Radio echoes and cosmic ray showers

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It is suggested that the origin of some of the transient ionic clouds, generally assumed to be responsible for the low level sporadic radio reflexions, may be due to large cosmic ray showers.

It is shown that cascade cosmic ray showers of sufficient energy to produce some of these radio reflexions certainly exist, but there is insufficient published evidence to decide whether any of the echoes already observed are actually due to such showers. More conclusive evidence could be obtained from the frequency-size distribution of the radio echoes observed from a horizontal or vertically directed beam.

1. Introduction

The anomalous 'scattering' of radio waves into the normal skip zone was reported by Eckersley in 1929 and subsequently by many other workers. Though the majority of these echoes appear to originate in the E layer (Appleton, Naismith and Ingram 1937), the work of Watson Watt Wilkins and Bowen (1937), Appleton and Piddington (1938), Colwell and Friend (1936, 1939) and others have proved the existence of reflexions from levels as low as 10 km. Little definite is known of the magnitude or frequency of these low level sporadics, but the work of Appleton and Piddington (1938) suggests reflexion coefficients of the order of 2×10^{-5} to 10^{-4}, while the frequency of occurrence appears to be of the order of several per minute both day and night.*

It is generally assumed that these sporadic reflexions in E regions must be due to transient ionic clouds, but a variety of opinions has been expressed as regards both the nature and origin of the tropospheric scattering centres. Suggestions have been made that they may be caused by solar activity, aurora phenomena, thunderstorms, meteorites and water vapour discontinuities. The object of this note is to draw attention to the possibility that some of these reflexions, particularly those at low levels, may be due to the ionization produced by large cosmic ray showers. It will be shown that the detection of these showers by modern high power pulse transmitters, such as are nowadays used in ionospheric and tropospheric investigations, should certainly be possible.

* Eckersley (1940) found one per 30,000 km.^{2}/sec. in the E layer, and a composite plate in the paper of Watson Watt *et al.* (1937) shows the frequency of occurrence of the low level sporadics to be about ten times as great.

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2. Comparison of energies

A cosmic ray shower of high energy produces a long narrow cylinder of ionization traversing the whole atmosphere. Consider a shower at a distance R from a powerful radio transmitter with a wave-length λ large compared with the diameter of the column of ionization. Diffraction theory shows that the amplitude of the reflected wave at the transmitter will be approximately equal to that which would be produced by a point cluster of n ions, where n is the number of ions contained in a column, whose length L is that of the first Fresnel zone, that is, where

$$L = \sqrt{\lambda R}.$$

From the cascade theory of showers, it can be calculated that the maximum number of electronic ions produced per centimetre of air at a pressure p, expressed as a fraction of an atmosphere, by an incident electron of energy E, is roughly given by

$$n = \tfrac{1}{2}10^{-7}pE. \tag{1}$$

Thus the number of electrons in the equivalent point cluster is

$$N = nL = \tfrac{1}{2}10^{-7}pE\sqrt{\lambda R}. \tag{2}$$

If the reflexion coefficient ρ is defined as the ratio of the reflected amplitude to that incident on the cluster, then a point cluster of N electrons at a distance R from the sender will have a reflexion coefficient

$$\rho = \frac{Nr}{R}, \tag{3}$$

where $r = \dfrac{e^2}{mc^2} = 2{\cdot}8 \times 10^{-13}$ cm.

Considering (2) and (3) we obtain for the reflexion coefficient of a shower of energy E at a distance R,

$$\rho = \tfrac{1}{2}10^{-7}pEr\sqrt{\frac{\lambda}{R}}. \tag{4}$$

For instance, putting $\rho = 2 \times 10^{-5}$, $p = 1$, $\lambda = 50$ m., $R = 10$ km. we get $E = 2 \times 10^{16}$ eV. Now showers of nearly this energy have already been observed directly by Auger and his collaborators (1939), Jánossy and Lovell (1938), Lovell and Wilson (1939) and others. We conclude therefore that cascade cosmic ray showers certainly exist of sufficient energy to produce measurable radio reflexions.

3. Frequency-size distribution

Whether some of those reflexions already observed are from such cosmic ray showers is difficult to decide without more evidence than appears to be available at present of the frequencies of the echoes. The frequency-size distribution of the echoes from cosmic ray showers will depend on the energy spectrum of the incident rays. Consider first, the reflexion of a nearly horizontally directed radio wave by a nearly vertical shower. If, as is probable, the number of rays with energy above E, falling on unit area from a nearly vertical direction is roughly of the form

$$G(E) = \alpha E^{-2}, \tag{5}$$

then the number of rays of energy greater than E which fall within a distance R and $\overline{R+dR}$ from the sender, will be equal to

$$v dR = 2\pi \frac{\alpha}{E^2} R dR. \tag{6}$$

Substituting E from (4) we get

$$v dR = \frac{\pi}{2} 10^{-14} \alpha p^2 r^2 \lambda \frac{dR}{\rho^2}. \tag{7}$$

We see therefore that the number of echoes between ranges R and $\overline{R+dR}$ with reflexion coefficients greater than ρ is inversely proportional to ρ^2, but is independent of the range R. If the observed echoes from a horizontally directed radio beam are found to obey this relation, it will be strong evidence that the echoes are from showers.

From the work of Auger (1939), it can be calculated that

$$G(E) \simeq 1{\cdot}6 \times 10^{-9}/\text{cm.}^2/\text{min.} \quad \text{for} \quad E = 10^{15}\,\text{eV};$$

whence $\alpha \simeq 1{\cdot}6 \times 10^{21}/\text{ergs}^2/\text{cm.}^2/\text{min.}^{-1}$. Taking again $p = 1$, $\lambda = 50$ m., we find

$$v dR = 10^{-14} dR/\rho^2. \tag{8}$$

The number of echoes with reflexion coefficients greater than 10^{-4} observable over a range $\delta R = 10$ km. should therefore be about one per minute. The observed echoes appear to occur with a frequency of this order of magnitude.

If we now consider a radio transmitter giving a directed beam vertically instead of horizontally, then it is clear that it will be the horizontal showers which give echoes. To take into account the decrease of pressure upwards we can write $p = e^{-\beta R}$ in (7). The frequency of the echoes will therefore fall off exponentially with R, in contrast to the case of a horizontally directed beam, which is shown above to give a frequency independent of R.

Numerical calculation shows that the observed E level sporadics are much too frequent to be explained in this way, and therefore are probably to be attributed to some other cause than cosmic ray showers.

With any normal radio transmitter, radiating in all directions, the frequency-size distribution will be too complicated to allow an easy test of the theory.

4. Duration of the echoes

The duration of an echo will be the lifetime of the free electronic ions, and this is governed mainly by the rate of attachment to molecules. Thus the duration of the echoes will be roughly inversely proportional to the pressure, and will have a value of 10^{-5} to 10^{-6} sec. at ground level and of the order of a second at 100 km. Thus, though the amplitude of an echo will decrease with the pressure, its duration will increase in the same proportion, leaving the product of amplitude and duration unchanged. It is possible that some types of receiving apparatus may not detect the very short echoes from low levels as easily as the smaller but longer echoes from greater altitudes. This might give an apparent maximum frequency of detectable echoes at a considerable altitude.

5. Conclusion

If the suggestion put forward here, that radio echoes should be detectable from cosmic ray showers, is substantiated by experiment, a new and powerful technique will be available for cosmic ray research, especially for the investigation of the energy spectrum at very high energies.

References

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