SPHERICAL FALLBACK ACCRETION -THE ENGINE GRB 050502B

By

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Abstract

Gamma ray bursts are energetic and most luminous objects in the universe. They emit the most energetic form of electromagnetic radiation with extremely short wavelength and high frequencies. The gamma ray burst which is detected by swift Burst Alert Telescope (BAT) with giant and bright flare is GRB 050502B with the energy band (0.3 - 10.0 keV). In this thesis we have tried to theoretically reconstruct the X-ray after-glow from GRB 050502B as observed by NASA‘s Swift satellite based on current GRB model.

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Acronyms

NSs - Neutron Stars

BHs - Black Holes

BAT - Burst Alert Telescope

XRT - X-ray Telescope

UVOT - Ultraviolet and Optical Telescope

BATES - Burst and Transient Source Experiment

CGRO - Compton Gamma Ray Observatory

GRB - Gamma-ray burst

LMXRBs - Low Mass X-ray Binaries

HMXRBs - High Mass X-ray Binaries

SNe - Supernovae

SN - Supernova

HNe - Hypernovae

CMS - Circumstellar Material

LGRB - Long Gamma ray Burst

XRF - X-ray Flash

ISM - Intersteller medium

HETE - High Energy Transient Explorer

Introduction: Compact Objects and their Characteristics

Compact objects which refers to white dwarfs, neutron stars, and black holes are born when normal stars die, that is, when most of their nuclear fuel has been consumed. The study of compact stars begins with the discovery of white dwarfs and the successful description of their properties by Fermi-Dirac statistics, assuming that they are held up against gravitational collapse by the degeneracy pressure of the Fermi electrons, an idea first proposed by Fowler in 1926 [3, 4].

White dwarfs (WDs) are much whiter than normal stars. White dwarfs can be observed directly in optical telescopes during their long cooling epoch. They are believed to originate from light stars with masses M $\leq$ 4 solar mass. The maximum allowed mass for white dwarfs is around $1.4M_{\odot}$ [4].

The existence of a new class of compact stars, with a large core of degenerate neutrons, was predicted as neutron stars (NS). The first NS model calculations were achieved by Oppenheimer and Volkoff in 1939 [3]. Neutron stars derive their name from the predominance of neutrons in their interior. Neutron stars can be observed directly as pulsating radio sources (pulsars) and indirectly as gas accreting, periodic X-ray sources (X-ray pulsars). Neutron stars also have a maximum mass (in the range of 1.4 - $3M_{\odot}$)

The third compact object is Black Holes (BHs), not even light (or anything else, for that matter), can escape. BHs are believed to originate from more massive stars.

A study of compact objects begins when normal stellar evolution ends. All these objects differ from normal stars in at least two aspects:

• They are not burning nuclear fuel, and they cannot support themselves against gravitational collapse by means of thermal pressure.

• The second characteristic property of compact stars is their compact size. They are much smaller than normal stars and therefore have much stronger surface gravitational fields.

• Compact objects carry strong magnetic fields, much stronger that found in normal stars [3].

Chapter 1

Neutron Stars

Neutron stars had been found at the end of the 1960s as radio pulsars and in the beginning of the 1970s as X-ray stars. Neutron stars may appear in supernova remnants, as isolated objects, or in binary systems. We will consider neutron star as our core star in the accretion process. In this chapter, we will see NS formation, its structure, and its accretion as a form of fallback.

1.1 Neutron star formation

Neutron stars are one of the possible end states for a massive star. They result from massive stars which have mass greater than 6 - 8 times that of our Sun. After these stars have finished burning their nuclear fuel, they undergo a supernova explosion. This explosion blows off the outer layers of the star into a beautiful supernova remnant. The central region of the star collapses under gravity. It collapses so much that protons and electrons combine to form neutrons. The existence of such exotic objects as neutron stars was first postulated by Lev Landau, as early as 1932. The fact that they appear as a result of supernovae was soon suggested by Walter Baade and Fritz Zwicky, in 1934, and the first physical model was offered by Robert Oppenheimer and George Volkoff in 1939 [9].

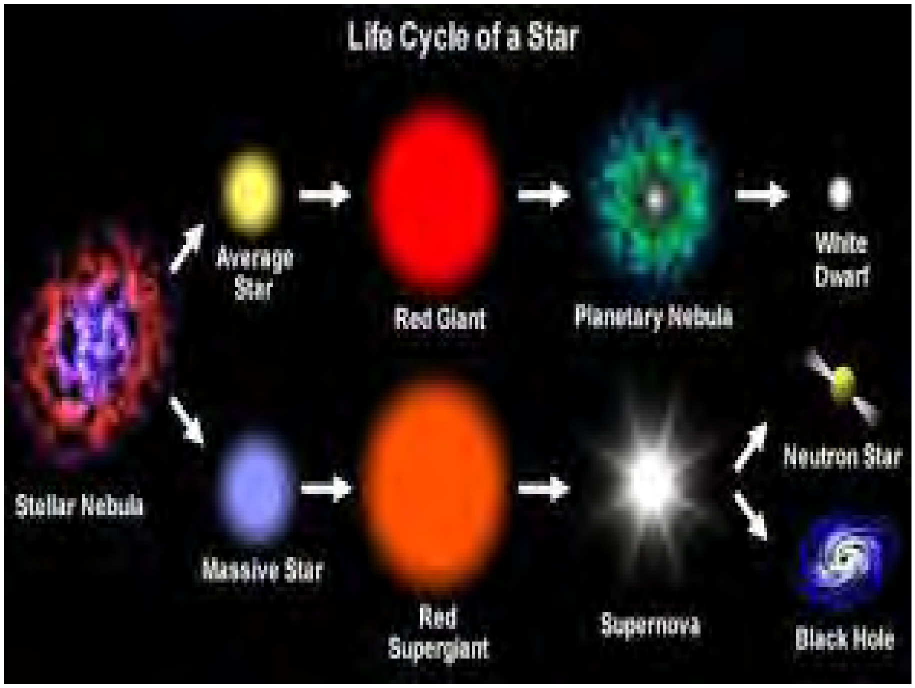

Figure 1.1: Neutron star formation.

In general neutron stars come from two possible evolutionary scenarios; as shown in Fig.1.1. This are

• Stars starting in the upper mass range eventually become SN of Type II or Type Ib. They shed their outer layers, and leave a rapidly spinning NS (a pulsar) as a final object.

• Stars of the lower mass range become WDs. Those in a binary system may accumulate mass, and become SN Type Ia and perhaps a NS remains [6].

As the core of a massive star is compressed during a Type II, Type Ib or Type Ic supernova, and collapses into a neutron star, it retains most of its angular momentum.

1.2 Neutron star structure

Neutron stars are the remnants of the supernova explosion of massive stars. NSs are composed of almost entirely of neutrons. Neutron star masses, determined by the evolutionary history of the supernova progenitor, are generally above $\sim 1.2M_{\odot}$ up to $\sim 2.5M_{\odot}$; the average mass of neutron stars detected in binary systems is of about $1.4M_{\odot}$.
A typical $1.4M_{\odot}$ neutron star has a radius of 10 - 15 km, central density of the order of 10^{14} - 10^{15} g cm^{-3} and temperatures below $\sim 5{\times}10^{6}$ K [7]. This means that a neutron star is so dense that on Earth, because of its small size and high density, a neutron star possesses a surface gravitational field of about 2×10^{11} times that of Earth. Neutron stars can also carry magnetic fields a million times stronger than the strongest magnetic fields produced on Earth [3].

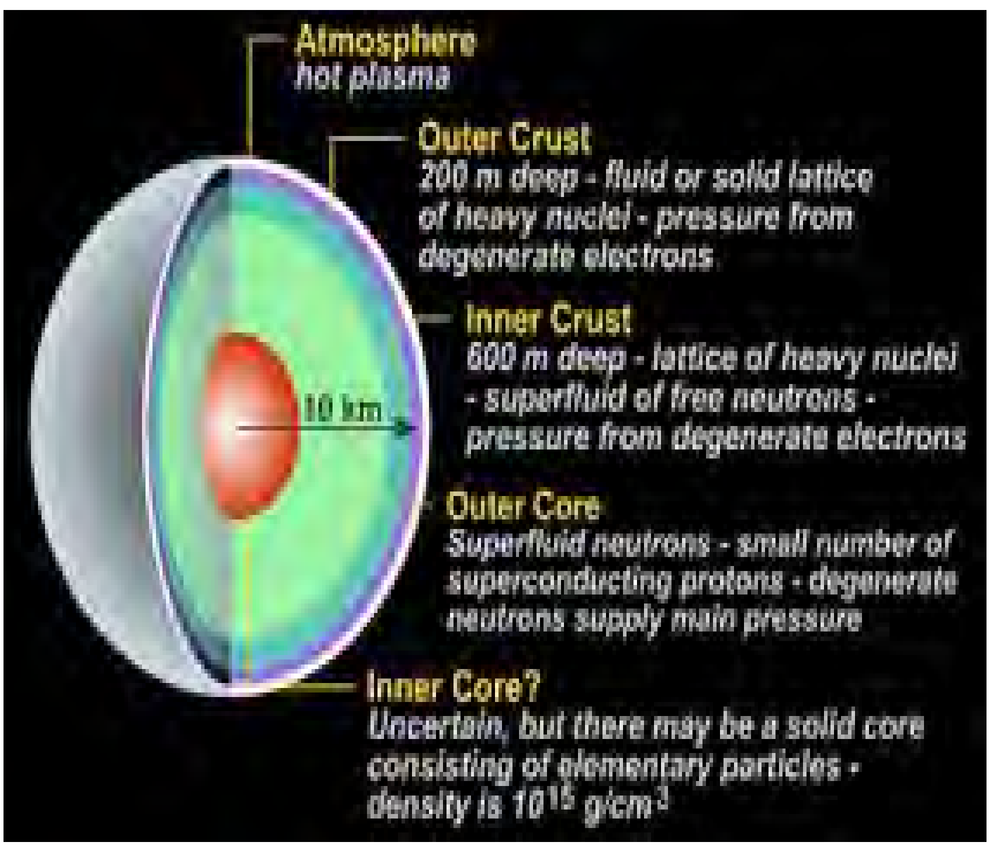

Figure 1.2: The cross section of neutron star.

The cross-section of a neutron star (see Fig.1.2) can roughly be divided into five distinct regions,

• The atmosphere which is only a few cm thick.

• The outer crust which consists of a lattice of atomic nuclei and Fermi liquid of relativistic degenerate electrons.

• The outer crust envelops the inner crust, which extends from the neutron drip density to a transition density $\rho_{tr} \simeq 1.7 \times 10^{14}$ g cm^{-3}.

• Beyond the transition density one enters the core, where all atomic nuclei have been dissolved into their constituents, neutrons and protons. Due to the high Fermi pressure, the core might also contain hyperons, more massive baryon resonances, and possibly a gas of free up, down and strange quarks.

• The composition of the central core is still unclear, but certainly consists in the outer part only of neutrons, protons, electrons and muons. where the core mainly consists of neutrons, protons and electrons. At high densities, however, also heavier baryons are excited, the neutron star now becomes a hyperon star [3].

1.3 Accretion onto a neutron star: as a form of fallback

Accretion may be defined as the gravitational attraction of material onto a compact object. The accretion of gas onto a compact object can be a very efficient way of converting gravitational potential energy into radiation. The accretion onto compact objects has been considered as an effective source of hard X-ray radiation.

1.3.1 Bondi accretion

It is spherical accretion onto a compact object traveling through the interstellar medium (ISM).

In this case the accretion is assumed to occur at a rate,

$$\dot{M}_o \simeq \pi R^2 \rho v, \tag{1.3.1}$$

where ρ and υ are the ambient density and velocity of the object or sound speed, respectively. We can find the radius R by equating the escape velocity and sound speed (c_s) and,

$$\sqrt{\frac{2GM}{R}} = c_s, \tag{1.3.2}$$

From this the accretion rate follow as

$$\dot{M}_o \backsimeq \frac{4\pi\rho G^2 M^2}{c_s^3}, \tag{1.3.3}$$

where ρ is the ambient density and M is mass of the in falling object in the interstellar medium.

Consider a neutron star of mass M and radius R. If a blob of hydrogen with mass $\dot{M}_o$ is allowed to drop onto the neutron star, starting at infinity, the amount of energy released is

$$\dot{E_{acc}} = \frac{GM\dot{M}_{tr}}{R}, \tag{1.3.4}$$

where $\dot{E_{acc}}$ is the luminosity (L) of the object. G = 6.6742 $m^3kg^{-1}s^{-2}$ is gravitational constant, and M = $1.4M_\odot$ and R = 10 km are mass and radius of the NS, respectively.

1.3.2 Fallback disk

Following the formation of a NS through the core collapse of its progenitor, a small amount of mass could fallback onto the compact object. Some of the fallback material may carry sufficient angular momentum to form an accretion disk of mass M_d around the NS.

The SN fallback material is assumed to form from the metal-rich ejecta of core collapse SNe. The formation of a fallback disk requires that at least part of the fallback material possesses sufficient angular momentum. Compared with the accretion disk in binaries, the lifetime of which may be comparable with the evolutionary time scale of the binary or the donor star, the fallback disk has much shorter duration [15].

The evolution of the mass transfer rate at the outer annulus of the disk $\dot{M}_{tr}$ can be written as:

$$\dot{M}_{tr} = \dot{M}_o(1 + \frac{t}{t_o})^{-\alpha} \tag{1.3.5}$$

where the power exponent α is $\frac{5}{4}$, $\dot{M}_o$ is mass transfer rate of the disk, and t_o is the time scale of the disk formation.

The initial transfer rate of the fallback material to the central object can be hypercritical and greatly exceed the Eddington limit [15].

Mass accretion could accelerate the NS's spin to millisecond, and decrease its magnetic field to $\sim 10^8 - 10^9$ G provided that there was sufficient mass ($\sim 0.1 M_\odot$) in the fallback disk [16]. Following the formation of an NS through the core collapse of its progenitor, a small amount of mass could fallback onto the compact object. Some of the fallback material may carry sufficient angular momentum to form an accretion disk of mass M_d around the NS [16].

Chapter 2

Rotating Neutron Star

The 1967 discovery of rotation powered pulsars at radio frequencies was the single most significant event responsible for the recognition of neutron stars. Pulsars are rotating neutron stars, so that it is essential to explore how the basic properties of neutron stars, such as: mass, radius, and shape are modified by rotation. In 1967 a group of Cambridge astronomers headed by Anthony Hewish detected astronomical objects emitting periodic pulses of radio waves. The existence of stable equilibrium stars more dense than white dwarfs had been predicted by a number of theoreticians, including Baade and Zwicky (1934) and Oppenheimer and Volkoff (1939). Baade and Zwicky (1934), Colgate and White (1966), and others suggested that such objects could be produced in supernova explosions. It was even surmised that initially they would be rapidly rotating, with strong magnetic field, and that the energy source of the Crab nebula might be a rotating neutron star. The first argument that the observed pulsars were in fact rotating neutron stars, with surface magnetic fields of around 10^{12} G, was put forward by Gold (1968). A pulsating neutron star has a density $\sim 10^6$ times the density of a white dwarf. Thus, the fundamental period is $\sim 10^{-3}$ s typically much too short. By a suitable choice of radius, one can arrange the orbital period of a binary neutron star system to lie in the observed range of 10^{-3} - 4 s [4]. There are two main effects that distinguish a rotating relativistic star from its non-rotating counterpart. The shape of the star is flattened by centrifugal forces (an effect that first appears at second order in the rotation rate), and the local inertial frames are dragged by the rotation of the source of the gravitational field [3].

2.1 Spin evolution of neutron star

The mode of mass transfer onto the neutron stars, which depends on the properties of the binary systems, also determines the spin evolution of the neutron stars. The short term dependence of the spin periods of neutron stars on the properties of the accretion flows was made possible because of the intense monitoring of several accretion powered pulsars with the BATSE experiment. Contrary to earlier results, the measurements with BATSE revealed that transient and persistent sources show two different types of spin period evolution. Transient accretion powered pulsars in outburst show a positive dependence of the accretion torque. As the accretion rate increases, the rate of angular momentum transfer from the accretion flow to the neutron star increases. At the limit of very low mass accretion rate, the neutron stars are expected to spin down, because the magnetic field lines that couple to the outer, slower accretion flow remove spin angular momentum from the neutron star, such spin down episodes have not been detected by BATSE. Over time, neutron stars slow down (spin down) because their rotating magnetic fields radiate energy; older neutron stars may take several seconds for each revolution, the slow rotation of the original star's core speeds up as it shrinks. A new-born neutron star can rotate several times a second; sometimes, the neutron star absorbs orbiting matter from a companion star, increasing the rotation to several hundred times per second, reshaping the neutron star into an oblate spheroid [5].

2.2 Neutron star magnetic field

Neutron star magnetic fields are large. NSs with magnetic fields thousands of times stronger than that of typical neutron stars is known as Magnetars. Canonical values for pulsars, both rotation and accretion powered, are in the range B $\sim 10^{12}$ - 10^{13} G. For LMXBs and recycled, rotation-powered pulsars, they are in the lower range B $\sim 10^{8}$ -

10^9 G. Since NSs normally rotate very fast, the spinning polarization (surface) charge is expected to generate a strong magnetic field. NSs could have very strong surface magnetic fields, up to B $\gg 10^{17}$ G , and these fields are the engines that drive the observed long Gamma Ray Bursts in SNeII [17].

The magnetic fields of the progenitors of neutron stars are amplified by the flux conservation process as matter is compressed enormously during the core collapse that produces the neutron star.

Consider the magnetic flux Φ through a progenitor star of radius R $\sim 10^{11}$ cm and magnetic field strength B $\sim 10^2$ G. Such magnetic fields in sun-like and more massive normal stars are thought to be produced by dynamos operating in appropriate regions of these stars. The corresponding flux is then $\Phi = \pi R^2\mathrm{B} \sim 3 \times 10^{24}$ G cm^2 . As Φ would be conserved in the collapse of fully ionized, highly conducting matter, the resulting neutron star with radius R $\sim 10^6$ cm will have a magnetic field of $\sim 10^{12}$ G, the canonical value for neutron stars [1].

Consider gas in a star with radiative energy transport. Assume further that the star has a weak, radially oriented magnetic field of strength B_r . When the star rotates differentially, any magnetic field present, however small, will be stretched horizontally and the field lines will be wound.This leads already after a few turns to a strong horizontal magnetic field, $B_\phi \gg B_r$. Magnetic fields will tend to drag gas along with rotation due to the coupling of the field to the charged particles. This means that the redistribution of angular momentum due to evolution in the MS phase will be restrained. It means that magnetic fields tend to reduce the overall rotation speed [7]. The presence of currents in a moving plasma modifies the magnetic field, while the electromagnetic field acts on the charges to produce currents. Therefore, in general, the influence of a magnetic field on the gas flow is quite complicated [2].

2.3 Supernovae

Supernovae (SNe) are extremely powerful explosions which terminate the life of some stars. Typically, some solar masses are ejected in the interstellar space with a kinetic energy of the order of 10^{51} erg. The ejecta contain heavy elements that are important for the chemical evolution of galaxies, stars, and planets. Bright SN 1987A was the first SN reported in 1987. Some SNe produce a compact remnant, a neutron star or a black hole. The study of SNe was initiated by W. Baade and F. Zwicky in the early 1930s. They already suggested that the source of the enormous quantity of energy released in SNe is the gravitational collapse of a star to a neutron star and that SNe may be sources of cosmic rays [10].

Supernova explosions are classified into two types according to their observed properties: the so-called Type I and Type II supernovae, as shown in Fig.2.1. The main distinguishing characteristic is the presence of hydrogen lines in the spectrum of the latter and their absence in the former. Each type has its own characteristic light curve, although a wide variety of deviations from the general shape is detected, resulting from individual properties [9].

Type I supernovae are those believed to arise from the collapse of white dwarfs that have reached the Chandrasekhar limiting mass, presumably by accretion. Since in a given stellar population white dwarfs form at all times, and since accretion rates may widely vary, there is nothing to prevent the occurrence of Type I supernovae in old population stars as in young. As we set out to explore the evolution of only single (isolated) stars, Type II supernovae that are associated with the collapse of the iron cores of massive stars. These stars have large hydrogen rich envelopes; hence the evidence of hydrogen in the spectrum. If a supernova's spectrum contains lines of hydrogen it is classified Type II; otherwise it is Type I. As massive stars evolve much more rapidly than low mass stars, old stellar populations, where no star formation occurs, have outgrown the Type II supernova

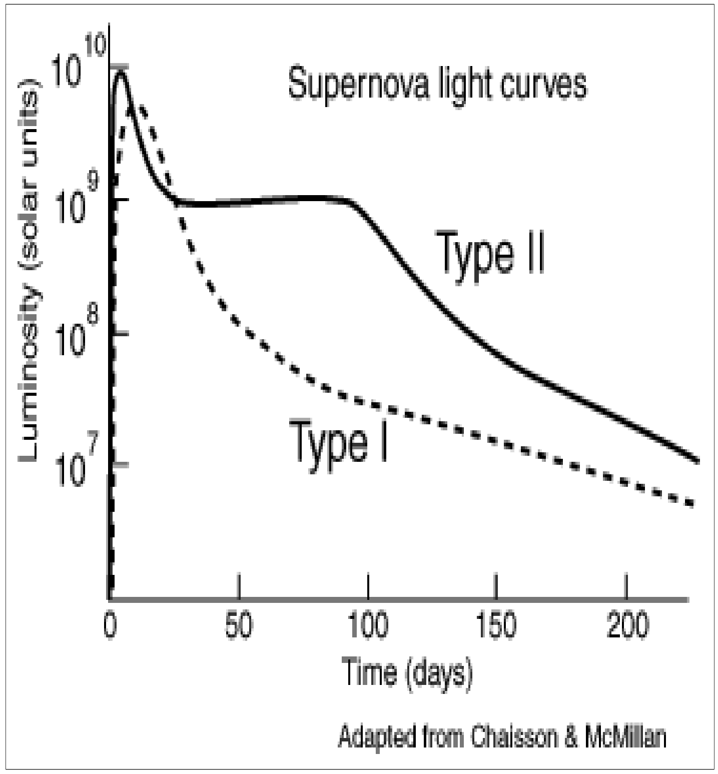

Figure 2.1: Supernova light curves

stage [9].

Type I supernova class is further divided in three additional sub-classes: Type Ia, Ib and Ic, according to the features observed in their early spectra. i.e. the spectra obtained a few days after the explosion. Type Ia supernovae are characterized by the presence of a clear Si II absorption line around $6150\AA$ and their late spectra show many lines associated with Fe emission. Type Ib and Ic supernovae do not show this ionized silicon (Si II) absorption line and are distinguished according to the presence or not, respectively, of moderately strong He I lines around $5876\AA$. The favored scenario for Type Ib and Ic supernovae is that both are a consequence of the explosion of massive stars that, owing to mass loss by strong stellar winds and, or mass exchange in a binary system, have lost the whole H-rich envelope.

The supernovae of Type II can also be sub-divided based on their spectra. While most Type II supernovae show very broad emission lines which indicate expansion velocities of many thousands of kilo-meters per second have relatively narrow features in their spectra. These are called Type IIn, where the 'n' stands for 'narrow'. They can potentially be produced by various types of core collapse in different progenitor stars, possibly even by type Ia white dwarf ignitions, although it seems that most will be from iron core collapse in luminous supergiants or hypergiants. The narrow spectral lines for which they are named occur because the supernova is expanding into a small dense cloud of circumstellar material.

The other sub class "Type IIb" is used to describe the combination of features normally associated with Types II and Ib. These supernovae, like those of Type II, are massive stars that undergo core collapse. However the stars which become Types Ib and Ic supernovae have lost most of their outer (hydrogen) envelopes due to strong stellar winds or else from interaction with a companion [7].

2.4 Supernova and gamma ray burst

The early 1980s flashes or bursts of γ-ray light were detected with space probes from diverse directions in the sky. It then also became known that the earlier US military satellites Vela (1967- 1984), designed to detect the γ-ray flash from atomic bomb explosions, had seen such bursts. With the Burst and Transient Source Experiment (BATSE), on board of the Compton Gamma Ray Observatory (CGRO), launched in 1991, many more such flashes were detected [6]. In the late 90s it was realized that, in addition to the normal core collapse and thermonuclear explosions, there are more energetic supernovae with an energy output $\gtrsim 10^{45}$ J, i.e., they are at least 10 times as energetic as a normal supernova that is 5 - 50×10^{44} J. These are now often referred to as hypernovae (HNe) or alternatively as broad lined supernovae, since they have very broad lines. SN 1998bw was also observed as an LGRB (long gamma ray burst), establishing the first connection between a GRB and a supernova, the death of a massive star [8].

In addition, many GRB afterglows show bumps in the light curve that are consistent with an underlying hypernova like event. Interestingly, at present all GRB supernovae are classified as SNe Ic, i.e., supernovae that have lost both their hydrogen and their helium envelopes [8].

Hypernovae are produced by more than one type of event: relativistic jets during formation of a black hole from fallback of material onto the neutron star core, the collapsar model,or during the last phases of the coalescence of neutron star binaries. These catastrophic events are believed to exist at the central engine of highly energetic gamma-ray bursts (GRBs) [3]. Stars with initial masses between about 25 and 90 times the sun develop cores large enough that after a supernova explosion, some material will fall back onto the neutron star core and create a black hole. In many cases this reduces the luminosity of the supernova, and above $90M_{\odot}$ the star collapses directly into a black hole without a supernova explosion. However, if the progenitor is spinning quickly enough the infalling material generates relativistic jets that emit more energy than the original explosion. In some cases these can produce gamma ray bursts, although not all gamma ray bursts are from supernovae.

Some black hole binaries appear to be linked to the hypernovae believed to power gamma-ray bursts [5].

In our GRB the materials are fallback but not a collapsar because the amount of falling mass is small and it don't have to be collapse in to Black Hole.

Chapter 3

GRBs and their Classification

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. Gamma ray bursts are brief flashes of high energy radiation that appear on average about once a day at an unpredictable time from unpredictable directions in the sky. Since their discovery in the late 1960s, several thousand bursts have been detected, most of them with the Burst and Transient Source Experiment (BATSE) on board the Compton Gamma Ray Observatory (CGRO). Their distribution on the sky is completely uniform. Gamma ray bursts (GRBs) are brief gamma ray flashes detected with space based detectors in the range 0.1 - 100 MeV, and durations of 0.1 - 1000 seconds [3].

Types of gamma ray bursts are:

(a) Long and short bursts. The duration distribution is bimodal, and the energy spectra of the short bursts are harder than those of the long bursts. Events with a duration of less than about two seconds are classified as short gamma ray bursts. These account for about 30 percent of gamma ray bursts. It has been speculated that the short bursts might arise from neutron - neutron star mergers. Most observed events (70 percent) have a duration of greater than two seconds and are classified as long gamma ray bursts. Long GRBs are the most powerful explosions in the universe, with the longest known having a duration of approximately 2000 seconds. Their standard total energy is typically greater than 10^{51} ergs, with the most energetic being measured at $\sim 10^{54}$ ergs.

Short GRBs clearly have energies less than 10^{51} ergs, and durations of less than 2 seconds [5].

(b) Dark bursts. On the speculative side, possibilities include absorbing the light in the host galaxy, placing the burst at high redshift, or invoking a flat spectral shape. Bursts can also appear to be dark if their afterglows are intrinsically weak and or rapidly fading. This has actually been observed, GRB 021211 is in this category. It was detected by the HETE spacecraft and its position was circulated to astronomers 22 s after the start of the burst. Long duration gamma ray bursts that leave little or no afterglow, comprising about 30 percent of all bursts. Such bursts are thought to be dark because:

(a) there is a lack of sufficient gas and dust in the interstellar medium to create the afterglow; or

(b) the burst is so enshrouded in dust that only gamma rays can escape [5].

(c) X-ray flashes (XRFs). These are bursts that resemble GRBs in almost every respect: durations, spatial distributions, etc. However, they display little or no emission above 25 keV [5].

X-ray flashes (XRFs) are events that are very similar to long GRBs, but they extend to a softer, fainter regime [23].

3.1 GRB 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. This fading emission would be called the "afterglow". The advent of modern gamma ray burst astronomy occurred in 1997 with the dramatic discovery by the Beppo-SAX satellite of the first GRB afterglow. This led to the identification of GRB host galaxies, the determination of their redshifts (and hence, their distances), and the measurement of important physical properties such as total energy. The Swift Gamma Ray Burst Explorer is a multi wavelength observatory specifically designed to study gamma ray burst evolution from their early stages. It is equipped with a wide field instrument, and it has three parts, the Burst Alert Telescope, covering the 15 - 350 keV energy band, and two narrow field instruments, the X-ray Telescope and the Ultraviolet/Optical Telescope, covering the 0.2 - 10 keV band and the 1700 - 6500 Å wavelength range, respectively [18].

Gamma ray bursts are the most powerful explosions since the Big-Bang, with typical energies around 10^{51} ergs. These bursts are often followed by an afterglow, a secondary burst of light in the form of X-rays, visible light, and radio waves. The afterglow can persist for hours, days, or even weeks. It deals with the emission on timescales much longer than that of the GRB [5].

The Swift XRT has been observing GRB afterglows. Since the Swift X-ray Telescope (XRT) provides unique X-ray observations of young GRB and X-ray flash (XRF) afterglows, beginning in the first few minutes after the burst. Here, we use the terms “burst ”and “prompt emission ”to refer to the burst seen in hard x- rays and gamma rays, and we use the term “afterglow ”to refer to the soft x-ray. Between 23 December 2004 and 5 May 2005, the XRT observed 13 afterglows within 200 seconds of the burst for GRBs discovered by the Swift Burst Alert Telescope (BAT) [26].

The XRT has shown that the early behavior of X-ray afterglows is typically much more complex than the simple power laws observed at later times with Beppo-SAX.

Beppo-SAX observed a wide range of celestial X-ray sources and also discovered the afterglow phenomenon from a burst on February 28, 1997. Beppo-SAX also helped find more precise locations of many gamma-ray bursts [11].

The afterglow emission from GRBs is generally well described by the blast wave model, this model details the temporal and spectral behavior of the emission that is created by external shocks when a collimated ultra-relativistic jet ploughs into the circumburst medium, driving a blast wave ahead of it [19].

3.2 X-ray binaries

The basic division of X-ray binaries into the high mass (HMXBs) depending on whether the mass of the companion star is lower or higher than about two solar masses, and low mass (LMXBs). In a massive double system, the primary evolves and explodes as SN Type I. When the massive secondary becomes a supergiant its strong stellar wind is accreted by the compact star which turns it into a powerful X-ray source, and the system is called a high mass X-ray binary. In a system with a massive and a lower mass star, the massive becomes SN Ib first. Much later, the low mass secondary evolves and starts mass transfer onto the primary neutron star.The accretion is erratic and leads to the low mass X-ray binary (LMXB) [6]. The nomenclature refers to the nature of the mass donor, with HMXBs normally taken to be $\geq$ 10 M of sun, and LMXBs $\leq$ 1M of sun. Nevertheless, the nature of the mass transfer process (stellar wind dominated in HMXBs, Roche lobe overflow in LMXBs) [5]. In low mass X-ray binaries (LMXBs), the compact object and its companion star orbit so closely that matter is stripped off the outer layers of the latter and becomes bound to the compact object. In high-mass X-ray binaries the mass transfer is mostly due to the strong stellar wind of the (early type) companion star. As this matter loses angular momentum and approaches the compact object, its gravitational energy is converted into kinetic energy, thermalized and radiated away in the form of X-rays.

3.3 X-ray flares

One of the key findings from the recently launched Swift satellite is the common presence of X-ray flares in the early afterglows of gamma ray bursts (GRBs). The flares typically occur at hundreds of seconds to hours after the trigger, but in some cases days after the trigger. The amplitude of the X-ray flare can be a factor of $\lesssim$ 500 for GRB050502B [12]. The rapid response of the pointed X-ray Telescope (XRT) instrument on Swift has led to the discovery that large X-ray flares are common in GRBs and occur at times well after the initial prompt emission. GRB 050502B is qualitatively different, with a giant flare that brightened by a factor of ~ 500 to a peak at T + 740 s. This flare contained roughly as much energy ($\sim 9\times 10^{-7}$ ergs cm^{-2}, 0.3 to 10 keV) as the prompt emission observed by the BAT (8×10^{-7} ergs cm^{-2}, 15 to 350 keV), something never before seen and quite unexpected [25].

X-ray flares, which are the extension of the GRB central engine activities to the weaker and softer regime. Some X-ray light curves show flares, which are a sudden increase in flux, with a very steep rise and followed by a similar steep decay, which cannot be explained within the framework of the standard afterglow model. X-ray flares are commonly observed in GRB afterglows, with the most known example being GRB 050502B.

The rapid rise and decay behavior of some flares suggests that they are caused by internal dissipation of energy due to late central engine activity [12]. The first phase of a GRB is the prompt phase. Most of the energy is released in gamma rays, although some GRBs have luminous optical counterparts as well.

3.4 GRB emission

Gamma ray bursts shining hundreds of times brighter than a supernova and as bright as a million trillion suns are quick bursts of gamma ray photons that satellites detect almost daily in wholly random directions of the sky. The bursts last from a few milliseconds to roughly 100 seconds. Early time optical emission (i.e., emission before $\sim 10^3$ sec after the GRB trigger) is an important tool to study the physics of Gamma Ray Bursts (GRBs). Especially when it is detected during the ongoing gamma ray emission, early time optical emission can help us understand true mechanisms behind prompt GRB emission and provide constraints on current and future GRB emission models. By analyzing the temporal profiles of prompt optical light curves, we can compare the characteristic time scales and temporal structure with those of prompt gamma ray light curves. Multi-wavelength spectral analysis can show if the spectral energy distribution is consistent with synchrotron emission, and whether optical and gamma ray emission originate from the same emission processes [13].

We can have more collisions happening at various regions in the flow, one producing brighter gamma ray emission and other producing brighter optical emission. Early time optical polarization measurements and its temporal evolution across various phases of optical light curve, coupled with polarization measurements in other wavelengths (gamma rays and radio), will provide vital information about the nature of GRB emission [13]. The prompt emission is that emitted directly during the burst. With Swift this emission is seen by the BAT but can also be detected by the XRT if the burst is long enough to last until the completion of the first slew to target. Most bursts observed by Swift typically have a 15 - 150 keV. BAT has detected and located on-board the prompt emission of GRBs at a rate of approximately 100 yr^{-1}. In terms of duration, BAT GRBs span the same range as those detected by the BATSE instrument. The BAT data are for those GRBs with values of T_{90} , 15 - 150 keV fluence. The early high energy emission from most GRBs appears to be dominated by central engine activity, which may continue low energy output for up to a day after the burst. This phase, plus X-ray flares, are seen in both long and short bursts. In a significant minority of GRBs, the early X-ray emission is consistent with a classical afterglow [14].

Any emission mechanism has to explain both the prompt emission and the afterglow, which cover many orders of magnitude in flux, frequency and time. The prompt emission from GRBs displays a power-law spectrum which is non-thermal in nature and implies that the emission originates from an optically thin region. Many GRBs display millisecond variability in their light curves which, given the finite speed of light, means that the emission region must be of a limited size, corresponding to a radius of the order of 1000 km. The emission from GRBs is non-thermal and in fact displays a synchrotron like spectrum consisting of various power-law segments. In each of these segments, the flux at a given time as a function of frequency is given as F $\propto \nu^{-\beta}$, where β is the spectral index [19].

3.5 Central engine

Different types of progenitor may result in a common central engine that powers the observed GRBs. Observations suggest that a GRB central engine should satisfy the following requirements:

1) It can drive an outflow with extremely high luminosity and energy.

(2) The ejecta need to be clean with small baryon contamination, so that they can achieve a relativistic speed, with Lorentz factorΓ typically greater than 100, some even close to 1000.

(3) The outflow needs to be collimated, with a beaming factor f $=\frac{\Delta\Omega}{4\pi}$ $\sim$1/500 for bright GRBs.

4) The engine needs in general to be intermittent, with a range of variability time scales.

(5) The engine can last long, with renewed, progressively less powerful late activities to power X-ray flares and other activities [20].

The central engine of a gamma-ray burst, whether originating from the collapse of a massive star as is the case in long bursts, or from the coalescing of two compacts objects as is in short bursts, is likely an accreting black hole. This central engine powers an outflow which causes electromagnetic radiation that allows us to see GRBs from across the Universe. The burst itself, which is observed in gamma-rays and X-rays for seconds, is followed by an afterglow which is observable in X-ray, optical, infrared, and radio wave, for days to months, even to years in some cases [19].

Chapter 4

Light Curve Analysis of GRBs

In Astronomy, light curves usually carry the information about the central objects. In stably rotating neutron star system like: radio pulsars and X - ray pulsars, strict periodicity is detected, which is related to the rotating period of the neutron star.

For transient objects such as GRBs and SGRs (short gamma rays), the light curves usually track the history of the central engine activities.

It is believed that due to the erratic activities of the central engine, one would not expect a repeatable pattern in GRB light curves [21].

The light curve of a GRB afterglow is dependent on the evolution of the synchrotron spectrum, which is in turn dependent on its evolving peak flux and peak frequencies. The XRT typically begins observing a GRB ~ 100 s after the trigger, and usually follows it for several days, and occasionally for months. However, creating light curves of the XRT data is a non-trivial process with many pitfalls.

The UK Swift Science Data Center is automatically generating light curves of GRBs and making them immediately available online.

In our case, to create GRB flux light curve which is starting from eq$\underline{n}$ (1.3.4) the flux is given by,

$$Flux = \frac{L}{4\pi r^2}, \tag{4.0.1}$$

where r is radius of the disk and can be find as: r = $\frac{GM}{c_s^2} = 1.57 \times 10^{15}$ m where M is mass of NSs.

The luminosity of the object depends on $\dot{M}_{tr}$. From eq$\underline{n}$ (1.3.5), the time scale of the disk formation can be calculated as:

$$t_o = \frac{R^2\Omega}{\alpha c_s^2} = 1.5 \times 10^8 s, \tag{4.0.2}$$

where $\alpha = 0.1$ (viscosity parameter), R is the radius of the central object, and Ω is the local Keplerian angular speed. Ω is given by $(\frac{GM}{r_o^3})^{\frac{1}{2}}$, where r_o is rotational radius.

X -ray pulsars, which generally possess surface magnetic field as strong as $10^{12} - 10^{13}$ G and hence $r_o \sim 10^8 - 10^9$ cm [22].

4.1 GRB 050502B

GRBs have been studied intensively in recent years, especially with the launch of the Swift satellite. Since its launch on 2004 November 20, Swift has provided detailed measurements of numerous gamma ray bursts (GRBs) and their afterglows with unprecedented reaction times. While both long (t >2 s) and short (t <2 s) GRBs exist, in general, long GRBs are known to have association with X- ray, optical, and radio afterglows [23].

GRB 050502B was detected by the Swift BAT at 09:25:40 UT on 2005 may 2, and it was classified as long GRB, and its overall light curve figure is given below . Since the flux was initially low, the XRT image mode data did not produce an initial on board centroid position. Following the initial low - flux detection by XRT, continued monitoring revealed increased flux that turned out to be the largest X - ray flare ever increased during a GRB afterglows. This giant X - ray flare was not accompanied by and detected emission in the BAT energy band [24].

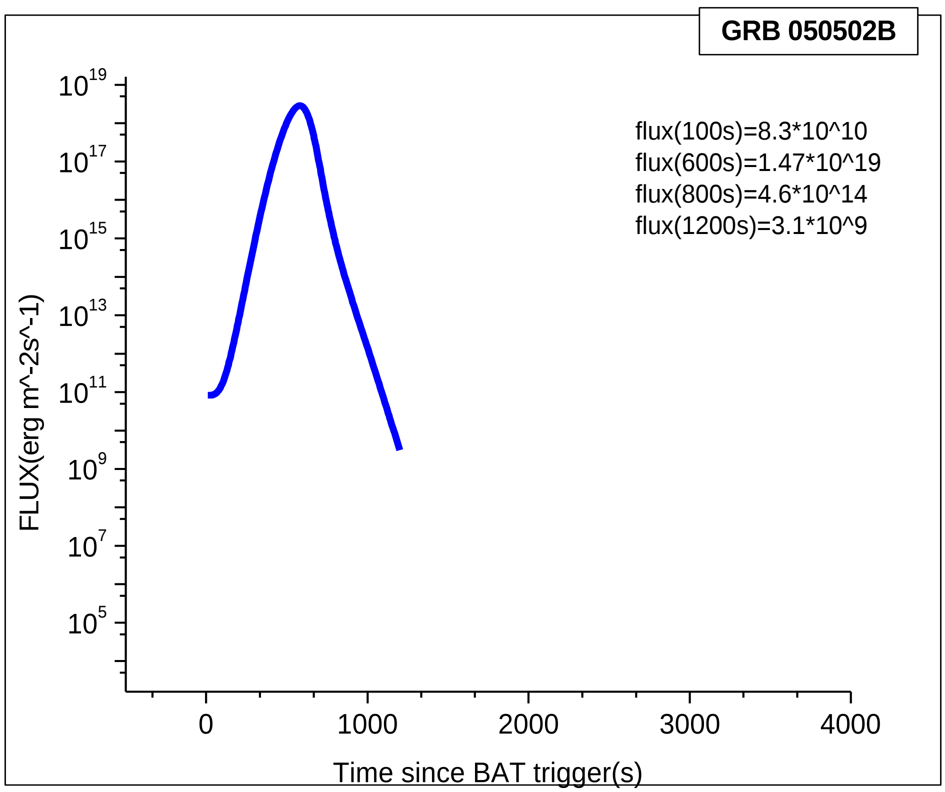

Figure 4.1: GRB 050502B afterglow fallback light curve

Chapter 5

Summary and Conclusion

Neutron stars (NSs) are one of the densest celestial objects known to exist in the universe. With radius of 10 km, they can have a mass of about twice that of the sun.

After NSs have finished burning their nuclear fuel, they undergo a supernova explosion. The supernova occurred when a rapidly rotating giant stars collapsed, transforming its core into ultra-dense NS.

Following the supernova explosion of a massive stars, a small amount of mass could fallback onto a newly formed NS.

A neutron star initially formed which then experience fallback accretion.

As the star's core collapse, its rotation rate increase as a result of conservation of angular momentum, hence NSs rotate up to several hundred times per second. In this way, they can emit beams of electromagnetic radiation that makes them detectable as pulsars.

A rapidly spinning, strong magnetized neutron star have been proposed as one possible candidate of the central engine of gamma ray bursts (GRBs).

Gamma rays are like X-rays, but even more energetic, the highest energy form of light.

GRBs can be produced by the electromagnetic process near the young magnetized neutron star.

When an infalling particle with conservation of its angular momentum is considered, the particle cannot go inward of the certain radius due to the centrifugal force. This is called as the centrifugal barrier.

GRB 050502B light curve is brightened dramatically starting some 400s after the initial burst because of the centrifugal barrier, rising to a peak which lasted for several hundreds second before its fading.

Pulsars frequency is very high at the beginning of mass falling due to fallback and it rejects mass, after span of time its frequency slows down very fast because it is radiating and its flux is rising, and then the accreted energy is changed into radiation.

Therefore, the spectrum of GRB 050502B is theoretically reconstructed.

The afterglow fallback is not only the property of a single observation but there are numerous other GRBs like GRB 930131A.

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Declaration

This thesis is my original work, has not been presented for a degree in any other university and that all the sources of material used for the thesis have been dully acknowledged.

Signature:− − − − − − − − − − − −

Place and date of submission: Addis Ababa University, September 2016

This thesis has been submitted for examination with my approval as University advisor.

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