SUPERNOVAE STUDIED WITH A GROUND-LEVEL ATMOSPHERIC FLUORESCENCE

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Current theoretical models on supernova explosions predict that supernovae are important sources of cosmic ray particles. Colgate's theory (Ref. 1) predicts that during the explosion phase, when the outer mantle of the star is accelerated by the hydromagnetic shockwave, an intense gamma ray burst will be produced that will contain energies up to 5×10^{40} J (5×10^{47} ergs). Because of the importance of the supernova theory and the possibility that other, as yet unknown exceptional phenomena might exist to produce similar bursts, we undertook a monitoring experiment in late 1968 to search for photon bursts of extraterrestrial origin. I would like to briefly describe our experiment and summarize the results of the observations to date.

Our method of detection employs ground-based photomultiplier tubes which are sensitive to the secondary fluorescence light that would be produced when the primary pulse is absorbed in the atmosphere.

Figure 1 shows a simplified picture of incident photons being absorbed at some depth *h* in the atmosphere and producing isotropic, secondary photon emission.

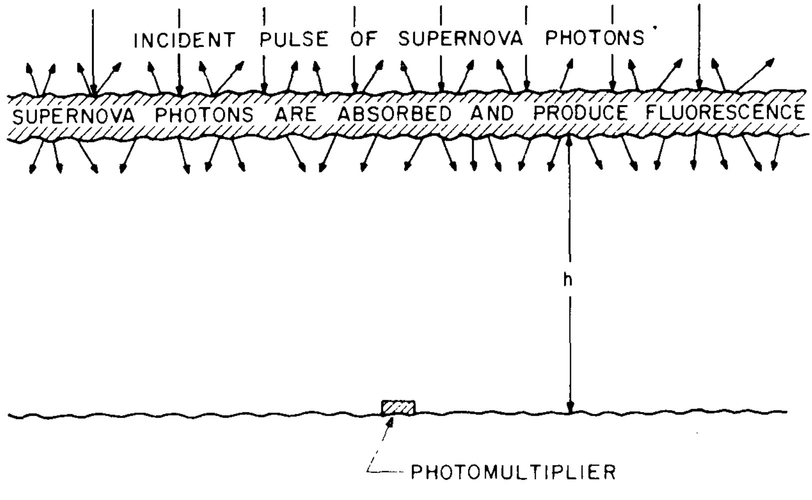

Figure 1—Absorption of incident photons in the atmosphere and resultant photon emission. The photomultiplier observes all of the fluorescence photons emitted in the proper solid angle.

From the work of Greisen and collaborators at Cornell (Refs. 2 and 3), it is known that the absorption occurs from 30 to 100 km in altitude, and that for a ground-based detector at least, the important emission is due to nitrogen molecular stimulation producing emission lines near 391.4 nm.

The whole process is fast. The primary pulse itself is expected to be submicrosecond in duration and its absorption in the atmosphere requires about 1 μs. For a wide-angle detector system at ground level, the observed pulse is broadened by the propagation time from different parts of the sky and has a total width of the order of 300 μs.

To observe fluorescence bursts, we operate ground-based detectors consisting of large photomultiplier tubes with optical filters whose response is keyed to the 391.4 nm emission that we expect. The output of each photomultiplier tube is displayed on an oscilloscope. When the incoming light exceeds a preset threshold level, the oscilloscope is triggered. An open-shutter camera views the trace and produces a data frame such as shown in Figure 2. The time scale is 1 ms across, and the amplitude is proportional to the amount of light incident on the tubes.

Three traces are shown in Figure 2, one for each tube. The upper one is inverted simply to distinguish it from the other two.

After a short amount of running time, we learned that there was a wide variety of background light from airplanes, lightning, distant city lights, and so forth, and as a result it was difficult to distinguish real, extraterrestrial events from the background light. To help resolve that question, we built a second station and located it several hundred miles from the first site. Accurate timing was installed in both stations so that we can determine whether events are in coincidence over a long baseline. In this manner, local background can be distinguished from signals of extraterrestrial origin. The timing given across the center of Figure 2 is simply the output of a time code generator and it is accurate to about 10 ms.

To date, we have looked at some 70 000 frames of data like the one in Figure 2. Table I summarizes the results from the two stations which have been operated at four different locations since late 1968. Each location has its own background peculiarities and this dictates the threshold levels to which the system can be set. Goddard, as you see, is a rather poor location because of the proximity of Washington and Baltimore. Here it is necessary to have pulses above 200 photons cm^{-2} in the 50-μs sampling time of the apparatus because of the level of the random background light. The best station is in Arizona, with a background of 50 photons cm^{-2}.

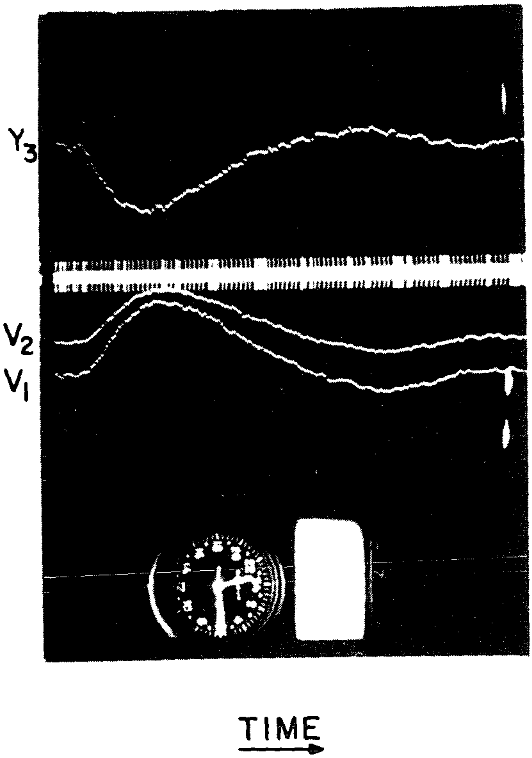

Figure 2—Data frame showing photomultiplier output.

Having established the threshold levels, the sensitive radius within which the apparatus can record a supernova is determined. Using this sensitive volume one can estimate the rate of occurrence of supernova. Taking Colgate's values for the photon emission, expect to observe supernova at the rate of one every 96 hr at Goddard and one every 13 hr in Arizona, for example, as shown in Table I.

During the time periods indicated in the table, we have accumulated a total of over 1200 hr of Moon-free, clear-sky running time. By operating in coincidence between Goddard and Fan Mountain, 170 hr of data have been collected. This period of time and the predicted rates given in the table indicate that we should have seen 1.7 supernova events. Likewise, coincidence operation between Virginia and Arizona produced 60 hr of running time. During this time, we should have found 2.7 supernova events.

TABLE I.—Summary of Supernova Running Times

Station location	Operation interval	Threshold, photons cm^{-2} in 50 μs	Expected supernova rate	Running time, hr	2-Station coincidence time, hr	Expected number coincident
Goddard, Maryland	Sept. 1968 to Sept. 1969	200	1/96	450		
					170	1.7
Fan Mountain, Virginia	June 1969 to Dec. 1969	70	1/21	350		
					60	2.7
Mount Hopkins, Arizona	Nov. 1969	50	1/13	60		
Middle East Tech. Univ., Turkey	June 1970 to Jan. 1971	100	1/36	376		
Number of events expected in single station runs, ~36; possible number observed, ~10						
Number of events expected in coincidence, ~4.4; observed number, 0.						

Altogether, we expected to observe 4.4 events, but have found none. From the single station data, we should have seen on the order of 36. There have been a possible number of 10 events that could be due to supernova. However, this must be regarded as an upper limit because of the noise ambiguity. Assuming that the parameters involved in estimating the rates are correct (e.g., the density of galaxies, the rate of supernovae per galaxy, etc.), we can place an upper limit on Colgate's photon energy of about one-half of what he said, namely 3×10^{40} J (3×10^{47} ergs).

However, many of the necessary parameters are uncertain so that this limit is still not very significant. We are continuing to observe and will either see supernovae or will be able to significantly improve that limit.

CHAIRMAN:

Are there questions?

MEMBER OF THE AUDIENCE:

What is the energy region of the primary photons?

DR. BERTSCH:

Colgate predicts energies up to 0.3 nJ (2 GeV), and probably down to 10^{-14} J (a few kiloelectron volts), so we expect a very wide band of energy emission from the supernova.

MEMBER OF THE AUDIENCE:

At what altitude in the atmosphere does the absorption of the primary pulse occur?

DR. BERTSCH:

You can excite fluorescence up to several hundred kilometers. The efficiency is dependent on the pressure; at 1.6 fJ (10 *K*eV), for example, photons are absorbed at about 100 km primarily by the photoelectric process, and for more energetic photons, say 16 fJ (100 *K*eV), the absorption is strongest at about 20 km, where the Compton process and pair production are the dominating processes.

MEMBER OF THE AUDIENCE:

What is the spectral response of your system?

DR. BERTSCH:

We have two wavelength regions that we monitor. One is in the fluorescence band near 391.4 nm and the other one begins at about 600 nm. Both of these observing bands are about 30 nm wide so it is a rather wideband system. Consequently, we record emission over most of the optical region. For a time we did monitor radio signals at ~100 MHz in Arizona, but we did not see any correlation between radio and optical emission.

REFERENCES

1. Colgate, S. A.: Can. J. Phys., vol. 46, 1968, p. S476.

2. Greisen, K.: Proc. 9th Int. Conf. Cosmic Rays (London), 1965, p. 609.

3. Bummer, A. M.: Cosmic Ray Detection by Atmospheric Fluorescence. Ph. D. thesis, Cornell Univ., 1966.