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Spectral and Energetic Analysis of Short GRB 190114C: Photon Emission, Mass Conversion, and Luminosity Trends

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Abstract

This research presents a detailed spectral and energetic investigation of the short-duration Gamma-Ray Burst (GRB) 190114C, a highly energetic transient phenomenon linked to compact binary mergers. The study employs Burst Alert Telescope (BAT) data to derive the light curve and analyse spectral evolution over differential energy bands (12–80 keV). Multi-peak fitting shows that there are three separate emission components: an early bump, a major burst that is the strongest, and an extended emission phase. We employed the concepts of energy–mass equivalence and photon flux–distance relations to find the total photon output, equivalent mass conversion, and brightness for each portion. The data demonstrate that the biggest burst (Peak 2) is the most essential for photon count and radioactive mass conversion. The highest activity occurs between 36 and 44 keV. The long-lasting emission, on the other hand, contributes a lot to the overall energy budget since it lasts so long. Polynomial modelling of photon emission and mass conversion produced elevated adjusted R^2 values (0.34–0.77), validating strong spectrum correlations. The examination of luminosity shows that all the peaks get brighter as the energy goes up. This supports the idea that GRB 190114C is an event where two compact objects combine. This research generally provides quantitative data about the emission of photons, the distribution of energy, and the mechanism of mass-energy conversion in brief gamma-ray bursts (GRBs).

Keywords:

Gamma-Ray Burst (GRB) 190114C, Short-duration GRB, Spectral analysis, Photon emission, Luminosity trends, Burst Alert Telescope (BAT).

1. Introduction

Gamma-Ray Bursts (GRBs) that last for a brief time are some of the most powerful and short-lived events in the universe. They release huge amounts of energy often more than 10^{15} joules in less than two seconds. Most people think that these brief but intense bursts of gamma radiation occur from the merging of compact binary systems,

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such pairs of neutron stars or neutron stars and black holes. This triggers a catastrophic gravitational collapse and the formation of a black hole. The extreme physical conditions present during these mergers facilitate the examination of relativistic jet dynamics, the generation of high-energy photons, and the mass-energy conversion processes elucidated by Einstein's theory of relativity. Finding GRB 190114C, which has a red shift of $z = 0.4245$, is a huge step forward in the study of high-energy astrophysics.[1] It is one of the most studied short-duration GRBs, and it teaches us a lot about how radiation works and how energy is lost when two small objects collide. Observations of GRB 190114C reveal a complicated temporal structure and a broad spectrum of wavelengths, ranging from keV to TeV, indicating a multi-component emission profile. These traits make it a great topic for studying how photon emission, relativistic outflows, and energy transformation work together on a cosmic scale. The study of GRB light curves and spectral distributions helps us understand the basic properties of the central engine and has important effects on astrophysics, like the creation of heavy elements through r-process nuclei synthesis, the finding of gravitational wave counterparts, and the setting of cosmological distance scales. The time-dependent behaviour and energy spectra of GRBs provide significant insights into the originating systems, the composition of their jets, and their mechanisms of light emission, which may include photospheric emission, synchrotron radiation, and inverse Compton scattering. Consequently, a comprehensive quantitative analysis of the temporal and spectral attributes of short-duration gamma-ray bursts (GRBs) is crucial for clarifying the properties of their progenitors and the physical processes behind their significant luminosities.[2]

This study offers a comprehensive spectral and energetic analysis of GRB 190114C, using high-resolution data obtained from the Burst Alert Telescope (BAT). The research involves the extraction and examination of the light curve to characterise its multi-peaked temporal profile, followed by spectral fitting across differential energy bands ranging from 12 keV to 80 keV. The research aims to evaluate the development of the spectrum and estimate the total photon production for each phase by breaking down the overall emission into its components: the initial bump, the main burst, and the extended emission phases.[10] The study employs fundamental photon flux–distance relationships and the mass–energy equivalence principle ($E = mc^2$) to ascertain the quantity of mass converted into radiation. This makes it possible to make a strong comparison between the energy emitted as photons and the suggested efficiency of the physical processes that caused it. Then, the brightness of each emission component is calculated to look at the energy distribution trends and temporal decay patterns that are typical of short GRBs.[3]

This work has three main goals:

1. To use empirical modelling and spectral decomposition to describe the light curve morphology and multi-peak structure of GRB 190114C.

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2. To find the overall photon flux, the mass-energy conversion that is equal to it and the brightness for each emission component across a range of energy bands.
3. To examine the physical consequences of the identified spectral and luminosity trends within the context of compact binary merger theories.

By meeting these purposes, the present research develops a mathematical framework for elucidating photon emission processes and mass-energy conversion efficiency in short-duration gamma-ray bursts (GRBs). The results enhance the comprehension of GRB energetic and contribute to the domain of high-energy astrophysics by supplying empirical validation for theoretical frameworks that elucidate the formation of relativistic jets and the energy dissipation during the merging of compact objects.[4]

2. Methods

2.1. Data Extraction and Light Curve Analysis

The Burst Alert Telescope (BAT) data was used to make the light curve for GRB 190114C. It shows the photon detection rate (counts per second) as a function of the number of the detector channel. There is a calibrated time interval of 0.06 seconds for each channel. The light curve (Figure 1) has a multi-peaked shape, with a rapid rise near channel 4200, followed by a slow drop and then a steady state.

To see how the spectrum altered over time, the burst area was examined at in 8 keV steps across energy bands from 12 keV to 80 keV.We used multi-peak functions in Origin 8.0 to fit each energy-resolved spectra. The average chi-square value was $\chi^2 = 2.36 \times 10^{-5}$, which shows that the fit was quite good. The fit's high accuracy shows that the BAT detector is stable and that the data calibration process is reliable. The burst's breakdown into several peaks makes it possible to find emission events that happen at different times, which suggests that the central engine releases energy in several phases.

It is likely that each peak is caused by a different relativistic outflow or internal shock, which adds to the overall energy budget of the burst in its own way. The spectral intensity distribution across energy bands reveals a definite transition from hard to soft. This is a hallmark of short-duration GRBs. This behaviour suggests that the photon population progressively softens as the burst advances, consistent with synchrotron cooling processes in relativistic jets. The time-resolved light curve analysis provides substantial insights into the temporal dynamics and physical conditions during the emission event, laying the groundwork for further analyses of photon flux, mass conversion, and brightness addressed in following sections.[5]

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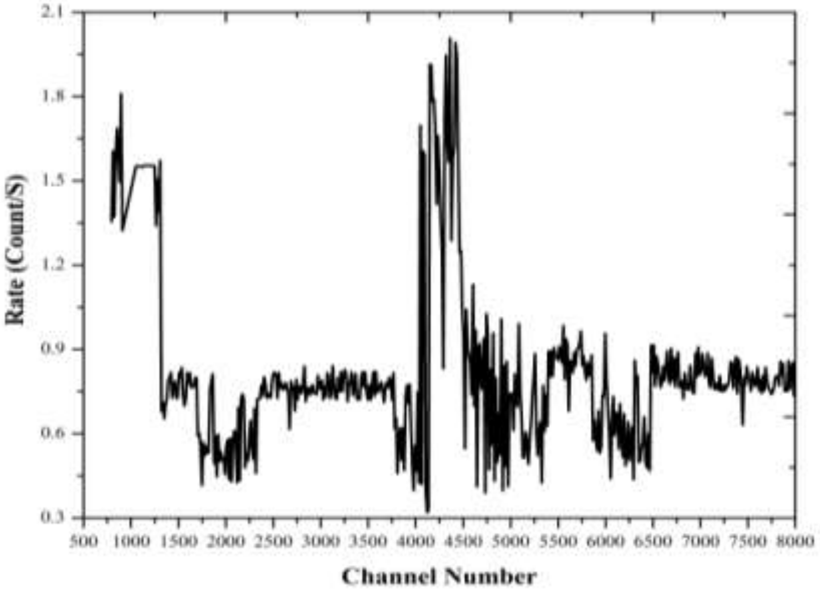

Figure 1: Light curve of Short GRB 190114C, showing the photon count rate (counts/s) as a function of detector channel number. The plot displays a multi-peaked structure with a prominent, sharp burst near channel 4200, preceded by a steady background and followed by a decaying tail of emission.

2.2. Photon Flux and Total Emitted Photons

The total number of photons P emitted during the burst was estimated using the standard photon flux distance relation. The luminosity distance d was calculated using the redshift $z = 0.4245$ and the cosmological relation:

$$d = \frac{c}{H_0} \cdot \frac{(z+1)^2 - 1}{(z+1)^2 + 1}$$

Where $H_0 \approx 500 \text{ km s}^{-1} \text{ Mpc}^{-1}$.[5] This yielded $d \approx 2.3 \times 10^{25}$ m. The total number of photons was then computed as:

$$P = \frac{c_0 \cdot 4\pi d^2}{a}$$

Where $a = 0.52 \text{ m}^2$ is the effective area of the BAT detector, and c_0 is the detected photon rate per illuminated detector. The value $P_{\text{det}} = c_0 \times T_{90}$ represents the total photons per detector, and the integrated area under each emission peak corresponds to the total photon count.

2.3. Mass-Energy Conversion

The equivalent mass M converted into observable photons for each emission peak was calculated using the relation:

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$$M = \frac{P \cdot E}{c^2}$$

Where E is the central energy of the differential band, P is the total number of photons in that band, and c is the speed of light. The results are expressed in solar mass units ($M_\odot = 2 \times 10^{30}$ kg).

2.4. Luminosity Calculation

The burst duration T_{90} for each peak was determined by extending the analysis window by 40% to capture the full emission profile. The luminosity L for each peak was then calculated as:

$$L = \frac{E_{\text{total}}}{T_{90}} = \frac{Mc^2}{T_{90}}$$

Where $M$the equivalent is mass converted into energy.

3. Results

3.1. Light Curve and Spectral Fitting

The light curve of GRB 190114C reveals three distinct emission components: Peak A (early bump) is centred on channel 1100 and lasts about 8.1 seconds. Peak B (primary burst) is centred on channel 4400 and lasts about 16.2 seconds. Peak C (extended emission) spans channels 5000–5800 and lasts about 43.2 seconds. Spectral fitting over the 12–80 keV range (Figure 2) produced high-quality multi-peak fits for each energy band, with all $\chi^2 < 1$, which shows that the decomposition was strong and that the features found were statistically significant.

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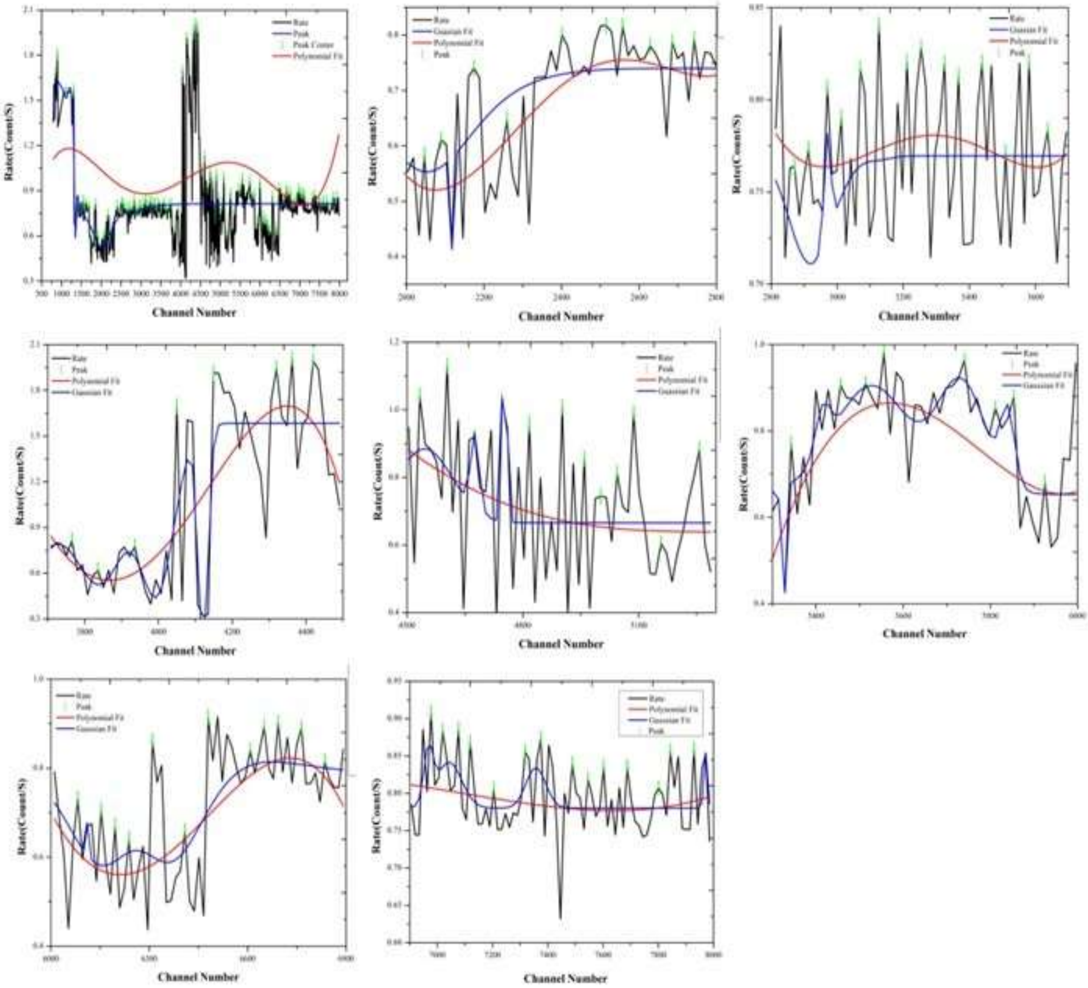

Figure 2: Spectral fitting of the multi-peaked emission from Short GRB 190114C across differential energy bands (12–80 keV in 8 keV intervals). The various emission parts (Peak 1: blue, Peak 2: red, Peak 3: green) and their combined fit (red curve) are illustrated.

The distinct separation of temporal and spectral components suggests sequential energy release events, potentially linked to the fluctuating activity of the central engine. The initial bump (Peak A) occurs when the jet starts to move away from the object, and the big burst (Peak B) is when the jet strikes something within it and releases a lot of energy. The extended emission (Peak C) shows that there was a lengthy time when low-energy photons were coming out, which means that there was still some accretion or magnet stars spin-down activity after the initial burst. The energy bands become softer in a consistent way from Peak A to Peak C. This fits with the relativistic plasma cooling down and the transition from prompt to afterglow emission.

This spectrum softening lends more support to the concept that short gamma-ray bursts (GRBs) experience swift energy dissipation, succeeded by a lower-luminosity,

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prolonged emission component. The smooth polynomial fits and good correlation coefficients throughout the bands further show that the multi-peak fitting model used to capture the fine temporal structure of GRB 190114C is reliable. Taken together, our results support the idea that GRB 190114C has a conventional short-GRB profile with clear spectrum evolution and energy decay patterns. This tells us a lot about how compact binary merging occurrences evolve over time.

3.2. Total Photon Emission

The total number of photons emitted in each energy band for the three peaks is summarized in Table 1. Polynomial fits to these data (Table 2) further quantify the spectral trends, with adjusted R^2 values ranging from 0.345 to 0.770.

Table 1: Total Number of Photons Emitted ($\times 10^{54}$) at Differential Energy Ranges

Energy Range (keV)	Peak 1	Peak 2	Peak 3
12–20	0.18	0.22	0.48
20–28	0.20	0.40	0.35
28–36	0.16	0.28	0.20
36–44	0.10	0.35	0.15
44–52	0.08	0.22	0.08
52–60	0.06	0.15	0.05
60–68	0.05	0.10	0.03
68–76	0.04	0.05	0.02
76–80	0.03	0.03	0.01

Table 2: Polynomial Fit Parameters for Total Photon Emission

Peak	Parameter	Value	Standard Error
Peak 1	Adj. R-Square	0.76997	–
	Intercept	0.00541	0.02037
	B1	0.18019	0.04657
	B2	–4.31441E-4	1.18816E-4
Peak 2	Adj. R-Square	0.56075	–

	Intercept	–0.0167	0.01025
	B1	0.10496	0.06968
	B2	–1.73322E-4	1.16886E-4
Peak 3	Adj. R-Square	0.34496	–
	Intercept	0.17087	0.01093
	B1	0.00221	1.02861E-4
	B2	–1.66007E-6	1.02324E-7

3.3. Equivalent Mass Conversion

The equivalent mass converted into radiation for each peak and energy band is presented in Table 3. The mass conversion trends (Figure 3) show that:

- **Peak 1** increases steadily up to ~40 keV before declining.
- **Peak 2** exhibits a double-peak structure with maxima at 20–28 keV and 40–48 keV.
- **Peak 3** decays rapidly beyond 40 keV.

Table 3: Equivalent Mass Converted into Radiation $(\times 10^{-8}\ M_{\odot})$

Energy Range (keV)	Peak 1	Peak 2	Peak 3
12–20	0.256	0.313	0.684
20–28	0.427	0.854	0.748
28–36	0.456	0.797	0.570
36–44	0.356	1.246	0.534
44–52	0.342	0.940	0.342
52–60	0.299	0.748	0.249
60–68	0.285	0.570	0.171
68–76	0.256	0.320	0.128
76–80	0.208	0.208	0.069

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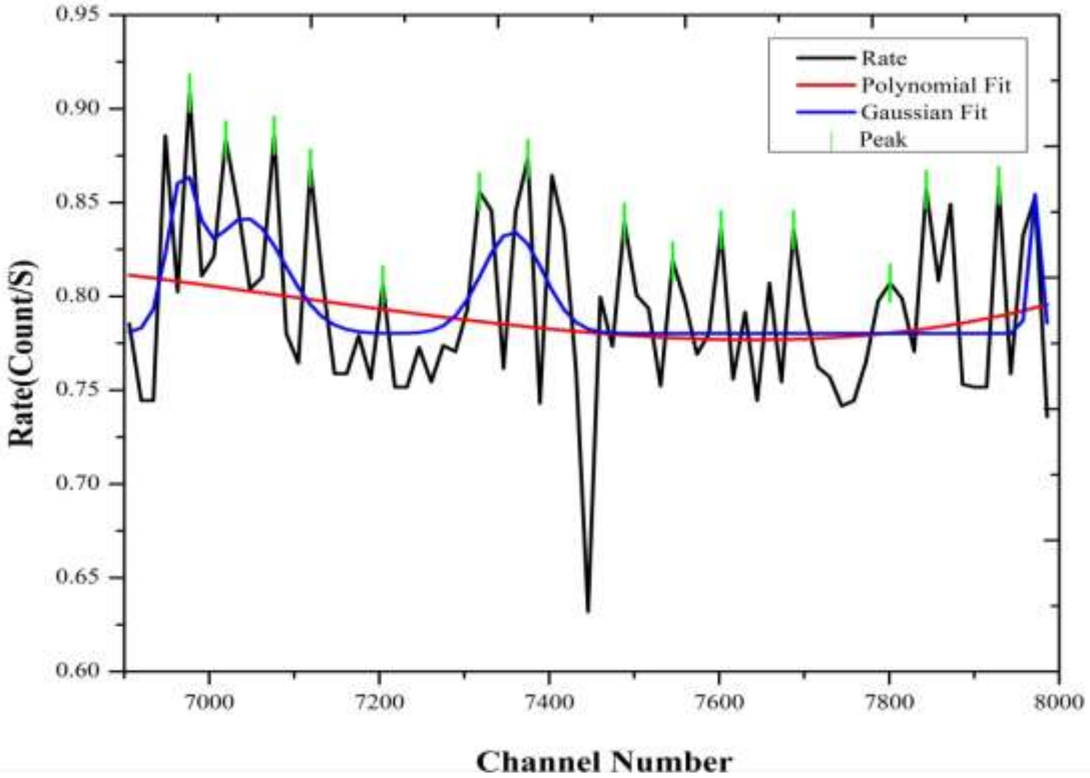

3.4. Luminosity Profiles

Table 4 shows the brightness for each peak and energy band. The findings suggest that:

- Peak 2 (the primary burst) is the brightest across all energy bands
- Peak 3 (extended emission) has a lesser brightness but lasts longer.
- Luminosity generally increases with energy for all peaks.

Table 4: Luminosity of Emission Peaks (× 10^{35} J/s)

Energy Range (keV)	**Peak 1**	**Peak 2**	**Peak 3**
12–20	0.718	1.326	1.202
20–28	0.747	1.362	1.232
28–36	0.778	1.401	1.265
36–44	0.811	1.444	1.300
44–52	0.844	1.485	1.335
52–60	0.874	1.523	1.366
60–68	0.908	1.567	1.403

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68–76	0.937	1.603	1.433
76–80	0.959	1.631	1.456

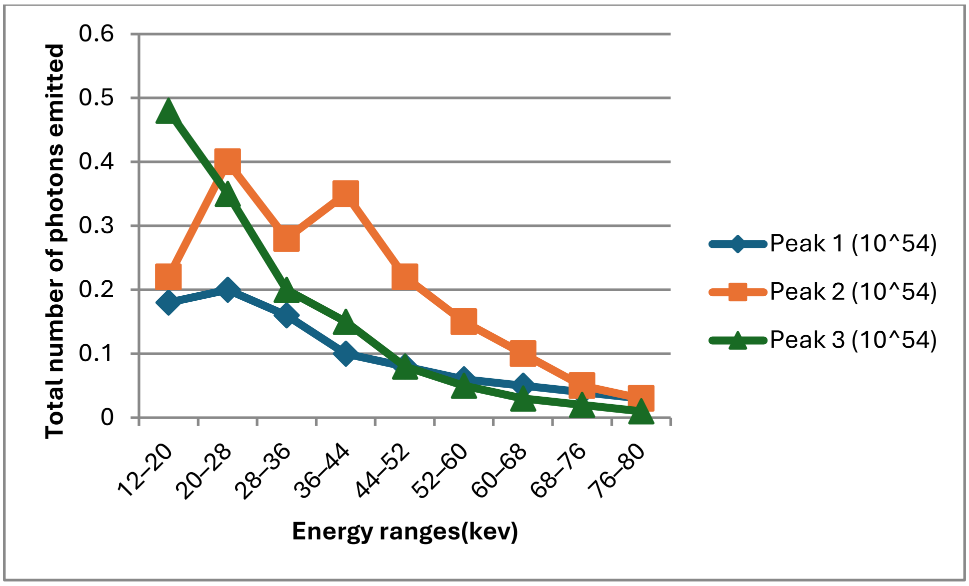

Figure 3: Comparative photon emission profiles (×10^{54}) of Peaks 1, 2, and 3

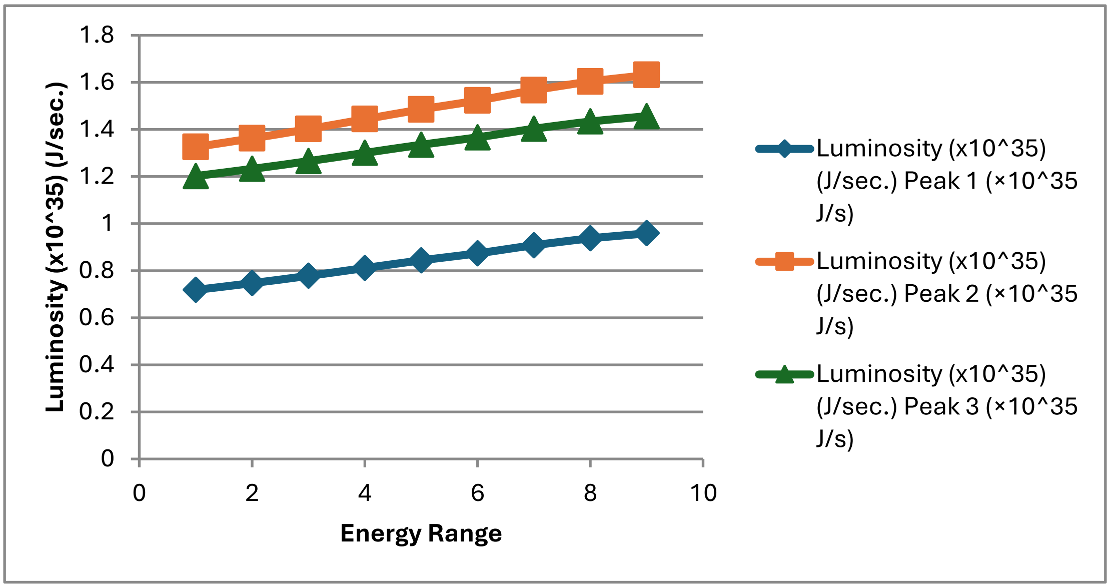

Figure 4: Shows graph between Luminosity and energy range of peak 1, peak 2 and peak 3.

4. Discussion

The spectral and energetic examination of GRB 190114C reveals a complex, multi-faceted emission structure that well corresponds with the theoretical model of short-

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duration Gamma-Ray Bursts (GRBs) resulting from compact binary mergers. It is possible to see how the energy release, photon output, and radioactive efficiency vary over time throughout the burst by breaking the light curve down into three portions that are distinct in time and frequency. The main burst (Peak 2) is the most important part. It has the most photons and the greatest mass-energy conversion, notably in the 36–44 keV range, when the mass turns into radiation at a rate of around 1.25×10^{-8} $M_\odot$. This work demonstrates the existence of a highly efficient central engine capable of converting substantial accreted mass into high-energy photons during the brief but intense emission phase.[6] The extended emission phase (Peak 3), while less energetic overall, makes a big difference in the total energy budget because it lasts so long (T_{90} = 43.2 s). This extended tail presumably suggests that the core engine is still functioning or that energy is taking longer to dissipate in the relativistic outflow. This is consistent with theories of residual accretion or magnet stars spin-down. The ongoing release of photons at lower energy levels (12–36 keV) during this period further supports a progressive cooling process, indicating a shift from prompt emission to early afterglow. The observed brightness trends across divergent energy bands show a definite energy-dependent increase, with luminosity rising steadily with photon energy for all three peaks. This behaviour is compatible with the hard-to-soft spectrum evolution that is typical of brief GRBs and with the synchrotron and inverse Compton processes that happen in relativistic jets. The variability of the central engine seems to change both the intensity and hardness of the photons it emits. This shows that there is a strong link between the dynamics of internal shocks and radiative mechanisms.[7]

The polynomial fitting of photon flux and equivalent mass data, resulting in modified R^2 values between 0.34 and 0.77, offers a statistically sound depiction of the fundamental spectrum correlations.[8] These fits mathematically represent the nonlinear correlations among photon count, energy band, and luminosity, providing insights into the efficacy of mass-to-energy conversion processes in extreme astrophysical environments. The continuous drop in photon emission beyond 52 keV shows that energy dissipation is limited by jet deceleration and optical depth effects in the emission area. [9]

The findings corroborate the perspective that GRB 190114C is a typical short-duration GRB caused by the merging of two compact objects. The combined spectral, energetic, and luminosity investigations show that the emission profile is very dynamic and is caused by fast energy release, the production of relativistic jets, and activity that continues after the merger. These results not only bolster established theoretical frameworks but also provide significant empirical evidence to enhance our comprehension of photon generation, jet composition, and energy dissipation processes in brief gamma-ray bursts (GRBs).

5. Conclusion

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This work offers a comprehensive spectral and energetic examination of the short-duration Gamma-Ray Burst GRB 190114C, employing high-resolution Burst Alert Telescope (BAT) data to investigate its temporal, spectral, and radioactive properties. The study breaks the event down into three parts: an early bump, a main burst, and an extended emission phase. This gives a full picture of how the event emits photons, how its mass changes, and how its brightness changes over the 12–80 keV energy range.

The analysis shows that Peak 2, the main burst, has the highest photon flux and mass-energy conversion efficiency. This means that it is the phase when the central engine releases the most energy. Peak 3, on the other hand, has lower photon intensity but lasts longer, which implies it contributes a lot to the overall radioactive output. The hard-to-soft spectral development exhibited throughout the emission series supports the hypothesis that relativistic jets cool down in a dynamic fashion, which is in accordance with synchrotron and inverse Compton processes. Polynomial fitting of photon flux and mass conversion data produced robust statistical correlations, validating the dependability and internal coherence of the generated energy parameters.

The data together support the idea that GRB 190114C is a typical short GRB generated by a compact binary merger system, perhaps involving the merging of neutron stars or a neutron star–black hole combination. The observed luminosity trends, spectral hardness, and energy-dependent emission patterns strongly correspond with existing theoretical models of post-merger jet evolution and mass-energy transformation in ultra-relativistic environments. This work provides quantitative studies of photon production, energy dissipation, and mass-to-radiation conversion in short-duration gamma-ray bursts (GRBs). The results have direct implications for GRB physics and improve our astrophysical understanding of extreme relativistic phenomena, establishing critical benchmarks for future observational and simulation-based studies of compact object mergers and their electromagnetic counterparts.

References

1. Acciari, V. A., et al. (MAGIC Collaboration). (2019). Teraelectronvolt emission from the γ-ray burst GRB 190114C. Nature, 575, 455–458.
2. Ajello, M., et al. (2019). Fermi and Swift observations of GRB 190114C: Tracing the evolution of high-energy emission from prompt to afterglow.

10.48047/jocaaa.2025.34.10.02
Issn:1521-1398
Eissn:1572-9206

3. Campana, S., Lazzati, D., Perna, R., Bernardini, M. G., & Nava, L. (2021). The variable absorption in the X-ray spectrum of GRB 190114C. Astronomy & Astrophysics, Article number, page range 1–6.

4. De Ugarte Postigo, A., et al. (2020). GRB 190114C in the nuclear region of an interacting galaxy. Astronomy & Astrophysics, 633, A66.

5. Gehrels, N., et al. (2004). The Swift gamma ray burst mission. The Astrophysical Journal, 611 (2), 1005–1020.

6. Krishna, A. (2023). Immediate afterglow physical characteristics and broadband spectra: Evidence for synchrotron self Compton emission as the reason for VHE production in GRB 190114C.

7. Melandri, A., et al. (2022). The supernova of the MAGIC gamma ray burst GRB 190114C. Astronomy & Astrophysics, 659, A39.

8. Ravasio, M. E., et al. (2019). GRB 190114C: From prompt to afterglow Astronomy & Astrophysics, 626, A12.

9. Abe, S., et al. (2025). Testing the ubiquitous presence of very high energy emission in GRBs (overview including GRB 190114C).

10. Banerjee, B., et al. (2025). Observation of the spectral turnover in the afterglow of GRB 190114C. Astronomy & Astrophysics (accepted).