SHORT TIME-SCALE OPTICAL PULSATIONS IN THE NIGHT SKY BACKGROUND

D. L. Bertsch

Goddard Space Flight Center, Greenbelt, Md. 20771

A. Fisher and H. Ogelman, Middle East Technical University, Ankara, Turkey

ABSTRACT

A network of monitoring stations designed to detect large scale fluorescence emission in the atmosphere has been in operation for over two years. The motivation for the search arises from the prediction by Colgate that an energetic photon burst would be produced in a supernova and this burst, when absorbed in the atmosphere, would produce fluorescence. This paper reports on observations up to February 1971. No supernova-like events have been found, although 4.4 were expected. One class of non-fluorescence events is described that evidence suggests is related to electrical discharge in the atmosphere. Another type of non-fluorescence pulse appears to be related to particle precipitation in the atmosphere.

1. Introduction

One of the most significant advances in astrophysics has been the development of a detailed theory describing a supernovae explosion and subsequent neutron star formation (Colgate and Johnson, 1960; Colgate and White, 1966; Arnett, 1967). Among the several important implications of this theory, a plausible mechanism for the production of cosmic rays is furnished. On the basis of a rather general argument, Colgate (1968) predicted energetic photons also will be produced during the relativistic shock expansion when the outer mantle of the star is accelerated to cosmic ray velocities. Basically these energetic photons result from optical photons that are Doppler shifted during the shock expansion. Colgate predicted that the photon pulse would contain a total energy $\sim 5 \times 10^{49}$ ergs with individual energies up to $\sim$ 2 GeV and with a pulse duration of $\sim$ tens of microseconds.

In an effort to detect the photon wave fronts predicted by Colgate, a monitoring program has been operated for more than two years. Details of the experiment have been presented previously (Fichtel and Ogelman, 1968; Ogelman and Bertsch, 1970). This paper reviews the experimental apparatus and summarizes the observations up to February 1, 1971. In searching for extraterrestrial events, local station records reveal two categories of events that apparently are related to geophysical effects and these are described.

2. Experimental Approach

The mode of operation of the experiment is to use a wide-angle, ground-based photomultiplier system designed to detect fluorescence emission that is expected to be produced by the absorption of the primary photon pulse in the atmosphere. It has long been known that the upper atmosphere fluoresces in the UV, visible, and infra-red spectral regions as a result of stimulation from a wide energy band of X-rays, γ-rays, and charged particles. Considerable work on the fluorescence phenomenon has been done by workers at Cornell (Greisen, 1965; Bunner, 1966) with the aim of utilizing fluorescence in air shower detection. Hartman (1963) made extensive laboratory studies of fluorescence phenomena. These studies show that for ground-based photomultiplier detectors, the only significant fluorescence emission is from the N_2^+ first negative band system of molecular nitrogen in the wavelength region from 3200 Å to 4500 Å with the principal contribution at 3914 Å. Absorption occurs in the atmosphere at altitudes that depend on the photon energy. Above 100 keV, Compton and pair production processes dominate and this occurs at 20 to 30 km with an efficiency of $\sim 5 \times 10^{-4}$. Below 10 keV, the photo-electric process is the most important. Here absorption occurs at $\sim$ 100 km, near the zero-pressure efficiency of 5×10^{-3}. The time-scale for the conversion is $\sim 1\ \mu$sec for absorption and $\sim$ 100 nsec. for the fluorescence emission. A large-scale primary pulse, however, is broadened by propagation delays from different regions of the sky to a width of 100 to 300 μsec.

In a given event, the number of fluorescence photons per unit area, N, of energy, E_ν that enter a photomultiplier tube as a result of a supernovae of energy, W, at distance, R and direction θ from the zenith can be written as

$$N = \frac{W\epsilon\lambda}{8\pi R^2 E_\nu} \cos\theta \quad \text{, photons/unit tube area}$$

where ϵ is the fluorescence efficiency and λ is the atmospheric absorption. If the triggering threshold of the detector is set at some level above background noise, say T, the requirement that $N > T$ in the equation given above defines a sensitive radius for the detector. Then by assuming that galaxies are uniformly distributed at a density of ρ and that supernova occur with frequency f, the predicted observation rate, integrated over θ in one hemisphere is

$$r = 0.0145\ \rho f \left(\frac{W\epsilon\lambda}{TE_\nu}\right)^{3/2} \quad \text{per unit time}$$

Using the following values for the parameters: $\rho = 5 \times 10^{-75}$ galaxies/cm^3, f = 1 supernova/100 years, $\epsilon = 10^{-3}$, $\lambda = 0.5$, $E_\nu = 5.1 \times 10^{-12}$ ergs and $W = 5 \times 10^{47}$ ergs gives for the rate:

$$r = \frac{28.5}{T^{3/2}} \quad \text{per hour}$$

where the threshold T is to be expressed in photons per cm^2 of tube area, that enter the tube during the integration time of the detector. Typically T varies from 50 to 200 photons/cm^2 in a 50 μsec sample time.

In order to determine that the fluorescence event is due to a large-scale, extraterrestrial source and is not locally produced, the stations are operated at well separated locations, and each event is accurately timed. Coincidence at different locations can then be required as a signature of a supernovae event.

3. Detector System

A detailed description of the detector system has been reported previously (Ogelman and Bertsch, 1969) and since no significant changes have been made, only the key features will be reviewed here. Figure 1 shows a block diagram of the system.

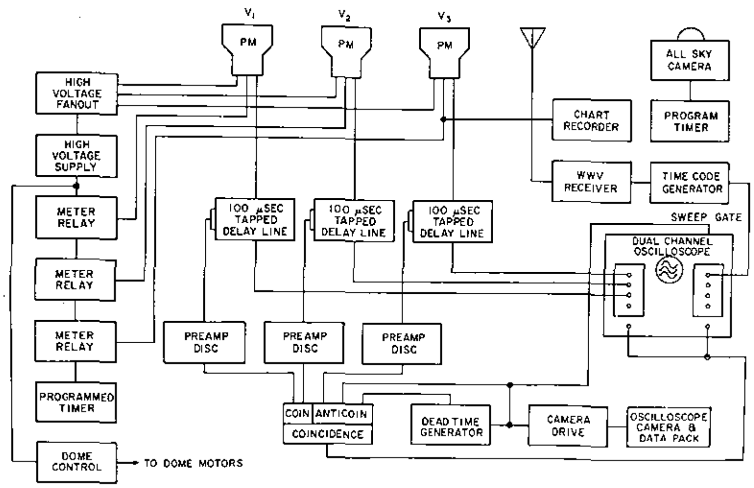

Figure 1. Block Diagram of the detector for a single station.

Three 12-inch photomultiplier tubes are employed. Two of these, V1 and V2 have transmission filters whose spectral response is between 3100 Å and 4300 Å, and hence are sensitive to the expected fluorescence bands near 3914 Å. The third tube Y3 has a filter whose lower wavelength cutoff is 4300 Å and consequently should not respond to fluorescence events. The output from each tube is connected through a 100 microsecond delay line to the chopped beam inputs of an oscilloscope. Each delay line has 5 μsec taps, ten of which are added to give a 50 μsec integrated signal that is tested by discriminator and logic circuits. If triggering levels are exceeded and coincidence requirements are met, the oscilloscope is triggered so that the beam is sweeping before the leading edge of the signal comes from the delay line. An open-shutter camera records the traces on film and at the end of the sweep, automatically moves a new frame into position. In order to time each event, the code from a time code generator is displayed in a one-second sweep on the second beam of the oscilloscope. Because V1 and V2 are sensitive to the same signals coincidence of signals is usually demanded to reduce noise.

4. Results

Two essentially identical systems of the design described in the preceding section have been operated at various locations since late 1968. Table 1 summarizes the supernova event monitoring up to February 1, 1971 at each location.

TABLE 1 SUMMARY OF SUPERNOVA RUNNING TIMES

Station Location	Operation Interval	Threshold (Photons/ cm^2 in 50 μsec	Expected Supernova Rate (Events/hr)	Running Time (hrs.)	2-Sta. Coinc. Time (hrs.)	Expected Number Coinc.
Goddard, Maryland	Sept 1968 -Sept 1969	200	1/96	450	170	1.7
Fan Mtn., Virginia	June 1969 -Dec 1969	70	1/21	350		
Mount Hopkins, Arizona	Nov 1969	50	1/13	60	60	2.7
Middle East Tech. Univ., Turkey	June 1970 -Jan 1971	100	1/36	376		
No. of Events Expected in Single Station Runs				~36	Possible No. ~10	
No. of Events Expected in Coincidence				~ 4.4	Observed No. = 0	

The triggering threshold values in this table are determined from calibration measurements and the level of threshold is set according to local background light conditions. The expected supernova rate is determined using the rate expression given in Section 2 along with the tabulated thresholds. During each time period, only the moon-free running times, totally clear of cloud cover were accepted in the analysis. Coincidence measurements were possible during two intervals: one from June to September 1969 between Goddard and Fan Mountain, Virginia where the baseline is 175 km, and the other during November 1969 between Fan Mountain and Mt. Hopkins, Arizona where the baseline is 3300 km. In the coincidence mode of operation, absolute time of each event to within ~ 10 millisec is recorded and the records from the two stations are compared later. The expected rate for coincidence is determined by the site with the lesser sensitivity. As shown in Table 1, no events that could be classified as supernova events on the basis of time scale and the absence of wavelengths above 4300 Å were observed in coincidence, although 4.4 were expected. The records of single station runs show a possible total of 10 while 36 were predicted. This result, however, must be viewed as an upper limit in view of the ambiguity with many background noise events.

Several distinct types of non-fluorescence events are apparent from the records. Two predominant ones are shown in Figures 2a and 2 b.

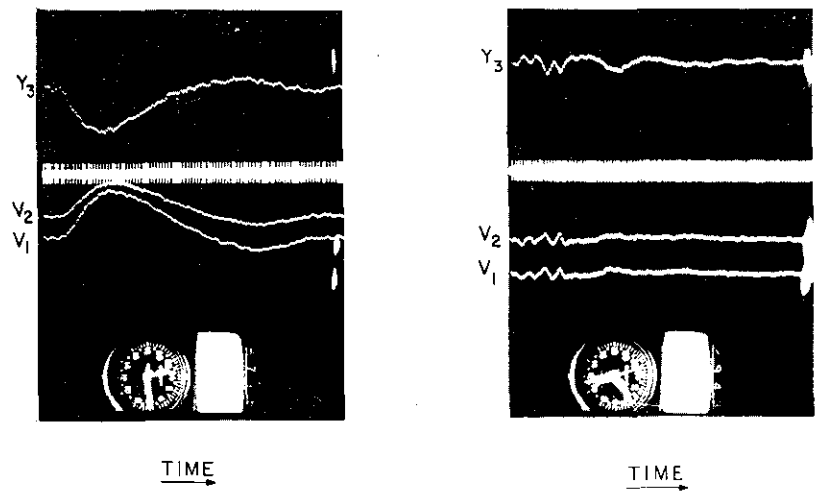

Fig. 2. Examples of non-fluorescence events. Y3 unit response is inverted for identification ease. Full scale time is 900 microseconds. A one second time frame of the NASA 36-bit code is displayed for timing. Fig. 2a on the left is an A-type of event, probably due to electrical discharge. Fig. 2b is an X-type of event, characterized by the high frequency components. See text for discussion.

The first, called an A-event, has the feature of a supernova event, except for the signal in Y3. Events like this have been seen in coincidence over the 175 km baseline, with events that have the characteristics of lightning. In the records of the Turkey station these events have a strong correlation with universal time, peaking at 1800 UT. It is known that the Earth's electric field also correlates with UT and reaches a maximum at 1800 UT. It is therefore probable that these events are due to electrical discharge in the atmosphere. It should be pointed out, however, that 1800 UT is near the turn-on time in Turkey when conditions may not be completely stabilized. An observation at another location would be useful to establish if these signals do in fact correlate with the electric field. Unforunately stations in the United States cannot operate at 1800 UT due to sunlight conditions.

The second type of event (called X-events) shown in Fig. 2 b is characterized by the high frequency structure with negative excursions. These events have also been observed over $\sim$ 175 baselines, but not over 3300 km baselines. However, for the large baseline, a night with a high rate in one location is accompanied by a high rate in the second station. This suggests a rather large-scale phenomenon with localized structure. It has been observed that on two occasions on November 10, 1969 and Jan. 25, 1971, during large magnetic storms, that the rate of X-events was unusually high. For moderate or small magnetic events, however, the correlation is not good. Other indicators of solar activity have also