Joint study of *Fermi*/LAT and *Swift*/XRT detected Gamma-Ray Bursts with Extended Afterglow Emission

M. Sc. Thesis

By

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Joint study of *Fermi*/LAT and *Swift*/XRT detected Gamma-Ray Bursts with Extended Afterglow Emission

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INDIAN INSTITUTE OF TECHNOLOGY INDORE

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INDIAN INSTITUTE OF TECHNOLOGY INDORE

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"Joint study of Fermi/LAT and Swift/XRT detected Gamma-Ray Bursts with Extended Afterglow Emission"** in the partial fulfillment of the requirements for the award of the degree of **Master of Science** and submitted in the **Department of Astronomy, Astrophysics and Space Engineering, Indian Institute of Technology, Indore**, is an authentic record of my own work carried out during the time period from August 2020 to May 2022 under the supervision of Dr. Amit Shukla, Assistant Professor, Indian Institute of Technology, Indore.

The matter presented in this thesis has not been submitted by me for the award of any other degree at this or any other institute.

Pawan Tiwari
May 21, 2022

Signature of the student with the date
(Pawan Tiwari)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

23-05-2022

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(Dr. Amit Shukla)

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Convener, DPGC
Date: 26/05/2022

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Date: 26/05/2022

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ABSTRACT

The main aim of the project is to do a joint study of *Fermi*/LAT and *Swift*/XRT detected gamma-ray bursts with extended afterglow emission. Gamma-Ray Bursts are the most energetic electromagnetic transients in Universe, spewing out intense bursts of photons from keV to TeV energies with a duration of a few milliseconds up to days. Depending on the duration, GRBs are classified into in two types: short GRBs (SGRBs) and long GRBs (LGRBs) with duration less than 2s and more than 2s, respectively. In the case of LGRBs, the collapse of a massive star produces an ultra-relativistic jet which gives rise to a highly variable and luminous gamma-ray emission. This prompt emission is then followed by a multi-wavelength afterglow emission due to the external dissipation of the jet in the circumburst medium. In most cases, the *Fermi*/LAT GRBs (0.1-100GeV) emission follows a regular decay pattern as expected from the standard afterglow model. However, some of the LAT-GRBs show slower decay. In this work, we select such GRBs from the latest *Fermi*/LAT catalog and quantify the disagreement between the observed emission and the prediction of the afterglow emission. In addition to that, we also studied the X-ray light curves in order to evaluate these cases in multi-wavelength scenarios.

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Chapter 1

Gamma-Ray Bursts

1.1 Introduction

Gamma-Ray Bursts (GRBs) are the most luminous and high energetic transient explosion that has been detected in our visible observable Universe. As the name suggests, GRBs release gamma-rays that lasts from a few milliseconds to thousands of seconds. GRBs are of extra-galactic origin and the typical isotropic luminosity in gamma-ray ranges in $\sim 10^{51} - 10^{53}$ erg/s (Nakar, 2007).
From the multi-wavelength observations, it is believed that GRBs must have at least two distinct physical origins (Piran et al., 2013). One is associated with the death of a star and the other origin is with the merger of a compact object like a black hole and a neutron star (Abbott et al., 2017). In either case, these catastrophic events are responsible for causing a gamma-ray burst that leaves behind a hyper-accreting Black Hole that serves as a central engine that emits a collimated

jet with relativistic speed.

In the present scenario, we observed GRBs in the temporal domain such as, minutes, hours, and days. In the spectral domain, the observation is done across the electromagnetic spectrum from radio to gamma-ray. GRBs are also believed as source of non-electromagnetic emission such as neutrinos, cosmic rays, and gravitational waves. The groundbreaking discovery of the association between the NS–NS merger gravitational wave source GW170817 and the short GRB 170817A confirms this (Abbott et al., 2017).

The observations and technical challenges in observing GRBs restrict to conclude the understanding of them. As a result, Gamma-Ray Bursts have been and will be an exciting and challenging subject to understand in contemporary astrophysics and astronomy.

1.2 Discovery

The discovery of the first gamma-ray burst was made accidentally in 1967 by *Vela* Satellite launched by the United States in order to monitor and check the Nuclear Test Ban Treaty in the year 1963. On July 2, 1967, *Vela* detected bursts of gamma-rays for the first time which we now named Gamma-Ray Burst. On the discovery of GRBs, the first paper was published almost 5 years later (Klebesadel et al., 1973). In the present era, we have Swift and Fermi Space Telescopes dedicated to search and study of high energy transient events like gamma-ray bursts.

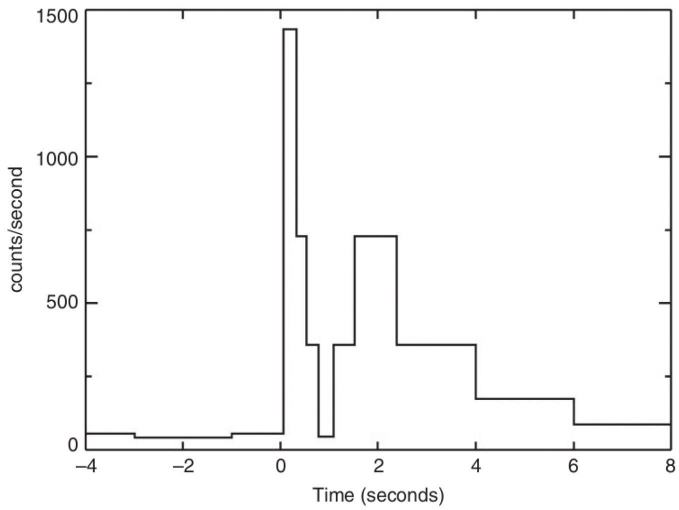

Figure 1.1: Light curve of the very first GRB detected on 2 July 1967 with the *Vela* satellite (Kouveliotou et al., 1993)

1.3 GRB Phenomenology

1.3.1 Classification of Gamma-Ray Bursts

Astronomers found two different classes of GRBs after studying the number of bursts versus the duration of bursts: the long-duration and the short-duration gamma-ray bursts (see (Zhang et al., 2012)(Lü et al., 2010). These classes of GRBs are probably to be produced by different processes, but in both cases, the product at the end of the event will be an accreting black hole that serves as a central engine for the jet.

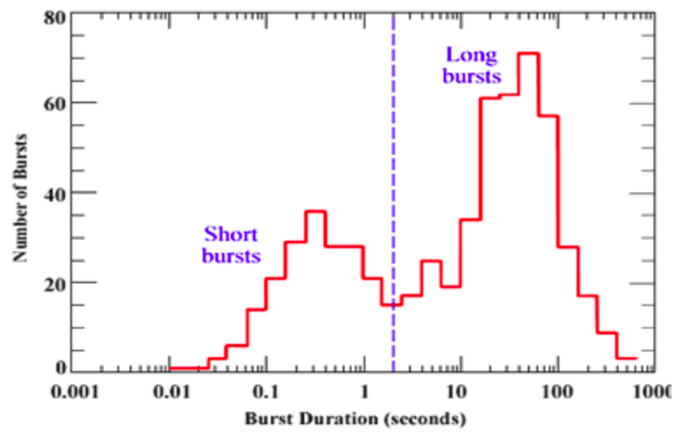

Figure 1.2: Plot between number of bursts and burst duration (seconds). Credits: Swinburne University of Technology[2]

Long-Duration Gamma-ray Bursts

Long-Duration gamma-ray bursts, abbreviated as LGRBs, produces emission for 2 seconds to a few hundred seconds (Greiner, 1999). It means T90 i.e.90 percent of photon counts of observation detected in that time of LGRB is more than 2 seconds (see Figure 1.3). Astronomers believe that LGRB is the product of the explosion of massive rotating stars in the supernova; though all LGRBs are not associated with the supernova.

Short-Duration Gamma-Ray Bursts

Short-Duration Gamma-Ray Bursts abbreviated as SGRBs, last not more than 2 seconds. The T90 of SGRBs are less and equal to 2 seconds (McGlynn et al., 2008). The time duration lies from a few milliseconds to less than or equal to 2

[2] https://astronomy.swin.edu.au/cosmos/G/gamma+ray+burst+types

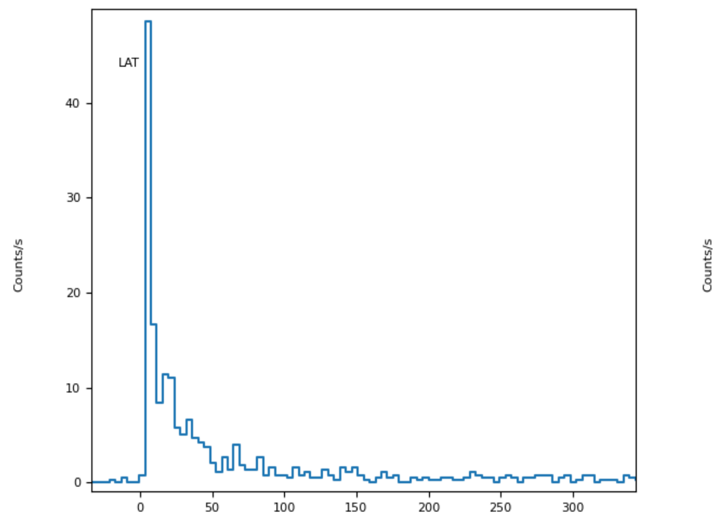

Figure 1.3: An example of Light-Curve of Long Duration GRB (GRB 080916C) (x axis: time (seconds))

seconds. It is believed that these SGRBs are created by the merger of a compact binary systems such as a binary Neutron star into a Black Hole or a neutron star with a black hole to form a larger new black hole (see Figure: 1.4). However, recent discovery of the kilonova with an extended emission from GRB 211211A has put a question on the population of the SGRBs as the result of the BNS merger (Gao et al., 2022)(Rastinejad et al., 2022)(Mei et al., 2022).

1.3.2 Production of Gamma-rays in a Gamma-Ray Burst

From the observation of GRBs, it is believed that GRBs have two main phases: prompt emission phase and afterglow (Panaitescu & Kumar, 2001). Prompt emission with many spikes is generally observed in gamma-ray wavelength while af-

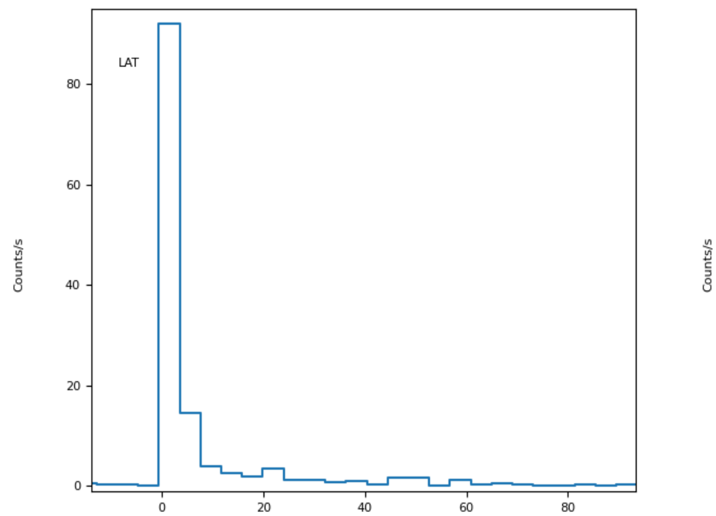

Figure 1.4: An example of Light-Curve of Short Duration GRB (GRB 090510)(x axis: time (seconds))

terglow is observed in higher wavelengths such as X-ray, optical, and radio. The formation of Gamma-Ray Bursts (GRBs) could begin either with the death of a massive star in the case of LGRB or with the compact binary coalescence (CBC) in the case of SGRB. Both events produce a black hole at the end with a disk of material rotating around the black hole. This system ejects out a jet of material at relativistic speed. The radiation in gamma-rays is the result of the internal shock within the blob. GRB light curve does not show any preferred pattern or signature i.e. two light curves of different GRBs show variability and have a different pattern. Hence, understanding the mechanism of GRB is really challenging. Here, in this thesis, I am considering the most favorable ”Classical Fireball model” to understand the mechanisms of GRBs and how they are produced and propagate in space (Piran, 1999).

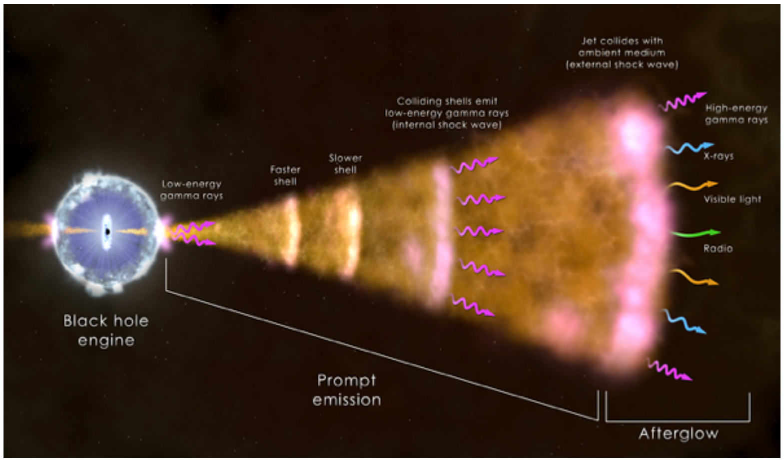

Figure 1.5: Fireball Mechanism Model. Credit: NASA/Fermi

Classical Fireball Model

Astronomers believed that GRB is produced when the kinetic energy of an ultra-relativistic flow from a CBC or during the death of a massive star is dissipated. In short, a compact source like a neutron source or black hole produces a fireball or shell moving at relativistic speed in space. A shell consists of plasma of photons, electron and positron pairs, and baryons in a very small amount. The fireball moves and expands to the stage where it becomes so much optically thin that photons can escape and it gets decelerated. When the faster blob which is emitted later collided with the slower blob emitted earlier, an internal shock phenomenon happens to result in the emission of gamma-ray radiation by the conversion of the bulk kinetic energy. This emission is called the prompt emission. After the prompt emission, the jet moves in space and interact with the ambient medium in space producing afterglow emission which is observed in various wavelengths such as very high energy gamma-rays, high energy gamma-rays, X-rays, optical UV, and radio.

A compact source releases a huge amount of energy in a form of a jet that consists of photons; electron-positron pairs, and fewer amounts of baryons in a very short time domain (Piran, 1999). The quantity of baryon is taken very small as the shell moves with relativistic velocity. At the start, the fireball is at high temperature (few millions Kelvin). At that temperature pairs production dominates. As the fireball or shell moves and expands, due to expansion cooling happens which results in the annihilation of the pairs. Eventually, the photons escape as the opacity decreases. The above process results in a quasi-thermal spectra but the observation follows power law which is the opposite in nature. Hence, there should be another dominating process involved in producing the prompt emission. In order to explain the prompt emission observation, the fireball needs to be expanded to the radius at which it becomes optically thin. At this point, photons can escape from the fireball and these photons result in prompt emission of the GRB.

There are two mechanisms that could be possible to produce and explain the prompt emission of GRB: external shocks and internal shocks. In the case of external shocks, when the fireball interacts with the ambient medium in space, then the radiation is produced. To explain observed variability, it is believed that it may be produced by the non-homogeneous nature of the external medium but it is very difficult to prove, and hence this theory is discarded for explaining the mechanism of prompt emission. In the case of internal shocks, the radiation is produced in shocks when a faster blob emitted at a later time collides with the slower one that is produced earlier. Internal shock clearly can explain the mechanism of prompt emission, the variability in light curves of bursts is associated with the emission of a new shell from the source or bursts in the GRB case. Therefore, for converting the bulk kinetic energy of the blob into radiation or the prompt emission, internal shock is responsible.

However, the problem is still not solved with perfection, and work on it still going due to limited observation for prompt emission and observation which do not agree with one shock model and with one progenitor's model. The mechanism responsible for the production of prompt emission radiation is still to be certain. One of the most currently favorable processes is synchrotron radiation of relativistic shock-accelerated electrons for the production of photons of prompt emission (Ghisellini et al., 2000), but the mechanism shows some limitations. According to new observation and understanding, possible modifications to this model are included but still more observations and modifications are required to explain the mechanism of prompt emission.

Astronomers from the observation of burst infer the afterglow emission is the end stage of the GRB event. After the prompt emission is produced, the fireball continues to expand, and eventually encounters ambient medium material in space. The afterglow emission is believed that external shocks between the fireball and the ambient medium material in space produce the photons at various higher wavelengths than prompt emissions such as in X-rays, optical, etc. From the observation, the afterglow emission follows a power law thus synchrotron radiation thought to be one of the best candidates responsible for the afterglow emission. Various theoretical models and simulations are made and used for explaining the mechanism of GRB afterglow and few of them have been very successful in reproducing light curves of afterglow with limits.

Chapter 2

Instrumentation and Data Analysis

2.1 Fermi Gamma Ray Telescope

The Fermi Gamma-ray Space Telescope (earlier known as GLAST) is a multi-agency international space observatory, launched on June 11, 2008, by U.S. NASA. It is designed to study the astronomical events in the energy ranges from 8 keV to more than 250 GeV (Sadrozinski, 2001).

Fermi Gamma-ray Telescope consist of two main science instruments:

1. Large Area Telescope (LAT)
2. Gamma-ray Burst Monitor (GBM)

Figure 2.1: Fermi Gamma-Ray Telescope (Artistic Impression) Credit: NASA/Fermi website [2]

2.1.1 Gamma-Ray Burst Monitor (GBM)

Gamma-ray Burst Monitor has a sensitivity to photons of energy from 8keV to 30 MeV. GBM consists of 12 low-energy GBM detectors for detecting hard X-rays and low-energy gamma rays, and high-energy GBM detectors for detection of gamma rays having high energy [3]. The GBM and the LAT work together to provide a powerful tool for detecting and studying GRBs at very high energy range. GBM has three main components:

[3] https://www.nasa.gov/content/goddard/fermi-spacecraft-and-instruments
[3] https://www.nasa.gov/content/goddard/fermi-spacecraft-and-instruments

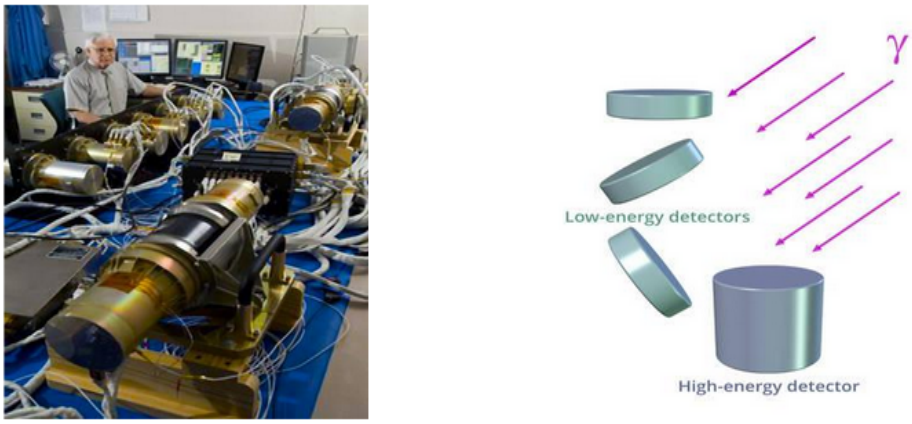

Figure 2.2: Gamma-Ray Burst Monitor. Credit: NASA/Fermi website [4]

Low-energy GBM Detectors

Low-energy GBM detectors are made up of NaI that detects X rays in the energy range of 8 keV to 1 MeV. They give the position of gamma-ray bursts to within a few degrees. The low-energy GBM detectors are positioned in four rows consisting of three detectors each. The orientation of these 12 detectors is in directions so that they see various parts of the sky. The GBM uses the information from the low-energy GBM detectors to detect the location of burst.

High-energy GBM Detectors

High-energy GBM detectors of *Fermi*/GBM are sensitive to the range of energy from about 150 keV to 30,000 keV. They are made up of bismuth germanate (BGO). Its energy range is bridged between the low energy detector of GBM and

[4] https://www.nasa.gov/content/goddard/fermi-spacecraft-and-instruments

the LAT. The property of BGO is such that gives good sensitivity at very high gamma-ray energies. The position of the high-energy GBM detector is in such a way that it covers a whole sky. They are placed on the opposite side of Fermi.

Data Processing Unit

The main work of the Data Processing Unit of GBM is to detect the bursts, determine the energy of the signal and their arrival direction, and send information to Fermi Telescope to Earth for scientific use. It consists of the electronics and microprocessors that receive and analyze the information from the low-energy GBM detectors and high-energy GBM detectors.

2.1.2 Large Area Telescope (LAT)

Large Area Telescope or simply *Fermi*/LAT detects photons of energy ranging from 20 MeV to 300 GeV [5]. *Fermi*/LAT has four main components working together to detect gamma rays and their source, localize the position of the source from where these gamma ray signal are coming, and also measures the energy of the same. LAT also has components that reject cosmic ray signals too to avoid contamination in the gamma-ray signals.

The four main components of LAT are:

(a) Tracker

(b) Calorimeter

[5] https://www.nasa.gov/content/goddard/fermi-spacecraft-and-instruments

(c) Anticoincidence Detector

(d) Data Acquisition System.

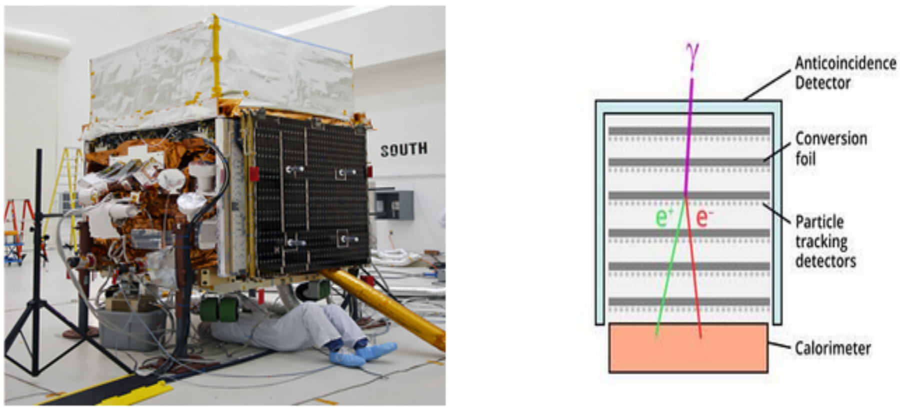

Figure 2.3: Large Area Telescope. Credit: NASA/Fermi website [6]

Tracker

The Tracker component of *Fermi*/LAT detects and localizes the position of gamma-ray and its source respectively. It is in the form of strips which is made up of silicon and interconnected with Tungsten(Sn) layers. Gamma-Ray when interacting with this detector emits an electron and positron. The path of these electron and positron generated are detected by *Fermi*/LAT tracker and helps in localizing the position of bursts.

[6] https://www.nasa.gov/content/goddard/fermi-spacecraft-and-instruments

Calorimeter

Calorimeter as the name suggests that it measures the energy of an interacted particle after being absorbed in it. Cesium Iodide is used for making the Fermi/LAT Calorimeter, which produces light flashes when any cosmic ray strikes it. The intensity of those flashes is directly proportional to cosmic-ray particle energies. It helps in excluding charged cosmic rays which get entered as the signature of deposition of energy of cosmic rays is totally different from the signature of energy deposition of gamma rays.

Anticoincidence Detector (ACD)

The Anticoincidence Detector (ACD) is the main component of Fermi/LAT which detects cosmic rays. It is made up of specially formulated plastic. It works in a manner when any charged-particle cosmic rays hit its surface, a flash of light is produced but it does not interact with neutral gamma rays and allows gamma signal to enter the LAT. The ACD is like a cap that covers Fermi/LAT tracker.

Data Acquisition System (DAQ)

Data Acquisition System (DAQ) is the most important component of Fermi/LAT which collects information from the Calorimeter, the Anticoincidence Detector, and the Tracker and excludes the noise such as cosmic rays from the gamma-ray signals. The signal relayed by *Fermi*/LAT on the ground is decided by DAQ.

Search for bursts is also performed by the DAQ. The Data Acquisition System instrument consists of specialized electronics and microprocessors.

2.2 Swift

Swift was launched on November 20, 2004. *Swift* is designed especially for detecting and understanding the transient source like gamma-ray bursts. *Swift* is a flexible satellite with three main scientific instruments on board, the Burst Area Telescope with a wide field of view; X-Ray, and Ultraviolet and optical telescope for observing bursts in X-ray and optical wavelength respectively having a narrow field of view. *Swift* detects bursts and covers a wide energy range of 0.002-150 keV and also calculates the position of the Gamma-Ray Bursts precisely(Gehrels et al., 2004).

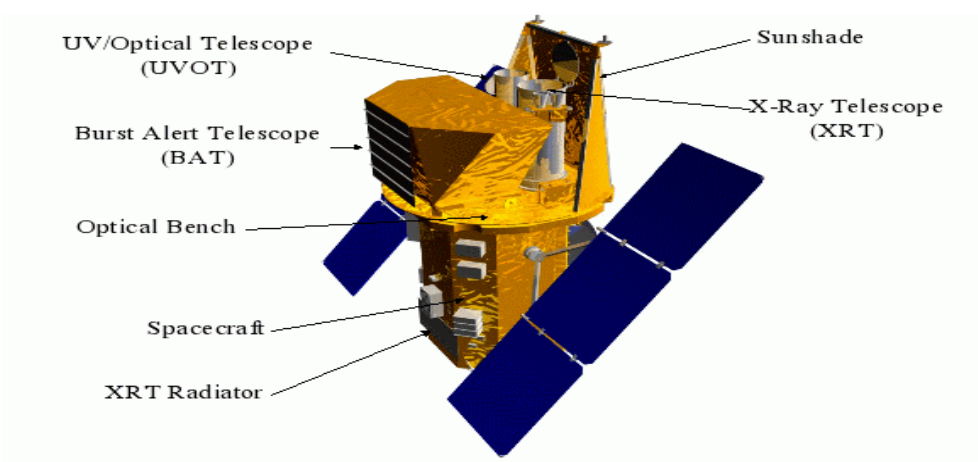

Figure 2.4: Swift Space Observatory. Credit: NASA/Swift website [7]

2.2.1 Burst Alert Telescope (BAT)

Burst Alert Telescope (BAT) is sensitive in the range of 15 to 150 keV energy(Barthelmy et al., 2005). It detects the gamma rays. It has high sensitivity and coded-aperture instrument, with a large field of view (2 steradians). The Burst Alert Telescope detects the initial position of the burst with the accuracy of about 3-arcmin and passes this information to XRT and UVOT so that the observation should also be made in X-rays and optical wavelengths too.

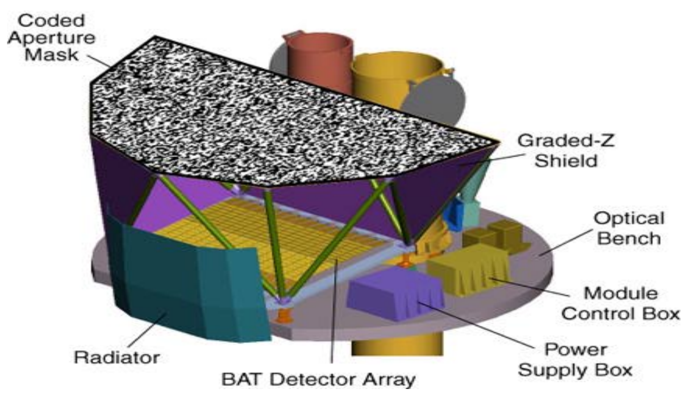

Figure 2.5: Burst Alert Telescope.Credit: NASA/Swift website [8]

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2.2.2 X-ray Telescope (XRT)

X-ray Telescope (XRT) works in a range of energy from 0.2-10 keV. Swift/XRT is a narrow-field telescope (Burrows et al., 2005), unlike BAT. It is aligned with Burst Alert Telescope. When the Swift/BAT detects the burst or a GRB, Swift slewed to

[7] https://www.nasa.gov/content/goddard/fermi-spacecraft-and-instruments
[8] https://www.nasa.gov/content/goddard/fermi-spacecraft-and-instruments

the localized position allowing the X-Ray Telescope to improve the position detected by the BAT, within a few seconds, localizing bursts to 5 arcsec or even less. The actual field of view of the X-Ray Telescope is 23.6 arcmin square. Depending on the flux of the GRB afterglow, X-Ray Telescope operates in 3 modes. XRT adjusts these modes totally on the basis of the brightness of afterglow emission of bursts detected by BAT.

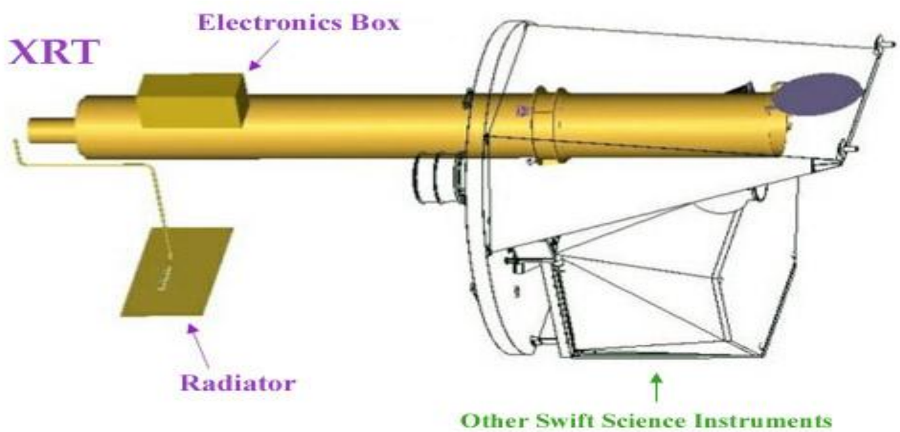

Figure 2.6: X-ray Telescope. Credit: NASA/Swift website [9]
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2.2.3 Ultraviolet and Optical Telescope (UVOT)

Ultraviolet and Optical Telescope (UVOT) works in optical range from 170-650 nm wavelength. It is also narrow field instrument like XRT aligned with BAT. It is mainly designed for detecting optical counterpart of afterglow known as optical

[9] https://www.nasa.gov/content/goddard/fermi-spacecraft-and-instruments

afterglow for a GRB (Roming et al., 2005).

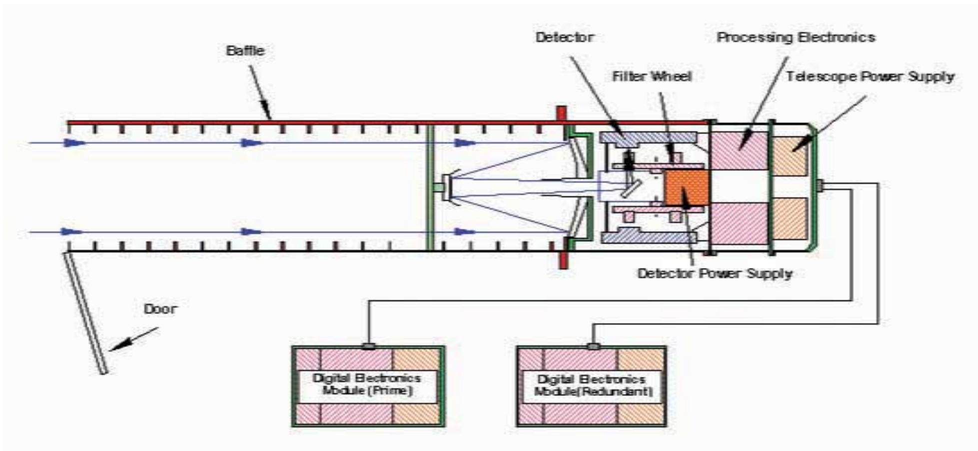

Figure 2.7: Ultraviolet and Optical Telescope. Credit: NASA/Swift website [10]
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2.3 Data Handling and Analysis

2.3.1 Data Reduction

Swift (XRT data)

The *Swift/XRT* data for light curve and spectral analysis are obtained from the *Swift/XRT* repository [11]. The light curve data obtained is already reduced and can be used for the result. The *Swift/XRT* repository provides an advantage of creating

[10] https://www.nasa.gov/content/goddard/fermi-spacecraft-and-instruments
[11] https://www.swift.ac.uk/xrt_products/

time-average spectra for a given GRB in a given sliced time window. According to our studies, we have created our time slice for each GRB and analyzed for plotting spectra. We have selected only those GRBs which have simultaneous data with *Fermi*/LAT.

Fermi (LAT data)

The LAT data of Fermi for analysis and making light curves and spectra is extracted from *gtBurst*[12]. The *gtburst* is a tool distributed as part of FermiTools (Fermi Science Support Development Team, 2019) which helps to do particularly, analysis of *Fermi*/LAT Telescope detected Gamma-Ray Bursts. The *Fermi*/LAT data was extracted for each GRB a 10,000 s after trigger time within a temporal window and photons(filtered) with energies in the range of 100 MeV–100 GeV range. A further selection of photons was done on the basis of zenith angle whose value is taken less than 100° from the spacecraft axis using navigation plots tools which is part of *gtBurst* to lower the impurities of photons added from the planet edge. Selection of GRBs on which analysis is performed is done on the basis of simultaneous data with *Swift*/XRT.

[12] https://fermi.gsfc.nasa.gov/ssc/data/analysis

2.3.2 Data Analysis

Swift (XRT data)

As *Swift*/XRT data for light-curve is already reduced, so we simply obtained the data and plotted it using *matplotlib*. The spectral data extracted after the time slice method is analyzed using tool XSPEC (Arnaud, 2016), the tool specially designed to analyze X-ray data. The data for energy bins greater than 0.3 keV and less than 10 keV is not considered for analysis. The result obtained from the analysis is further used to plot the spectra.

Fermi (LAT data)

In collaboration with the groups of IIT Indore and GSSI Italy, we have developed analysis pipeline for analyzing *Fermi*/LAT data. The developed pipeline is based on *gtBurst* but is more time economical and easy to use. Prerequisites for analyzing a particular GRB with the pipeline are GRB data which includes photon events file, spacecraft file, rsp and php file along with RA, Dec, and trigger-time of that GRB. Pipeline also gives user an advantage of selecting time interval manually. The pipeline for analysis uses a region of interest (ROI) of 12° by default but is subject to change. The ”powerlaw2”, ”isotr template” and ”template (fixed norm.)” are considered as the spectral model, particle background and the Galactic component respectively. The estimation of flux in the energy between 100 MeV to 10 GeV is performed with the ”unbinned likelihood analysis”. The time-bins for the joint spectral analysis were chosen requiring significant *Fermi*/LAT detections (minimum test statistics TS > 10). The result after analyzing the GRB is used for plotting their respective light curve and also photon index vs time with the help of *matplotlib*.

Chapter 3

Results and Discussion

There are 200 GRBs published in Fermi Second Catalog Paper published in 2019 ranging from the year 2008 to 2018 (Ajello et al., 2019). In total 72 GRBs in that are found which are also detected by the Swift/XRT Telescope but in those only 15 GRBs are found which have simultaneous data at the same time or have little or complete overlap in that time domain. Analysis of all 15 GRBs *Fermi*/LAT data is performed using developed GRB_ analysis pipeline and for *Swift*/XRT data, the results are obtained directly from the *Swift*/XRT repository. In those 15 GRBs, five GRBs are found that show extended afterglow emission. Spectral energy distribution (SED) for these five GRBs has been plotted. The result of 3 GRBs are listed below.

3.1 GRB 110625A

GRB 110625A is detected on June 25, 2011, at 21:08:18 UT is classified as long-duration gamma-ray bursts. RA and Dec of this GRB are $286.38°$ and $6.4°$ respectively. GRB 110625A is an interesting GRB. Its light curve and SED for both Swift/XRT and Fermi/LAT shows this character (see Figure 3.1). Spectral Energy Distribution (SED) for the four-time intervals is plotted and these time intervals are chosen on the basis of the overlap of simultaneous data for both telescopes and the flux value having no upper limit. The simultaneous time bands for spectra are 200s-240s, 240s-280s, 400s-500s, and 500s-1000s (see Figure: 3.1).

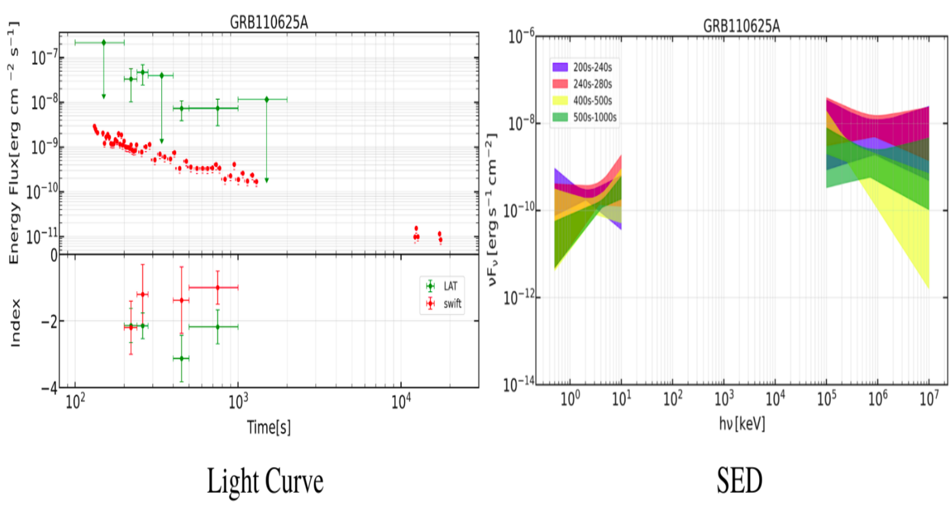


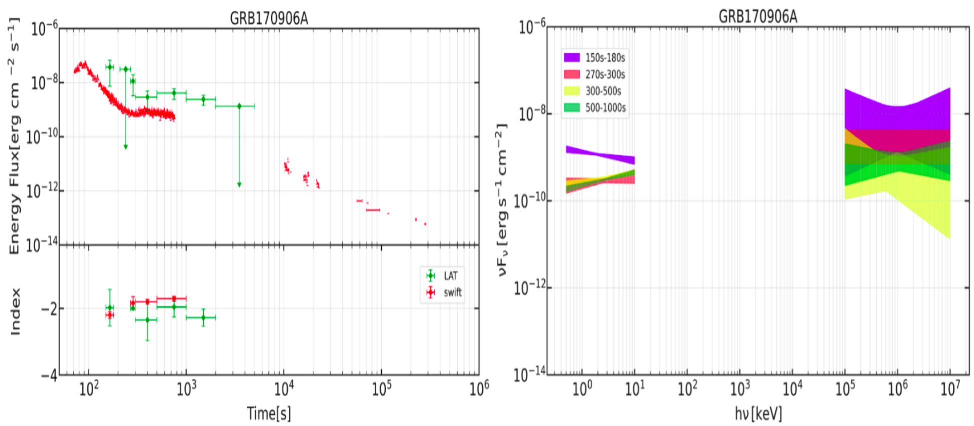
Figure 3.1: Light Curve and SED of GRB 110625A

3.2 GRB 170906A

GRB 170906A is detected on September 06, 2017, at 00:43:08 UT. GRB 170906A is categorized as LGRB. RA and Dec of this GRB are $203.94°$ and $-47.12°$ respectively. GRB 170906A is an interesting GRB as it is not following standard afterglow model. The light curve clear shows a plateau part in both *Swift*/XRT and *Fermi*/LAT (Figure 3.2).he simultaneous time bands for spectra are 150s-180s, 270s-300s, 300s-500s, and 500s-1000s. The SED plot also shows this behavior by the slope which is different in the time interval of the plateau part and in the time interval, light curve following the standard afterglow model. The curve shows a change in behaviour from 150s to 180s to other time interval. This 150 to 180s interval spectra follows a synchrotron spectra in X-ray band which is rarely seen. Synchrotron emission are observed generally in low energy i.e. radio ones. Shocks may be the reason for this behaviour of this GRB 170906A. Further theoretical modelling is still needed to conclude.

3.3 GRB 171120A

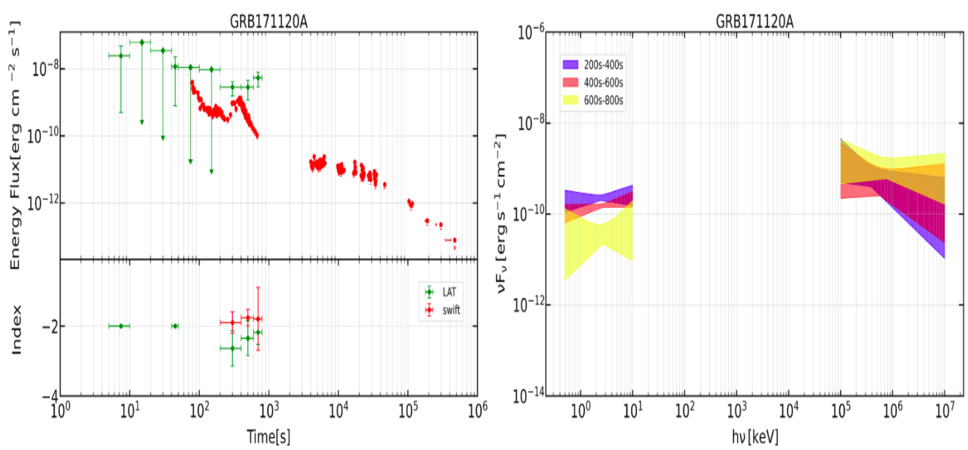
GRB 171120A is detected on November 20, 2017, at 13:20:02 UT. RA and Dec of GRB 171120A are $163.82°$ and $22.41°$ respectively. GRB 171120A is long-duration GRB.The light curve of GRB 171120A in Swift/XRT shows a peak and follows a pattern like *Fermi*/LAT (Figure 3.3).The simultaneous time bins for spectra are 200s-400s, 400s-600s, and 600s-800s. From the light curve and the SED



LightCurve SED

Figure 3.2: Light Curve and SED of GRB 170906A

plotted for time-interval overlap for both telescope data, there is possible plateau region in LAT gamma-ray energy band.



Light Curve SED

Figure 3.3: Light Curve and SED of GRB 171120A

Chapter 4

Conclusion

4.1 Summary

Gamma-Ray Burst (GRB) is the biggest astrophysical challenging event to understand at present, as the study of their light curve shows that there is no similarity in any two of them. In this thesis, I have tried to study the *Fermi*/LAT detected GRBs which are simultaneously detected by Swift Observatory. The first problem which I addressed and worked is to develop an analysis pipeline for *Fermi*/LAT detected GRB data. Next, I have done a survey of *Fermi's* Second Catalog published in 2019 (Ajello et al., 2019). From there we have chosen those GRBs which are also detected by Swift along with they have data overlapping with LAT data in the time domain. After analyzing those, we found a total of 5 GRBs that do not follow the standard afterglow model. They have slower decay in their afterglow part and noticed an anomaly such as plateau and X-ray flares in their light curve.

The SEDs of these GRBs are explored to understand phenomenon and physics for the plateau emission in afterglow phase.

4.2 Future Direction

In the present astrophysical era, Gamma-Ray Bursts are one of the hot subjects. Lots of research are going on to understand them. In this work, we tried to make a formalism to set up an analysis package which can be used to make the analysis faster and in an user friendly way. No such package exists in the public domain as far as we are aware of. Yet a lot of scope of future work is there to be carried out. In the future, we are planning to do model fitting and try to interpret the SED with theoretical models.

APPENDIX

Comparative study of *Fermi*/LAT and *Swift*XRT detected 15 GRBs

These 15 GRbs are selected from Fermi Second Catalog Paper published in 2019 ranging from the year 2008 to 2018 (Ajello et al., 2019) on the basis of simultaneous overlap data for both the telescope. Figure 4.1 and Figure 4.2 shows a plot between Photon Index vs Energy Flux for *Fermi*/LAT and *Swift*/XRT respectively. Figure 4.3 is plot between Photon Index of GRBs for (*Swift*/XRT) vs (*Fermi*/LAT) data. Figure 4.4 is plot between Energy flux of GRBs for (*Swift*/XRT) vs (*Fermi*/LAT) data. From these plots, we can inferred how GRBs flux and index are distributed for both the telescope.

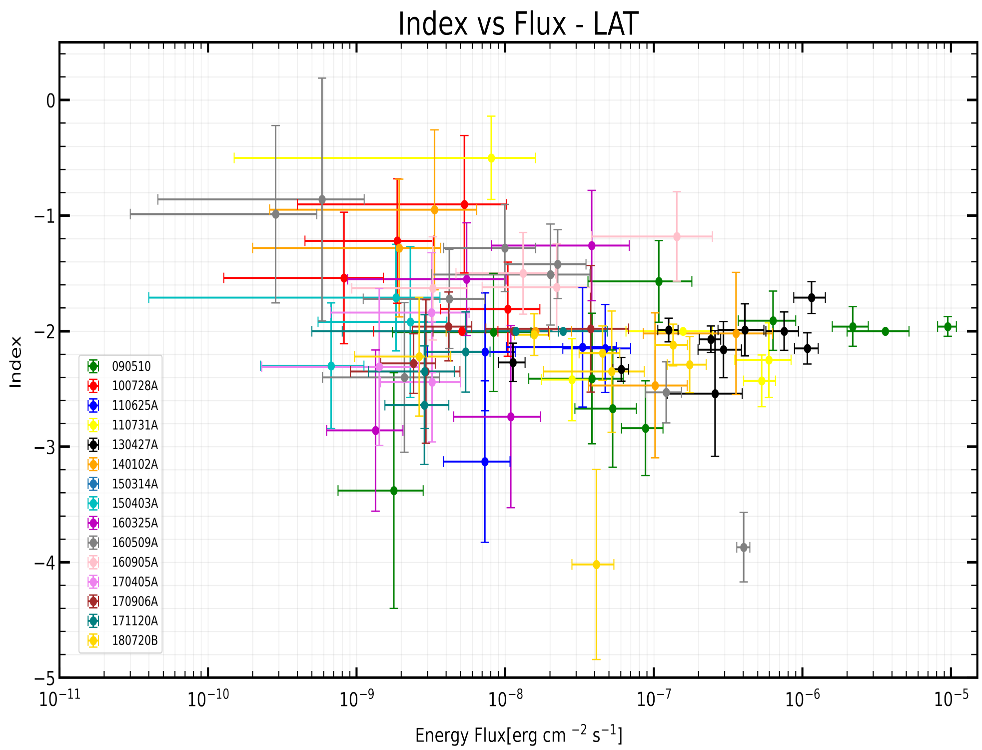


Figure 4.1: Plot between Index vs Flux for *Fermi*/LAT

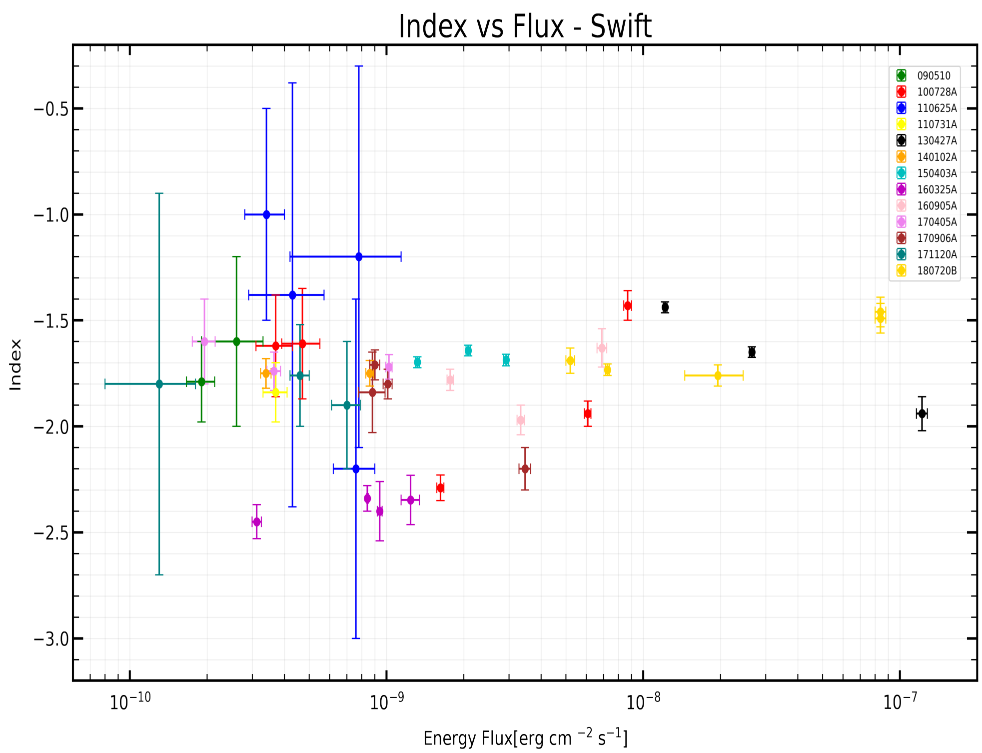


Figure 4.2: Plot between Index vs Flux for *Swift*/XRT

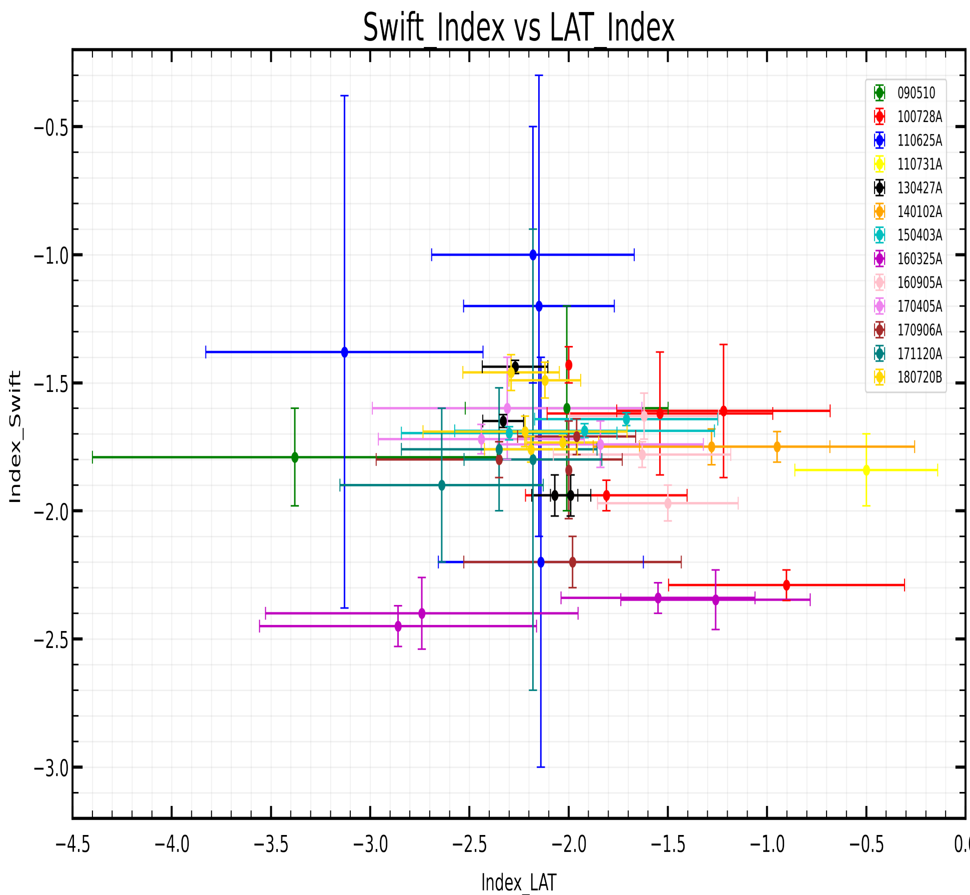


Figure 4.3: Plot between Index (*Swift*/XRT) vs Index (*Fermi*/LAT)

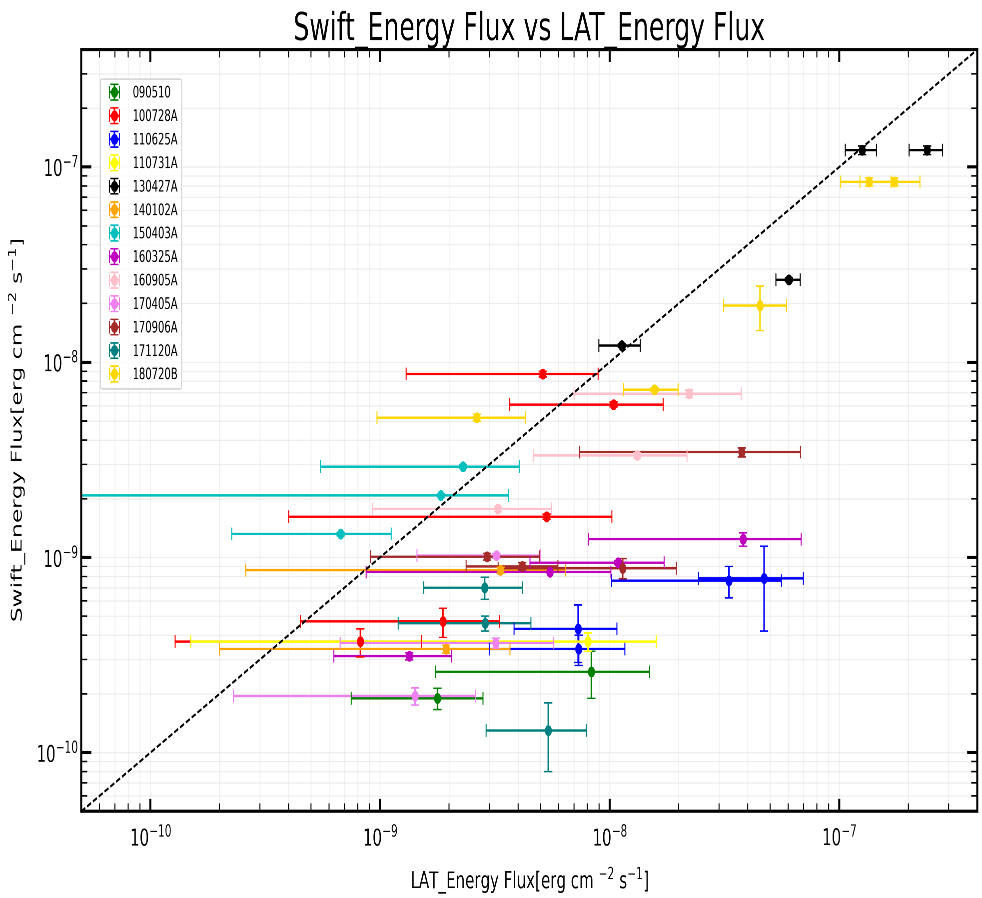


Figure 4.4: Plot between Flux (*Swift*/XRT) vs Flux (*Fermi*/LAT)

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