A search for pulses of fluorescence produced by supernovae in the upper atmosphere

1972 J. Phys. A: Gen. Phys. 5 773

(http://iopscience.iop.org/0022-3689/5/5/019)

J. Phys. A: Gen. Phys., Vol. 5, May 1972. Printed in Great Britain

A search for pulses of fluorescence produced by supernovae in the upper atmosphere

W N CHARMAN† and J V JELLEY

Nuclear Physics Division, AERE Harwell, Didcot, Berkshire, UK

MS received 22 July 1971, in final revised form 17 January 1972

Abstract. Colgate has suggested that an exploding supernova should release an intense burst lasting a few microseconds of x and gamma ray photons. When it impinges on the upper atmosphere this burst produces a corresponding pulse of optical emission by fluorescence. A search has been made for such light pulses, using a system of coincident light receivers. Although many pulses having the appropriate temporal characteristics were observed, their other properties appear to rule out their having an origin in supernova explosions. The character and possible origin of these events are discussed and their intrinsic interest is pointed out.

1. Introduction

Developing the suggestion by Colgate (1968), that the outburst of a supernova should be accompanied by a pulse of x and γ ray photons lasting a few microseconds, and a corresponding flash of optical radiation in the upper atmosphere, from fluorescence, Fichtel and Ögelman (1968) proposed an experiment to search for supernovae by this method. Ögelman and Bertsch (1970) have since conducted a preliminary search for such light flashes and, in a limited observing period, found no convincing evidence for their detection. We now present the results of rather similar experiments conducted on a dark site at Grove, Berkshire, England.

2. Theoretical basis

This has been fully reviewed by earlier authors (Colgate 1968, Fichtel and Ögelman 1968, Ögelman and Bertsch 1970). Briefly, Colgate postulates that the high energy photon pulse emitted by the exploding supernova should be about 10 μs long, the photons having energies up to 1 GeV, or higher (Colgate 1970). When it reaches the earth, this burst of photons deposits its energy at altitudes between 30 and 100 km and the fluorescent light is emitted on a time scale of the order of 1 μs, mainly in the nitrogen bands in the spectral region 3200–4500 Å (Charman *et al* 1970, Fichtel and Ögelman 1968, Ögelman and Bertsch 1970). The pulse observed by a suitable light receiver will thus normally have a duration and shape dictated primarily by the geometry of the field of view of the receiver and the arrival direction of the high energy photons; typically,

---

† Now at Department of Ophthalmic Optics, University of Manchester Institute of Science and Technology, PO Box 88, Sackville Street, Manchester 1, UK.

observed pulse lengths 30 to 300 μs might be expected with a wide-angle system. If the theoretical estimates are correct, supernovae occurring at distances up to of the order of 50 Mpc might be observable, events being detected at a rate of about one per night.

3. Experimental

The equipment used in our observations is shown schematically in figure 1. Two light receiver channels were employed, each consisting of a 150 cm diameter, f/0·5, rhodium-coated searchlight mirror with a 30 cm diameter EMI type 9545 photomultiplier (PMT) at its focus. The S-11 cathodes were screened with Corning No 7-59 amethyst filters to optimize the discrimination in favour of the near-ultraviolet signal from the night-sky background. Each PMT signal was fed to an amplifier having an integration time of 10 μs and a differentiation time constant of 300 μs.

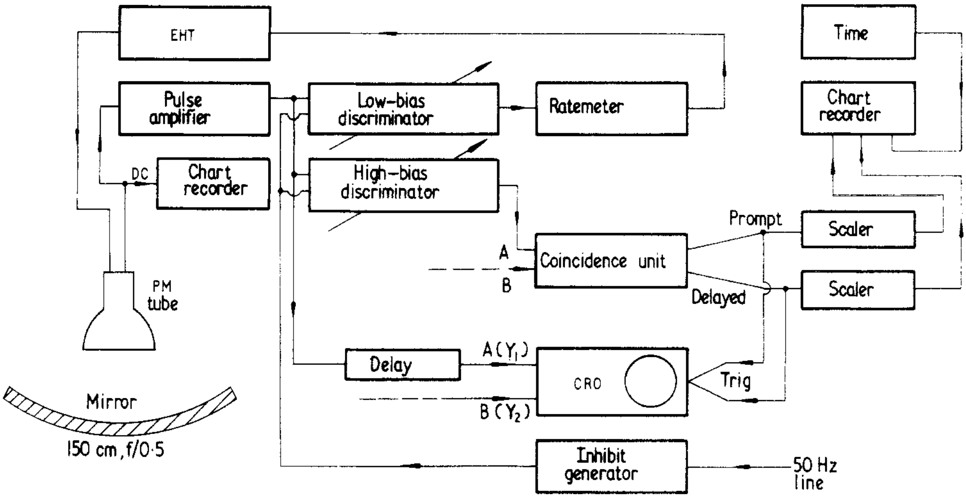

Figure 1. Schematic layout of the equipment used in the experiment.

Since the system was designed to work unattended under varying levels of sky brightness, due, for example, to cloud, a ratemeter-controlled servo loop operating on the photomultiplier EHT's was employed (Fruin and Jelley 1968). The amplified PMT signals were each fed to two discriminators, one set at a low bias to give a rate 500 s^{-1} to operate the loop, the other set at a higher level, typically to give counting rates of about 1 s^{-1}. The two single rates from the high-bias discriminators were then fed into a coincidence unit with a resolving time of 100 μs. This unit gave an output pulse both for prompt coincidences and for coincidences occurring when one channel was undelayed and the other channel was delayed by 250 μs; provision was made for distinguishing between the 'prompt' and 'delayed' coincidences. Throughout the experiment the 'delayed' (ie chance) rate was very low as compared with the rate of 'prompt' coincidences. It can be shown, furthermore, that the probability of 'prompt' coincidences occurring due to the direct effect of core particles from very large cosmic ray air showers on the photomultipliers was extremely small for the high photoelectron current conditions under which the tubes were operated. Any such pulses would be bandwidth-limited, as were the atmospheric Čerenkov events (see § 4 below), and would occur at a roughly constant rate from night to night. All the electronics (UKAEA '2000 Series' units) were well screened against electromagnetic pick-up and were fully stabilized against possible fluctuations or 'spikes' in the main's power supply. Tests using lamps in the light receivers to simulate the sky brightness showed that, under these conditions, the 'prompt' and 'delayed' coincidence rates were equal. Both 'prompt' and 'delayed' coincidences triggered the 1 ms timebase of an oscilloscope, where the outputs of the two light receivers were displayed, with a suitable delay of 100 μs. These traces were recorded, together with an illuminated watch dial, on continuously moving film. More accurate timing (±6 s) was available from chart recordings of the events and 1 min timemarks derived from a crystal oscillator and standard time signals.

In the early stages of the experiment, it was found that although the site was apparently fairly dark, in practice, with the time constants in use, troublesome interference locked to the 50 Hz mains supply occurred from street lighting in a nearby town. This interference took the form principally of 'spikes' about 0·5 ms wide occurring every 10 ms, so that the equipment tended to trigger on each of the 'spikes'. To circumvent this problem, a mains-locked inhibit gate was developed, which inhibited all the discriminators for a 2 ms period centred on each spike. The effective running time was therefore only 80% of the elapsed time.

Housing the light receivers in large boxes with the lids made of suitably transmitting glass allowed the whole equipment to be automated and run completely unattended. Checks of film and chart recordings were normally only necessary during daytime hours.

Figure 2 shows the pulse shapes expected for supernova events for our optical system and its associated electronics, calculated on the assumption that the light originates at

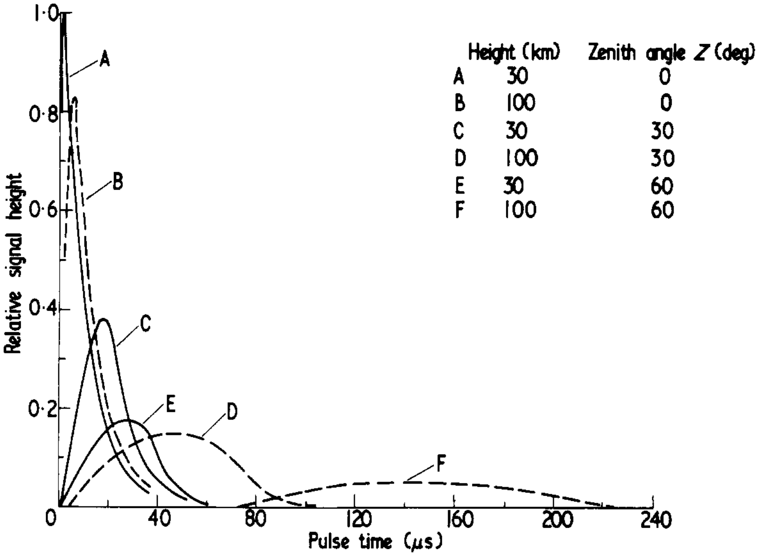

Figure 2. Calculated expected oscilloscope pulse shapes for the present light receivers and associated electronics for a delta function excitation pulse incident at angles of 0°, 30° and 60° with respect to the zenith. The full and broken curves represent energy deposition at altitudes of 30 km and 100 km respectively and the axes of the receivers are directed at the zenith. It has been assumed that for each zenith angle Z the integrated amount of fluorescent light received from both altitudes is the same, and is proportional to cos Z.

altitudes of 30 km or 100 km, and that the high energy photon burst lasts for about 10 μs. The actual pulse shape observed, which corresponds to the sum of such pulse shapes for all altitudes, weighted according to the light emission from each altitude, clearly depends on the spectrum of the high energy photons, since this controls the relative importance of the contributions from different levels in the atmosphere. Only very approximate predictions of the shape of this spectrum have as yet been made (Colgate 1968). In general, a pulse which rises rather more steeply than it decays would be expected, and the system will tend to detect with greater efficiency those supernovae which occur near the zenith.

4. Results

The equipment was operated for a total of about 70 moonless nights during the period December 1969–April 1970.

During the first two months of operation, the axes of the two mirrors were aligned and pointed at the zenith. It soon became obvious from the film records that the bulk of events recorded on clear nights were pulses which were bandwidth-limited, that is, they had durations which were less than the integration time of the equipment; on cloudy nights these pulses were greatly reduced in frequency. We attribute these pulses to Čerenkov light emitted in the atmosphere from cosmic ray showers (Jelley 1967) and, using the observed rate of such pulses ($\sim 4\times10^{-3}$ s^{-1}), an angular field of 0·12 sr, the cosmic ray primary spectrum of Greisen (1965), and the calculations of Zatsepin and Chudakov (1962) for the yield of Čerenkov light from EAS, we find that the showers which were triggering the equipment on clear nights must have had energies of about 3×10^{15} eV, corresponding to the arrival within 10 μs of approximately 30 photons cm^{-2} in the band 3400–4300 Å. This is comparable with the average triggering threshold sensitivity of about 100 photons cm^{-2} for the equipment used by Ögelman and Bertsch (1970).

In addition to the Čerenkov pulses, a small fraction ($\sim 10\%$) of the triggering pulses had a quite different form, with durations up to 1 ms. Some examples of the pulses recorded are shown in figure 3. Broadly speaking, it is possible to distinguish between two types of 'anomalous' event: those having a symmetrical structure and those having a fast (~ 50 μs) rise and a slow (~ 500 μs) delay. Study of the occurrence properties on clear and cloudy nights of these different types of pulses is instructive. If, using the records of PMT current, we categorize successive hours of operation as either 'clear' or 'cloudy', we can plot histograms showing the hourly occurrence rates of 'Čerenkov' and 'anomalous' pulses (figure 4). As might be expected, on 'clear' nights the Čerenkov rates show a fairly symmetrical scatter about the mean rate (~ 11 h^{-1}). On 'cloudy' nights the mean rate falls to about 1·1 h^{-1} with a roughly Poisson distribution. This reduction clearly corresponds to the increase in the shower energy threshold of the equipment, considered as a Čerenkov light receiver, caused by the attenuation of the directional Čerenkov light coming from those parts of the shower track above the cloud base. The situation with the 'anomalous' pulse is quite different. In most hours of observation, few, if any, pulses are observed; occasionally, however, a very high (~ 8 h^{-1}) rate is observed. Essentially, the same distribution in rates of 'anomalous' pulses is observed on 'clear' and 'cloudy' nights. More detailed study suggests that most 'anomalous' events occur on a few 'good' nights comprising 15% of the total number of nights of observation.

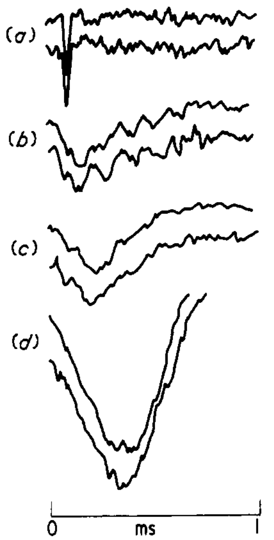

Figure 3. Examples of the optical pulses recorded by the two light receivers (*a*) is assumed to be a Čerenkov event, (*b*), (*c*) and (*d*) are 'anomalous' pulses of different shapes. Event (*b*) appears to display substructure at a frequency of about 10 kHz.

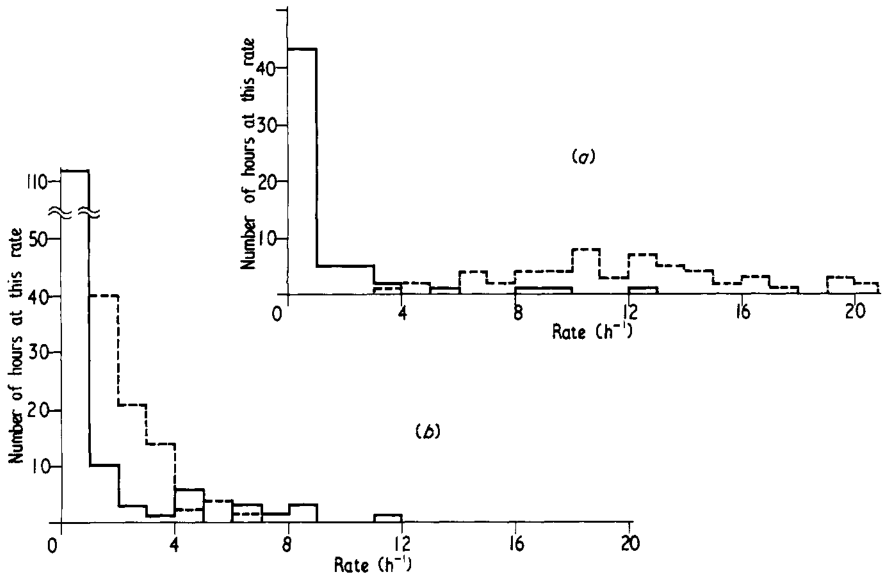

Figure 4. The distribution of hourly occurrence rates of Čerenkov and 'anomalous' pulses when the two receiver axes were parallel and directed at the zenith. (*a*) Clear nights, 57 h; full line: anomalous (mean rate 0·93 h^{-1}); broken line: Čerenkov (mean rate 11 h^{-1}). (*b*) Cloudy nights 136 h; full line: anomalous (mean rate 0·64 h^{-1}); broken line: Čerenkov (mean rate 1·1 h^{-1}).

While some caution must be exercised when comparing event rates under differing sky conditions, due to the action of the servo loop, the interpretation of these results must be that the rate of occurrence of 'anomalous' pulses is little affected by cloud. Our records do not, of course, give any indication of either the height or thickness of the cloud layers, although these probably vary considerably on different nights. If the light for these events originates in the high atmosphere it is surprising that cloud does not affect the rates more. Even if we assume that an extensive region of the atmosphere acts as a source, the effects of scattering would be expected to significantly attenuate the signal. On the other hand, it is equally difficult to see how light which is scattered or reflected from distant man-made sources can cause such pulses, as in this case one would again expect such factors as the height of the cloud and clarity of the atmosphere to greatly affect the efficiency with which pulses were detected.

Having established some of the properties of the system with the mirror axes parallel, it was decided to run for the rest of the winter with the fields of view of the receivers averted. In this way, coincidences due to directional Čerenkov light could largely be eliminated, and it could be established whether the 'anomalous' pulses were at all changed. Using directions which minimized the effect of obvious sources of stray light from street lighting, the two mirror axes were therefore each tilted to an angle of 18° with respect to the zenith and directed at azimuths which differed by 90°. There was then no overlap between the projections of the two fields, of nominal 12° radius, on the sky. The coincidence resolving time was lengthened to 200 μs to allow for possible propogation delays between the two fields of view.

It soon became obvious that, whereas the rate of Čerenkov pulses was, indeed much diminished in this arrangement, the 'anomalous' pulses continued to occur. Figure 5 shows that the rates of 'anomalous' pulses remain very similar to those found when the

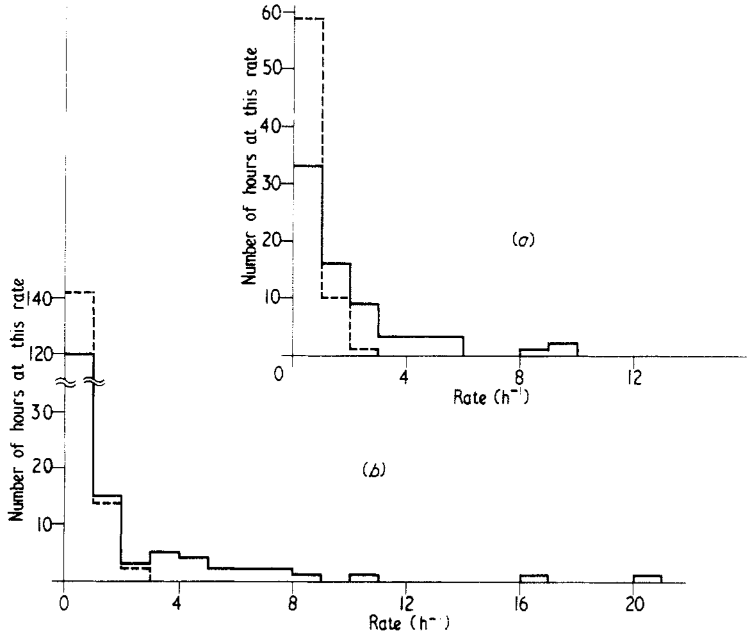

Figure 5. The distribution of hourly occurrence rates of Čerenkov and 'anomalous' pulses when the two receiver fields of view were averted. (*a*) Clear nights 70 h; full line: anomalous (mean rate $\simeq 1{\cdot}4\ \mathrm{h}^{-1}$); broken line: Čerenkov (mean rate $\simeq 0{\cdot}17\ \mathrm{h}^{-1}$). (*b*) Cloudy nights 158 h; full line: anomalous (mean rate $\simeq 0{\cdot}90\ \mathrm{h}^{-1}$); broken line: Čerenkov (mean rate $\simeq 0{\cdot}11\ \mathrm{h}^{-1}$).

must arise locally from large showers which pass very close to the receivers, it is not surprising that the small Čerenkov rate is not too greatly affected by cloud. Again, however, the comparative lack of dependence of the rate of 'anomalous' events on atmospheric conditions is puzzling. The shapes of the coincident 'anomalous' pulses as seen by the two averted receivers were always essentially the same and it was not found possible to isolate any events which showed delays between the two channels due to the different fields of the two receivers. As the two averted receivers view quite different areas of the upper atmosphere, only supernovae occurring in a very limited region of the sky would be expected to produce simultaneous fluorescence pulses of identical shape at the two receivers. Hence, it is again very unlikely that the 'anomalous' pulses could be caused by high altitude fluorescent light from supernova outbursts.

5. Discussion

It is clear that our single station coincidence system observes a considerable number of light pulses which have a shape and duration broadly similar to those predicted as arising from the burst of high energy photons from a supernova explosion. However, the distribution in arrival times of the pulses, with many being observed on certain nights and few at other times, makes it improbable that they originate in supernova explosions, as these may reasonably be expected to occur at random rather than in groups. This conclusion is reinforced by the fact that the pulses continue to be observed under conditions of total cloud cover, and that the pulse shapes and delays do not apparently depend greatly upon the area of the sky viewed. If indeed the 'anomalous' pulses may be observed at any site, and they are not due to supernovae, then not only do they represent an unexpected background against which any true supernova effects must be detected and which hence tend to raise the threshold for detecting supernovae above that predicted by Fichtel and Ögelman (1968) but also they have intrinsic interest as possibly representing some new, unexpected, atmospheric phenomenon.

As these events were observed at about the same rate with and without cloud cover, it is suggested that the light associated with the events may have originated at quite low altitude (~ 1 km). The pulse shape would then be intrinsic to the event rather than a property of the geometry of the receiver. Observation of the anomalous events with the mirror axes both parallel and averted implies that the light must have been emitted fairly isotropically.

One important property of the events on which our single station gives no information is the lateral extent over which the light may be observed. Supernova fluorescence effects should, of course, be detectable up to several thousand kilometres whereas local atmospheric or man-made events would normally only be detectable over much shorter distances. We have, however, attempted to compare the rates of arrival of our anomalous events with records of meteorological, electrical, and geomagnetic activity, in the hope that some instructive correlations might emerge to clarify the origins of the events. As already noted, there is no correlation of the 'anomalous' event rate with cloud; this is also true for precipitation and frost. Lightning is rare in the British Isles during the winter months and there are no records of thunderstorms within several hundred kilometres during the relevant periods. Moreover, a nearby 150 MHz radio system (2 MHz bandwidth) which was running continuously during the observing period in connection with a different experiment, showed no evidence of increased radio interference during those periods when usually high rates of 'anomalous' pulses were observed.

Again the occurrence of these high rates appeared to be unrelated to any index of geomagnetic activity, such as the Kp index, or with neutron monitor count rates. We recognize, however, that as our light receivers were only operated on moonless nights and had a sensitivity which varied in an unknown way with the presence of cloud and other factors, difficulty would be expected in establishing any convincing correlation between our events and other phenomena.

Comparison of the shape of our 'anomalous' events with the shapes of some of the light pulses observed by Ögelman and Bertsch (1970) suggests that similar phenomena may have been observed in both experiments. Clearly, incorporation of more and spaced light receivers to give additional spectral and directional information would be most desirable.

6. Conclusions

These experiments, like those of Ögelman and Bertsch (1970), provide no definite evidence for the detection of supernova outbursts. Light pulses having durations of about 10–1000 μs are, however, observed. While some man-made source for these events cannot be ruled out entirely, the evidence indicates that they probably originate in the lower atmosphere. At present we have been unable to isolate any mechanism for the production of such light pulses and feel that they are interesting enough to deserve further study.

Acknowledgments

We would like to thank Mr J H Fruin and Mr W McKellar for building and maintaining the installation and its associated electronics.

References

Charman W N *et al* 1970 *IAU Symp. No* 37 *on Nonsolar x and Gamma Ray Astronomy* ed L Gratton (London: Academic Press) pp 41–9

Colgate S A 1968 *Can. J. Phys.* **46** S476–81

—— 1970 *Acta Phys. Acad. Sci. Hung.* **29** *Suppl.* 1 OG–5

Fichtel C E and Ögelman H B 1968 *NASA Technical Note No* 4732

Fruin J H and Jelley J V 1968 *Can J. Phys.* **46** S1118–22

Greisen K 1965 *Proc. 9th Int. Conf. on Cosmic Rays, London* 1965 vol 2 (London: The Institute of Physics and the Physical Society) pp 609–15

Jelley J V 1967 *Progress in Elementary Particle and Cosmic Ray Physics* vol 9 eds J G Wilson and S A Woothuysen (Amsterdam: North Holland) chap 2

Ögelman H B and Bertsch D 1970 *Acta Phys. Acad. Sci. Hung.* **29** *Suppl.* 1 OG-15

Zatsepin V I and Chudakov A E 1962 *Sov. Phys.-JETP* **15** 1126–30