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The Ionosphere as a Gamma-Ray Burst Detector

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Unlike all man made detectors, which are only sensitive to relative narrow regions of the electromagnetic spectrum, the ionosphere is practically a perfect detector for high energy radiation because it absorbs all radiation from the far-ultraviolet to the highest energy gamma-rays ($\lambda \leq 1350$ Å or $E \geq 9.2$ eV). Therefore, it may be possible to employ the terrestrial atmosphere as a detector of high energy celestial photons.

This is an old idea. As early as the 1940's solar flares were detected by the disturbance they cause to the ionosphere. The VLF (3 - 30 kHz) approach for detecting ionospheric disturbances is based on the following physical circumstance: celestial high energy radiation ionizes the atoms of the earth's ionosphere leading to the production of free electrons. These free electrons influence the propagation of electromagnetic waves. By studying the phase and amplitude changes of VLF radio waves propagating in the earth-ionosphere waveguide we can hope to ascertain the electron density in these regions and draw conclusions about the celestial radiation which caused them.

This method has been and still is used to detect solar flares. The basic question of this research project is: Can the method be employed to detect gamma-ray bursts?

The method is based on the detection of free electrons. The maximum value of electron production rate created by a gamma-ray burst occurs at altitudes of 25-70 km (Brown 1973, Baird 1974, Kasturirangan et al 1975; 1976, O'Mongain & Baird 1976, Weekes 1976). The exact altitude for each burst depends upon the spectrum and zenith angle of the burst. There is a principle problem in detecting free electrons created in this altitude range. Because the recombination coefficient here is order of magnitudes higher than that at 85 km (the nighttime reflection height of VLF radio waves), the electrons created are immediately lost. This is the reason why the detection of only one ionospheric disturbance caused by a gamma-ray burst has been reported so far (Fishman and Inan, 1988) despite a number of attempts (Drever et.al, 1973; Kasturirangan, 1975; and Flickinger. 1990).

We must improve our VLF methods of detection so that significant numbers of gamma-ray bursts can be detected. Because of high recombination rates at lower altitudes, we are forced to look for gamma-ray bursts at the 85 km altitude of VLF nighttime reflection. The question is how?

Our situation is characterized by a meager number of detected gamma-ray bursts. Why have so few been detected? Because the peak in electron production occurs at an altitude where the recombination coefficient is prohibitively large. So we see, somehow we must observe the peak intensity not at lower altitudes where the recombination coefficient is large but at higher altitudes, where it is lower. But, how are we going to observe the peak at higher altitudes? The answer is: We must observe a burst at a large zenith angle. Brown (1973) has shown that at large zenith angles the altitude of peak energy deposition shifts by a significant amount (more than 10 km) to higher altitudes.

Unfortunately, as a celestial source is detected at ever larger zenith angles in order to observe the peak at higher altitudes, where the recombination coefficient is sufficiently small, the amount of energy in the peak is declines dramatically (Brown 1973). So when we get up to a zenith angle or altitude, where we may be able to see the burst, the energy per unit volume is much too low. So we have another problem. How are we going to solve this problem?

We must observe the burst in such a way that it is aligned along the propagation path. This means the azimuth of the burst at all points along the burst must be the same. If this is the case most of the energy of the burst will be deposited in the plane formed by the propagation path and the transmitter and receiver.

We now have two conditions for the optimal detection of a gamma-ray burst.

1. large zenith angle
2. alignment of burst and propagation path (same azimuth of burst along propagation path).

In the VLF databank at Stanford University we looked for gamma-ray burst, 1B910503, one of the strongest bursts seen by the gamma-ray burst detector (BATSE) of the Gamma-Ray Observatory. It occurred on 3 May 1991. The figure shows the amplitude vs. time plot of two completely different propagation paths. For the first path the transmitter (NLK) is located at Jim Creek in Washington State and the receiver at Houston, Texas. For the second path the transmitter (NAA) is at Cutler, Maine and the receiver at Arecibo, Puerto Rico. The black arrows above and below denote the start time (7:4:14.72 UT) of the gamma-ray burst according to BATSE.

The ionospheric disturbance begins <u>simultaneously</u> along both propagation paths. This time is 7:5:15 one minute after the burst begin according to BATSE. Because of the ionospheric response time it is not expected for the ionospheric disturbance to begin at the same time as the initial gamma-ray impulse. It is well known that this is generally true for solar flares too. Recently Blair (1992) confirmed this delay for solar flares. He finds that the average time delay between the GOES satellite and VLF is 2 to 3 minutes.

The following table presents data on the zenith angle and azimuth of 1B910503 as seen from both the transmitters (48.5,NAA,NAU,NLK,NPM,NSS) and receivers (Arecibo and Houston). The last two columns contain the azimuth values relative to the azimuth values of the two receivers.

Azimuth and Zenith Angle

Location	Azimuth	Zenith Angle	Arecibo	Houston
NPM(Hawaii)	309°14′	67°25′	-42°14′	-23°23′
NAA(Maine)	352°20′	91°42′	20′	19°43′
48.5(Nebraska)	331°28′	87°43′	-20°32′	-1° 9′
NLK(Washington)	315°56′	72°12′	-36° 4′	-16°41′
NAU(Aquadilla)	351°27′	117°42′	33′	18°50′
NSS(Annapolis)	345°41′	95°57′	-6° 19′	13° 4′
Arecibo	352° 0′	117°56′		
Houston	332°37′	99°19′		

Their is only a 20′ difference between the azimuth values of the burst seen at Arceibo (receiver) and Cutler, Maine (transmitter). Thus, the burst is aligned almost exactly along the propagation path and it is here that we see the maximum amplitude change of 0.3 dB. The other values are significantly greater except for NAU but it is also on Puerto Rico and Arecibo is receiving only the ground wave.

The situation along the propagation paths to Houston is not quite so clear. There are two paths with lower azimuth differences - Nebraska and Annapolis. Nebraska ,however, is an LF (long wave) transmitter and the reflection height is higher than the 85 km for VLF, so it is not expected to see the burst. Annapolis - Houston also is closer aligned with the burst than NLK, but the burst is always below the horizon and never less than 6° from the horizon. So NLK appears to be the most likely path to see the burst and indeed we find a 0.2 dB amplitude change.

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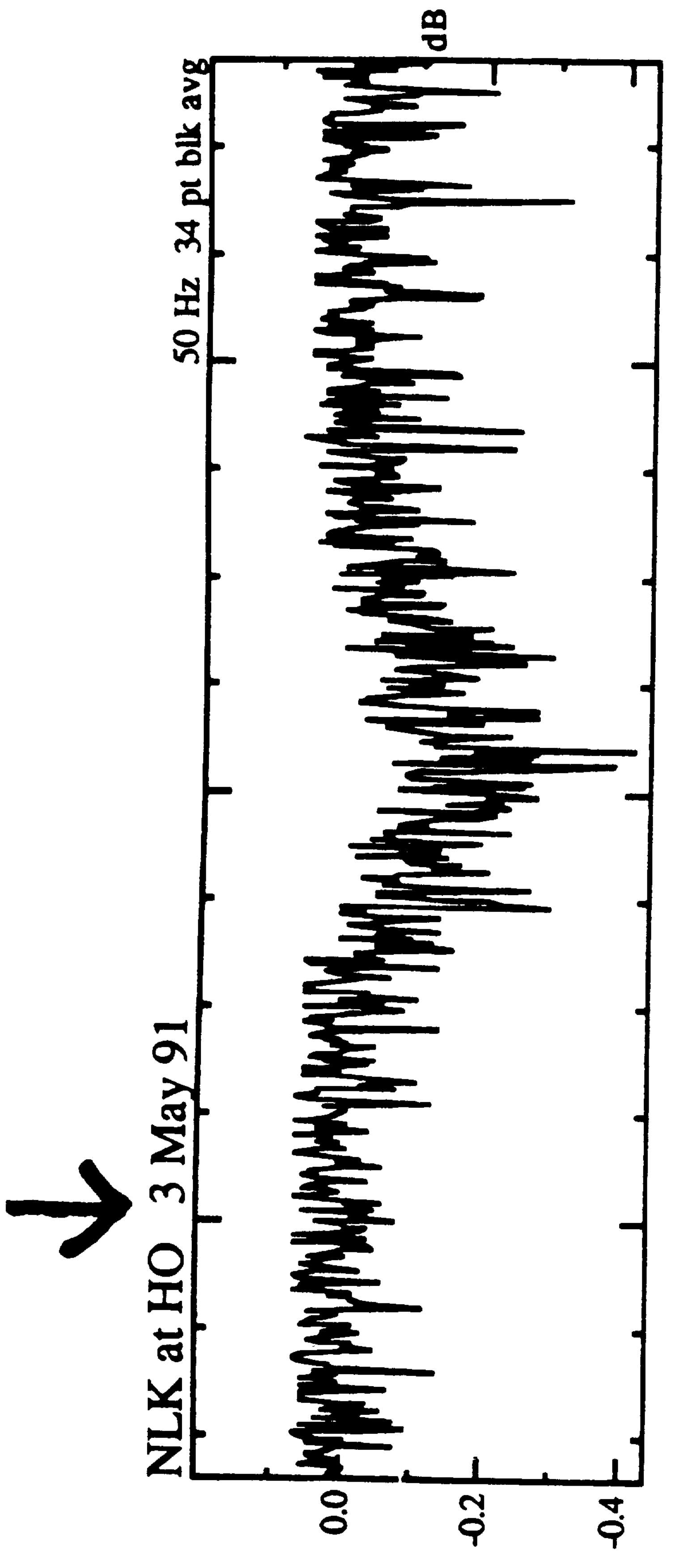
NLK at HO 3 May 91
50 Hz 34 pt blk avg
dB
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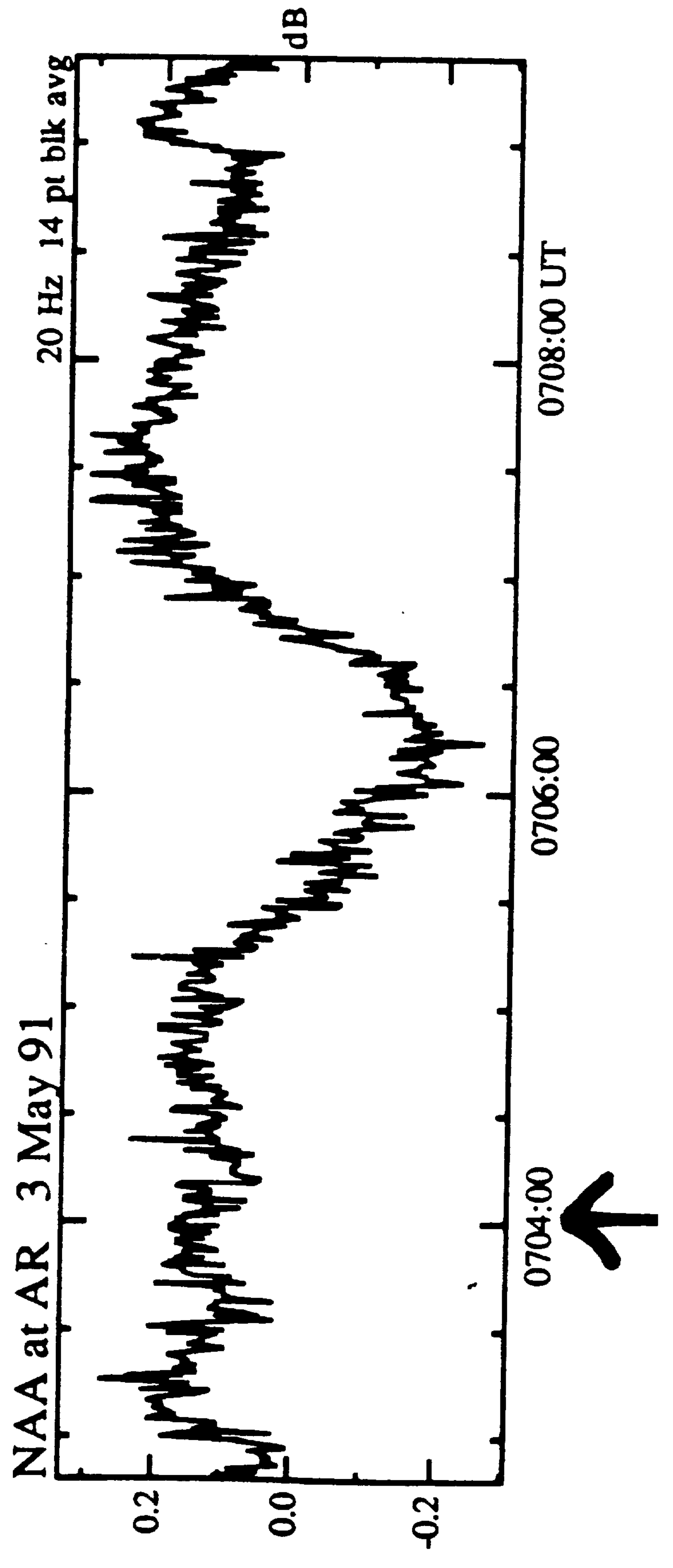
-0.2
-0.4


NAA at AR 3 May 91
20 Hz 14 pt blk avg
dB
0.2
0.0
-0.2
0704:00
0706:00
0708:00 UT