Detection of Gamma Ray Bursts and X-ray transient SGR1806-20 with VLF Radio Telescopes

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Abstract: The VLF computer model proposed in this paper examines whether gamma ray bursts (GRB) or X-ray transient flux from distant supernova 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 GRB 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 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, which impact the lower ionosphere layers. Local atmospherics such as lightening, and sprites also confound detection of SN GRB. Only events of very long duration, such as the nighttime ionosphere disturbance from SRG1900+14, or a recent 'super flare' from SGR1806-20 located toward the center of our galaxy 45,000 light years away from earth, and GRB030329 http://www.konkoly.hu/cgi-bin/IBVS?5415 have been detected at Very Low Frequencies (Peterson and Price et. al, 2003, Price et. al, 2004).

Introduction

VLF detection of short-hard GRB or X-ray bursts depends on line of sight geometry of the impact with ionosphere layers and the orientation of VLF receiver and transmitter. Intense flux density which impacts the upper thermosphere from coronal mass ejections and other solar plasma phenomena interact with the earth's magnetosphere, thermosphere. With ion-electron plasma interactions from the sun the fraction of the energy that goes into the electrons affects the upper thermosphere and magnetosphere rather than the ionosphere. GRB and X-ray transient interactions are dependent on ion proportion of heated solar plasma and penetration into the cooler ionized particles at lower layers (Lyon J.G, 2000). Shock waves from 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. Detection of these shock waves depends on the geometry, or line of sight, between the shock wave, receiver and VLF transmitting stations on the ground. Shock waves created from high-energy electron emissions colliding with ionized particles may be twisted in the magnetic field. Solar X-rays or high energy transient X-rays from GRB or magnetars penetrate the cooler F, E and D layers through the magnetic field but do not affect direct free electron interaction at the poles (Hill T.W., Dessler A.J, 1991).

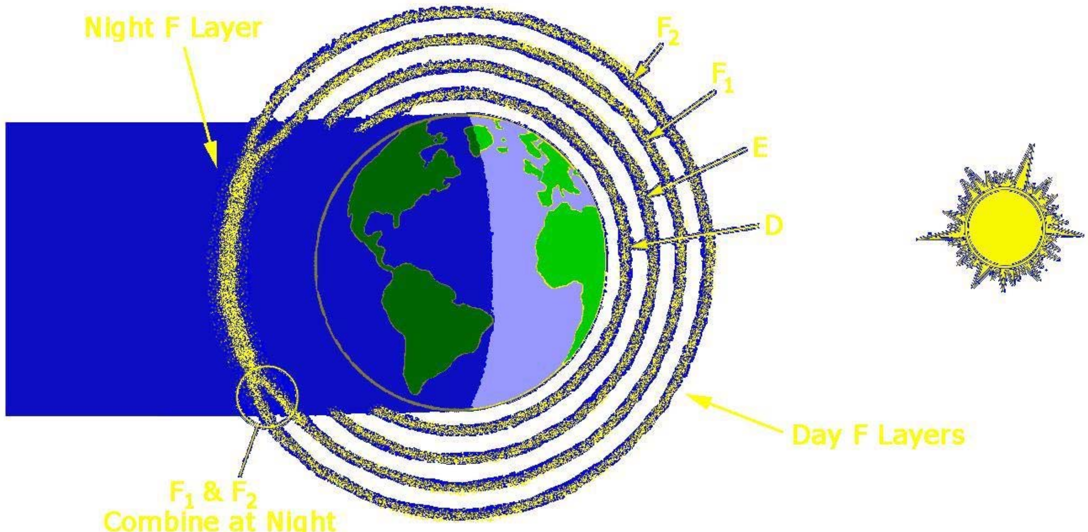

Figure 1, shows the splitting up of the ionosphere during the day into various layers, and reconnection of these layers during the night, courtesy of Joseph DiVerdi.

Solar plasma interaction is different than interaction of extra-galactic short-hard Gamma Ray Bursts or X-ray transients (XRB) from objects like magnetars. A GRB will interact with the earth's upper thermosphere directly with much less flux density and are not influenced by the outer magnetosphere like solar plasma from solar coronal mass ejections or proton-electron plasma flares. On the other hand, GRB photons may cause a detectable Compton Effect (CE), which 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 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 often seen in VLF recorded voltages of solar plasma interactions. However, Solar X-ray flares that have the energy to cross into lower F, E and D layers of the ionosphere are detectable as a SID with VLF radios. It is possible GRB or hard X-ray transient signatures will show a slight drop in VLF signal during local nighttime hours, although, to-date most VLF detection of GRB and X-ray transients have been recorded during the day as a SID type signature. However, any VLF detection of GRB or X-ray transients and magnetars such as SGR1806-20 and SGR1900+14, rely on the geometry of the incoming flux density and the line of sight arrangement of the receivers and transmitters on the ground.

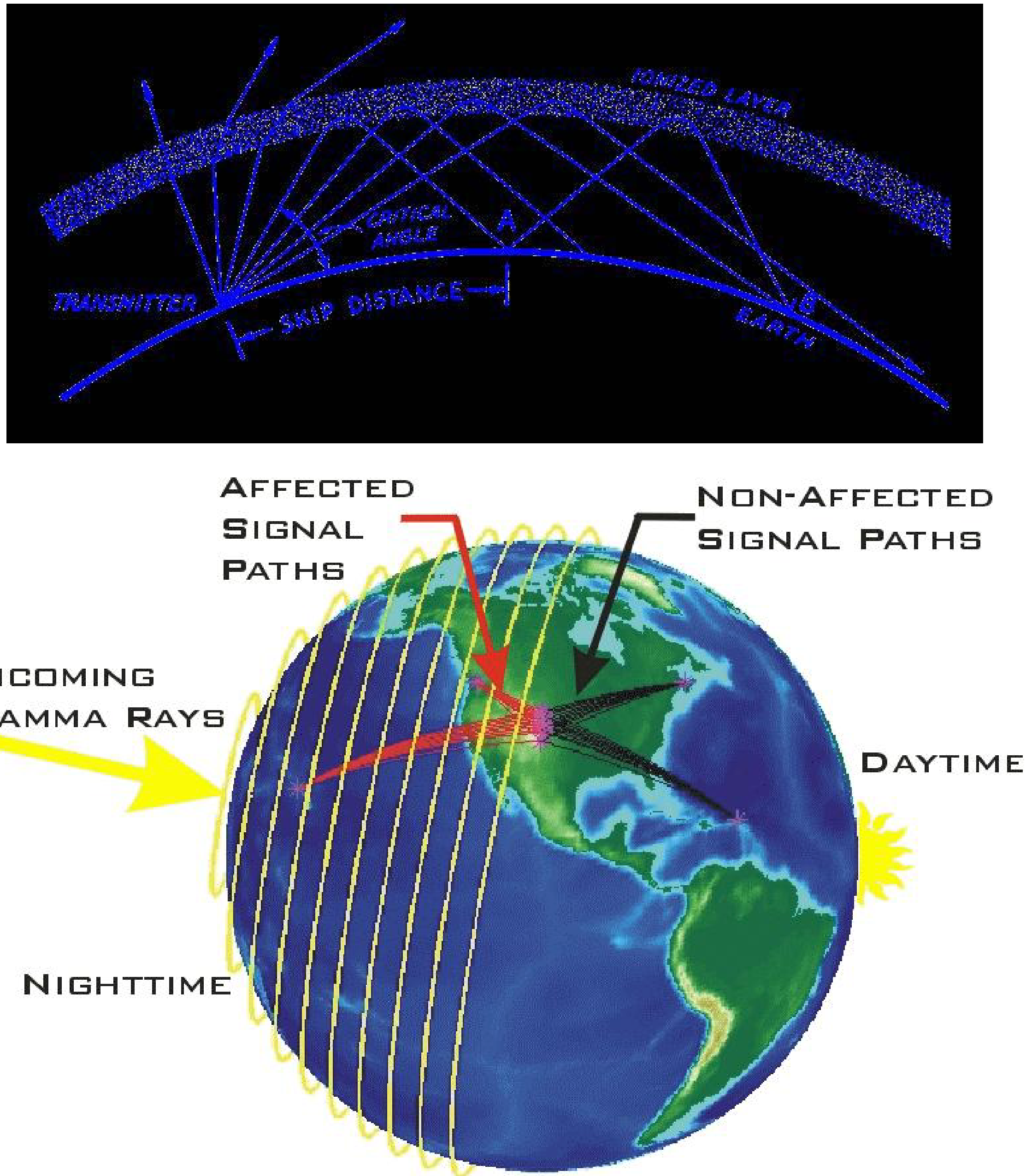

Figure 2, shows the propagation of waves coming in from a gamma ray burst and being in the correct geometry for VLF detection from signals from Hawaii to Colorado, Inan et al., 1999a, University of Stanford's HAIL project: http://www-star.stanford.edu/~vlf/hail/hail.htm

Current thinking, about the origin of extra-galactic high-energy events, such as a magnetar X-Ray transients or GRB, appear to be focused on progenitors of either neutron stars, perhaps in a binary system, or the collapse of massive young star, which creates a supernovae (Shilling, 2002). The model presented in this paper assumes that a SN GRB or X-ray transient is the result of massive O and B type star collapse, with subsequent rapid spin-up of the resulting remnant neutron star. These stellar 'collapsars' create a distant supernova remnant, which in turn creates an incredible amount of energy (D. Ward-Thompson, 2002). The magnetar type event is caused by a massive rotating neutron star, which emits high energy X-rays because of a reduction in angular momentum, causing a 'star quake'.(Dr. Chryssa Kouveliotou and Dr. Robert Duncan of the University of Texas at Austin and Dr. Christopher Thompson of the University of North Carolina , 2005. For VLF detection of these events they have to be of long duration, greater than 20 seconds, perhaps up to 400 seconds.

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 in the ionosphere. Chrong-Yuan's construct is adapted for earth's thermosphere. Raw GRB or X-ray transient flux density data collected by the HETE II, INTEGRAL, SWIFT 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.

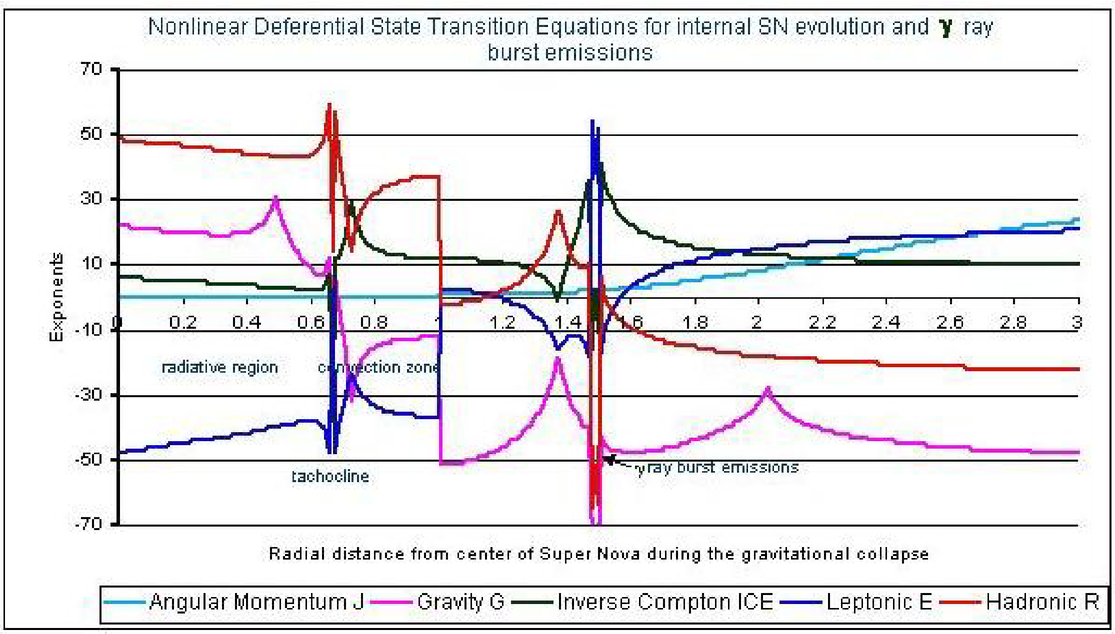

Figure 3, is an example of a model of a large stellar collapse (greater than 15 solar masses), creating gamma ray emissions. Notice the intensity of the emissions reach upwards of 10^{53} ergs.

Detectable GRB and X-ray transient flux density 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 density 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 density and varies from 10^{-3} to 10^{-7} ergs, averaged over a 1 second interval. The one second interval is chosen as the best the Gyrator II VLF radio can resolve with confidence.

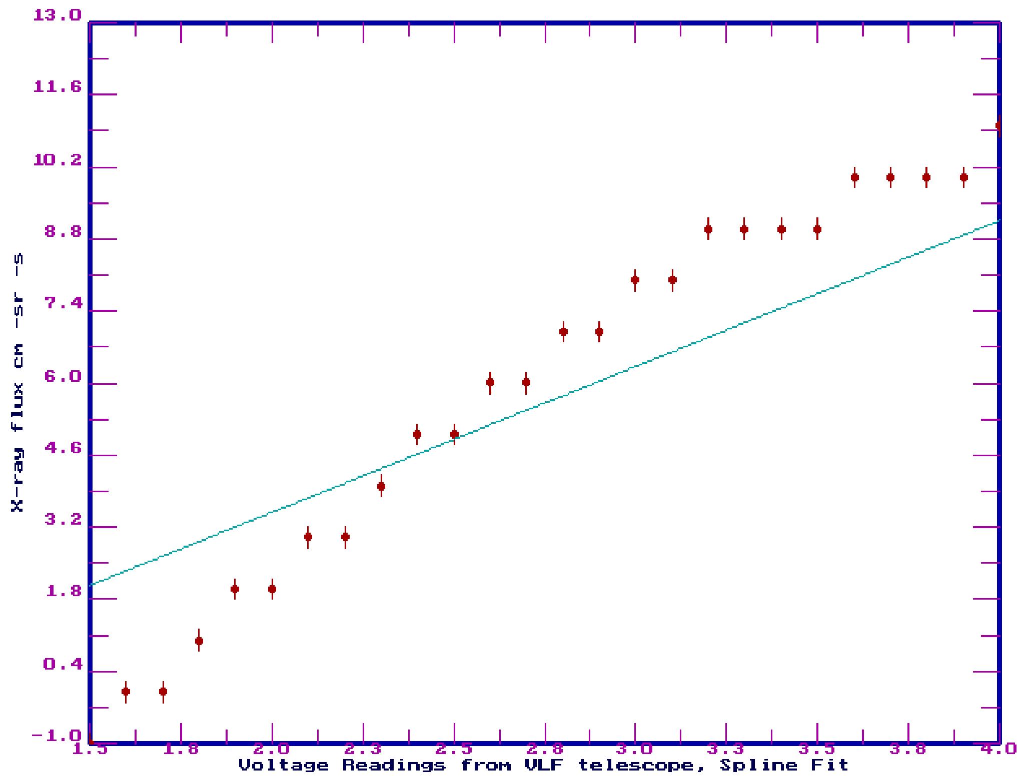

Figure 4, this graph is a model and assumes an incoming burst temperature equivalent to 1,200 K per steradian per cm per second, this would be a large event at 10^{-4} ergs, and quiescent thermosphere temperature at ` 220 K. Compton Effect photon density at the thermosphere is considered a specific heat 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 density per volt recorded at the VLF telescope (red dots). The y-axis, on this graph, estimates the equivalent GRB or X-ray flux density 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 density 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 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 $f \sim 0$, 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. However, this is considerably below a calibrated maximum level of 4+ volts for average nighttime ionosphere measures of VLF radios. At voltage ranges greater than 1.5 to 2.3 the GRB or X-ray transient flux density could represent a major SID affecting the ionosphere such as SRG1900+14, or SGR1806-20.

The VLF model expresses the increase of *k*T, as a Compton Effect (CE) temperature or the re-ionization of the thermosphere. As gamma ray and X-ray photons create emissions in free electrons in the higher layers of the thermosphere creating radiometer temperatures which 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, which might confound detection as noise in the atmosphere layers.

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. (Burst estimates can be gathered from the GCN circular on the event.) These values are normalized to give a ratio for *k*T. 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 density on the y-axis of a graph (Figure 4) 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 and SGR1806-20, or not-so distant supernova explosions such as SN2003dh (GRB030329) may be detectable.

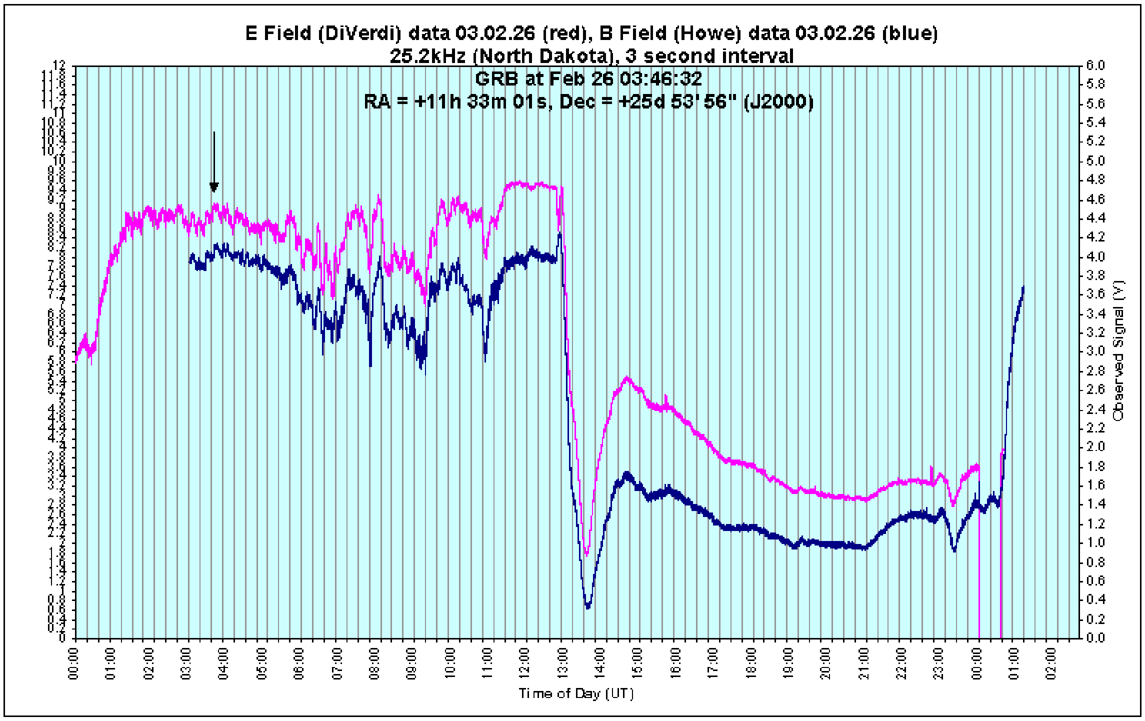

Figure 5, shows two different radio configurations, the Gyrator II with a 1.5 meter B-field loop antenna, (Cap Hossfield 2001), and Joseph DiVerdi's VLF radio with an E-field 2 meter whip antenna. These data show a daily trace where there was a weak GRB at 03:46:31.99 UT. There was very slight increase 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)

Figure 6 below is a detail 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 4). Nighttime is the worst time for detection due to all the atmospherics and lack of ionization, but there is a noticeable 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 there was detection.

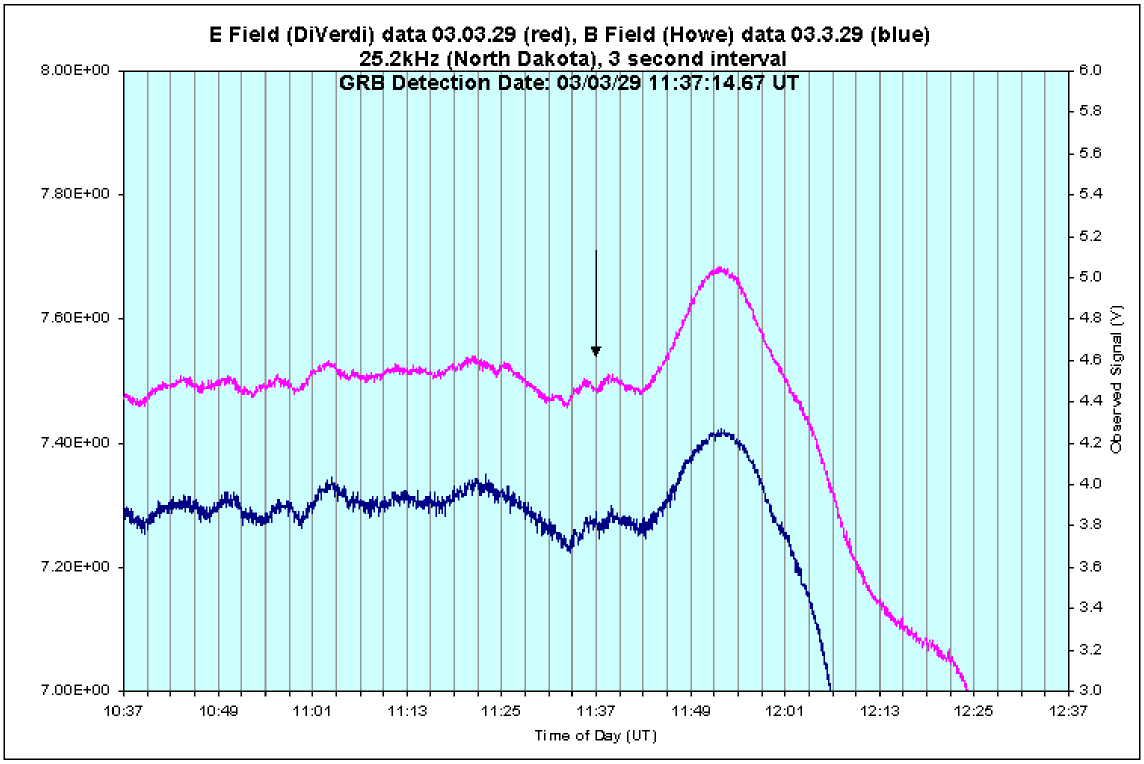

Figure 6, GRB030329 was detected by HETE-II satellite on 29 March 2003 at 11:37:14.67 UT. Optical spectroscopic observations determined its red shift to be z = 0.168 (Uemura, M. et. al, 2003). These data represent two VLF radio receivers, one recording with a 2 meter whip antenna (red line) and one with 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 explanations 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.

Magnetars:

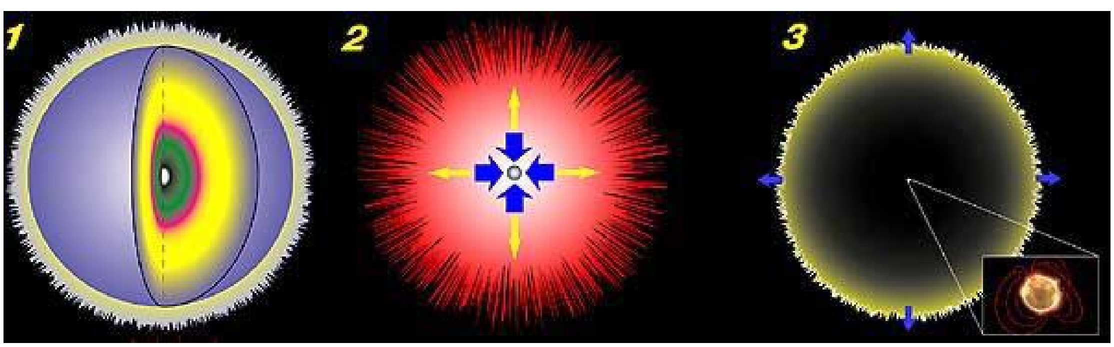

Figure 7, making a neutron star - and a magnetar - starts (1) with a massive star that has burned up all of its fuel, then (2) collapses and causes a massive explosion, the supernova, which blows off the outer layers and (3) compresses the core.
http://science.nasa.gov/newhome/headlines/ast19jul99_1.htm

- TITLE: GCN GRB OBSERVATION REPORT
- NUMBER: 2932
- SUBJECT: SGR1806: Detection of a Sudden Ionospheric Disturbance
- DATE: 05/01/03 23:21:47 GMT
- FROM: AAVSO GRB Network at AAVSO <aavso@aavso.org>

- P. Campbell, M. Hill, R. Howe, J.F. Kielkopf, N. Lewis, J.
- Mandaville, A. McWilliams, W. Moos, D. Samouce, J. Winkler, G.J.
- Fishman, A. Price, D.L. Welch, P. Schnoor, A. Clerkin, and D. Saum
- report, on behalf of the AAVSO International High Energy Network
- and SID Program, on the detection of the Dec. 27 outburst from SGR
- 1806-20 (GCN #2920; Borkowski, et. al) as a sudden ionospheric
- disturbance (SID) in the Earth's atmosphere.

A disturbance of the Earth's ionosphere was observed coincident with the INTEGRAL detection of a burst from SGR 1806-20. This SID was seen as a change in the signal strength from Very Low Frequency (VLF) radio transmitters being monitored by stations around the globe. Note: This is not a radio detection of SGR 1806-20; this disturbance was caused by the prompt X-rays from SGR 1806-20 ionizing the upper atmosphere and modifying the radio propagation properties of the Earth's ionosphere.

The observing method employs the monitoring of distant, powerful VLF radio transmitters; this is a sensitive monitor of the state of the lower ionosphere along the radio propagation path. Due to the sub-burst longitude and latitude and the geographical distribution of LF/VLF beacons and monitoring stations, this burst was not detected by active monitoring stations in Germany, Australia and Canada. However, one monitoring station in Massachusetts, USA (separate from Hill) did not detect the SID while being in a good location to do so. (Aaron Price, 2004).

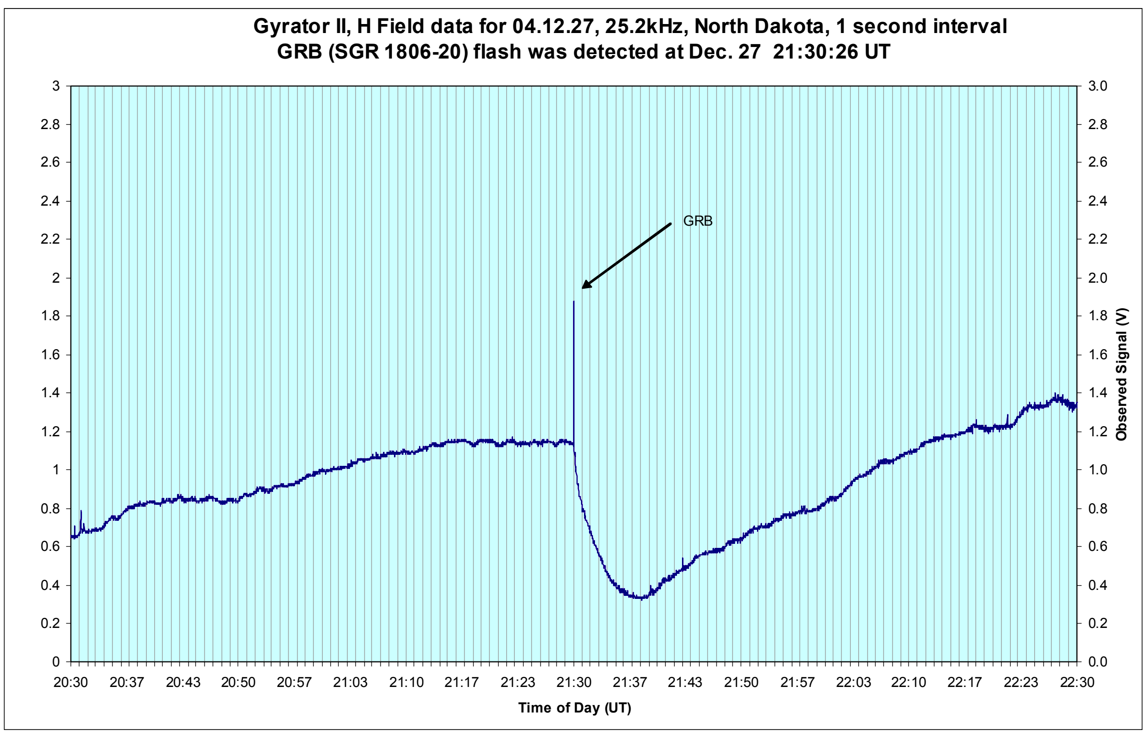

Figure 8, SGR1806-20 was detected by Swift satellite on December 27, 2004 at 21:30:26 UT. http://gcn.gsfc.nasa.gov/gcn3/2944.gcn3 Observers of this event were as follows:

Observer	Receiver Location	Transmitter and Location
Moos	Switzerland	FTA - St. Assie, France
Hill	Massachusetts, USA	NAA - Cutler, ME, USA
Winkler	Texas, USA	NAA - Cutler, ME, USA
Kielkopf	Kentucky, USA	NAA - Cutler, ME, USA
Campbell	Alberta, CA	NLK - Jim Creek, WA, USA
Howe	Colorado, USA	NML - LaMoure, ND, USA
Mc. Williams	Minnesota, USA	NML - LaMoure, ND, USA
Samouce	Montana, USA	NML - LaMoure, ND, USA
Kielkopf	Kentucky, USA	NPM - Lualualei, HI, USA (2nd receiver)
Mandaville	Arizona, USA	NPM - Lualualei, HI, USA
Lewis	California, USA	NPM - Lualualei, HI, USA
Winkler	Texas, USA	NPM - Lualualei, HI, USA (2nd receiver)

Discussion

SGR1806-20 (Figure 8) shows a spike of 1.5 volt difference from the minimum to maximum. This sets the incoming burst temperature equivalent to almost a 1,000 K per steradian per cm per second given the geometry of the VLF receiver and VLF transmitter. This would be a large event at 10^{-4} ergs, if the quiescent thermosphere were at a temperature of ` 220 K. Compton Effect photon density at the thermosphere, if considered as a specific heat, measured as kT, would be the difference between the CE photon burst and thermosphere temperatures, resulting in an increase in the amount of re-ionization of the ionosphere. The measured flux density per volt recorded at the VLF telescope would suggest 10^5 eV were recorded in the atmosphere in the line of sight.

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. 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. However, the current computer model results predict photon flux levels, which translate to voltage level expectations for VLF receivers provided the geometry of burst, receiver and transmitter are optimal. 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, and the most recent SGR1806-20 super flare (Price, et al. 2003, 2004).

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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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