Gamma Ray Bursts

when you've seen one GRB, you've seen one GRB

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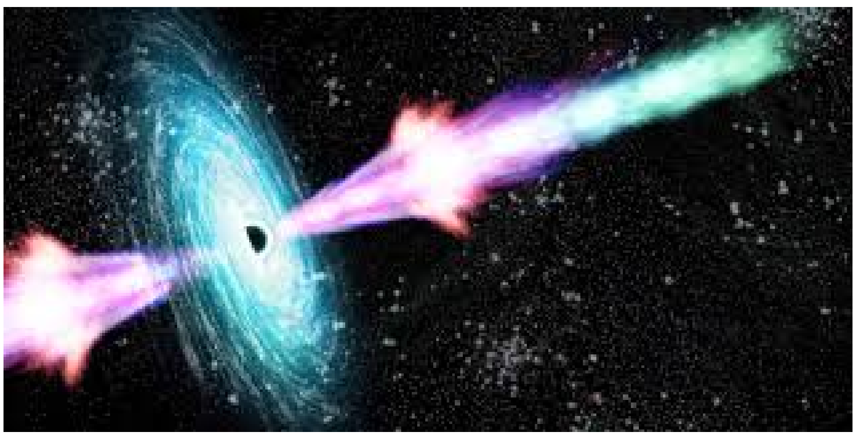


Contents

1 Introduction

Gamma-ray bursts (GRBs) are extremely energetic events occurring in distant galaxies which represent the brightest and most powerful class of explosion in the universe. These extreme electromagnetic emissions are second only to the Big Bang as the most energetic and luminous phenomenon ever known.Gamma-ray bursts can last from a few milliseconds to several hours.

They can be classified into several types based on their duration (namely **Long GRBs, Short GRBs and UltraLong GRBs**), their progenitors, the intensity of radiation, their origin, nature of detectors and many such factors.

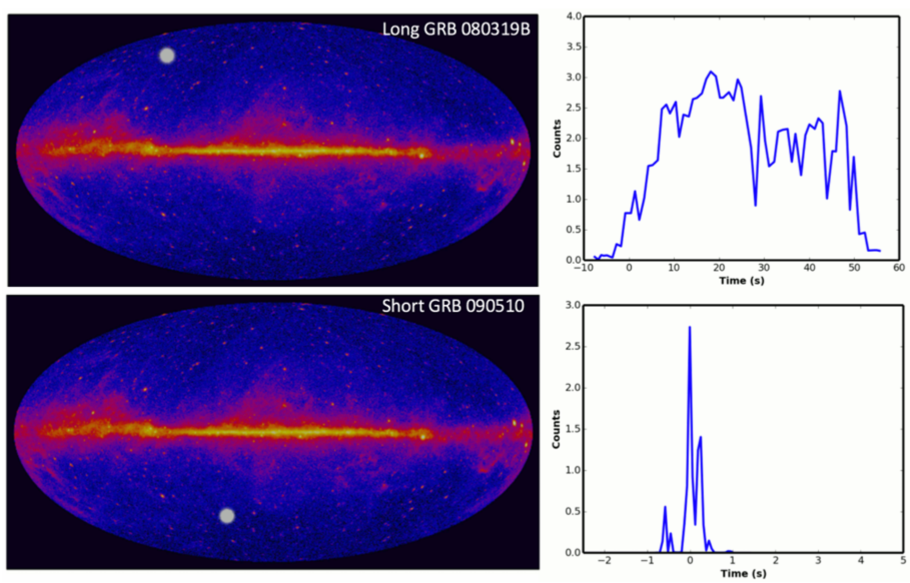


Figure 1: Simulations of the appearance of GRBs on the-ray sky (background from the *Fermi* Large Area Telescope). The bursts appear as the brightest sources in the-ray sky and then fade away. The right hand figures show the lightcurves of the two GRBs.

Their discoveries can be traced back to the 1960s when the Soviet Vela Satellites detected the first GRBs, pretty much unknowingly(see 2). Much of the work did upto the 90s raised several questions such as the origin, triggering mechanism, position and impact of GRBs. Pretty much of these questions could be solved after the first-ever recorded *AfterGlow* in the late 90s. And, after the 2000s with the fast-paced developments in science and technology the analysis of GRBs became easier and some of the mysteries could be concluded.

The main fields of research under GRBs can be divided under two categories:

1.1 Prompt Emission

The initial, intense burst of gamma-ray radiation that is observed immediately following the burst event.Prompt emission is the defining characteristic of GRBs, and it is the first observed signal of these powerful explosions. It typically lasts from a fraction of a second to a few hundred seconds.

1.2 Afterglow

GRB afterglows are the fainter, longer-lasting emissions of light that follow the initial, intense flash of a GRB. These afterglows, detectable at longer wavelengths like X-ray, optical, and radio, are produced as the relativistic jet from the GRB interacts with the surrounding interstellar medium. The can happen days, months even years after the prompt emission.

2 Historical Contexts

2.1 Discovery

Historians may remember the partial nuclear test ban treaty of 1963 was a vital step in the de-escalation of the cold war, and in controlling the proliferation of nuclear weapons, and their tests. However, astronomers will likely relate much more strongly to the role in the origins of gamma-ray astronomy, and in particular as a route to the discovery of the cos mic gamma-ray bursts (GRBs). Originally envisaged as a complete ban on nuclear testing, compromises during negotiation led to a partial ban, largely due to concerns about means of verifying underground nuclear tests.

The US Vela and Soviet Kosmos satellites were launched. Each was equipped with rather rudimentary ray detectors, that could identify significant increases in high energy photons above the background rate.

It remains unclear if these satellites ever detected ilicit nuclear tests, although it does seem probable that the Vela Incident of 1979 was due to an atmospheric nuclear test. How ever, the Vela satellites are far more famous– at least in astronomical circles– for their discovery of GRBs. They were initially detected as brief flashes in detectors onboard the Vela spacecraft, and were first reported to the community in 1973 [62]. Some events were seen simultaneously on the US OSO-7andIMP-6spacecraft [112], adding weight to their as trophysical reality, while a confirmation of their detection from the Soviet Kosmos spacecraft (Kosmos-461) was also rapidly forthcoming.

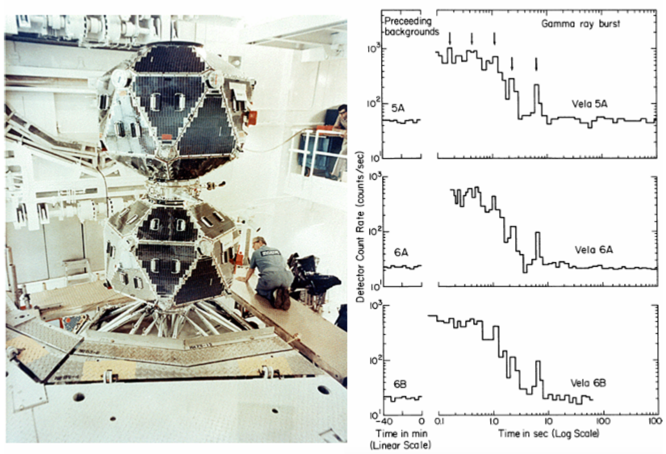


Figure 2: *Left*: A US Vela satellite, responsible for the first detections of GRBs in the late 1960s Image obtained from https://heasarc.gsfc.nasa.gov/Images/vela5b/vela5b 2.gif. Right: The lightcurve of GRB 700822 (22nd August 1970), from [62]. The burst is seen with a similar morphology in three different detectors (the Vela 5A, 6A and 6B satellites), confirming its reality.

2.2 The Early Years

Through the late 1960's and early 1970s GRBs were detected through scintillation detectors installed on satellites. Some of these were designed to search for gamma-ray emission from nuclear tests, while others were intended to track background radiation levels, or measure high energy emission from the Sun. They were not designed for the study of GRBs, and combined with the limited sensitivity this meant that only a handful of such bursts were detected. The first GRB catalogs from this period contained tens to perhaps 100 bursts, and in most cases are limited to light curves in a range of different energy bands, making direct comparison extremely challenging.

However, even these early data enabled significant insight into the GRB phenomena. The light travel time arguments meant that theories of GRB creation needed to concentrate on compact regions, either individual dense stars (e.g. neutron stars or black holes) or sub regions of larger objects, such as the cores of massive stars, or stellar coronae.

3 Research and Developments post discovery

Many models were forthcoming in the few years following the detections of the first bursts. Indeed, by the end of the 1970's over 30 models had been proposed, only one of which represented a "prediction" of gamma-ray emission in being published prior the the first detection of GRBs. These models largely came from three different families; those which were powered by accretion power, accreting mass onto a white dwarf, neutron star or black hole (with various different origins for the accreted material including comets and flares from companion stars, , those related to stellar activity (e.g. directed stellar flares and those due to the catastrophic destruction of stellar sized objects.

Although this is by no means an exhaustive list of the possibilities that have been discussed which are as extreme as GRBs originating from white holes or cosmic strings (neither of which have actually been identif ied). Indeed, a comprehensive list of models up until 1992 published by Robert Nemiroff contains a total of 118 different models for the creation of GRBs. Remarkably, many of the different physical mechanisms suggested in this list have subsequently been shown to occur in the Universe, and may well result in observable electromagnetic emission. However, the vast majority do not create GRBs. Indeed it is striking that the model commonly invoked today to explain the origin of most bursts is not on this list as it was not published until 1993.

3.1 The Great Debate: Galactic or Cosmological

Through the late 1980s, the absence of precise GRB positions precluded the identification of their nature, and the controversy over the origin of GRBs intensified. Two camps made strong arguments between Galactic and extragalactic models. While many models fell by the wayside in this period, those involving neutron stars either within or outside the Milky Way continued to gain traction.

In 1995, a "great" debate on the issue was held, honouring an earlier debate in 1920 discussing the scale of the Universe. While perhaps somewhat less all encompassing, the scale of GRBs was clearly one of the major issues in astronomy at the time. In this debate Bodhan Paczynski argued for a a Cosmological origin , while Don Lamb presented the case for a Galactic origin . The debate was heavily skewed by the recent announcements from the BATSE mission about the isotropy of GRBs on the sky (see below). Both parties agreed that further observations were necessary, noting the importance of measuring redshifts, either from the bursts themselves, or from counterparts identified at other wavelengths. Redshifts are nothing but a measure of how distant is a GRB and how old was the universe at the time the GRB happened. For ex, a redshift of z=2 means the GRB is about 16 billion light years away and light has travelled for billions of years to reach us after the GRB.

3.2 Important instrumental developments

Throughout the 1980s more efforts were made to understand the nature of GRBs, and their origin became one of the headline questions in astrophysics. Recognising this newfound importance their study rapidly became a motivation for new astrophysical satellites, perhaps most notably as part of NASAs Great Observatories programme. Probably the most impact ful series of scientific instruments of all time, these satellites– the Compton Gamma-ray Observatory (CGRO), the Hubble Space Telescope (HST), the Chandra X-ray Observatory (CXO), and the Spitzer Space Telescope– have revolutionised our view of the Universe across the electromagnetic spectrum. While each of them have made major contributions of the field of GRBs, it is CGRO that made the most immediate impact following its launch.

This is because of the presence of the Burst and Transient Source Experiment (BATSE) on board the satellite. BATSE consisted of 16 scintillation-ray detectors, with two placed on each corner of the instrument. One of these was optimised for burst detection, providing a large field of view and a route to determining directionality. The other was designed to enable higher energy resolution and better spectroscopy of the detected bursts.

BATSE delivered crucial diagnostics into bursts thanks to two vital improvements. Firstly, the sensitivity of the detectors meant that for the first time bursts were able to be detected in large enough numbers, and with a sufficiently well understood selection function, that statis tical studies gained much more power. Second, the error regions obtain for BATSE bursts, while very large for typical optical telescopes (several degrees in diameter) were sufficient to identify any signatures of large scale structure on the sky.

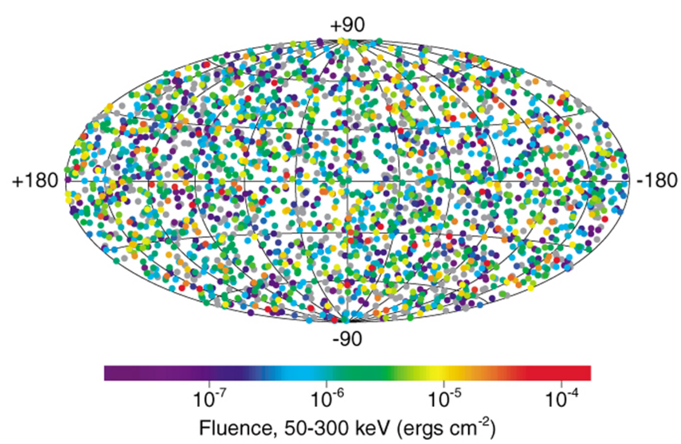


Figure 3: The distribution of BATSE GRBs on the sky, colour coded by the measured fluence of the burst

3.3 Duration Distribution of GRBs

The duration distribution of GRBs offers another handle on their properties, and is perhaps one of the characteristics of the prompt emission that has proved most valuable in identifying multiple classes of GRB. the duration distinction which has been most widely usedis **T90**, the duration over which90% of the total fluence of a given burst is recorded. In essence, T90 can be obtained by integrating the observed GRB lightcurve, and then determining the times within the lightcurve when 5% and 95% of the total fluence has been observed. even tighter restrictions such as T50 (the duration over which 50% of the fluence is observed) are also used.

The duration distribution of BATSE GRBs is shown in Figure 4. In this it is clear that there are two classes of GRB with durations of about 0.5 s, and 30 s . When examining the spectral properties of these bursts the distinction becomes even cleaner, the shorter GRBs emit more high energy emission than the longer bursts. This leads to the identification of two population of GRB– short hard bursts, and long soft bursts.

It should be stressed that T90, while powerful, is a blunt tool for measuring GRB durations. More sensitive detectors may track emission for longer, while bursts also have dif fering durations in different energy bands. Hence, the measurement is detector dependent.d that the distinction between long and short GRBs at 2 s, is only approximate.

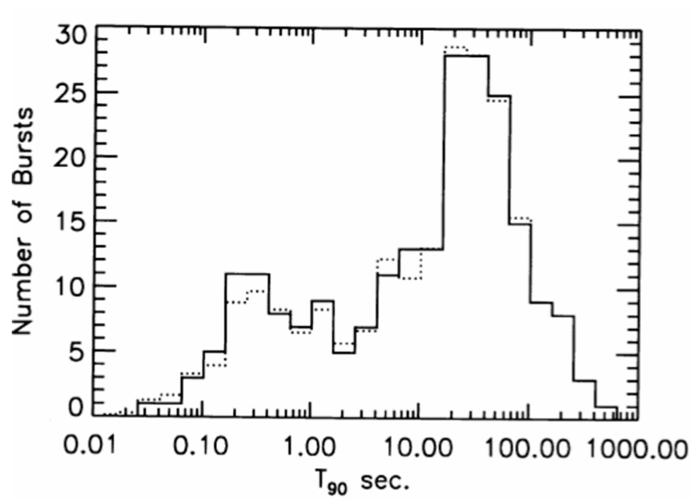


Figure 4: The duration distribution of BATSE gamma-ray bursts from . The two populations are clearly visible a short and long GRBs.

3.4 The Fireball Shock Model

The basic premise of this model is that the energy deposition within a small volume drives a relativistic expansion from the source. This reduces the photon energy in their rest frame (where they are generated) by a factor of Γ^{-1}, where Γ is the bulk Lorentz factor of the outflow. Driving such a powerful outflow, reaching Lorentz factors of several hundred is possible if the initial explosion energy is very high, and the outflow contains little matter– so called weak baryon loading.

Since γ-ray bursts exhibit significant variability, it is apparent that the source of the en ergy is, in general, not steady, but variable. If the energy input at the base of the explosion varies, and one might expect the Lorentz factor of material emitted at different times during the explosion to vary as well. In this case, as the material streams out at ultrarelativistic velocities some ejecta will be moving more quickly that other parts of the ejecta. Eventually the frame of the ejecta, or the observed burst) ejecta emitted at different times will inter act. These shocks can create-rays, and could therefore explain the observed properties and energies of the GRBs.

This was an important breakthrough in the understanding of GRBs, but perhaps more im portantly, the interaction of this outgoing relativistic flow with whatever material surrounded the star would potentially created much longer lived emission, an **afterglow**. Such an afterglow could be found at different wavelengths, with much more sensitive instrumenta tion, offering the possibility of pinpointing GRBs on the sky and resolving questions of their distance and energetics. This prediction gave new impetus to attempts to identify GRBs outside the-ray regime.

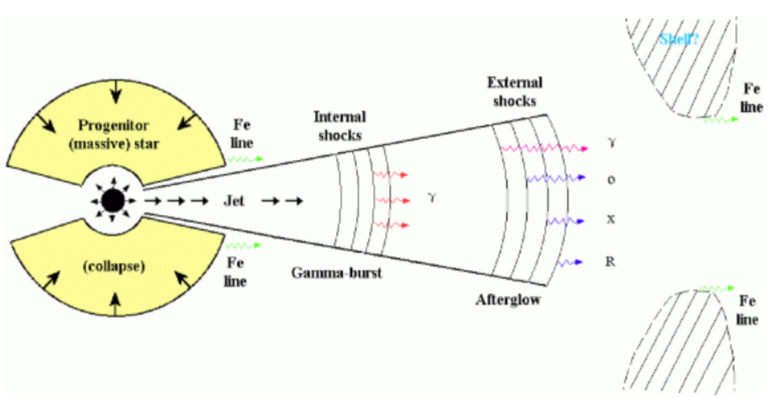


Figure 5: Fireball Shock model

3.5 The Supernova Connection

The possibility that supernovae connections could be directly tested was clearly demonstrated in May 1998, with the discovery of the burst GRB 980425. This long burst overlapped a local galaxy (ESO 184-G082) with a known redshift of z = 00085. Observations taken of the burst over the few days after its occurrence revealed not a fading afterglow, but an apparently rising supernova, named SN 1998bw [. This supernova was extremely bright compared to the majority of SNe observed, peaking at an absolute magnitude of MB 193, a factor of 10 brighter than most core collapse events, and comparable to a SN Ia. The presence of such a rare supernova, spatially and temporally coincident with a GRB was extremely unlikely by chance, and was strongly suggestive of an association. However, such an association was non-trivial to interpret; where was the afterglow? was this very nearby burst, with an energy 10,000 times less than most GRBs in any way related to the "normal" GRBs? Indeed, these questions remain relevant today, and GRB980425 remains the closest GRB ever seen by some margin.RB980425 remains the closest GRB ever seen by some margin.

3.5.1 The Collapsar Model

Importantly, the supernova in GRB 980425 provided a guide as to what could be ob served in more distant, and typical, GRBs. The supernova was bright, perhaps in contrast to some models of so called **collapsars** for the creation of GRBs, in which material would be accreted directly onto the newly formed black hole, and any supernova shock may be weak (or even absent). This meant that such bumps could in theory be detected by current technology out to $z \sim 1$. Such searches were naturally undertaken, and it rapidly became apparent that many bursts had the decay of their optical afterglows halted, and often reversed by a rising component, strikingly similar to the supernova seen in GRB 980425. Further observations moved beyond single colours, and showed that this similarity extended into the spectral regime, the bumps not only had a similar shape and luminosity to SN 1998bw, they also exhibited the same colours. From this a consensus gradually built that long-GRBs were essentially always associated with broad-lined (high velocity) type Ic supernovae, with a rather narrow range of peak brightness.

4 Prompt Emissions

The brief flash of gamma-rays emitted in the creation of a GRB was the route by which GRBs were detected and the property from which they are named. The prompt emission is readily detected, even by rudimentary space-based gamma-ray detectors, due to the extreme high energy photon budget that GRBs exhibit. Indeed, at peak GRBs outshine all other sources within the ray sky, including the Sun.

GRB prompt emission is hugely vari able burst to burst. There are no two bursts with the same duration and lightcurves that look identical. Some bursts are smooth, others highly erratic, some last for a fraction of a second, others for several hours. The prompt gamma-ray lightcurves of several well-known GRBs are shown in Figure 6. These demonstrate the range of behaviour that is commonly seen.

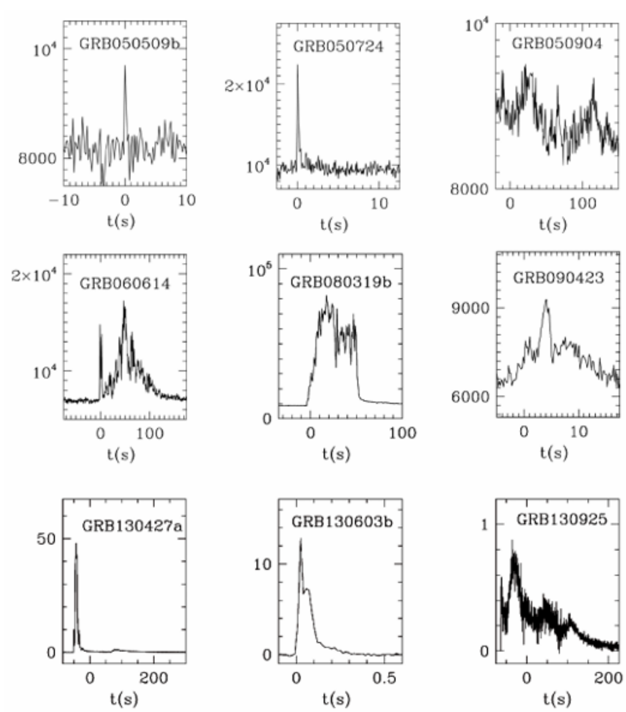


Figure 6: Prompt γ ray lightcurves from the *Swift*-BAT for a set of well studied Swift bursts. Swift is a satellite launched by NASA for studying GRBs.The wide range of durations and burst morphologies can be clearly seen, highlighting the diversity of GRB prompt emission.

4.1 Duration of Bursts

Perhaps the most natural property to consider is the duration of the burst, measuring how long the gamma-rays are visible. The most commonly used measure of duration is the so called T90.

The advantage of a duration measurement is that it is independent of the morphology of the lightcurve. It hence allows highly variable bursts to be compared to those with much smoother lightcurves regarding the duration over which the prompt emission is active. Du ration measurements were used to investigate possible distinctions between populations of GRBs as early as the 1980s . From the measured durations, it became apparent that there are at least two broad populations of GRBs. One, so-called short bursts, have a typical duration of 1s and the other, long bursts, have an average duration of about 30 s . The distribution of durations in both populations is reasonably modelled by a log-normal distribution, with a dividing line between the two groups customarily drawn at T90 = 2 s. However, it is clearly the case that the distributions of both groups continue beyond this, short bursts can have durations T90 > 2s and long burst can have T90 $< 2s$.

The duration of a burst as recorded is a function of the energy range and sensitivity of the detector used to make the observations. These differing durations imply that the distinction between long and short GRBs is not as clean as initially suspected, and instead is a function of the detector used to make the observation. Indeed, while it appears that 2 seconds is a good divide for the BATSE population, it has been suggested that for the Swift Burst Alert Telescope, whose soft response extends to 15 keV, the duration at which there is a 50% chance of lying in either population is in fact at T90 $\sim 0.7s$

4.2 Spectral Structure

GRBs also exhibit a wide range of spectral structure, that becomes increasingly apparent as the range of energies considered is increased. The emission is frequently non-thermal, or at least contains a non-thermal component. Many observations (for example those with Swift) are adequately fit with simple power-law prescriptions, which dominate over large regions. For the relatively wide bandpass used by BATSE (25 keV to >1 MeV) a frequently found best-fit model consists of two smoothly joined power-laws with an exponential cut-off, often described as a Band function

An example of such a spectrum from the famous burst GRB 990123 which reached a peak visual magnitude of 9 is shown in Figure 7. This demonstrates the broken power-law appearance and the clear peak energy. It also shows that over wide ranges of energy the source will be observed as a single power-law. This explains whysimple power-laws often provide very good representations of the observations from the Swift-BAT, since the 15-350 keV range often does not contain the peak energy, or does not have sufficient lever arm around it to resolve the smooth break between the two regimes.

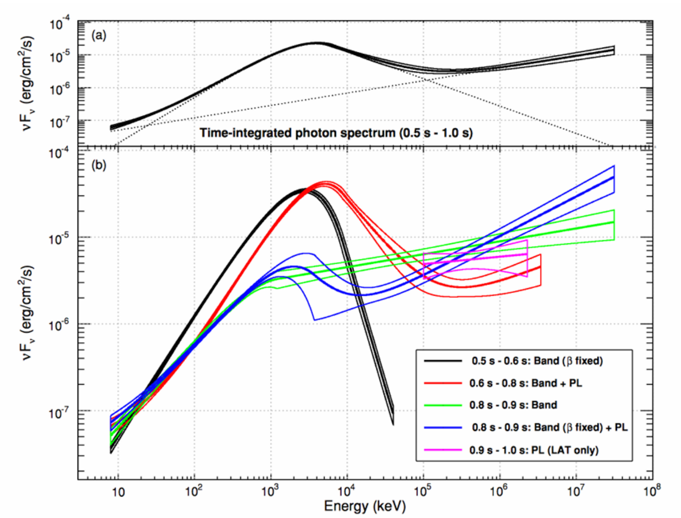


Figure 7: The spectrum of the short GRB 090510 as observed by the Fermi GBM and LAT instruments . The Band function at energies of hundreds of keV can clearly be seen, but the burst is notable for a further upturn at very high GeV energies, inconsistent with the extrapolation of a Band function.

However, while this spectral function generally provided a good description of the observed spectrum observed by BATSE it suffered because it offered very limited physical insight, since it was empirically fit to the data, and didn't provide direct information about the physical processes that produced it. More recent observations enable far greater sensitiv ity and a much broader energy band. These observations have yielded several new insights into the nature of the prompt phase.The spectrum of the short GRB 090510 as observed by the Fermi GBM and LAT instruments . The Band function at energies of hundreds of keV can clearly be seen, but the burst is notable for a further upturn at very high GeV energies, inconsistent with the extrapolation of a Band function.

4.3 Origin of the Prompt Emission

Despite 50 years of observations, there remain central questions as to the origin of the prompt emission. The most popular model to describe the evolution of the GRB from its formation to late times (both GRB and afterglow) has been the fireball model, Although there is little matter entrained within the jet, the high velocities mean there is significant kinetic energy, and so much of the thermal energy initially deposited at the base of the jet has been converted. It is likely that the initially released material, that may have to escape through some more heavily baryon loaded material will move at speeds lower than that released later in the process. This difference in velocities of shells of material ejected at different times creates interactions– shocks. Since all of these velocities are very close to the speed of light, these shocks do not occur close to the energy source, but instead at much larger radii. This distance can in principle be estimated as the time between the ejection of two shells with different Lorentz factors. If these are emitted with a time gap of δt and with Lorentz factors $\Gamma1$ and $\Gamma2$ then time in which they will interact is given by δt$\Gamma1\Gamma2$ and the distance from the source (given that the velocity is approximately the speed of light) is given by:

$$R_{prompt} = c\delta t\Gamma1\Gamma2$$

For a time difference of 100 ms, and $\Gamma1 \sim \Gamma2 \sim 100$ this corresponds to 3 x $10^{11}m$(2 AU or 400$R_{\odot}$) . This radius is well beyond the radius of the majority of massive stars, certainly the hydrogen-poor Wolf-Rayet stars that are favoured as the progenitors of long GRBs.

5 Afterglow Emission

Gamma-ray burst afterglows are long lived (seconds-days-weeks) emission viewed in the aftermath of the burst It is afterglows that precisely locate GRBs on the sky, enable redshift measurements and identify host galaxies.

GRBs are defined by their prompt emission, but much of what is known of them arises from studies of their afterglows. Afterglows are necessary to pinpoint GRBs on the sky, measure their redshifts and hence define their energetics, identify their host galaxies, and observe rising supernovae or kilonovae that pinpoint the progenitors of long- and short GRBs respectively.

5.1 Early afterglow searches

The search for, and discovery of GRB afterglows was not an accident. The models that begin to explain the prompt emission, described in chapter 2, almost required them. In particular, the spatial distribution of bursts on the sky, available in the early 1990s ruled out Galactic models for all but very special scenarios, and strongly favoured cosmological bursts. For these extragalactic models the GRB properties could only be explained by the creation of a relativistic outflow, and popular models at the time created the GRBs from shocks between material emitted at different Lorentz factors. However, these outflows were not expanding into a perfect vacuum, but into some circumstellar medium around the progenitor star. The blastwave itself must contain very little mass to achieve relativistic velocities, but has signif icant energy, thus as it slows down by ploughing into the surrounding medium it will collect many times its own mass in a shock front. This is often called an external shock, to differ entiate it from the internal shocks which in the same model create the prompt emission. The dissipation of energy within this shock will then naturally lead to longer lived emission at lower photon energies. This is the basic principle of a GRB afterglow, and was the signature searched for through the early 1990s.

The major breakthrough arose through observations with the Italian-Dutch satel lite BeppoSAX, launched in April 1996. The crucial breakthrough came on 28 February 1997, when GRB 970228 was detected by the WFC and Gamma-ray burst monitor, as a classic long duration GRB with a duration of around a minute. The position was sufficiently accurate (initially 10 arcminutes, but nar rowed down to 3 on a timescale of a few hours), that it was possible to observe the location with the narrow field X-ray telescope, in observations taken 8 hours later. These obser vations, described in full in [5] then revealed a much longer lived source, which was shown to fade on timescales of several days, appearing a factor of almost 20 fainter in observations taken on 3 March 1997. This was the first X-ray afterglow to a GRB, see Figure 8.

5.2 X-Ray Afterglows

X-ray afterglows are now almost ubiquitous to GRBsX-ray afterglows with Swift have now been observed over 7 orders of magnitude of bright ness, and 6 orders of magnitude in time.A typical X-ray afterglow is shown in Figure 9.

5.3 Optical Afterglows

Optical afterglows were discovered near simultaneously with X-ray afterglows. Since the spatial resolution of optical imaging is typically far higher than for X-ray imaging, optical counterparts in general provide the most accurate positions for GRBs, especially when the goal is to measure this location relative to the host galaxy, or star forming regions within it.

Optical counterparts are also the route through which GRB distances can be obtained since they illuminate their line of sight from the burst to us, and the imprint of lines from the interstellar medium upon the afterglow enables a direct measurement of the redshift of the absorbing material.

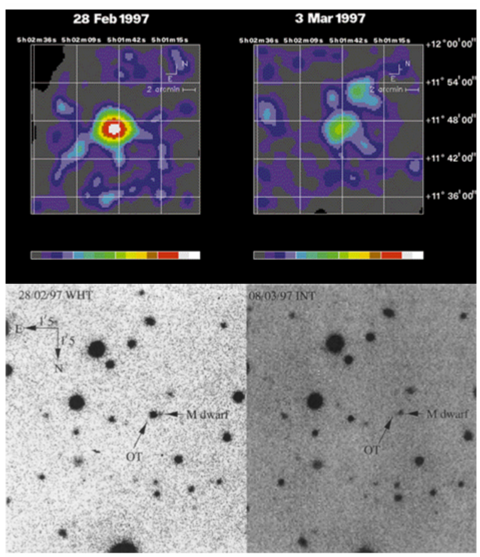


Figure 8: Images of the discovery of the X-ray (top,) and optical (bottom,) after glow of GRB 970228, the first GRB for which an afterglow was discovered. Observations on timescales of 1 day and 1 week revealed a fading X-ray and optical source in the region of the sky from which the GRB was identified. It is striking to note the timescale for the searches in this case was hours to days, whereas GRB searches today are often undertaken in seconds

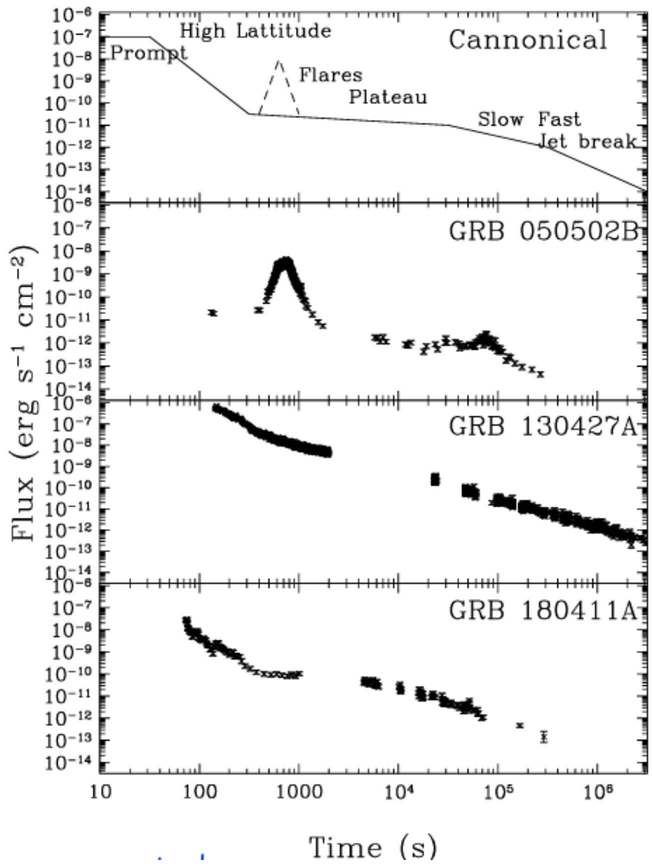


Figure 9: The cannonical lightcurve of a X-ray afterglow (top) with typical features marked. Also shown are several GRBs which exhibit some of these features. In most cases not all of the features are seen, often due to observational effects (e.g. orbits gaps, later starting observations). In other cases it is clear that not all features are seen in all lightcurves. For example some bursts do not show flares or plateaux.

5.4 Relativistic Beaming

The above discussion is valid for isotropic emission, although for the early phases of the GRB afterglow still provides a good description even if the GRB is highly collimated since the individual emitting regions of the outflow are not in causal contact at large angles, and so behave as though they are expanding isotropically (see below). If the emission from the GRB itself is confined into a relativistic jet with some half opening angle, j, then the true burst energy is not that observed by a GRB detector, but is modified by the fraction of the sky illuminated by the jet. This is only strictly true for a so-called top hat jet, where the energy per solid angle is the same for any observer, but is commonly assumed. In this case, the correction from the measured energy of the burst $E_{\rm iso}$ to its true energy E_γ is given by

$$E_\gamma = E_{iso}(1 - cos\theta_j) \approx E_{iso}(\theta_j)^2/2$$

where the geometric term is often expressed as the beaming fraction

$$f_b = (1 - cos\theta_j)$$

The impact of this beaming is clearly significant since 5 degree jets imply a modification of the total energy budget by a factor of 250, combined with a the same factor increase in the true astrophysical rate. Hence, there is significant importance in identifying the true beaming angles of GRBs, and the best route to achieving this comes from late time multiwavelength monitoring of their afterglow to search for so-called *jet breaks*.

5.5 Jet Breaks

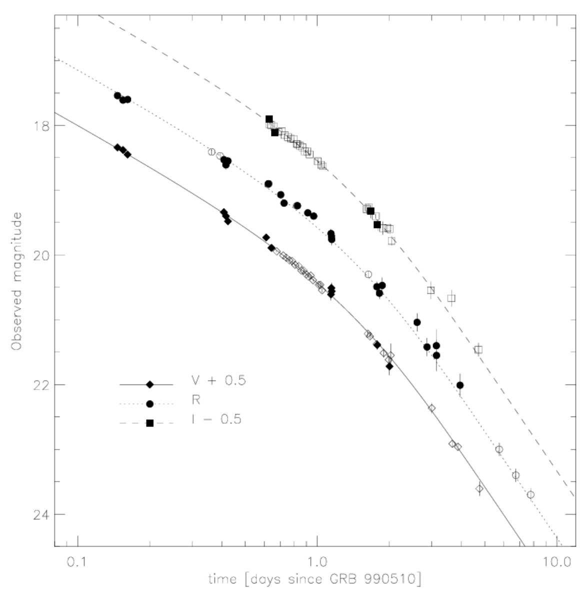


Figure 10: An early example of a jet-break in a GRB afterglow, GRB 990510

During a jet-break, the two sides of the jet are in causal contact. Beyond this crucial point, the afterglow is expected to fade more rapidly, yielding a steepening of the slope. It is therefore broadly agreed that the jet-break provides a route to measuring GRB beam ing and occurs when =1 j. However,the physical processes which shape this change are somewhat less clear. In principle, beyond this point the Lorentz factor declines exponentially with radius, yielding much lower energy input . The jet should feel its pressure, at the point that it becomes causally connected and should expand sideways. Finally, there are geometric effects; as the jet edges become visible, and the observer integrates over a region of emission to obtain a brightness, there is no additional emission from outside the jet cone, and so the source appears to fade more rapidly.

6 Fitting the Light Curve of GRB170817

6.1 Objective

The goal of this assignment is to model the afterglow light curve of GRB170817A using a smooth broken power-law and fit it to real data using Markov Chain Monte Carlo (MCMC) sampling.

6.2 Model

The flux density is modeled using the smooth broken power-law function:

$$F(t,\nu) = \left(\frac{\nu}{3\,\mathrm{GHz}}\right)^{\beta} F_p \left[\left(\frac{t}{t_p}\right)^{-s\alpha_1} + \left(\frac{t}{t_p}\right)^{-s\alpha_2}\right]^{-1/s} \tag{1}$$

where:

- μ is the observing frequency
- F_p is the peak flux
- t is the time post merger
- t_p is the time of peak flux
- β is the spectral index
- α_1, α_2 are the power-law slopes before and after t_p
- s is the smoothness parameter

The data was taken from: `http://www.tauceti.caltech.edu/kunal/gw170817/gw170817_afterglow_data_full.txt`.

You can find the Jupyter notebook here: View notebook on Google Drive.You can view it on any text editor.

6.3 Obervations for VLA 3GHz

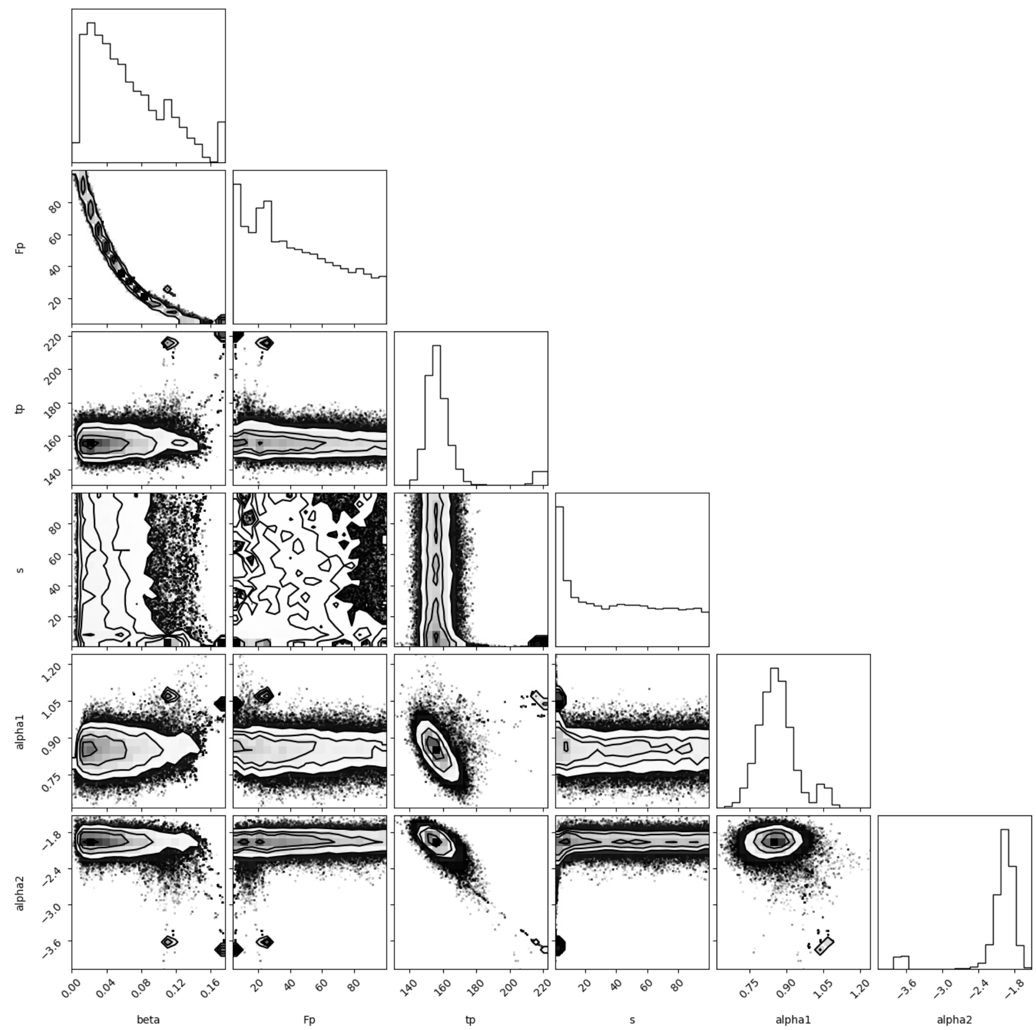
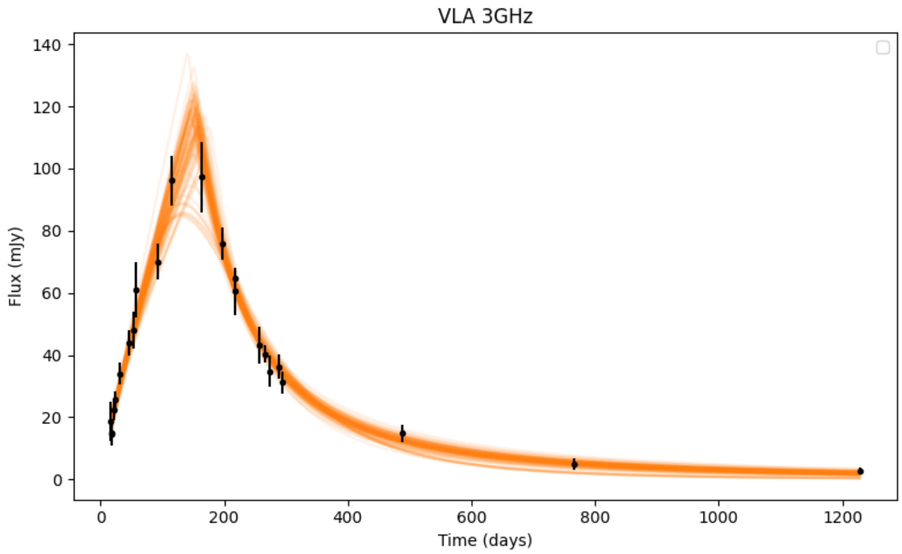


Figure 11: Sampling plots of parameters


VLA 3GHz
Flux (mJy)
Time (days)
0
20
40
60
80
100
120
140
0
200
400
600
800
1000
1200

6.4 Obervations for Chandra X-Ray

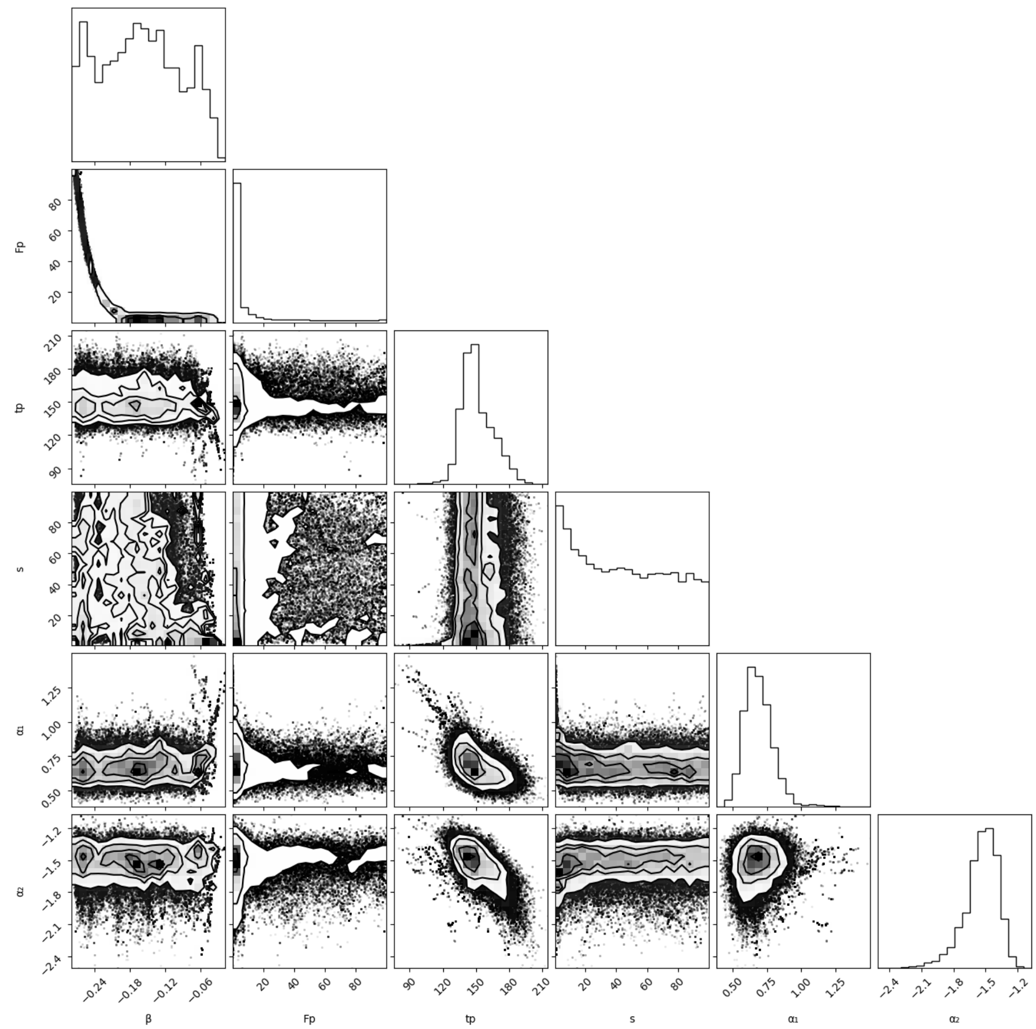
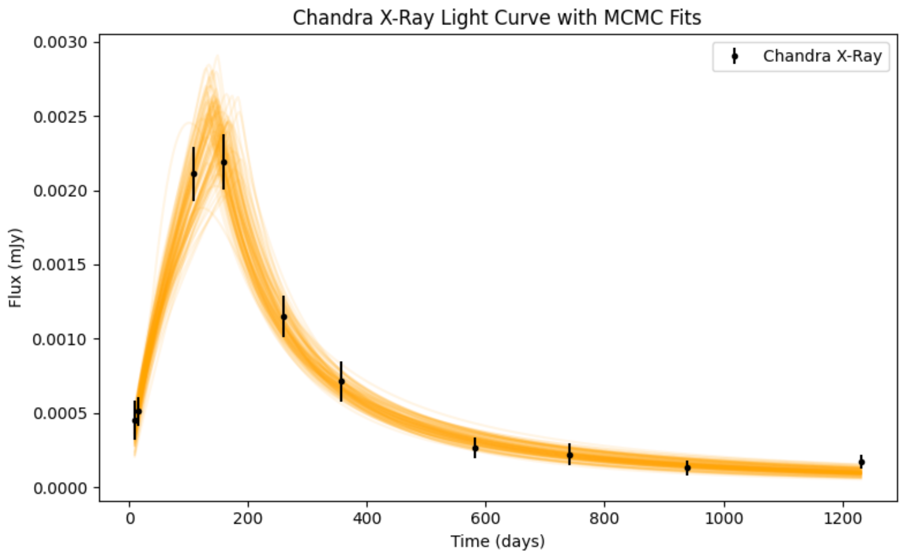


Figure 12: Sampling plots of parameters


Chandra X-Ray Light Curve with MCMC Fits
Chandra X-Ray
Flux (mJy)
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
0
200
400
600
800
1000
1200
Time (days)