RADIO BURST PRIMER

“Radio Burst Network”

A Preliminary Description of Radio Pulses/Bursts

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By

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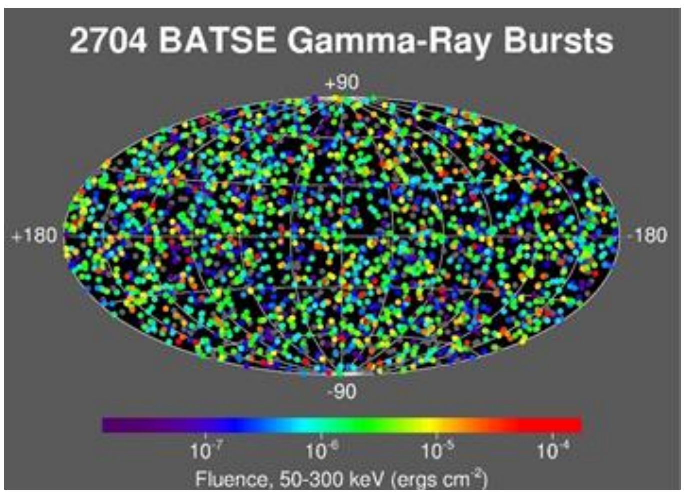
Radio Astronomy Supplies



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1. Introduction

Over the past 20 years or so, indications of fast rise and decay type pulses have been witnessed by some in the radio astronomy community, both amateur and professional. Pulsars however, have been seen since 1967 - In July 1967 (or November as per chart), Susan Jocelyn Bell Burnell DBE FRS FRSE FRAS detected a bit of "scruff" on her chart-recorder papers that tracked across the sky with the stars. She discovered that the signal was pulsing with great regularity, at a rate of about one pulse per second. Temporarily dubbed "Little Green Man 1" (LGM-1) the source (now known as PSR B1919+21), See Figure 1. was identified after several years as a rapidly rotating neutron star. This was later documented by the BBC Horizon series.

(extract http://www.bbc.co.uk/programmes/p009s61s)
(https://en.wikipedia.org/wiki/Jocelyn_Bell_Burnell)

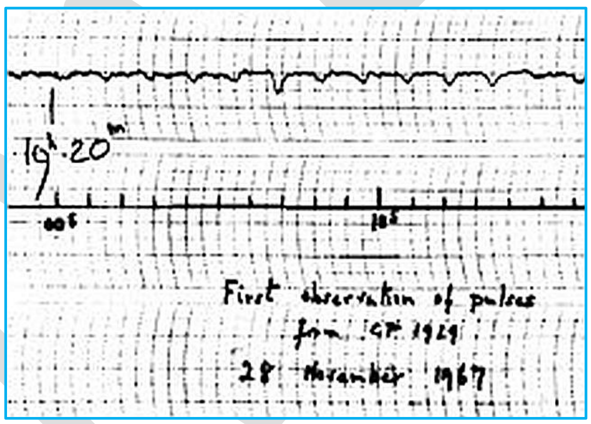


Figure 1. Recording of first Pulsar (Bell)

2. Fast Radio Burst (FRB)

From Wikipedia, the free encyclopedia
https://en.wikipedia.org/wiki/Fast_radio_burst

A **Fast Radio Burst** (**FRB**) is a high-energy astrophysical phenomenon manifested as a transient radio pulse lasting only a few milliseconds. These are bright, unresolved, broadband, millisecond flashes found in parts of the sky outside the Milky Way. The component frequencies of each burst are delayed by different amounts of time depending on the wavelength. This delay is described by a value referred to as a dispersion measure. Fast radio bursts have dispersion measures which are: much larger than expected for a source inside the Milky Way;[1] and consistent with propagation through an ionized plasma.[2]

The origin of fast radio bursts is not known. It is conjectured to be extragalactic because of the anomalously high value of pulse dispersion observed. Some have speculated that these signals might be signs of extraterrestrial intelligence.[3][4]

Fast radio bursts are named by the date the signal was recorded, as "YYMMDD". For example, one on 26 June 2011 would be called FRB 110626.[5] The first FRB found was FRB 010621. On 19 January 2015, astronomers at Australia's national science agency (CSIRO) reported from Parkes that a fast radio burst had been observed for the first time live.[6]

2.1 Lorimer Burst

The Lorimer Burst (FRB 010724) was discovered in archived data taken in 2001 by the Parkes radio dish in Australia.[7] Analysis of the survey data found a 30-jansky dispersed burst which occurred on 24 July 2001,[2] less than 5 milliseconds in duration, located 3° from the Small Magellanic Cloud. The reported burst properties argue against a physical association with the Milky Way galaxy or the Small Magellanic Cloud. The burst became known as the Lorimer Burst.[8] The discoverers argue that current models for the free electron content in the universe imply that the burst is less than 1 gigaparsec distant. The fact that no further bursts were seen in 90 hours of additional observations implies that it was a singular event such as a supernova or merger of relativistic objects.[2] It is suggested that hundreds of similar events could occur every day and, if detected, could serve as cosmological probes.[9]

2.2 Further developments

In 2010 there was a new report of 16 similar pulses: clearly of terrestrial origin; detected by the Parkes radio telescope; and given the name perytons.[10] In 2015 perytons were shown to be generated when microwave oven doors were suddenly opened during a heating cycle, with emission generated by the magnetron.[11]

An observation in 2012 of a fast radio burst (FRB 121102) in the direction of Auriga in the northern hemisphere using the Arecibo radio telescope confirmed the extragalactic origin of fast radio pulses by an effect known as plasma dispersion. Victoria Kaspi of the McGill University estimates that as many as 10,000 fast radio bursts may occur per day over the entire sky.[12]

In 2013 four bursts were identified that supported the likelihood of extragalactic sources.[5]

FRB 140514, caught 'live', was found to be 21% (+/- 7%) circularly polarized.[6]

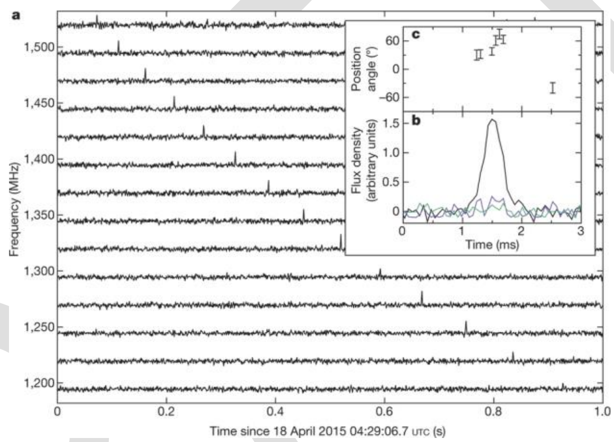
Fast radio bursts discovered up until 2015 had dispersion measures that were close to multiples of 187.5 cm^{-3} pc.[13] However subsequent observations do not fit this pattern.

In 2015, FRB 110523 was discovered in archival data from the Green Bank Telescope.[14] It was the first FRB for which linear polarization was detected (allowing, with the detection of circular polarization, a calculation of Faraday rotation). Measurement of the signal's dispersion delay suggested that this burst is of extragalactic origin, possibly up to 6 billion light years away.[15]

The upcoming and unusual Canadian radio telescope called CHIME will also be used to detect "hundreds" of fast radio bursts as its secondary objective.[16][17]

2.2.1 FRB 150418 (http://www.nature.com/nature/journal/v530/n7591/fig_tab/nature17140_F1.html)

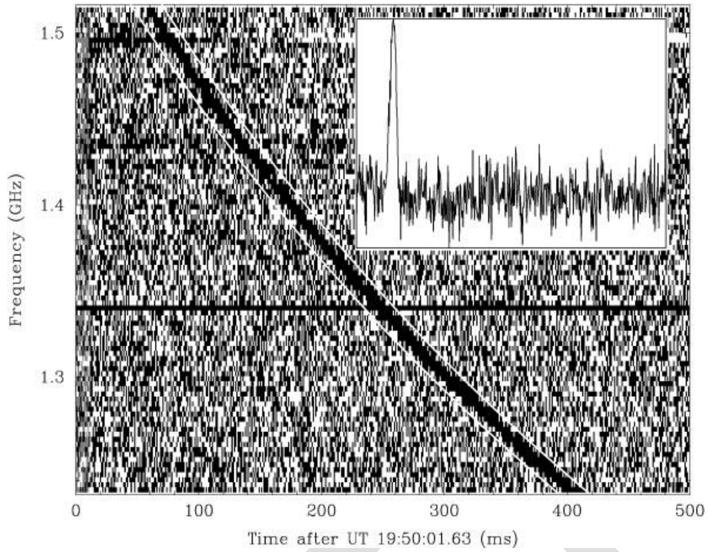
On 18 April 2015, FRB 150418 was detected by the Parkes observatory and within hours, several telescopes including the Australia Telescope Compact Array caught an "afterglow" of the flash, which took six days to fade.[18][19][20] The Subaru telescope was used to find what was thought to be the host galaxy and determine its redshift and the implied distance to the burst.[21]



However, the origin of the burst was soon disputed,[22][23][24] and by April 2016 it was established that the emission instead originates from an active galactic nucleus that is powered by a supermassive black hole with dual jets blasting outward from the black hole.[25] It was also noted that what was thought to be an "afterglow", never goes away, meaning that it cannot be associated with the fast radio burst.[25]

2.2.2 FRB 121102 (http://venus.fandm.edu/~pulsar/frb/index.html)

In November 2015, astronomer Paul Scholz at McGill University in Canada, found ten non-periodically repeated fast radio pulses in archival data gathered in May and June 2015 by the Arecibo radio telescope.[17] The ten bursts have dispersion measures and sky positions consistent with the original burst FRB 121102, detected in 2012.[17] Like the 2012 burst, the 10 bursts have three times the maximum plasma dispersion measure from a source in the Milky Way Galaxy. The team thinks that this finding rules out self-destructive, cataclysmic events that could only occur once, such as the explosion of a black hole or the collision between two neutron stars.[26] According to the scientists, the data support an origin in a young rotating neutron star (pulsar), or in a highly magnetized neutron star (magnetar).[17][26][27][28]



2.3 Hypotheses

Because of the isolated nature of the observed phenomenon, the nature of the source remains speculative. As of 2016, there is no generally accepted explanation. The emission region is estimated to be no larger than a few hundred kilometers. If the bursts come from cosmological distances, their sources must be very bright.[29] One possible explanation would be a collision between very dense objects like collapsing black holes or neutron stars.[7] Blitzars are another proposed explanation.[29] It has been suggested that there is a connection to gamma-ray bursts.[30][31]

In 2007, just after the publication of the e-print with the first discovery, it was proposed that fast radio bursts could be related to hyper flares of magnetars.[32][33] In 2015 three studies supported the magnetars hypothesis.[14][34][35][36] It has also been proposed that if fast radio bursts originate in black hole explosions, FRBs would be the first detection of quantum gravity effects.[7][37] Table 2.1 FRB List, (Swinburne University of Technology)

2.4 List of bursts

Name	date-time UTC for 1581.804688 MHz	RA J2000	Dec J2000	DM $cm^{-3}pc$	width ms	peak flux Jy	Notes
FRB 010724[2]	2001/07/24 19:50:01.63	01h18′	-75°12′	375	4.6	30	"Lorimer Burst"
FRB 010621[38]	2001/06/21 13:02:10.795	18h52′	-08°29′	746	7.8	0.4	
FRB 110220[5]	2011/02/20 01:55:48.957	22h34′	-12°24′	944.38	5.6	1.3	
FRB 110627[5]	2011/06/27 21:33:17.474	21h03′	-44°44′	723.0	<1.4	0.4	
FRB 110703[5]	2011/07/03 18:59:40.591	23h30′	-02°52′	1103.6	<4.3	0.5	
FRB 120127[5]	2012/01/27 08:11:21.723	23h15′	-18°25′	553.3	<1.1	0.5	
FRB 011025[39]	2001/10/25 00:29:13.23	19h07′	-40°37′	790	9.4	0.3	
FRB 121002[40]	2012/10/02 13:09:18.402	18h14′	-85°11′	1628.76	2.1; 3.7	0.35	double pulse 5.1 ms apart
FRB 121002[41]	2012/10/02 13:09:18.50	18h14'	-85°11'	1629.18	<0.3	>2.3	
FRB 121102[42]	2012/11/02 06:35:53.244	05h32′	33°05'	557	3.0	0.4	by Arecibo radio telescope
	2015	05h32′~	33°05'~	557~			10 repeat bursts: 6 bursts in 10 minutes, 3 bursts weeks apart.[28][27]

FRB 131104[43]	2013/11/04 18:04:01.2	06h44′	-51°17′	779.0	<0.64	1.12	'near' Carina Dwarf Spheroidal Galaxy
FRB 140514[44]	2014/05/14 17:14:11.06	22h34′	-12°18′	562.7	2.8	0.47	21 ± 7 per cent (3σ) circular polarization
FRB 090625[41]	2009/06/25 21:53:52.85	03h07′	-29°55′	899.6	<1.9	>2.2	
FRB 130626[41]	2013/06/26 14:56:00.06	16h27'	-07°27'	952.4	<0.12	>1.5	
FRB 130628[41]	2013/06/28 03:58:00.02	09h03'	+03°26'	469.88	<0.05	>1.2	
FRB 130729[41]	2013/07/29 09:01:52.64	13h41'	-05°59'	861	<4	>3.5	
FRB 110523 [14][15][45]	2011/05/23	21h45'	-00°12'	623.30	1.73	0.6	700-900 MHz at Green Bank radio telescope, detection of both circular and linear polarization.
FRB 150418	2015/04/18 04h29'	07h16'	−19° 00′	776.2	0.8	2.4	Detection of linear polarization. The origin of the burst is disputed.[22][23][24][25]

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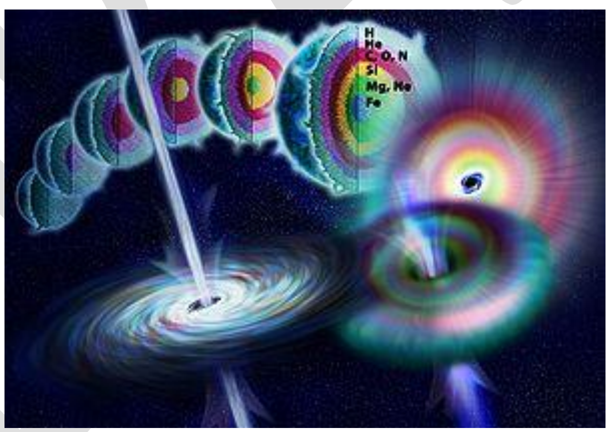
Notes:

3. Gamma-Ray Burst (GRB)

From Wikipedia, the free encyclopedia https://en.wikipedia.org/wiki/Gamma-ray_burst
For bursts of gamma rays of terrestrial origin, see Terrestrial gamma-ray flash.

Gamma-Ray Bursts (**GRBs**) are extremely energetic explosions that have been observed in distant galaxies. They are the brightest electromagnetic events known to occur in the universe.[1] Bursts can last from ten milliseconds to several hours.[2][3][4] After an initial flash of gamma rays, a longer-lived "afterglow" is usually emitted at longer wavelengths (X-ray, ultraviolet, optical, infrared, microwave and radio).[5]



Artist's illustration showing the life of a massive star as nuclear fusion converts lighter elements into heavier ones. When fusion no longer generates enough pressure to counteract gravity, the star rapidly collapses to form a black hole. Theoretically, energy may be released during the collapse along the axis of rotation to form a gamma-ray burst.

The intense radiation of most observed GRBs is believed to be released during a supernova or hypernova as a rapidly rotating, high-mass star collapses to form a neutron star, quark star, or black hole. A subclass of GRBs (the "short" bursts) appear to originate from a different process: the merger of binary neutron stars. The cause of the precursor burst observed in some of these short events may be due to the development of a resonance between the crust and core of such stars as a result of the massive tidal forces experienced in the seconds leading up to their collision, causing the entire crust of the star to shatter.[6]

The sources of most GRBs are billions of light years away from Earth, implying that the explosions are both extremely energetic (a typical burst releases as much energy in a few seconds as the Sun will in its entire 10-billion-year lifetime) and extremely rare (a few per galaxy per million years[7]). All observed GRBs have originated from outside the Milky Way galaxy, although a related class of phenomena, soft gamma repeater flares, are associated with magnetars within the Milky Way. It has been hypothesized that a gamma-ray burst in the Milky Way, pointing directly towards the Earth, could cause a mass extinction event.[8]

GRBs were first detected in 1967 by the Vela satellites, a series of satellites designed to detect covert nuclear weapons tests. Hundreds of theoretical models were proposed to explain these bursts in the years following their discovery, such as collisions between comets and neutron stars.[9] Little information was available to verify these models until the 1997 detection of the first X-ray and optical afterglows and direct measurement of their redshifts using optical spectroscopy, and thus their distances and energy outputs. These discoveries, and subsequent studies of the galaxies and supernovae associated with the bursts, clarified the distance and luminosity of GRBs. These facts definitively placed them in distant galaxies and also connected long GRBs with the explosion of massive stars, the only possible source for the energy outputs observed.

3.1 History

Main article: History of gamma-ray burst research

Referring to Figure 3.1, Gamma-ray bursts were first observed in the late 1960s by the U.S. Vela satellites, which were built to detect gamma radiation pulses emitted by nuclear weapons tested in space. The United States suspected that the USSR might attempt to conduct secret nuclear tests after signing the Nuclear Test Ban Treaty in 1963. On July 2, 1967, at 14:19 UTC, the Vela 4 and Vela 3 satellites detected a flash of gamma radiation unlike any known nuclear weapons signature.[10] Uncertain what had happened but not considering the matter particularly urgent, the team at the Los Alamos Scientific Laboratory, led by Ray Klebesadel, filed the data away for investigation. As additional Vela satellites were launched with better instruments, the Los Alamos team continued to find inexplicable gamma-ray bursts in their data. By analyzing the different arrival times of the bursts as detected by different satellites, the team was able to determine rough estimates for the sky positions of sixteen bursts[10] and definitively rule out a terrestrial or solar origin. The discovery was declassified and published in 1973 as an *Astrophysical Journal* article entitled "Observations of Gamma-Ray Bursts of Cosmic Origin".[11]

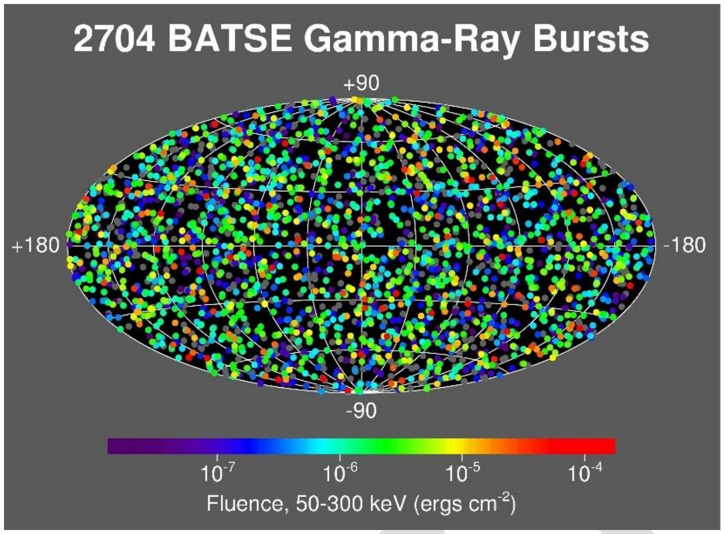


Figure 3.1 Positions on the sky of all gamma-ray bursts detected during the BATSE mission. The distribution is isotropic, with no concentration towards the plane of the Milky Way, which runs horizontally through the center of the image. (http://gammaray.nsstc.nasa.gov/batse/grb/skymap/)

Many theories were advanced to explain these bursts, most of which posited nearby sources within the Milky Way Galaxy. Little progress was made until the 1991 launch of the Compton Gamma Ray Observatory and its Burst and Transient Source Explorer (BATSE) instrument, an extremely sensitive gamma-ray detector. This instrument provided crucial data that showed the distribution of GRBs is isotropic—not biased towards any particular direction in space, such as toward the galactic plane or the galactic center.[12] Because of the flattened shape of the Milky Way Galaxy, if the sources were from within our own galaxy they would be strongly concentrated in or near the galactic plane. The absence of any such pattern in the case of GRBs provided strong evidence that gamma-ray bursts must come from beyond the Milky Way.[13][14][15][16] However, some Milky Way models are still consistent with an isotropic distribution.[13][17]

3.1.1 Counterpart objects as candidate sources

For decades after the discovery of GRBs, astronomers searched for a counterpart at other wavelengths: i.e., any astronomical object in positional coincidence with a recently observed burst. Astronomers considered many distinct classes of objects, including white dwarfs, pulsars, supernovae, globular clusters, quasars, Seyfert galaxies, and BL Lac objects.[18] All such searches were unsuccessful,[nb 1] and in a few cases particularly well-localized bursts (those whose positions were determined with what was then a high degree of accuracy) could be clearly shown to have no bright objects of any nature consistent with the position derived from the detecting satellites. This suggested an origin of either very faint stars or extremely distant galaxies.[19][20] Even the most accurate positions contained numerous faint stars and galaxies, and it was widely agreed that final resolution of the origins of cosmic gamma-ray bursts would require both new satellites and faster communication.[21]

3.1.2 Afterglow

Several models for the origin of gamma-ray bursts postulated that the initial burst of gamma rays should be followed by slowly fading emission at longer wavelengths created by collisions between the burst ejecta and interstellar gas.[22] This fading emission would be called the "afterglow." Early searches for this afterglow were unsuccessful, largely due to the difficulties in observing a burst's position at longer wavelengths immediately after the initial burst. The breakthrough came in February 1997 when the satellite BeppoSAX detected a gamma-ray burst (GRB 970228[nb 2]) and when the X-ray camera was pointed towards the direction from which the burst had originated, it detected fading X-ray emission. The William Herschel Telescope identified a fading optical counterpart 20 hours after the burst.[23] Once the GRB faded, deep imaging was able to identify a faint, distant host galaxy at the location of the GRB as pinpointed by the optical afterglow.[24][25]

Because of the very faint luminosity of this galaxy, its exact distance was not measured for several years. Well before then, another major breakthrough occurred with the next event registered by BeppoSAX, GRB 970508. This event was localized within four hours of its discovery, allowing research teams to begin making observations much sooner than any previous burst. The spectrum of the object revealed a redshift of $z = 0.835$, placing the burst at a distance of roughly 6 billion light years from Earth.[26] This was the first accurate determination of the distance to a GRB, and together with the discovery of the host galaxy of 970228 proved that GRBs occur in extremely distant galaxies.[24][27] Within a few months, the controversy about the distance scale ended: GRBs were extragalactic events originating within faint galaxies at enormous distances. The following year, GRB 980425 was followed within a day by a coincident bright supernova (SN 1998bw), indicating a clear connection between GRBs and the deaths of very massive stars. This burst provided the first strong clue about the nature of the systems that produce GRBs.[28] Figure 3.2 The Italian–Dutch satellite BeppoSAX.

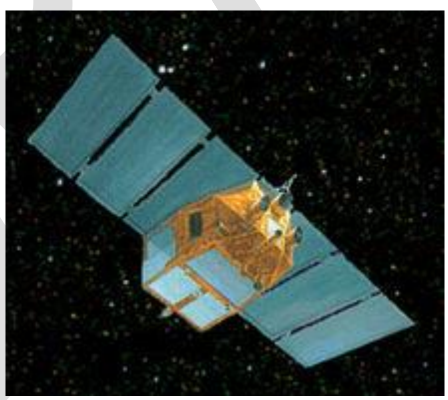


Figure 3.2 The Italian–Dutch satellite BeppoSAX, launched in April 1996, provided the first accurate positions of gamma-ray bursts, allowing follow-up observations and identification of the sources.

BeppoSAX functioned until 2002 and CGRO (with BATSE) was deorbited in 2000. However, the revolution in the study of gamma-ray bursts motivated the development of a number of additional instruments designed specifically to explore the nature of GRBs, especially in the earliest moments following the explosion. The first such mission, HETE-2,[29] launched in 2000 and functioned until 2006, providing most of the major discoveries during this period. One of the most successful space missions to date, Swift (Figure 3.3), was launched in 2004 and as of 2016 is still operational.[30][31] Swift is equipped with a very sensitive gamma ray detector as well as on-board X-ray and optical telescopes, which can be rapidly and automatically slewed to observe afterglow emission following a burst. More recently, the Fermi mission was launched carrying the Gamma-Ray Burst Monitor, which detects bursts at a rate of several hundred per year, some of which are bright enough to be observed at extremely high energies with Fermi's Large Area Telescope. Meanwhile, on the ground, numerous optical telescopes have been built or modified to incorporate robotic control software that responds immediately to signals sent through the Gamma-ray Burst Coordinates Network. This allows the telescopes to rapidly repoint towards a GRB, often within seconds of receiving the signal and while the gamma-ray emission itself is still ongoing.[32][33]

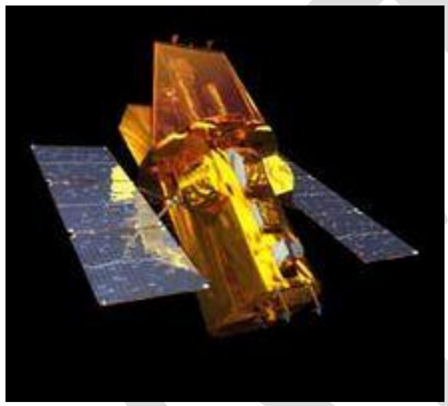


Figure 3.3 NASA's Swift Spacecraft launched in November 2004

New developments over the past few years include the recognition of short gamma-ray bursts as a separate class (likely due to merging neutron stars and not associated with supernovae), the discovery of extended, erratic flaring activity at X-ray wavelengths lasting for many minutes after most GRBs, and the discovery of the most luminous (GRB 080319B) and the former most distant (GRB 090423) objects in the universe.[34][35] The most distant known GRB, GRB 090429B, is now the most distant known object in the universe.

3.1.3 Classification

Referring to Figure 3.4, the light curves of gamma-ray bursts are extremely diverse and complex.[36] No two gamma-ray burst light curves are identical,[37] with large variation observed in almost every property: the duration of observable emission can vary from milliseconds to tens of minutes, there can be a single peak or several individual subpulses, and individual peaks can be symmetric or with fast brightening and very slow fading. Some bursts are preceded by a "precursor" event, a weak burst that is then followed (after seconds to minutes of no emission at all) by the much more intense "true" bursting episode.[38] The light curves of some events have extremely chaotic and complicated profiles with almost no discernible patterns.[21]

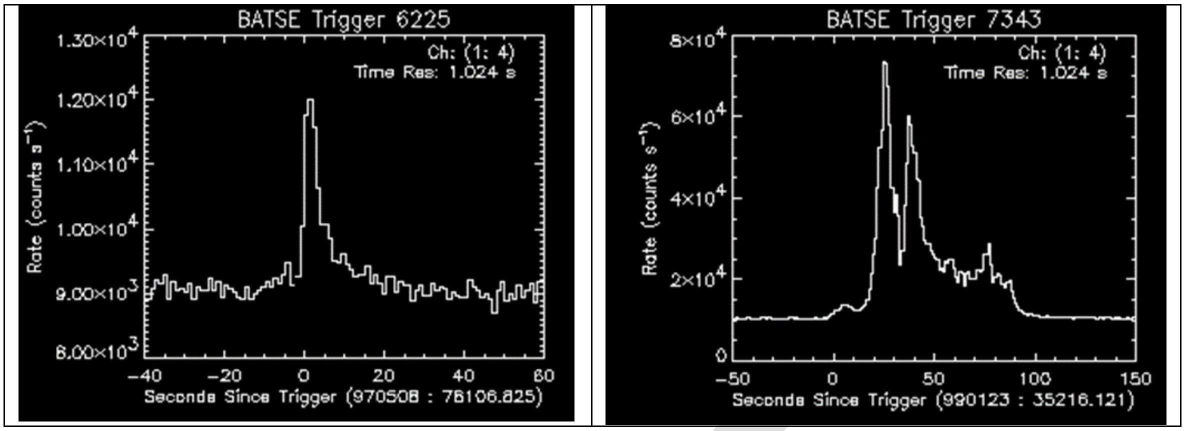


Figure 3.4 Gamma-Ray Burst light curves

Although some light curves can be roughly reproduced using certain simplified models,[39] little progress has been made in understanding the full diversity observed. Many classification schemes have been proposed, but these are often based solely on differences in the appearance of light curves and may not always reflect a true physical difference in the progenitors of the explosions. However, plots of the distribution of the observed duration[nb 3] for a large number of gamma-ray bursts show a clear bimodality, suggesting the existence of two separate populations: a "short" population with an average duration of about 0.3 seconds and a "long" population with an average duration of about 30 seconds.[40] Both distributions are very broad with a significant overlap region in which the identity of a given event is not clear from duration alone. Additional classes beyond this two-tiered system have been proposed on both observational and theoretical grounds.[41][42][43][44]

3.1.4 Short Gamma-Ray Bursts

Events with a duration of less than about two seconds are classified as short gamma-ray bursts. These account for about 30% of gamma-ray bursts, but until 2005, no afterglow had been successfully detected from any short event and little was known about their origins.[46] Since then, several dozen short gamma-ray burst afterglows have been detected and localized, several of which are associated with regions of little or no star formation, such as large elliptical galaxies and the central regions of large galaxy clusters.[47][48][49][50] This rules out a link to massive stars, confirming that short events are physically distinct from long events. In addition, there has been no association with supernovae.[51]

The true nature of these objects (or even whether the current classification scheme is accurate) remains unknown, although the leading hypothesis is that they originate from the mergers of binary neutron stars[52] or a neutron star with a black hole. Such mergers might also be expected to produce kilonovae,[53] (Figure 3.5) and evidence for a kilonova associated with GRB 130603B has been seen.[54][55][56] The mean duration of these events of 0.2 seconds suggests a source of very small physical diameter in stellar terms; less than 0.2 light-seconds (about 37,000 miles—four times the Earth's diameter). This further suggests a very compact object as the source. The observation of minutes to hours of X-ray flashes after a short gamma-ray burst is consistent with small particles of a primary object like a neutron star initially swallowed by a black hole in less than two seconds, followed by some hours of lesser energy events, as remaining fragments of tidally disrupted neutron star material (no longer neutronium) remain in orbit to spiral into the black hole, over a longer period of time.[46] A small fraction of short gamma-ray bursts are probably produced by giant flares from soft gamma repeaters in nearby galaxies.[57][58]

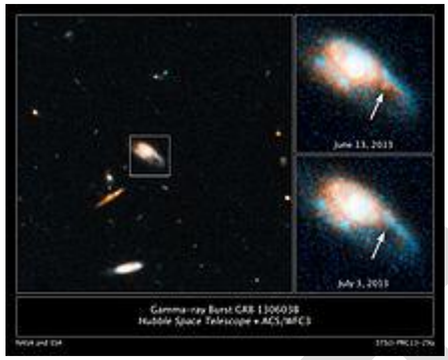


Figure 3.5 Hubble captures infrared glow of a kilonova blast.[45]

3.1.5 Long Gamma-Ray Bursts

Most observed events (70%) have a duration of greater than two seconds and are classified as long gamma-ray bursts. Because these events constitute the majority of the population and because they tend to have the brightest afterglows, they have been studied in much greater detail than their short counterparts. Almost every well-studied long gamma-ray burst has been linked to a galaxy with rapid star formation, and in many cases to a core-collapse supernova as well, unambiguously associating long GRBs with the deaths of massive stars.[59] Long GRB afterglow observations, at high redshift, are also consistent with the GRB having originated in star-forming regions.[60]

3.1.6 Ultra-Long Gamma-Ray Bursts

These events are at the tail end of the long GRB duration distribution, lasting more than 10,000 seconds. They have been proposed to form a separate class, possibly the result of the collapse of a blue supergiant star.[61] Only a small number have been identified to date, their primary characteristic being their gamma ray emission duration. So far, the known and well established ultra-long GRBs are GRB 091024A, GRB 101225A, and GRB 111209A.[62][63] A recent study,[64] on the other hand, shows that the existing evidence for a separate ultra-long GRB population with a new type of progenitor is inconclusive, and further multi-wavelength observations are needed to draw a firmer conclusion.

3.1.7 Energetics and beaming

Gamma-ray bursts are very bright (Figure 3.6) as observed from Earth despite their typically immense distances. An average long GRB has a bolometric flux comparable to a bright star of our galaxy despite a distance of billions of light years (compared to a few tens of light years for most visible stars). Most of this energy is released in gamma rays, although some GRBs have extremely luminous optical counterparts as well. GRB 080319B, for example, was accompanied by an optical counterpart that peaked at a visible magnitude of 5.8,[65] comparable to that of the dimmest naked-eye stars despite the burst's distance of 7.5 billion light years. This combination of brightness and distance implies an extremely energetic source. Assuming the gamma-ray explosion to be spherical, the energy output of GRB 080319B would be within a factor of two of the rest-mass energy of the Sun (the energy which would be released were the Sun to be converted entirely into radiation).[34]

Figure 3.6 Artist's illustration of a bright gamma-ray burst occurring in a star-forming region. Energy from the explosion is beamed into two narrow, oppositely directed jets.

No known process in the universe can produce this much energy in such a short time. Rather, gamma-ray bursts are thought to be highly focused explosions, with most of the explosion energy collimated into a narrow jet traveling at speeds exceeding 99.995%[*not in citation given*] of the speed of light.[66][67] The approximate angular width of the jet (that is, the degree of spread of the beam) can be estimated directly by observing the achromatic "jet breaks" in afterglow light curves: a time after which the slowly decaying afterglow begins to fade rapidly as the jet slows and can no longer beam its radiation as effectively.[68][69] Observations suggest significant variation in the jet angle from between 2 and 20 degrees.[70]

Because their energy is strongly focused, the gamma rays emitted by most bursts are expected to miss the Earth and never be detected. When a gamma-ray burst is pointed towards Earth, the focusing of its energy along a relatively narrow beam causes the burst to appear much brighter than it would have been were its energy emitted spherically. When this effect is taken into account, typical gamma-ray bursts are observed to have a true energy release of about 10^{44} J, or about 1/2000 of a Solar mass ($M_{\odot}$) energy equivalent[70]—which is still many times the mass-energy equivalent of the Earth (about 5.5×10^{41} J). This is comparable to the energy released in a bright type Ib/c supernova and within the range of theoretical models. Very bright supernovae have been observed to accompany several of the nearest GRBs.[28] Additional support for focusing of the output of GRBs has come from observations of strong asymmetries in the spectra of nearby type Ic supernova[71] and from radio observations taken long after bursts when their jets are no longer relativistic.[72]

Short (time duration) GRBs appear to come from a lower-redshift (i.e. less distant) population and are less luminous than long GRBs.[73] The degree of beaming in short bursts has not been accurately measured, but as a population they are likely less collimated than long GRBs[74] or possibly not collimated at all in some cases.[75]

3.1.8 Gamma-Ray Burst progenitors

Because of the immense distances of most gamma-ray burst sources from Earth, identification of the progenitors, the systems that produce these explosions, is particularly challenging. The association of some long GRBs with supernovae and the fact that their host galaxies are rapidly star-forming offer very strong evidence that long gamma-ray bursts are associated with massive stars. The most widely accepted mechanism for the origin of long-duration GRBs is the collapsar model,[76] in which the core of an extremely massive, low-metallicity, rapidly rotating star collapses into a black hole in the final stages of its evolution. Matter near the star's core rains down towards the center and swirls into a high-density accretion disk. The infall of this material into a black hole drives a pair of relativistic jets out along the rotational axis, which pummel through the stellar envelope and eventually break through the stellar surface and radiate as gamma rays. Some alternative models replace the black hole with a newly formed magnetar,[77][78] although most other aspects of the model (the collapse of the core of a massive star and the formation of relativistic jets) are the same.

The closest analogs within the Milky Way galaxy of the stars producing long gamma-ray bursts are likely the Wolf–Rayet stars (Figure 3.7), extremely hot and massive stars which have shed most or all of their hydrogen due to radiation pressure. Eta Carinae and WR 104 have been cited as possible future gamma-ray burst progenitors.[79] It is unclear if any star in the Milky Way has the appropriate characteristics to produce a gamma-ray burst.[80]

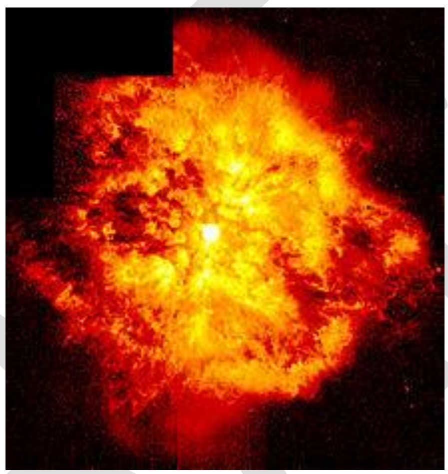


Figure 3.7 Hubble Space Telescope image of Wolf–Rayet star WR 124 and its surrounding nebula. Wolf–Rayet stars are candidates for being progenitors of long-duration GRBs.

The massive-star model probably does not explain all types of gamma-ray burst. There is strong evidence that some short-duration gamma-ray bursts occur in systems with no star formation and where no massive stars are present, such as elliptical galaxies and galaxy halos.[73] The favored theory for the origin of most short gamma-ray bursts is the merger of a binary system consisting of two neutron stars. According to this model, the two stars in a binary slowly spiral towards each other due to the release of energy via gravitational radiation[81][82] until the neutron stars suddenly rip each other apart due to tidal forces and collapse into a single black hole. The infall of matter into the new black hole produces an accretion disk and releases a burst of energy, analogous to the collapsar model. Numerous other models have also been proposed to explain short gamma-ray bursts, including the merger of a neutron star and a black hole, the accretion-induced collapse of a neutron star, or the evaporation of primordial black holes.[83][84][85][86]

An alternative explanation proposed by Friedwardt Winterberg is that in the course of a gravitational collapse and in reaching the event horizon of a black hole, all matter disintegrates into a burst of gamma radiation.[87]

3.1.9 Tidal disruption events

This new class of GRB-like events was first discovered through the detection of GRB 110328A by the Swift Gamma-Ray Burst Mission on 28 March 2011. This event had a gamma-ray duration of about 2 days, much longer than even ultra-long GRBs, and was detected in X-rays for many months. It occurred at the center of a small elliptical galaxy at redshift z = 0.3534. There is an ongoing debate as to whether the explosion was the result of stellar collapse or a tidal disruption event accompanied by a relativistic jet, although the latter explanation has become widely favored.

A tidal disruption event of this sort is when a star interacts with a supermassive black hole shredding the star, and in some cases creating a relativistic jet which produces bright emission of gamma ray radiation. The event GRB 110328A (also denoted Swift J1644+57) was initially argued to be produced by the disruption of main sequence star by a black hole of several million times the mass of the Sun,[88][89][90] although it has subsequently been argued that the disruption of a white dwarf by a black hole of mass about 10 thousand times the Sun may be more likely.[91]

3.1.10 Gamma-Ray Burst Emission mechanisms

The means by which gamma-ray bursts convert energy into radiation remains poorly understood, and as of 2010 there was still no generally accepted model for how this process occurs.[92] Any successful model of GRB emission must explain the physical process for generating gamma-ray emission that matches the observed diversity of light curves, spectra, and other characteristics.[93] Particularly challenging is the need to explain the very high efficiencies that are inferred from some explosions: some gamma-ray bursts may convert as much as half (or more) of the explosion energy into gamma-rays.[94] Early observations of the bright optical counterparts to GRB 990123 and to GRB 080319B, whose optical light curves were extrapolations of the gamma-ray light spectra,[65][95] have suggested that inverse Compton may be the dominant process in some events. In this model, pre-existing low-energy photons are scattered by relativistic electrons within the explosion, augmenting their energy by a large factor and transforming them into gamma-rays.[96]

The nature of the longer-wavelength afterglow emission (ranging from X-ray through radio) that follows gamma-ray bursts is better understood. Any energy released by the explosion not radiated away in the burst itself takes the form of matter or energy moving outward at nearly the speed of light. As this matter collides with the surrounding interstellar gas, it creates a relativistic shock wave that then propagates forward into interstellar space. A second shock wave, the reverse shock, may propagate back into the ejected matter. Extremely energetic electrons within the shock wave are accelerated by strong local magnetic fields and radiate as synchrotron emission across most of the electromagnetic spectrum.[97][98] This model has generally been successful in modeling the behavior of many observed afterglows at late times (generally, hours to days after the explosion), although there are difficulties explaining all features of the afterglow very shortly after the gamma-ray burst has occurred.[99]

3.1.11 Rate of occurrence and potential effects on life

Gamma ray bursts can have harmful or destructive effects on life. Considering the universe as a whole, the safest environments for life similar to that on Earth are the lowest density regions in the outskirts of large galaxies. Our knowledge of galaxy types and their distribution suggests that life as we know it can only exist in about 10% of all galaxies. Furthermore, galaxies with a redshift of z higher than 0.5 are unsuitable for life as we know it, due to their higher rate of GRBs and their stellar compactness.[101][102]

All GRBs observed to date have occurred well outside the Milky Way galaxy and have been harmless to Earth. However, if a GRB were to occur within the Milky Way and its emission were beamed straight towards Earth, the effects could be harmful and potentially devastating for the ecosystems. Currently, orbiting satellites detect on average approximately one GRB per day. The closest observed GRB as of March 2014 was GRB 980425, located 40 megaparsecs (130,000,000 ly)[103] away (z=0.0085) in a SBc-type dwarf galaxy.[104] GRB 980425 was far less energetic than the average GRB and was associated with the Type Ib supernova SN 1998bw.[105]

Estimating the exact rate at which GRBs occur is difficult, but for a galaxy of approximately the same size as the Milky Way the expected rate (for long-duration GRBs) is about one burst every 100,000 to 1,000,000 years.[106] Only a small percentage of these would be beamed towards Earth. Estimates of rate of occurrence of short-duration GRBs are even more uncertain because of the unknown degree of collimation, but are probably comparable.[107] Figure 3.8, Swift satellite discovered its 1000th gamma-ray burst (GRB)

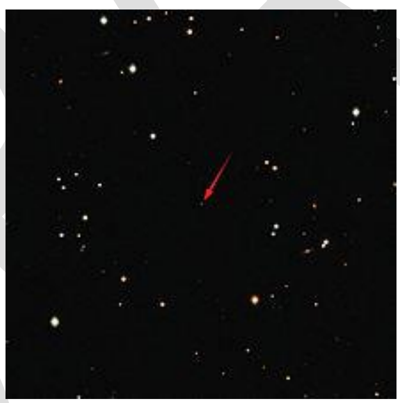


Figure 3.8 On 27 October 2015, at 22:40 GMT, the NASA/ASI/UKSA Swift satellite discovered its 1000th gamma-ray burst (GRB).[100]

Since GRBs are thought to involve beamed emission along two jets in opposing directions, only planets in the path of these jets would be subjected to the high energy gamma radiation.[108]

Although nearby GRBs hitting Earth with a destructive shower of gamma rays are only hypothetical events, high energy processes in the nearby universe are well-known to affect the Earth's atmosphere.[109]

3.1.12 Effects on Earth

Earth's atmosphere is very effective at absorbing high energy electromagnetic radiation such as x-rays and gamma rays, so these types of radiation would not reach any dangerous levels at the surface during the burst event itself. The immediate effect on life on Earth from a GRB within a few parsecs would only be a short increase in ultraviolet radiation at ground level, lasting from less than a second to tens of seconds. This ultraviolet radiation could potentially reach dangerous levels depending on the exact nature and distance of the burst, but it seems unlikely to be able to cause a global catastrophe for life on Earth.

The long term effects from a nearby burst are more dangerous. Gamma rays cause chemical reactions in the atmosphere involving oxygen and nitrogen molecules, creating first nitrogen oxide then nitrogen dioxide gas. The nitrogen oxides cause dangerous effects on three levels. First, they deplete ozone, with models showing a possible global reduction of 25-35%, with as much as 75% in certain locations, an effect that would last for years. This reduction is enough to cause a dangerously elevated UV index at the surface. Secondly, the nitrogen oxides cause photochemical smog, which darkens the sky and blocks out parts of the sunlight spectrum. This would affect photosynthesis, but models show only about a 1% reduction of the total sunlight spectrum, lasting a few years. However, the smog could potentially cause a cooling effect on Earth's climate, producing a "cosmic winter" (similar to an impact winter, but without an impact), but only if it occurs simultaneously with a global climate instability. Thirdly, the elevated nitrogen levels in the atmosphere would wash out and produce nitric acid rain. This substance is toxic to a variety of organisms, including amphibian life, but models show that it cannot reach levels that would cause a serious global effect. The nitrates might in fact be of benefit to some plants.

All in all, a GRB within a few parsecs, with its energy directed towards Earth, will mostly damage life by raising the UV levels. Models shows that the destructive effects of this increase can cause up to 16 times the normal levels of DNA damage. It has proved difficult to assess a reliable evaluation of the consequences of this on the terrestrial ecosystem, because of the uncertainty in biological field and laboratory data.[110][111]

Ordinary supernova explosions can have the same effects as GRBs on Earth's atmosphere because they are more frequent events with a possibility of occurring closer to Earth. The rate and distribution of supernovas are used to define what is known as the Galactic Habitable Zone in the field of astrobiology.[111]

3.1.13 Hypothetical effects on Earth in the past

GRBs close enough to affect life in some way might occur once every five million years or so – around a thousand times since life on Earth began.[112]

The major Ordovician–Silurian extinction events 450 million years ago may have been caused by a GRB. The late Ordovician species of trilobite that spent some of its life in the plankton layer near the ocean surface was much harder hit than deep-water dwellers, which tended to remain within quite restricted areas. Usually it is the more widely spread species that fare better in extinction, hence this unusual pattern could be explained by a GRB. This would probably devastate creatures living on land and near the ocean surface, but leave deep-sea creatures relatively unharmed.[8]

A case has been made that the 774–775 carbon-14 spike was the result of a short GRB,[113][114] though a very strong solar flare is another possibility.[115]

3.1.14 WR 104: A nearby GRB candidate

A Wolf–Rayet star in WR 104, about 8,000 light-years (2,500 pc) away, is considered a nearby GRB candidate that could have destructive effects on terrestrial life. It is expected to explode in a core-collapse-supernova at some point within the next 500,000 years and there is a chance that this explosion will create a GRB. If that happens, there is a small chance that Earth will be in the path of its gamma ray jet.[116][117][118]

3.1.15 GRB candidates in the Milky Way

- GRB 130427A
- GRB 080916C
- Soft gamma repeater
- Gamma-ray Search for Extraterrestrial Intelligence
- Stellar evolution
- Terrestrial gamma-ray flashes
- Fast radio burst

Footnotes

1. A notable exception is the 5 March event of 1979, an extremely bright burst that was successfully localized to supernova remnant N49 in the Large Magellanic Cloud. This event is now interpreted as a magnetar giant flare, more related to SGR flares than "true" gamma-ray bursts.
2. GRBs are named after the date on which they are discovered: the first two digits being the year, followed by the two-digit month and two-digit day and a letter with the order they were detected during that day. The letter 'A' is appended to the name for the first burst identified, 'B' for the second, and so on. For bursts before the year 2010 this letter was only appended if more than one burst occurred that day.
3. The duration of a burst is typically measured by T90, the duration of the period which 90 percent of the burst's energy is emitted. Recently some otherwise "short" GRBs have been shown to be followed by a second, much longer emission episode that when included in the burst light curve results in T90 durations of up to several minutes: these events are only short in the literal sense when this component is excluded.

No gamma-ray burst has been observed from within our own galaxy the Milky Way Galaxy and it is an unresolved matter if there has ever occurred one.

With the evolving understanding of the mechanisms behind gamma-ray bursts and the progenitors that triggers them, a growing number of local past and future GRB candidates are emerging in the scientific literature. Long duration GRBs are strongly tied to superluminous supernovae, also referred to as hypernovae and most luminous blue variables (LBVs) and rapidly spinning Wolf–Rayet stars are believed to end their life cycles in core-collapse-supernovae with an associated long duration GRB. Our knowledge of GRBs however is gained exclusively from metal-poor galaxies of former epochs of the universe' evolution and it is not possible to directly extrapolate this general knowledge to encompass more evolved galaxies and environments with higher metallicity like the Milky Way.[119][120][121]

See also

- Gamma-ray astronomy
- List of gamma-ray bursts
    - GRB 020813

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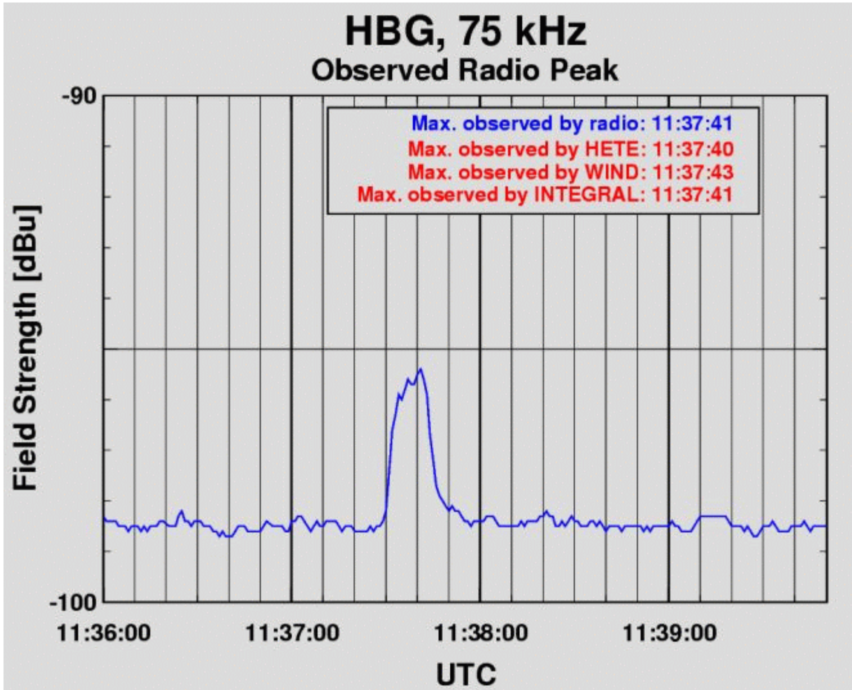
4. Observing Techniques and Protocol

For any scientific program, a guideline must be followed for the purpose of good data recording and validadation of data.

The observer should keep notes for every observing session. The following items should be part of the record sheet:

- **DATE**
- **OBSERVERS NAME**
- **LOCATION**
- **WEATHER CONDITIONS**
- **OBJECT BEING OBSERVED**
- **FREQUENCY**
- **SYSTEM CONFIGURATION**
- **NOTES**

5. Actual Recordings for user Identification



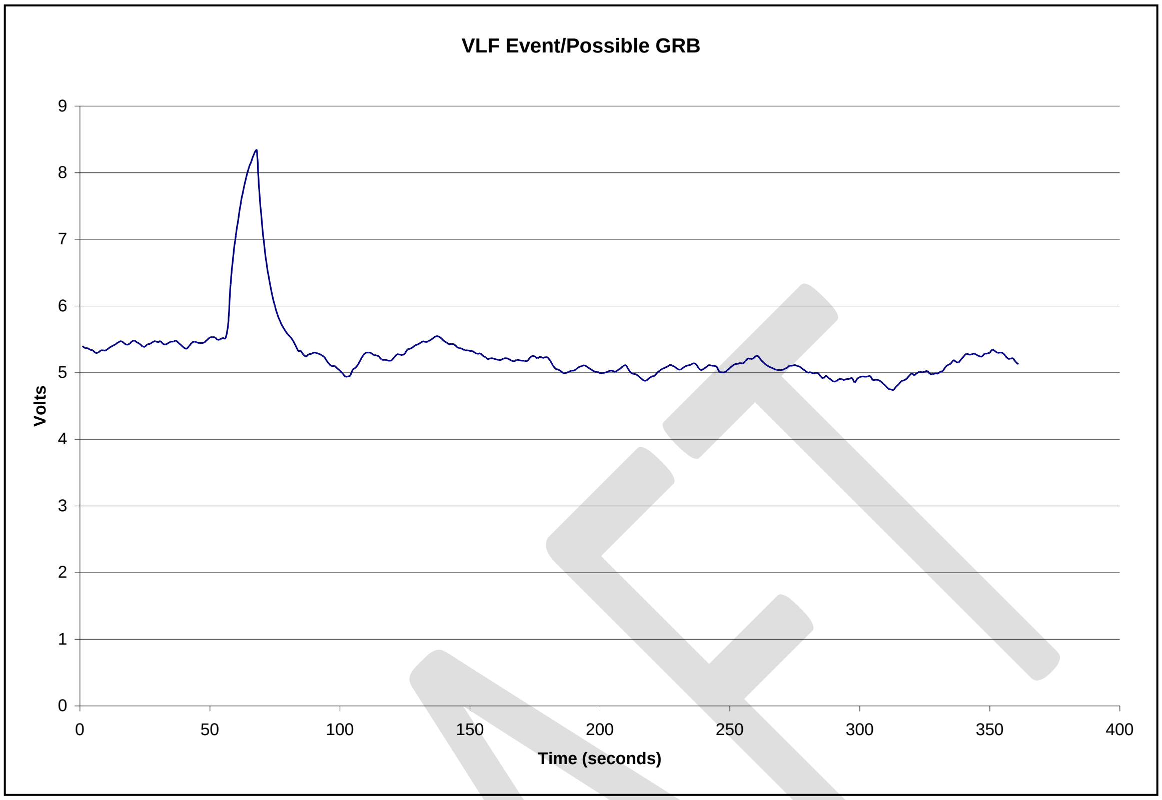
Gamma Ray Burst detection at 75 KHz.

TITLE: GCN GRB OBSERVATION REPORT
NUMBER: 2176
SUBJECT: GRB030329 observed as a sudden ionospheric disturbance (SID)
DATE: 03/04/28 22:38:19 GMT
FROM: Doug Welch at McMaster U, PhysAstro. <welch@physics.mcmaster.ca>

P.W. Schnoor, D.L. Welch, G.J. Fishman and A. Price report, on behalf of the AAVSO GRB-SID Network, on the detection of GRB030329 as a sudden ionospheric disturbance (SID), observed by Peter Schnoor of Kiel, Germany.

http://www.qsl.net/df3lp/projects/sid/

http://gcn.gsfc.nasa.gov/gcn3/2176.gcn3, http://www.konkoly.hu/cgi-bin/IBVS?5415

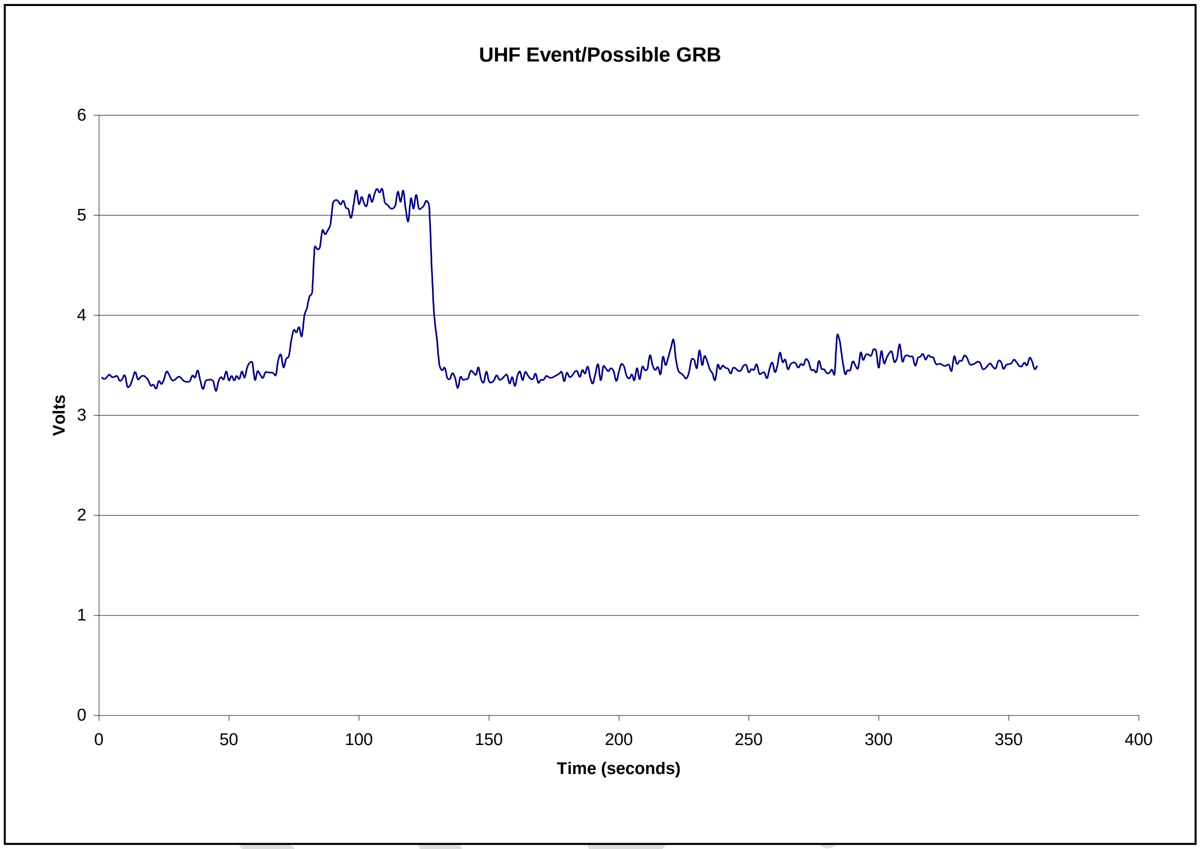


GRB (Van Prooyen @ 40 KHz.)

SWIFT spacecraft also report a GRB at about the same time giving the event it official name GRB080919

<u>Time Line VLF Event:</u>

The plots both start at 19:48:31 Eastern time or 23:48:31 universal time.
The VLF Event start is 23:49:28 universal.
High point of the VLF Event is at 23: 49:39
End of the VLF Event is at 23:50:00



GRB (Van Prooyen @ 406.7 MHz.)

Time Line UHF Event:

The plots both start at 19:48:31 Eastern time or 23:48:31 universal time.

The UHF Event starts at 23:49:40.

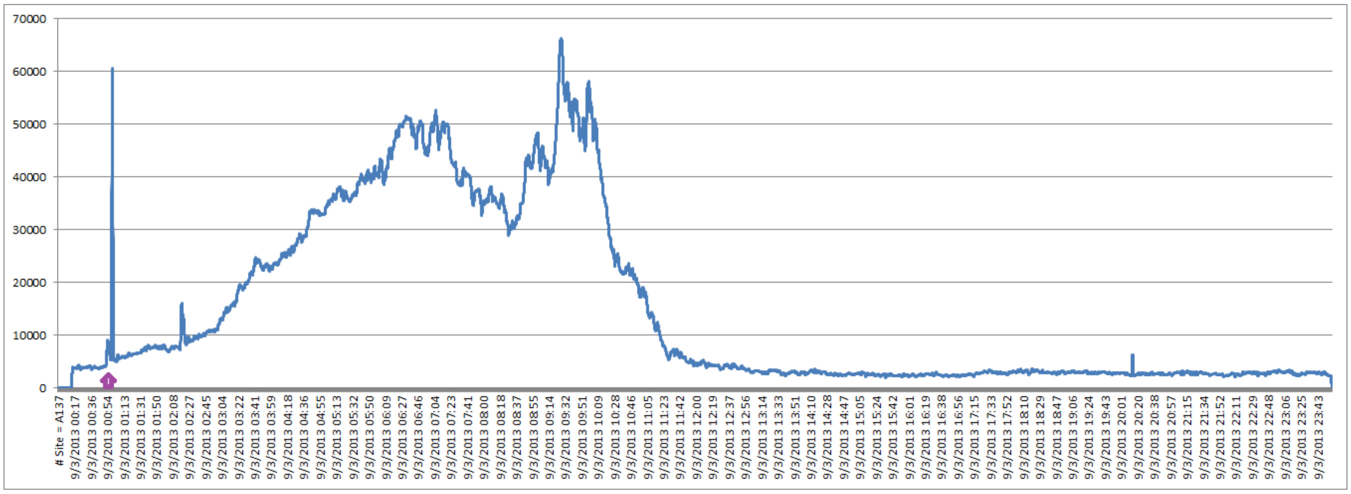
Current calibration of the UHF (406.7 MHz) radio telescope is 213 jy per volt.

Based on this the HEP was 401.5 jy over the background noise.

SWIFT Satellite Observations:

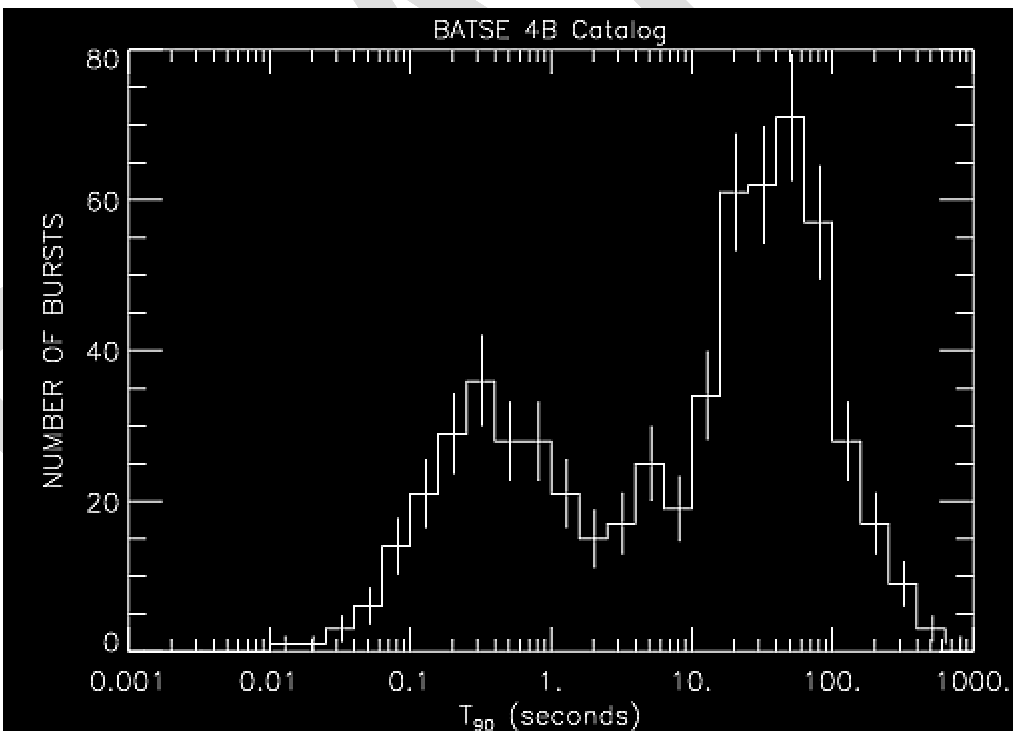
A search of the GRB data base's found that Gamma-ray Burst 080919 was observed at about the same time see the web page listed below for more information:

http://www.mpe.mpg.de/~jcg/grb080919.html



130903 24 Hr SCAN / NAA / 24.0 Detection of GRB 130903A / 00:50 0054 0057 / Second Peak: 0057 0100 0101 / Burst Trigger occurred at: 00:47:20

Dennis Koawl, Alaska, 24 KHz.

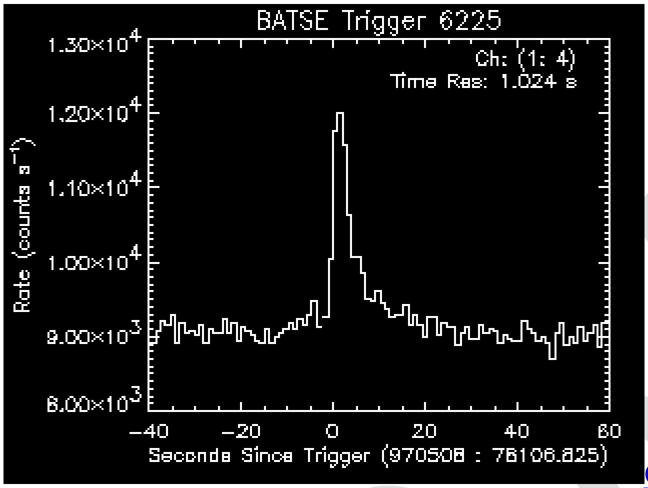


This image shows the durations of the 4B Catalog Gamma-Ray Bursts recorded with the Burst and Transient Source Experiment on board NASA's Compton Gamma-Ray Observatory. The duration parameter used is T90, which is the time over which a burst emits from 5% of its total measured counts to 95%. The data used for the calculation are the BATSE 4 energy channel discriminator data. Light curves used for the calculation of T90 are integrated over all 4 channels (E > 20 keV). (http://gammaray.nsstc.nasa.gov/batse/grb/duration/)

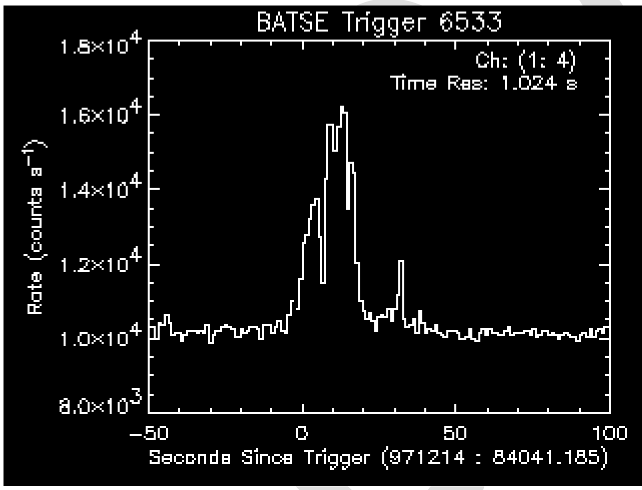
BATSE Light Curves of GRBs with Counterpart Observations

This page presents the lightcurves observed with BATSE of GRBs that have been observed at other wavelengths. These gamma ray lightcurves are shown in four different energy channels, covering the energy range of approximately E > 20 keV. Select the small images to lightcurves in the separate energy channels. (http://gammaray.nsstc.nasa.gov/batse/grb/lightcurve/counterparts/)

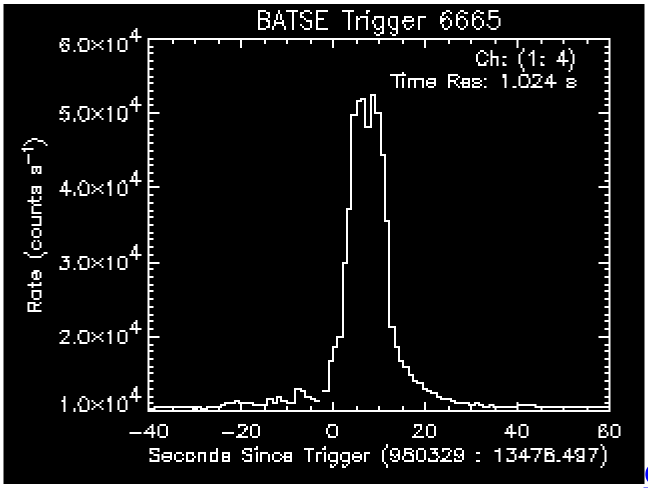
Lightcurves of other BATSE GRBs are also available. For more detailed information on GRB counterpart observations, see Jochen Greiner's Gamma-Ray Burst Page.



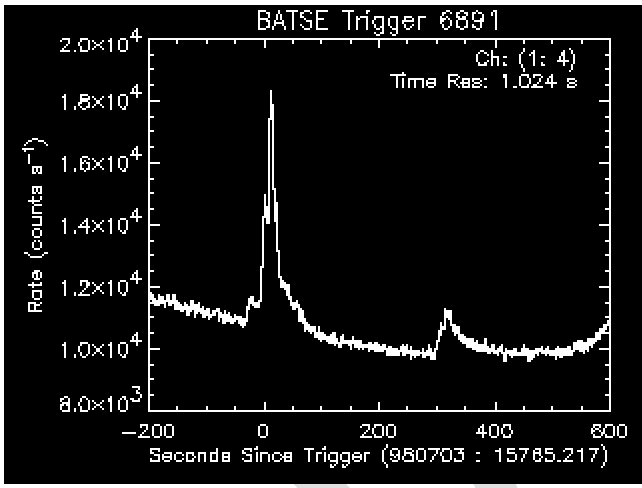
GRB 970508, BATSE Trigger 6225



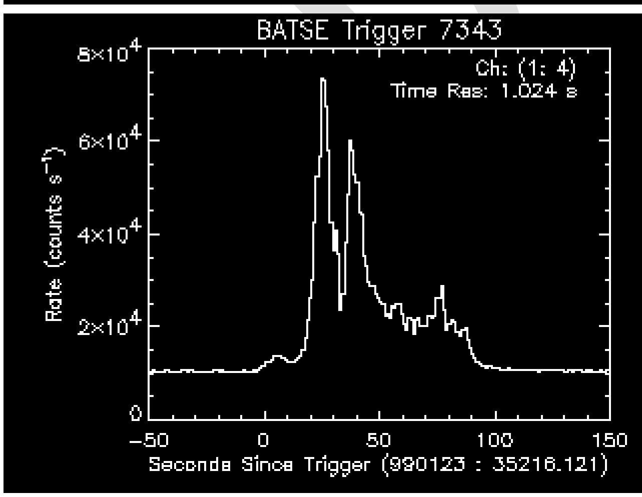
GRB 971214, BATSE Trigger 6533



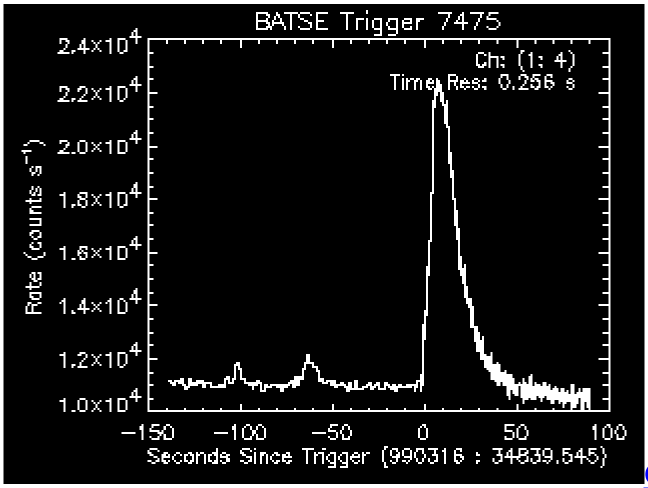
[GRB 980329, BATSE Trigger 6665]



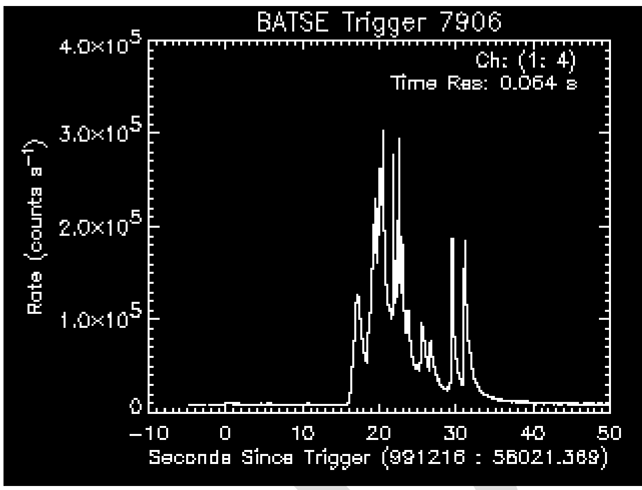
[GRB 980703, BATSE Trigger 6891]



[GRB 990123, BATSE Trigger 7343]



[GRB 990316, BATSE Trigger 7475]



[GRB 991216, BATSE Trigger 7906]

Modification date: 29 Jan, 2014

Author: Robert S. Mallozzi

Appendix A - Source Information

Gamma Ray Burst Astrophysics

http://gammaray.nsstc.nasa.gov/batse/grb/

http://gammaray.nsstc.nasa.gov/batse/grb/lightcurve/

Links to GRB catalog and GRB afterglow pages

http://www.mpe.mpg.de/~jcg/grblink.html

Gamma Ray Realtime Sky Map

http://grb.sonoma.edu/

NASA Gama Ray Bursts

http://www.nasa.gov/mission_pages/swift/bursts/

Detection of a Gamma Ray Burst by Observing Radio Signals

http://www.qsl.net/df3lp/projects/sid/

Fast Radio Bursts (FRBs)

http://venus.fandm.edu/~pulsar/frb/

Cosmological Origin for FRB 150418? Not So Fast

http://newton.cx/~peter/wp/wp-content/uploads/2016/02/note-rev1.pdf

Transient Science with the VLASS

https://science.nrao.edu/science/surveys/vlass/Hallinan_WP_r1.pdf

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Books

Vedrenne, G; Atteia, J.-L. (2009). Gamma-Ray Bursts: The brightest explosions in the Universe. Springer. ISBN 978-3-540-39085-5.

Chryssa Kouveliotou; Stanford E. Woosley; Ralph A. M. J., eds. (2012). Gamma-ray bursts. Cambridge: Cambridge University Press. ISBN 0-521-66209-5.

Appendix B - A Computer Model for Detection of Gamma Ray Bursts and X-Ray Transients at Very Low Frequency Radio Telescopes

By Rodney Howe, 040224

Abstract: The VLF computer model proposed in this paper examines whether gamma ray bursts (GRB) or x-ray transient flux from distant supernovae can be detected by amateur VLF radios. Arguments presented in this paper compare how GRBs created from supernova events might cause detectable signatures similar to magnetar or other local x-ray transient Sudden Ionospheric Disturbances (SID). High-energy GRBs and short x-ray transients of supernova (SN) origin affect the upper ionosphere through Compton free electron interaction and not through magnetic field reconnection as local solar plasma or x-ray flares might affect the earth's magnetosphere. Gamma ray and x-ray ionization of the upper F2 layer, or thermosphere, should be a measure of ionizing radiation as small as 10^{-6} ergs, yet may not be detectable with amateur VLF radios. High-energy solar plasma interactions causing ionization have larger energy regimes that impact the lower ionosphere layers. Local atmospherics such as lightening, and sprites also confound detection of SN GRBs. Only events of very long duration, such as the nighttime ionosphere disturbance from SRG1900+14 magnetar, located at the edge of our galaxy 23,000 light years away from earth (Inan et al., 1999a, University of Stanford's HAIL project: http://www-star.stanford.edu/~vlf/hail/hail.htm), and possibly GRB030329 http://www.konkoly.hu/cgi-bin/IBVS?5415 have been detected at Very Low Frequencies (Peterson and Price et.al, 2003).

Introduction

VLF detection of short-hard GRB or x-ray bursts depend on how they differ, in their impact of the upper thermosphere, from solar flares and other solar phenomena that interact with the earth's magnetosphere, thermosphere and lower ionosphere layers. In ion-electron plasma interactions from the sun, the fraction of the energy that goes into the electrons effects magnetosphere. Interactions are dependent on the ion proportion of heated solar plasma and penetration into the cooler ionized particles at lower layers (Lyon J.G, 2000). Shock waves from solar x-ray transients result in high-energy electrons crossing into previously ionized cooler layers. The resulting shock waves are influenced by the angular momentum of the earth. Shock waves created as high-energy electron emissions collide with ionized particles, which are then twisted in the magnetic field. Solar x-rays penetrate the cooler F, E and D layers through the magnetic field as well as direct free electron interaction at the poles (Hill T.W., Dessler A.J, 1991).

The solar plasma and intense solar flare interaction is quite different than interaction of extra-galactic short-hard Gamma Ray Bursts or x-ray transients (XRB). GRBs interact with the earth's upper thermosphere directly with much less flux and are not influenced by the outer magnetosphere like solar plasma or high-energy x-rays from solar flares. On the other hand, GRB photons should cause a detectable Compton Effect (CE) that is measurable as electron-volt-flux in square centimeters per steradian per second. As GRB photons interact with free electrons in the upper thermosphere the free electrons will re-emit lower frequency ultraviolet-light and perhaps synchrotron radio waves as the result of the Compton Effect. Signatures from the GRB-CE may not create the sudden rise and gentle fall-off seen in VLF recorded voltages of solar plasma or solar x-ray flares that have the energy to cross into lower F, E and D layers of the ionosphere and are detectable as SIDs. It is possible the GRB or x-ray transient signature will show a slight drop in VLF during local nighttime hours.

Current thinking, about the origin of extra-galactic high-energy events (GRBs), appear to be focused on progenitors of either neutron stars in a binary system, magnetars or the collapse of massive young stars which create supernovae (Shilling, 2002). The model presented in this paper assumes that GRBs are the result of massive O and B type stars that create a distant supernova event, which in turn create an incredible amount of energy, assuming an un-beamed source. (D. Ward-Thompson, 2002) This energy though, is for a very short duration, 100 ms, to 400 seconds, with and average of between 1 and 20 seconds. (Data from BATSE, 200 most intense events, Jerry Fishman, NASA, 2000 http://www.qsl.net/SARA/projects/grb.htm)

Methods

The computer model described here uses the Chrong-Yuan (1997) equations for Compton photon density at energy ε, scattered by high-energy photons as they descend into the earth's thermosphere and interact with free electrons. Chrong-Yuan's construct is adapted for earth's thermosphere. Raw GRB or XRB flux data collected by the HETE II, INTEGRAL or other satellites are considered conforming to:

$$\varepsilon = (3\pi c^3 h^3)^{-1} (3e/4\pi m_e c)^{kT} \qquad (4)$$

e is the electron charge, c is the speed of light, h is the Planck's constant, m_e is the mass of the electron being energized from the CE.

Detectable GRB and XRB energy intensities ranging from perhaps 10^{-7} to ~ 10^{-3} ergs per square centimeter per steradian per second, which may be energetic enough to cause re-emission of free electrons in the thermosphere, can be modeled as producing ultraviolet light and then re-ionization with energy values given by equation (4). (For equations 1 - 3 see the reference section.) Estimates for VLF detection of the gamma ray, x-ray flux ε as the high-energy photons interact with free electrons in the upper thermosphere can be derived from the following basic assumption, that the voltage received at the VLF radio telescope is a measure of:

$$f = \varepsilon mc^2 \qquad (5)$$

f is the x-ray 'flux' varies from 10^{-3} to 10^{-7} ergs, averaged over a 3 second interval. The three- second interval is chosen as the best the Gyrator II VLF radio can resolve with confidence.

The VLF computer model converts f into voltage measurements for the Gyrator II radio telescope. For voltage values less than 1.5 volts, measured as an offset above the 'background' where the value of f ~ 0, there would be no CE thermosphere signal. The model calculates voltage drops below the 1.5 'background' as a large drop in f. This means that any value within the range of 1.75 volts to 2.8 volts as recorded by the VLF radio would potentially represent enough energy to be considered a GRB or x-ray transient event. (See Figure 2) Unfortunately, this is considerably below a calibrated maximum level of 4+ volts for average nighttime ionospheric measures of VLF radios. (See Figure 1) At voltage ranges greater than 3.0 the GRB or XRB flux could represent a major SID affecting the ionosphere such as SRG1900+14. However, it is possible even with SRG1900+14, nighttime 'spherics' of the ionosphere would drown out the magnatar's signal.

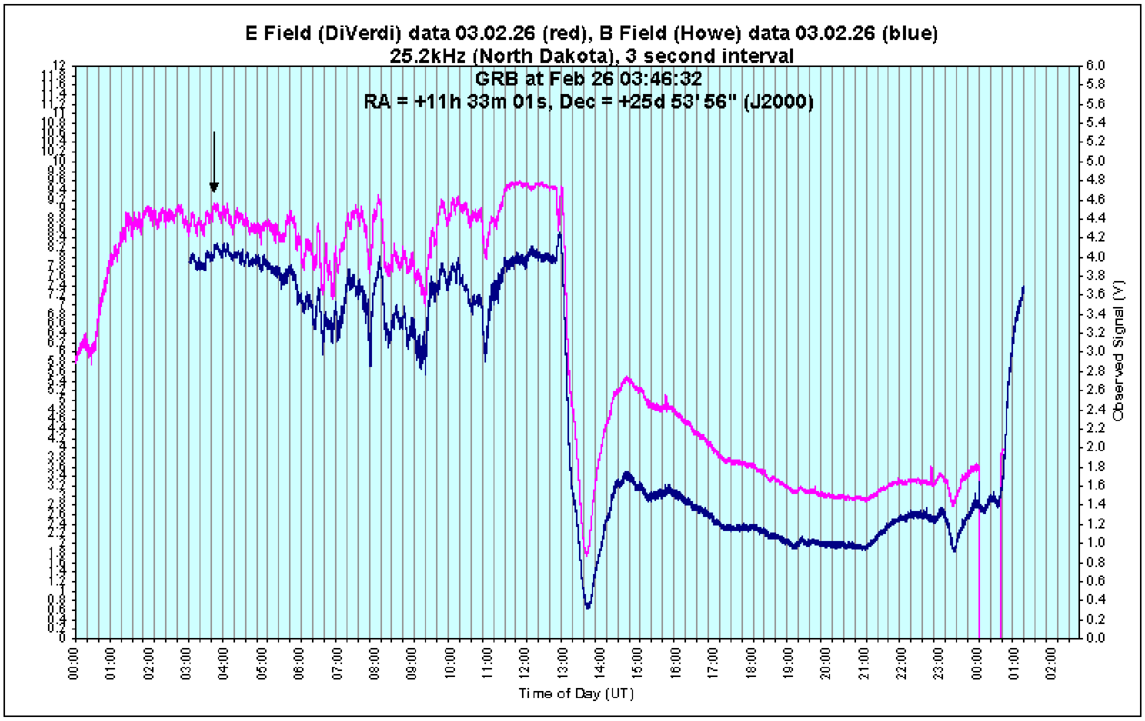
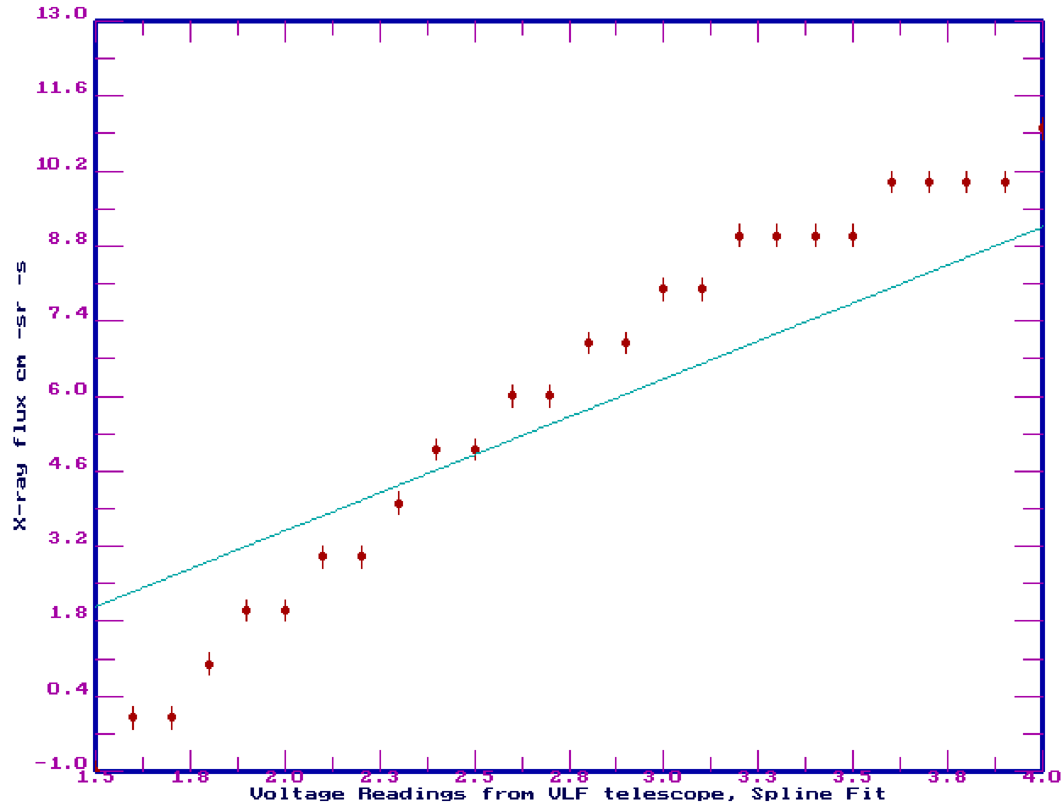


Figure 1, shows two different radio configurations, the Gyrator II with a 1.5 meter B-field loop antenna, (Cap Hossfield 2001), and Joseph DiVerdi's VLF radio with an E-field 2 meter whip antenna (http://xtrsystems.com/vlf). These data show a dialy trace where there was a weak GRB at 03:46:31.99 UT.There was very slight increase in voltage close to a recorded GRB event at 3:46UT, February 26, 2003. But with all the nighttime atmospherics it is very difficult to declare detection. (GRB Detection Date (see references): 03/02/26 03:46:31.99 UT GRB Notice Date: Wed 26 Feb 03 05:47:21 UT)

The VLF model expresses the increase of *k*T, as a Compton Effect (CE) temperature or the re-ionization of the thermosphere. Where gamma ray and x-ray photons create emissions in free electrons in the higher layers of the thermosphere creating radiometer temperatures that the VLF radio converts to DC voltages. The VLF model has a low-energy break below 1.57 volts at normal CE thermosphere temperature differences.



In figure 2, this graph is a model and assumes an incoming burst temperature equivalent to 1,200 K per steradian per cm per second, this would be a large event at 10^{-4} ergs, and quiescent thermosphere temperature at ` 220 K. Compton Effect photon density at the thermosphere is considered a specific heat in the current model and is measured as kT. As the difference between the CE photon burst and thermosphere temperatures increase there is an increase in the amount of re-ionization. This is measured as flux per volt recorded at the VLF telescope (red dots). The y-axis, on this graph, estimates the equivalent GRB or x-ray flux converted to electron volts (eV) in square centimeters per steradian per second. Units on the y-axis are powers of 10 exponents (eV). VLF voltages are on the x-axis. For example: 2 volts on the x-axis, would be approximately 10^2 eV on the y-axis. A GRB or x-ray flux detected at 2.3 volts on the x-axis would be approximately 10^4 eV on the y-axis. Any GRB or x-ray event at 2.8 volts on the x-axis, 10^6 eV, should be detectable, i.e. above the fitted line.

The VLF computer model requires an estimate of the temperature of the incoming burst, expressed in Kelvin's, and an estimate of the ionosphere temperature also measured in Kelvin's. (The burst estimates can be gathered from the GCN circular on the event, for example, see references section for GCN 1924.) These values are normalized to give a ratio for kT. Boltzmann's constant k is converted to decibels and used as the exponent of ε. ε the ion energy and is multiplied by mc^2 to estimate the energy of the high-energy x-ray emission as the Compton Effect re-ionizes the thermosphere. Units are in centimeters per steradians per second. All quantum values are measured in the same units and expressed as coupled non-linear equations dependent on the voltage as detected from the VLF telescope. Output from the model, at this time, displays an estimate of x-ray flux on the y-axis of a graph (Figure 2) and the VLF voltage on the x-axis of the graph.

Results

Gamma Ray Bursts or short-hard x-ray transients of short duration such as GCN 1924 have little chance of being detected by amateur VLF receivers such as those being used today. However, longer, higher-

energy bursts from magnetars like SRG1900+14, or not-so distant supernova explosions such as SN2003dh (GRB030329) may be detectable.
Figure 3 below is a detail graph of VLF data collected at the time of GRB030329. The VLF receivers recording the event are located in Fort Collins, CO, at approximately Longitude -105.08 and Latitude 40.54. This event happened before dawn during the nighttime hours where the signals were between 3.6 at 4.2 Volts (right y-axis on Figure 3). Nighttime is the worst time for detection due to all the atmospherics and lack of ionization, but there is a noticable drop in signal during the GRB event. As there were no other confirmations of this event from other AAVSO VLF receivers in North America, it is difficult to say we had detection.

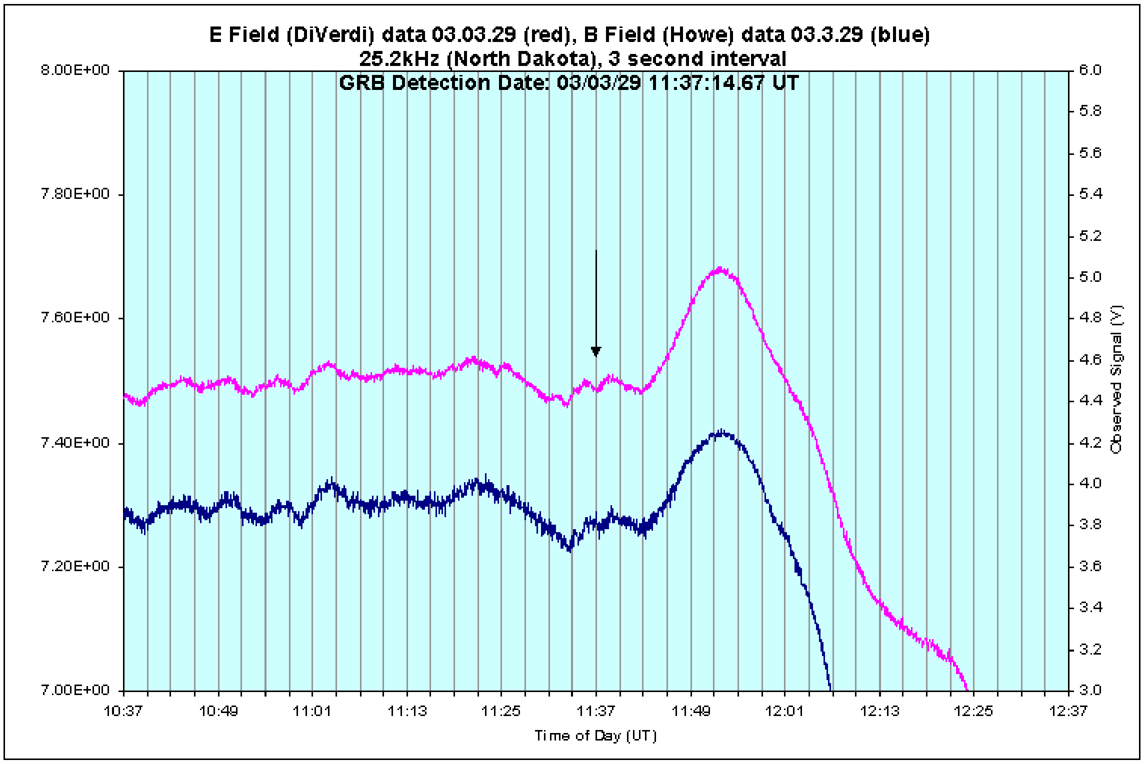


Figure 3. GRB030329 was detected by HETE-II satellite on 29 March 2003 at 11:37:14.67 UT. Optical spectroscopic observations determined its redshift to be z = 0.168 (Uemura, M. et. al, 2003). These data represent two VLF radio receivers, one recording with a 2 meter whip antenna (red line) and one with a 1.5 meter loop (blue line). Both receivers show a slight drop at the onset of this event with a rise and fall off, but there are other possible explainations for these dips, especially during nighttime hours. The large rise in the signals at 11:55 UT is a result of the sun's ionizing the ionosphere as it rises over the horizon. The signal will continue to drop to close to zero volts throughout the day. See Figure 1 for a full day's recording.

Discussion

There are other dynamics involved in VLF detection, which need further study, such as, where is the optimum location of the VLF receiver when the burst wave hits the earth's thermosphere. This computer model does not attempt to answer this question but enhancements could be made in the future should more computerized data on GRB detections become available.

Gamma ray and short-hard x-ray transients from supernovae explosions should exhibit a response based on the measure of the Compton Effect from high-energy photons causing ultraviolet re-emission and possibly re-ionization of earth's upper thermosphere. Re-ionization at ultraviolet radiation levels needs further study, but model results predict photon flux levels, which translate to voltage level expectations for VLF receivers. Most GRB and x-ray transient events looked at so far have not been of high enough energy to detect with current VLF equipment, with the exception of GRB030329 (Price, et al. 2003).

References

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>
> An example of a possible X-ray transient detection with a VLF radio tuned to the VLF station NWC at Northwest Cape West Australia transmitting on 19.8 kHz was made by Len Anderson of South Perth, West Australia (3). The GCN GRB observation report for assigned the number 1383 for this event; from Jean in't Zand, Fabrizio Reali, Stafano Granata, Paul Lowes and Luigi Piro on behalf of the BeppoSAX team. They detected a fast X-ray transient on April 27 at 3:48:40 UT. Their quick -look analysis showed it lasted 1.1 minutes, with a rise time of 0.1 minute. They classified the event as an X-ray flash rather than an X-ray burst because 1) the time profile was unusual [short] for and X-ray burst; 2) there was no evidence for softening in the decay; 3) the galactic latitude of -44.2 deg is unusual for an X-ray burst.

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The computer model described in this paper uses the following formulation from G. R. Blumanthal and R. J. Gould, Rev, Mod. Phys. 42. 237(1970) -

Equation (1),

$$\varepsilon = (3\pi c^3 h^3)^{-1} (3e/4\pi m_e c)^{-(p-3)/2}$$

imultiplied by equation (2) and equation (3):

$$(kT)^{(p+5)/2} B^{0\ -(p+1)/2} F(p)/a(p) v^{(p-1)/2} \qquad (2)$$

$$Ss(v),^{-(p+1)/2} \qquad (3)$$

GRB photons, where k is Boltzmann's constant, T is the temperature, B^0 is the average magnetic field in the magnetosphere, and F(p) and a(p) are the parameter functions defined by Blumenthal and Gould.

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COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 5415

TITLE: GCN GRB OBSERVATION REPORT
NUMBER: 1924
SUBJECT: Chandra detection of the X-ray afterglow of GRB 030226
DATE: 03/03/05 11:49:59 GMT
FROM: Jens Hjorth at U.Copenhagen <jens@astro.ku.dk>

Kristian Pedersen (U. of Copenhagen), Johan Fynbo (U. of Aarhus),
Jens Hjorth (U. of Copenhagen), Darach Watson (U. of Copenhagen)
report on behalf of the GRACE collaboration:

"Chandra X-ray Observatory observed the field of the GRB 030226 (Suzuki et al., GCN 1888) with the ACIS-S3 detector for a total of 11.9 hours, starting Feb 27, 16:49 UT, 37.1 hours after the GRB trigger. Based on a preliminary analysis we identify a previously unknown, fading X-ray source at the position

RA (J2000.0) = 11 33 04.93, Dec (J2000.0) = +25 53 55.3

consistent with the position of the optical transient (Price et al., GCN 1880). The positional accuracy is better than one arcsec. Hence we identify the source as the X-ray afterglow of GRB 030226.

The 0.3-10 keV count rate averaged over the observation is 9.7e-03 counts/s, and the average 2-10 keV flux is 3.2e-14 erg/cm^2/s. The spectrum is well fitted by an absorbed power law with spectral index 1.0 +/-0.2, absorption fixed at the Galactic value (1.6e20 cm^2), and an absorbing column density of 1e22 +/- 0.5e22 cm^-2 at a redshift of 1.98. A power law with Galactic absorption only is not an acceptable fit to the soft part of the Chandra spectrum. No other obvious spectral features are detected.

We thank Harvey Tananbaum for rapidly approving Director's Discretionary Time for this observation, and the staff at the Chandra Science Center for smoothly implementing and processing the observation."

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http://www-star.stanford.edu/~vlf/runaway/

Auroral Electrojet Research Studies http://www-star.stanford.edu/~vlf/ejet/electrojet.html

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