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A Search for Isolated Microwave Pulses from the Perseus Cluster of Galaxies

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Summary. The paper describes a search for prompt microwave emissions from supernovae in the central region of the Perseus cluster of galaxies, using a coincidence technique involving five tracking radiometers located at widely spaced sites. No coincidences were found between January and December, 1973, and no supernovae were reported during this period from the optical surveys, in that region of sky.

Key words: supernovae — perseus cluster of galaxies — radio pulses

1. Introduction

An experiment designed to search for prompt microwave bursts from supernovae (SN) in the Coma cluster of galaxies has already been described elsewhere (Jelley *et al.*, 1974, subsequently referred to as Paper I). We present here the results from extended observations at five widely separated sites, on the central region of the Perseus cluster of galaxies, along with a calibration carried out on Solar flares.

Colgate and Noerdlinger (1971) predicted, from the original shock-wave model of supernovae (Colgate and White, 1966), that prompt bursts of radio emission would be expected from supernova explosions. LeBlanc and Wilson (1970) show, on a different model of stellar collapse, that large amounts of energy in various forms may be released in periods $\sim 0.1-3$ s. It is not however clear in this model that the energy can escape through the outer layers of the star. Our sensitivity is such that we could have detected a pulse having an energy over the entire microwave spectrum (taken arbitrarily to be $3-30$ GHz) of 8.8×10^{-5} of an assumed total prompt energy release in a SN of $\sim 10^{51}$ erg, if this were at the distance of the Perseus cluster. This figure is deduced on the assumption of a flat spectrum.

Recently, isolated, intense and short bursts of X- and γ-ray emission have been discovered (Klebesadel *et al.*, 1973). The origin of these pulses have not yet been identified though on some models it has been suggested that these may arise from supernovae.

Since supernovae are rare, it is important to eliminate any spurious events without significantly increasing the energy threshold of the system. This was achieved by using a coincidence technique, and in this experiment five widely spaced stations were used.

The general arguments for using microwave frequencies as opposed to VHF have been outlined already in Paper I, but may be summarised as follows: (1) the absorption and dispersion in a plasma at microwave frequencies is considerably less than at VHF. (2) the interference from the Sun is negligible and sources of man-made interference are also much less severe; Furthermore, several searches for isolated radio pulses have already been carried out in the VHF and UHF bands (e.g. Smith, 1950; Charman *et al.*, 1970; Colgate *et al.*, 1972; Huguenin and Moore, 1974).

The intrinsically low rate of occurrence of supernovae from individual galaxies necessitated choosing large clusters for the purpose of these experiments.

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2. Instrumentation and Calibration

The radiometers at all five sites, (Bologna, Dublin, Glasgow, Harwell and Haverford) were essentially similar. The basic system consisted of a superhetroydne receiver which was switched, at approximately 270 Hz, between the main dish antenna, (between 2.1° and 2.8°, to -3dB, for the various installations) and a reference horn ($\sim 30°$ beamwidth). The main antenna tracked the selected object while the reference horn pointed near the direction of the north celestial pole. The overall system bandwidth was 40 MHz around a central frequency of 10.0 GHz. The post detection integration was set with an RC time-constant of 0.3 s, and time marks were inserted on the paper charts used to record the data.

It is important in any coincidence experiment not only to establish the sensitivity of the separate receivers but also to determine the overall coincidence efficiency. Fortunately in this experiment, the Sun can be used as a source of microwave pulses of similar character to those expected from SN. As a calibration, therefore, the four radiometers located in Europe were set to track the Sun simultaneously for a period of approximately 2 weeks. A search of the solar data charts, using the same criterion as in the routine analysis of the cluster data, revealed one 4-fold coincidence and one 3-fold coincidence (the fourth station was off at the time). The 4-fold event was reported in Solar Geophysical Data as having a peak flux of $24.6 \times 10^{-22} \mathrm{W\,m^{-2}\,Hz^{-1}}$ at 8800 MHz. This flux agrees within a factor of 2 with our estimates, based on internal calibrations and measurements of the system temperature. The 3-fold event was not reported as a microwave event in the Solar Geophysical Data, possibly due to its short duration. A subsequent search through the Solar Geophysical Data yielded only one other possible event during the period of our observations, at a peak flux level of $13.1 \times 10^{-22} \mathrm{W\,m^{-2}\,Hz^{-1}}$. This event was subsequently found on the charts from all of the stations, but at a level such that it would have escaped detection in our routine analysis. This experimentally set the overall sensitivity at $20 \times 10^{-22} \mathrm{W\,m^{-2}\,Hz^{-1}}$ [or $\sim 8.10^{-11}$ erg cm^{-2} (event)$^{-1}$ in our bandwidth for a pulse lasting ~ 1 s], and showed that the coincidence detection efficiency was probably high.

3. Observations

Three of the radiometers routinely tracked the centre of the Perseus cluster from 1973 January to December, while a fourth radiometer began operation on 1973 August 1st. The fifth radiometer, the one located at Haverford, came into operation on 4th February 1973. The overlapping time for observations between this station and the four European ones was somewhat restricted by the large differences in terrestial longitude, and limitations in the range of hour angles that could be attained with the existing installation at that site.

Lists of times (± 10 s) of pulses exceeding 3 times peak-to-peak noise were prepared at each site and subsequently compared by computer, in which the coincidence resolving time was set at ± 2 min. A certain amount of running time was occasionally lost at each site due to rain and operational problems. Among the four European stations, there were in all 3110 hrs of coincident 3-fold operation, and 286 hrs of coincident 4-fold operation on the Perseus cluster available for analysis.

In addition to the above, a certain amount of data was available from the fifth station at Haverford. The list of event times from this site was compared to the 2-fold event lists from the other sites. Only two 3-fold coincidences were observed, and subsequent comparison of the charts eliminated these from consideration. The search failed to yield either any 4-fold or a 3-fold coincidence with a resolving time of ± 2 min, and the 2-fold rate did not exceed the random expectation. The expected random rate of coincidence events was established from the singles rates at each station by introducing arbitrary delays and searching again for coincidences, as before. The expected number of random 3-fold events, deduced on this basis, was less than unity.

4. Discussion and Conclusions

It is an extremely complicated problem to estimate reliably the supernovae rate in a cluster. This is due not only to the uncertainty in the average supernova rate per galaxy but also to the uncertainty in the number of galaxies in the cluster. A conservative approach is to restrict the count to galaxies with magnitude $m_p \leqslant 15.7$ (Zwicky's catalogue, 1961—1967) and to apply the supernova rate as a function of luminosity (Tammann, 1974). This approach produced an estimated rate of $0.1-1$ supernovae/year in our beam, for the region in the Perseus cluster observed, the main uncertainties arising from the values adopted for the Hubble constant. A higher estimate is however obtained by using galaxy counts down to much fainter levels [Rudniki (1963) and Bahcall (1974)] and assuming an average supernova rate of one per 100 years per average galaxy. This implies that many supernovae are missed in the optical searches. This procedure yields a rate of $6-7$ events per year within the beam, but this estimate is probably unduly optimistic.

Our results on the Perseus cluster are therefore consistent with the conservative approach. However, if we take the second estimate of the rate, our results imply an absence of prompt microwave emission within the 40 MHz bandwidth of our receivers ex-

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ceeding $7\times10^{43}\,\mathrm{erg\,s^{-1}}$ at the source, assuming $H=50\,\mathrm{km\,s^{-1}\,(Mpc)^{-1}}$ and $z=0.0183$ for this cluster. No optical supernovae were reported in the Perseus cluster during the period of our observations. Further theoretical analysis and observations will be carried out.

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