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GROUND-BASED HIGH ENERGY ASTRONOMY

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I. Introduction

The electromagnetic spectrum is divided into six parts. Astronomical observations of half of these parts, namely the long wave parts, are ground-based. "Ground-based" means the measuring instruments are located on the earth's surface. The short wave or high energy parts of the electromagnetic spectrum are not ground-based. Instruments for measuring these celestial radiations are carried aloof by balloons or rockets. The reason why there is no ground-based high energy astronomy is because these radiations do not reach the earth's surface. They are absorbed in the earth's atmosphere. So it appears that ground-based high energy observational astronomy is impossible. Nevertheless, my basic aim is to develop a ground-based high energy astronomy.

To see how this just may be possible we ask: What happens to the high energy photons when they interact with the earth's atmosphere? The answer is: they ionize the atoms of the earth's atmosphere. Thus, celestial high energy radiation - that is the far ultraviolet, X-Ray and Gamma Rays - lead to the production of free electrons. How can we detect these electrons? Free electrons in general influence the propagation of electromagnetic radiation. So, if we send radio waves of an appropriate frequency (VLF - very low frequency) into the region of the atmosphere (the ionosphere), where the free electrons are produced, then by studying the received radio waves we can hope to ascertain the electron density in these regions and draw conclusions about the celestial radiation which caused them.

Why develop a ground-based high energy astronomy? After all we have short wave detectors on board satellites, which lie outside the earth's atmosphere. There are two major advantages that our technique possesses. They are:

1. financial - compared to any other technique this method is cheap. The Gamma-Ray Observatory (GRO) for example cost about $560 million, whereas a VLF radio monitoring facility in the thousands.
2. The possibility of all sky observations on a 24 hour continuous around the clock basis. Satellites like GRO can not see at any given time about 30% of the sky. This is because the earth blocks the satellite's view. A world wide VLF radio monitoring network would be capable of all sky observations.

The specific aim of the project at hand is to study the changes in amplitude and phase of VLF radio waves to see if we can detect the ionospheric disturbance (that is the change in electron density) caused by a Gamma-Ray burst[1].

The possible advantages of observing gamma-ray bursts through ionospheric disturbances are[1]:

1. better localization of burst directions through a large network of VLF receiving points.
2. Measurement of total ionizing fluence of gamma-ray bursts.
3. comparison with satellite data (GOES and GRO) to derive properties of the ionosphere

There is a major problem here: The ionospheric disturbance caused by a Gamma-Ray burst is at best extremely difficult and at worse impossible to detect. So far only one event has been detected via this method. Therefore, it was decided to study the ionospheric disturbance caused by solar flares first with the hope that they will teach us how to detect the elusive Gamma-Ray bursts. Much is to be learned about the ionosphere and its reaction to impulsive ionization.

II. VLF Radio Monitoring Facility

My basic aim this summer was: To secure VLF data so that it could be analyzed at Fisk University in Nashville. This proved to be a major task. Huntsville does have a VLF monitoring facility, but it had three major problems

(1) it was only operating 67% of the time.

(2) The number of 9 track tapes was too cumbersome. Two tapes a day or 730 tapes a year if operation time were 100%. Just copying the tapes takes a lot of time. All tapes had to be copied because the originals must go to Stanford University, the owners of the Huntsville VLF-receiving equipment.

(3) Many tapes contained numerous parity errors. Some tapes were almost completely unusable.

All of the above problems have been solved by introducing the Exobyte tape drive. It employs 8mm tapes which have a capacity of 2.239 Gigabytes. We now:

(1) operate 90% of the time

(2) have only two small cassette tapes per week and

(3) no more parity errors.

The Huntsville facility received during the period of observation (May-July 1991) VLF radio waves from the following transmitters:

Area	City	frequency
Australia	Perth	22.3 kHz
Hawaii	Lualualei	23.4 kHz
Maine	Cutler	24.0 kHz
Nebraska	Silver Creek	24.8 kHz
Washington	Jim Creek	48.5 kHz
Puerto Rico	Aquadilla	28.5 kHz

III. Results

As a first step to developing this method, ground-based observations of solar flares were correlated with satellite observations from the Gamma-Ray Observatory and the GOES satellite. The results are summarized as follows:

Total number of VLF - solar flares:	75
Comparison with GOES-West Satellite:	
Percent of VLF found in GOES:	96%
Number of VLF not found in GOES:	3
Comparison with Gamma Ray Observatory(GRO)	
Percent of VLF found in GRO:	55%
Percent of VLF not found in GRO:	45%
Percent not found due to occultation:	28%
Percent of VLF missed in GRO:	17%

Firstly, we discuss the comparison of ionospheric disturbances attributed to solar flares with the GOES-West satellite. We see that 96% were actually solar flares according to the GOES-West satellite. These results clearly demonstrate the ability of the method to differentiate between ionospheric disturbances caused by a celestial source and those due to ionospheric and magnetospheric effects. All three of the VLF-solar flares that were not considered solar flares by GOES did show significant flux increases in the hard X-Ray region (0.5-4Å) according to GOES but were too weak in the soft X-Ray region (1-8Å) to be classified as solar flares. Thus, all of the ionospheric disturbances which were interrupted to be solar flares actually corresponded to flux increases in the solar hard X-Ray emission.

Secondly, we discuss the comparison of VLF-found solar flares with the solar flares found by the BATSE detectors of the Gamma-Ray Observatory (GRO). A large percentage (45%) were not classified as solar flares according to BATSE. However, 28% of the total or 62% of those that could not be found by BATSE were due to the fact that GRO could not see the sun because the earth was in between the spacecraft and the sun (occultation).

IV. Research Plan

A. The Search for Gamma-Ray Bursts

1. So far not a single Gamma-Ray Burst is readily apparent in the low time resolution data used for detection of the above mentioned solar flares. To find Gamma-Ray Bursts the following approach will be used: Low intensity solar flares are to be located in the VLF data using the GOES and BATSE flares as a guide. Hopefully, this will teach us how Gamma-Ray Bursts will look like in the VLF-data since they are in general of low intensity in the spectral region, which above VLF frequencies seem to be capable of detecting.
2. Search along different propagation paths - variation of both transmitter and receiver points.
3. Search at other frequencies.

B. Comparison with GOES and BATSE

1. Starting from GOES and BATSE to see how many flares are not contained in the VLF data and to understand why they are missing.
2. Derivation of the threshold value for solar flares by comparing VLF with GOES and BATSE.
3. Comparison of (a) onset, rise, maximum and decay times of VLF with the corresponding values for GOES and BATSE to derive the properties of the ionosphere.

C. VLF-solar flares

The study of solar flares in the VLF data in reference to: (a) changes in amplitude and phase of the VLF (b) zenith angle dependency (c) frequency dependency and (d) dependency on the propagation path of the VLF signal.

D. Theoretical

1. Detailed calculations of electron density distributions during solar flares from the known irradiation according to GOES-West and during gamma-ray bursts from the known irradiation according to BATSE are to be carried out. Specifically, the time dependency of the irradiation will be incorporated, which is generally not done.
2. Dropping the assumption of a simple exponential electron density distribution and the concept of "reflection height" in the standard model for VLF wave propagation in the terrestrial waveguide[2], the temporal behavior of the VLF amplitude is to be reconciled with observations.

References:

1. Fishman, G.J. & Inan, U.S. Nature 331, 418-420 (1988)
2. Wait, J.R. & Spies, K.P. NBS TN 300 (1964)