The Global Spectral Properties of X-ray and Gamma-ray Bursts from SGR 1806-20

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Abstract

Magnetars are cosmic sources of high energy radiations that emit short, intense bursts of X-rays and Γ-rays. Studying the spectral and temporal properties of these bursts allows us to identify the physical mechanism responsible for their emission and to probe the interaction of radiation and matter at extreme conditions of temperature, gravity, and magnetic field that cannot be reproduced in laboratories or particle accelerators. Using the data obtained from NASA archives, We study burst observations from SGR 1806-20 in order to investigate the spectral and temporal characteristics of the source and examine possible correlations between the spectral and temporal properties of the bursts. In search for the best-fit models of the burst continuum, we study the bursts with ten trial models. We examine possible correlations between the spectral and temporal parameters of the best-fit models. In our analysis, we classify the bursts according to their temporal profile to single-peak, multi-peak & multi-bursts and according to their duration to short and long burst classes and we study each class separately. We discuss the physical interpretation of the results and its implications on the magnetar properties and structure in the context of the magnetar model.

List of Publications

- Alaa I. Ibrahim, Hisham Anwer, Mohamed H. Soleiman, Nicholas Mackie-Jones, Kalvir S. Dhuga, William C. Parke, Jean H. Swank, Tilan Ukwatta, M. T. Hussein, T. El-Sherbini. On the Iron Interpretation of the 6.4 KeV Emission Line from SGR 1900+14, 2007, *Astrophysics and space science*, V 308, Number 1-4, 535-539.

- Alaa I. Ibrahim, William C. Parke, Jean H. Swank, Hisham Anwer, Roberto Turolla, Silvia Zane, M. T. Hussein, T. El-Sherbini. The Continuum and Line Spectra of SGR 1806-20 Bursts, 2007, *Astrophysics and space science*, V 308, Number 1-4, 43-50.

- Hisham Anwer, Alaa I. Ibrahim, M. T. Hussein, T. El-Sherbini, A. Y. Ellithi and Mohamed H. Soleiman. Global Spectral Analysis of SGR 1806-20 bursts observed by RXTE, AIP Conf. Proc. 2010.

- Hisham Anwer, Alaa I. Ibrahim, M. T. Hussein, T. El-Sherbini, A. Y. Ellithi and Mohamed H. Soleiman. Spectral Temporal Correlations in SGR 1806-20 bursts, To be published.

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Chapter 1

The Physics of Neutron Stars

1.1 Motivation

After the discovery of the neutron by Chadwick [1], Baade and Zwicky [2] proposed the existence of the neutron stars. Decades later Hewish et al. [3] discovered the first rapidly rotating neutron star, or pulsar. The discovery of a pulsar in the crab nebula [4] represented a confirmation on the idea that a supernova action would yield a neutron star. This thesis is on a class of neutron stars known as magnetars that have extremely powerful magnetic field. In this chapter we review the properties of neutron stars in general, and in the next chapter we discuss the physics of magnetars.

1.2 Formation of Neutron Stars

At the end of the life of a massive star it reaches a point where it can no longer support itself against gravity. The stellar core collapses and triggers an explosion which releases an enormous amount of energy in a supernova action. Supernova explosions are so bright that they can outshine our galaxy for a brief period of time [5]. The star subsequently blows off some of its outer envelope which expands into the local interstellar medium. Depending on its age, composition and the density of the medium it is expanding into, it might be possible to observe this ejected shell as a supernova remnant [6]. What remains of the original star is a compact core, whose further collapse cannot be stopped by thermal pressure [5]. In the free space a neutron will decay into a proton, an electron and a neutrino with a half life of 10.25 min. This process will be suppressed in the core, and the upper limit of the energy of the electron is given by the mass difference between the proton and neutron, $(m_n m_p)c^2 = 1.293$ MeV, which is well below the Fermi energy of the electron gas in the core.

$$n \longrightarrow p + e^- + \bar{\upsilon}_e \tag{1.1}$$

If the mass of the core is greater than $M_{Ch} = 1.4 M_\odot$ [7], the gravitational pressure is so strong that the inverse beta reaction (Eq. 1.2) becomes important. This process of converting protons to neutrons is usually referred as neutronization, and It is this process makes the core become neutron rich.

$$p + e^- \longrightarrow n + \upsilon_e \tag{1.2}$$

If the neutrons provide enough degeneracy pressure to balance gravity, then we are left with a neutron star. For collapsed core with a mass greater than $\sim 4\ M_\odot$, neutron degeneracy pressure will not suffice to balance gravity [5] and a black hole is what will be left over.

1.3 Neutron Star Characteristics

1.3.1 Estimation of Mass, Radius and Acceleration due to Gravity

During core collapse, gravity will squeeze the particles together, and Pauli's exclusion principle sets a limit on how close the particles can get. The degeneracy pressure could be estimated by considering the simple case of particles in a cubical box with sides of length L. The solution of Schrödinger's equation for such a system is

$$E = \frac{\pi^2 \hbar^2}{2mL^2} \ \ (n_x^2 + n_y^2 + n_z^2), \tag{1.3}$$

where E is the particle energy, m the particle mass, and n_x, n_y, n_z are the number of quantum states in a given direction. If we plot these states in three dimensions, then the number of particles with energy E or less can be approximated by the volume of an octant of a sphere with radius R, i.e. $(1/8)(4\pi R^3/3) = \pi R^3/6$, where $R^2 = n_x^2 + n_y^2 + n_z^2$. The particles might also have spin; thus, to obtain the total number of particles we must also multiply by their spin degeneracy, $g_s = 2s + 1$, where s is the spin of the particles. For electrons and protons, i.e. fermions with $s = 1/2, g_s = 2$. Using Equation 1.3, the total number of particles that have energy E or less takes the following form

$$N = g_s \frac{\pi}{6} \left(\frac{2mV^{2/3}E}{\pi^2\hbar^2} \right)^{3/2} \tag{1.4}$$

rearranging the above equation we get that

$$E = E_F = \frac{\hbar^2}{2m} \left(\frac{6\pi^2 N}{g_s V} \right)^{2/3}. \tag{1.5}$$

Integrating over the number of particles we get the total energy of the system

$$U = \frac{3\hbar^2}{10m} \left(\frac{6\pi^2}{g_s} \right)^{2/3} \left(\frac{N}{V} \right)^{5/3} V. \tag{1.6}$$

The pressure could be deduced as follows

$$P = -\partial U/\partial V = \frac{3\hbar^2}{10m} \left(\frac{6\pi^2}{g_s} \right)^{2/3} n^{5/3}, \tag{1.7}$$

where $n = N/V$ is the number density. Eq 1.7 describes the degeneracy pressure for non-relativistic particles. If we write the number density in terms of the mass density, i.e. $\rho = mn$, notice that the above equation describes an adiabatic equation of state

$$P = K\rho^\gamma = K\rho^{1+1/\alpha}, \tag{1.8}$$