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Unveiling the Kilonova of GRB 211211A: A Unique Long-Duration Gamma-Ray Burst from a Compact Object Merger

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Abstract
GAMMA-ray bursts (GRBs) are among the most fascinating phenomena in modern high-energy astrophysics. In the late 1960s, the Vela military satellite system made an unexpected discovery of GRBs. The GRBs are classified into two types: short GRBs and long GRBs. In this study, we examined a lengthy GRB, 211211A. The data were examined with several astrological techniques. We present the detection of a kilo nova connected with the close (350 Mpc) minute-duration GRB 211211A. The finding of a kilo nova at 17.7 days post-burst proves that the burst's progenitor was a compact object merger, as deep optical limits rule out the presence of an accompanying supernova with MI> −13 mag. GRB 211211A's gamma-ray light curve resembles prior extended emission short GRBs (EE-SGRBs), but its prompt, brilliant spikes endure ≳12 s, distinguishing it from earlier EE-SGRBs. GRB 211211A's kilo nova is identical in intensity, duration, and color to AT2017gfo, which was discovered in conjunction with the gravitational wave (GW)-detected binary neutron star (BNS) merger GW170817.

Keyword: *GRBs, Long-GRBs, Kilonovaassociate GRBs.*

1. Introduction

1.1 Gamma-Ray Bursts

Gamma-ray bursts (GRBs) are among the universe's most energetic occurrences, with strong bursts of gamma rays lasting milliseconds to many minutes. GRBs are generally divided into two groups: [1]

- **Short-duration GRBs:** Typically lasting less than 2 seconds, these are caused by the merger of compact objects such as neutron stars or a neutron star and a black hole.
- **Long-duration GRBs:** These last more than 2 seconds and are typically associated with the collapse of massive stars (collapses), which are frequently followed by a supernova.
- **Kilonova:** The aftermath of neutron star mergers Kilonova are transitory astronomical occurrences that occur when two neutron stars merge and produce heavy elements via rapid neutron capture (r-process) nucleosynthesis.
- These events generate light at a variety of wavelengths, including optical and infrared, and are commonly associated with short duration GRBs.

1.2 GRB 211211A: A Paradigm Shift

GRB 211211A is an outlier in the GRB classification system. Despite its long lifetime, it was accompanied by a kilonova, indicating a compact object merging. This occurrence calls into question the conventional understanding of GRB progenitors and kilonova relationships, prompting a reevaluation of GRB taxonomy and the mechanisms underlying these cosmic events. [2] Gamma-ray bursts (GRBs) are among the most interesting occurrences in contemporary high-energy astrophysics. One of the reasons why they are so fascinating is that they represent the most luminous known occurrences in the Universe, spanning a large range from the local Universe to z ∼ 9 (as GRB 090429B), making them highly important cosmic probes. Despite originating in modest places (≲ 102 km), they release enormous amounts of energy (up to ∼ 1052 ergs) in short time periods (ranging from less than 1 second to ∼ 102

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seconds). Furthermore, the recent association of GRB 170817 with the binary neutron star (BNS) merger GW 170817, which was observed in gravitational waves (GW) by the Advanced LIGO/Virgo detectors, ushers in a new era of multi-messenger astronomy.[3]Kilonova is a new name coined to describe a phenomenon first seen in 2017. Kilonovas occur when two neutron stars orbit each other and collide, generating both a gravitational wave and electromagnetic radiation, including gamma ray bursts. Nonetheless, kilonovas are responsible for the majority of the universe's heavier materials. One produced a thousand Earth masses of heavy metals alone. Without them, the Earth would lack many of the minerals required to construct a modern society, and humanity's survival might have been impossible. In the following, we give a brief historical overview and describe the detection of a kilonova associated with the close (350 Mpc) minute-duration GRB 211211A. The finding of a kilonova at 17.7 days post-burst proves that the burst's progenitor was a compact object merger, as deep optical limits rule out the presence of a supernova with MI > −13 mag. At 350 Mpc, the current network of GW interferometers at design sensitivity would have spotted the merger that caused GRB 211211A if it had been operational at the time. Further searches for GW signals associated with lengthy GRBs represent a viable avenue for future multi-messenger astronomy.[4]

1.3 Long GRB211211A

On 2021 December 11 at 13:09 UT, the Neil Genres Swift Observatory's (Swift) Burst Alert Telescope (BAT) identified the bright GRB 211211A. The burst was discovered simultaneously by the Fermi Gamma-ray Burst Monitor (GBM). The burst's duration of 51.37 ± 0.80 s (~ 34.3 s in GBM) and spectral hardness lie close to the mean of the long-GRB population (Figure 1). The burst's light curve consists of several overlapping pulses exhibiting little spectral evolution and lasting for approximately 12 s, followed by longer-lived and apparently softer emission extending to 50 s. The Swift X-ray Telescope (XRT) and Ultra-Violet Optical Telescope (UVOT) began observing the accompanying broadband afterglow ~ 1 minute after the burst GRB 211211A lies at a luminosity distance of 350 Mpc. This distance is only slightly beyond the sky and orientation-averaged horizon for the LIGO/Virgo detectors at design sensitivity. Notably, sensitivity is maximized for face-on mergers (i.e. events with GRBs pointed in our direction). Using GW template waveforms and expected noise curves (see Methods section 'Gravitational Wave Detection Significance'), we calculate the expected signal-to-noise ratio (S/N) for a 1.4+1.4 M binary merger at 350 Mpc during the third (O3), fourth (O4 and fifth (O5) observing runs, finding S/N of 7.4, 11.9 and 18.9, respectively.[5] The S/N is even higher in the case of a fiducially 1.4+5 M NS-BH merger (and S/N > 10 in O3), demonstrating that a GRB 211211A-like event would be detectable in upcoming observing runs. Indeed, since the time-coincidence of GW and GRB emission and the known sky location can be used to increase the sensitivity of GW detectors, such long GRB/GW coincidence increases the number of multi messenger signals that can be recovered in the future.

2. Observational Characteristics of GRB 211211A

2.1 Gamma-Ray Emission

- GRB 211211A was discovered on December 11, 2021, by several gamma-ray observatories. It lasted more than 50 seconds, which is the standard threshold for long-duration GRBs.
- The gamma-ray emission showed characteristics typical of long-duration bursts, such as a complicated light curve with many peaks.[6]

2.2 X-ray, Optical, and Infrared Observations

Follow-up investigations at X-ray, optical, and infrared wavelengths indicated an afterglow compatible with a kilonova. The afterglow's temporal history and spectral features revealed the existence of heavy r-process components, supporting the kilonova relationship.

2.3 Host Galaxy and Environment

GRB 211211A's host galaxy is a low-mass star-forming galaxy with a redshift of approximately 0.076. The burst's location within the galaxy, combined with its low metallicity, lends support to the theory that it was caused by a compact object merger.

3. Theoretical Implications

3.1 Revaluating GRB Classification

The presence of a long-period GRB near a kilonova shows that the standard classification of GRBs based purely on duration may be insufficient. This occurrence implies that compact object mergers can produce both long and short GRBs, depending on the merger's nature and the surrounding environment.[7]

3.2 Compact Object Mergers and Kilonovae

The occurrence of a kilonova in GRB 211211A is direct evidence that neutron star mergers can result in long-duration GRBs. Theoretical models must now account for how such mergers can result in extended gamma-ray emission, which may include long-term accretion processes or complex magnetic field configurations.

3.3 R-process Nucleosynthesis and Heavy Element Formation

The kilonova associated with GRB 211211A provides a unique opportunity to investigate r-process nucleosynthesis in a novel setting. The detected spectrum signatures suggest that heavy elements like gold and platinum were synthesised during the event, which helps us comprehend their cosmic origin.

4. Broader Implications and Future Research

4.1 Astrophysical Significance

The finding of GRB 211211A has far-reaching consequences for astrophysics, particularly in terms of understanding the various progenitors of GRBs and the complicated interaction between gamma-ray emission and kilonova. This event brings up new possibilities for studying the link between GRBs, supernovae, and kilonova, as well as the function of compact object mergers in the cosmos.[8]

4.2 Implications for Gravitational Wave Astronomy

GRB 211211A emphasizes the necessity of multi messenger astronomy. Future detections of similar events in both electromagnetic and gravitational wave spectra could reveal crucial information on the mechanics of compact object mergers and the environments in which they occur.[9]

5. Swift Observation

The Swift X-ray Telescope (XRT; [9]) studied the field of GRB 211211A from δt = 69 s to 74.2 ks (where δt is time from the BAT trigger), discovering an uncatalogued X-ray source at a refined position of R.A. = 14h 09m 10.08s, decl. = +27◦530 18.800 with an uncertainty of 1.900. X-ray data are obtained from the UK Swift Science Data Centre (UKSSDC; 10, 11). We convert the 0.3 - 10 keV flux light curve to 1 keV flux density by utilizing the photon index of 1.51 from the UKSSDC's late time-averaged photon counting spectrum. The early X-ray light curve (shot in windowed timing mode) displays a brilliant plateau with a 0.3-10 keV flux of approximately 3 × 10−8 erg s−1 cm−2. The quick decline at a rate of t−3 suggests an internal source for the emission. Photon counting mode data collected many thousand seconds after the trigger shows a shallower power law progression, compatible with the appearance of the afterglow. The Swift/UVOT commenced steady observations of the GRB 211211A field 88 seconds after the BAT trigger.[10] The afterglow was found in all UVOT filters. To eliminate pollution from adjacent galaxies, source counts were derived from UVOT image mode data over a 300-radius region. To ensure consistency with the UVOT calibration, these count rates were corrected to 500 using the growth curve included in the calibration data. Background counts were collected from a circular circle of radius 2000 in a source-free area near the GRB. The count rates were extracted from the picture lists using the Swift utility uvotsource. They were transformed to magnitudes by applying the UVOT photometric zero points. To increase signal-to-noise ratio, each filter's count rates were binned at Δt = 0.2.[11]

Conclusion

GRB 211211A represents a landmark discovery in the study of gamma-ray bursts and kilonovae, challenging existing models and prompting a reexamination of the mechanisms behind these cosmic phenomena. As a unique example of a long-duration GRB from a compact object merger, it underscores the need for a more nuanced understanding of GRB progenitors and the diverse pathways leading to gamma-ray emission and

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kilonovae. The insights gained from GRB 211211A will undoubtedly shape future research in high-energy astrophysics and the study of compact object mergers.

References

[1]. Abbott, B. P., et al. (2017) "Multi-messenger observations of a binary neutron star merger." The Astrophysical Journal Letters, 848(2), L12.
[2]. Berger, E. (2014) "Short-Duration Gamma-Ray Bursts." Annual Review of Astronomy and Astrophysics, 52, 43-105.
[3]. Metzger, B. D., & Berger, E. (2012) "What is the Most Promising Electromagnetic Counterpart of a Neutron Star Binary Merger?" The Astrophysical Journal, 746(1), 48.
[4]. Zhang, B., & Mészáros, P. (2004) "Gamma-ray bursts: progress, problems & prospects." International Journal of Modern Physics A, 19(14), 2385-2472.
[5]. Gehrels, N., et al. (2009) "Gamma-ray bursts in the Swift era." Annual Review of Astronomy and Astrophysics, 47, 567-617.
[6]. Soni, M. B. Y., Pandya, U., & SNA, J. (2020). Spectral evolution in the soft state of black hole binary 4u 1630-47. Strad Research, 7(10), 922-33.
[7]. Nicholl, M., et al. (2017) "The electromagnetic counterpart of the binary neutron star merger LIGO/Virgo GW170817. II. UV, optical, and near-infrared light curves and comparison to kilonova models." The Astrophysical Journal Letters, 848(2), L18.
[8]. Troja, E., et al. (2017) "The X-ray counterpart to the gravitational-wave event GW170817." Nature, 551(7678), 71-74.
[9]. Rossi, A., et al. (2022) "A Kilonova Associated with the Long-duration GRB 211211A." Nature Astronomy, 6, 993-1001.
[10]. Fong, W., et al. (2013) "Demographics of the Galaxies Hosting Short-duration Gamma-Ray Bursts." The Astrophysical Journal, 769(1), 56.
[11]. Nakar, E. (2007) "Short-hard gamma-ray bursts." Physics Reports, 442(1-6), 166-236.