New Evidence Supporting Magnetar Origin of GRBs

By SONG Jianlan

How gamma-ray bursts (GRBs), the most powerful and spectacular explosions known in the universe since the Big Bang, fuel their high-energy radiations? What kind of physical reactions can trigger and sustain such violent, energetic outflow? This has captivated astronomers. Over the past decades, thousands of GRBs have been observed; however, the origin and the product of the burst – the central celestial body, or the "central engine", is still pending for identification.

Possible Mechanisms

Different models have been proposed to fathom this mystery. Blackholes, with their horrible, disruptive pulls on subjects within their gravitational reach, could accrete the ambient matter to form rapidly spinning, hot accreting disks; this accretion, according to some theoretical analyses, can trigger relativistic jets and hence could launch a GRB. Besides, a type of highly magnetized neutron stars, which keep spinning at millisecond periods and hence got the name millisecond magnetars, are also suggested to be possible "central engines" for both long and short GRBs. Their extremely strong magnetic fields, trillions of times stronger than the Earth's, can release a large amount of magnetic energy to support the bursts. Particularly, some interesting spectral features in the X-ray afterglow of some short GRBs indirectly indicated that at their centers could exist magnetars. These magnetars, astronomers reckon, might have emerged from the merging of binary compact object systems, like neutron stars. Still, however, "smoking gun" evidence remains missing for this scenario, and some theories challenged this model. Multi-waveband observations and comprehensive analyses are hence awaited to address this issue.

The Progenitor

Now new findings might fill the gap. The synergic observations by the Lobster Eye Imager for Astronomy (LEIA), an experimental pathfinder for the scientific satellite Einstein Probe (EP), and GECAM, the Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor, both run by the Chinese Academy of Sciences, offer clear-cut evidence to support the magnetar model. The result, published online on December 16 in the journal *National Science Review*, indicates that a millisecond magnetar could have risen from the merging of two compact objects, probably neutron stars, and triggered the flashes of GRB 230307A, a peculiar, extremely bright GRB detected on March 7, 2023.

The two instruments captured the prompt emission of the event from different wavebands – LEIA from soft X-ray band and GECAM from hard X-ray and soft gamma-ray bands, covering a wide range of energies from 0.5 to 6,000 keV. After a comprehensive analysis of the observational data from GRB 230307A and the significant offset of its location from the host galaxy, the authors found that the features of the prompt emission are consistent with that of a binary compact-star merger, which are also consistent with the findings of a kilonova associated with this event.

When the gamma-ray emission died out, the team noticed, an extended X-ray "plateau" showed up, lasting much longer than the gamma-ray emission. This indicates an emission source distinctive from that of the gamma rays.

Magnetar Engine

After modeling analysis, the team determined that the behavior of the X-ray component is consistent with the magnetic dipole radiation from a newborn, rapidly spinning magnetar. According to

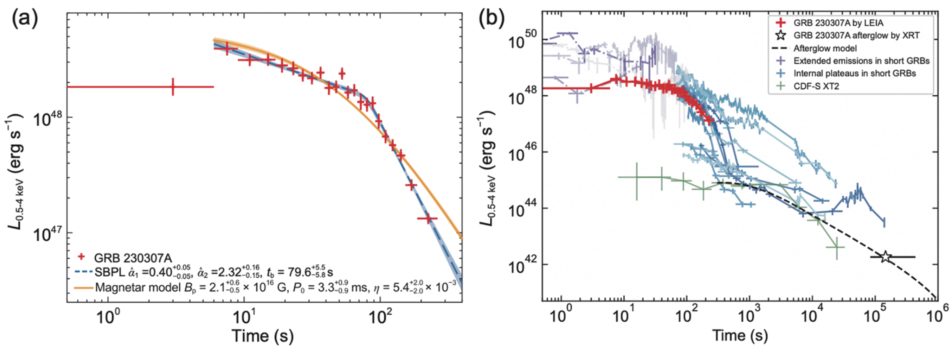

Figure 1: The X-ray light curve of GRB 230307A in comparison with the modeling result of the radiation from a magnetar as the central engine (Sun *et al*, 2024). The team found consistency between the observed and the theoretical results.

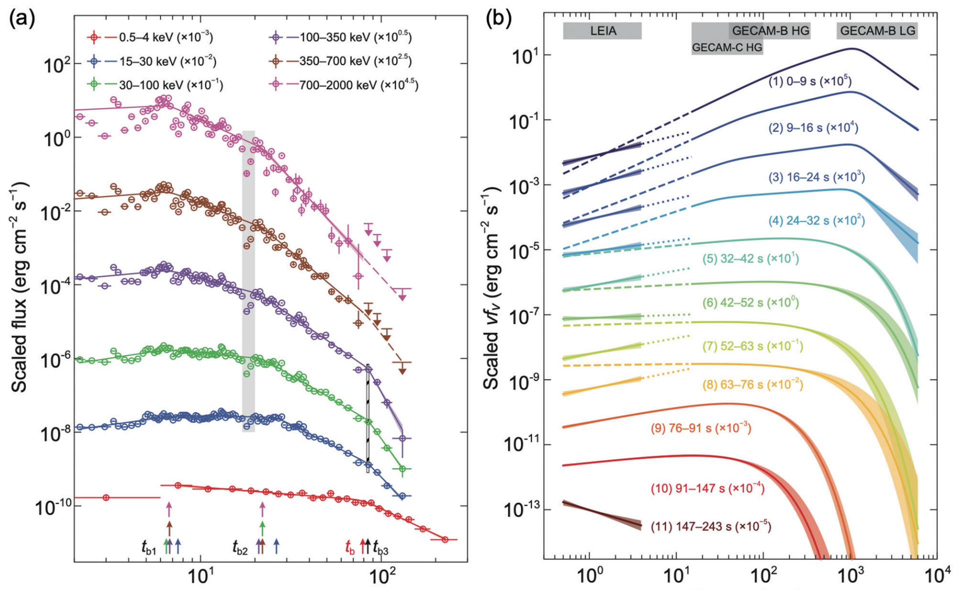

Figure 2: Multi-band light curve and spectral energy distribution obtained by the coordinated observation by LEIA and GECAM. (Sun *et al*, 2024)

Dr. SUN Hui from the National Astronomical Observatories of CAS (NAOC), co-first author of the paper, the violent merger could have left behind a magnetar and triggered relativistic jets to produce the high energy gamma rays. The long-lasting X-ray radiations could have been powered by the consequent magnetar wind dissipation. In conclusion, the new-born magnetar could have worked as the central engine for the GRB.

The team also identified an achromatic temporal break in the high-energy band during the prompt emission. This phenomenon, never observed before, revealed the appearance of a narrow jet thrusting from the source to power the gamma-ray emission, they analyzed.

All in all, the entire spectral energy distribution of the prompt emission can be interpreted as a combination of the prompt emission that declines quickly at low energies, and the overlapping X-ray emission from the newborn magnetar.

The findings might inspire examinations into other GRB events, and later research in the nature of the matter in neutron stars, providing valuable constraints on some parameters. Prof. ZHANG Binbin from Nanjing University (NJU), also a co-corresponding author of the paper, comments: "The discovery of GRB 230307A demonstrates that many mysteries of gamma-ray bursts remain unsolved in the soft X-ray domain. This is precisely where the Einstein Probe mission can showcase its full potential, and it is doing so."

LEIA and GECAM

"The data obtained by LEIA are highly valuable. It successfully captured the prompt emission of the GRB 230307A, and revealed the special properties of the burst," comments Prof. YUAN Weimin, principal investigator of EP and a researcher of NAOC. "This discovery not only has demonstrated that GRBs can have magnetar central engines, but also provided important clues for research into the nature, formation, and evolution of compact celestial bodies," he adds.

"As an experimental module of EP, the flight of LEIA means a lot," says Prof. LING Zhixing from NAOC. LING is the chief engineer in charge of LEIA and a co-corresponding author of the paper. "The flight offered the wide-field X-ray telescope (WXT) now carried by EP an opportunity for in-orbit calibration and tests, which helped secure that the WXT performs as expected in space."

"The GRB 230307A is a second extremely bright GRB detected by GECAM following its accurate measurement of the GRB 221009A, the brightest-ever GRB observed by humans," introduces co-corresponding author Prof. XIONG Shaolin, a researcher from the Institute of High Energy Physics (IHEP) and the principal investigator of GECAM. "Of note, GECAM first detected the GRB 230307A and swiftly shared the alert with the international astronomical community. This has made possible the coordinated observations across the globe," he irritates.

This research has joined forces from three institutions under CAS, including NAOC, IHEP and the Purple Mountain Observatory, and cooperators from NJU of China and University of Nevada, Las Vegas of the USA.

Both EP and GECAM are initiated and supported by CAS under its Strategic Priority Program on Space Science; and both have listed in their scientific objectives the detection and observation on electromagnetic counterparts of gravitational wave sources. EP is meanwhile supported by the European Space Agency (ESA) as a mission of opportunity; the Max Planck Institute for Extraterrestrial Physics and the Centre National d'Études Spatiales in France also participate in the project as a cooperator. Powered with Lobster-eye micro-pore optics, a state-of-the-art wide-field X-ray focusing imaging technology, the WXT module onboard LEIA is developed by CAS, and ESA contributes to the development via provision of independent tests, calibration of the devices and mirror assembly.

Reference

Sun, H., Wang, C., Yang, J., *et al*. (2025) Magnetar emergence in a peculiar gamma-ray burst from a compact star merger. *National Science Review*, 12(3), nwae401. doi:10.1093/nsr/nwae401