polarisation and concluded the fields had long-since been destroyed, but could not say when or how. In contrast, a team of Japanese astronomers announced an intriguing detection of 10% polarised light in a GRB, which they interpreted as a polarised forward shock with long-lasting ordered magnetic fields.

Lead author of the new study, Bath Ph.D. student Nuria Jordana-Mitjans, said: "These rare observations were difficult to compare, as they probed very different timescales and physics. There was no way to reconcile them in the standard model."

The mystery remained unsolved for over a decade, until the Bath team's analysis of GRB 141220A.

In the new paper, published today in the *Monthly Notices of the Royal Astronomical Society*, Professor Mundell's team report the discovery of very low polarisation in forward-shock light detected just 90 seconds after the blast of GRB 141220A. The super-speedy observations were made possible by the team's intelligent software on the fully autonomous robotic Liverpool Telescope and the novel RINGO3 polarimeter—the instrument that logged the GRB's colour, brightness, polarisation and rate of fade. Putting together this data, the team was able to prove that:

- The light originated in the forward shock.
- The magnetic field length scales were much smaller than the

Japanese team inferred.

- The blast was likely powered by the collapse of ordered magnetic fields in the first moments of the formation of a new black hole.
- The mysterious detection of polarisation by the Japanese team could be explained by a contribution of polarised light from the primordial magnetic field before it was destroyed in the shock.

Ms Jordana-Mitjans said: "This new study builds on our research that has shown the most powerful GRBs can be powered by large-scale ordered magnetic fields, but only the fastest telescopes will catch a glimpse of their characteristic polarisation signal before they are lost to the blast."

Professor Mundell added: "We now need to push the frontiers of technology to probe the earliest moments of these blasts, capture statistically significant numbers of bursts for polarisation studies and put our research into the wider context of real-time multimessenger follow-up of the extreme Universe."

More information: N Jordana-Mitjans et al, Coherence scale of magnetic fields generated in early-time forward shocks of GRBs, *Monthly Notices of the Royal Astronomical Society* (2021). DOI: 10.1093/mnras/stab1003

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