PAPER 102

THE ORIGIN OF THE BELT OF GALACTIC RADIO WAVES

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Most of the background of cosmic radio waves comes from our own Galaxy. In the equatorial plane this origin is evident, and the obvious features can be directly related to the Galaxy's structure. Away from the plane the emission comes from a roughly spherical halo, which accounts for most of the total emission from the Galaxy. Some features in this part of the sky are not evident from optical studies; the most important is a circular belt of emission passing not far from the center and the anti-center. It is impossible that this should be extragalactic in origin, since it is more than twice as bright as the brightest estimates of the whole galactic component, and optical evidence would be expected of such a major irregularity in the distribution of the galaxies, or indeed of a single spiral galaxy close to or enveloping our own. We turn therefore to a suggestion of an origin in our own Galaxy.

The Galaxy, apart from its H II regions, emits radio waves by the synchrotron process. Support for this assertion comes largely from the lack of any other plausible hypothesis; we note, however, that the spectrum of the background, which is also the spectrum of the belt radiation, is related by this hypothesis to the energy spectrum of the cosmic-ray electrons. The peculiar features of the synchrotron radiation which would prove the hypothesis are directivity and polarization. Polarization has been observed in discrete sources, but J. H. Thomson has shown by experiment that it is present in the background radiation only in rather a small degree, making even its detection uncertain. This difficulty could be accounted for by the effects of the Faraday rotation. Directivity has not been much considered, since radiation perpendicular to magnetic fields would not show it in a randomly directed magnetic field. However, we shall invoke this property of directivity in explaining the belt of radiation.

There is only one such belt in the sky, and it extends fairly clearly around a whole circle. If it were a small feature, say near the galactic center, we could possibly consider it as a discrete source of emission, perhaps a region of abnormally high magnetic field. But a unique ring of emission can only indicate either that we are in the center of some unique object, or that the belt is not an object but an appearance that depends on direction only. The second possibility is for us the more attractive, and is in fact to be expected from synchrotron radiation.

A rainbow furnishes an example of bright emission that depends on direction only and does not involve a large volume emissivity. Emission of synchrotron radiation takes place in the direction of motion of the electrons.

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The electron energies must be at least 10^9 electron volts, and are here supposed to be generated in regions away from the sun, closer to the galactic center. Near the sun the magnetic field is directed along the spiral arm, forming a tube down which the electrons diffuse, spiraling smoothly with a radius of curvature of about 2×10^{-7} parsecs. Assuming that their original motions are randomly oriented, some electrons with considerable velocity along the spiral arm will diffuse fast, and will soon be lost. Those whose velocities are nearly perpendicular to the field will diffuse slowly, and will form a large population of electrons moving in nearly circular paths. The emission from them is directed perpendicular to the spiral arm. An observer outside the arm would see the arm bright at the point where it is perpendicular to the line of sight: one inside would see a bright ring whose axis is the direction of the field. The width of the ring is determined by the inhomogeneity of the field, which might resemble the fibers of a strand of wool, aligned but not exactly parallel.

A more detailed discussion is given by Harriet Tunmer (*Phil. Mag.* **28**, 370, 1958).

Discussion

Erickson: The correspondence of the $l = 0$ belt with the 21-cm emission feature is very crude, since it only agrees within about 20 or 30 degrees.

F. G. Smith: The belt crosses the galactic equator near $l = 0$. The correspondence with the observations in neutral hydrogen refers primarily to the difference in intensity at the positive and negative galactic latitudes.

Davis: The distribution in angle of the highly relativistic electrons should have some relation to that of cosmic rays, which are substantially isotropic. It would seem wiser to consider that the synchrotron radiation comes from an isotropic distribution of electrons in a nearly uniform magnetic field. Even here one gets an anisotropic distribution of radio noise. The total power radiated into unit solid angle per unit volume is proportional to $\sin^2 \theta$, where θ is the angle between the magnetic field and the direction of radiation. If the magnetic field lies along the spiral arm, the path length depends on θ and the intensity received should be proportional to $\sin \theta$.

Smith: A directivity of this nature is insufficient to explain the belt. The isotropy of cosmic rays refers to protons, but in any case protons of much higher energies than the electrons involved here would be made isotropic by the solar magnetic field.

Davis: It is true, as you say, that low-energy cosmic rays should be isotropic because of local disturbances in the magnetic field near the solar system, but this cannot be important at 10^{14} and 10^{15} eV, where cosmic rays are still isotropic to within at least 1 per cent.

Mills: The interpretation of this galactic feature in terms of the directivity effect of synchrotron radiation does not appear consistent with our results, given in paper 79, which suggest a more or less isotropic radiation from a spiral arm.

Smith: We would expect the radiation in the belt to be only a sharp maximum, with radiation in other directions originating in electrons with correspondingly directed velocities and moving in magnetic fields not exactly aligned along a perfect spiral. A maximum might be seen along the direction of an arm that contains deviations of the magnetic field of 5 degrees or so.

Oort: I am not very happy about associating the large irregularity in high latitudes with the spiral-arm structure. We know that the continuous radiation comes partly from a very thin disk (and thus from the spiral arms) and partly from a wide distribution which up to the present has been associated with a halo. Although the flare discussed is undoubtedly the most striking feature in high latitudes, there are many other small irregularities, suggesting that the halo itself contains large-scale structures. If Mrs. Tunmer's idea were correct the nonthermal radiation received from other arms should be strongly concentrated in directions near the anti-center and the center. Nothing of the kind is observed.

Smith: Of course it is not possible as yet to rule out for this belt an origin in a physically localized region of the halo, but it does not seem to be a very probable situation, since such a feature would be the only one of its kind in the whole Galaxy.

van de Hulst: In his presentation Dr. Smith did not comment on the agreement or disagreement of this belt with the plane perpendicular to the spiral arm observed optically and in the 21-cm line. In comparing the printed paper with our data at Leiden we found fairly serious discrepancies. Also the theoretical basis of this paper is open to discussion. We may even argue precisely the opposite point as follows. If the high-energy electrons are accelerated at a place in the Galaxy where the magnetic field is relatively strong, as seems likely, any initially isotropic distribution of velocities will change as the electrons drift to regions where the field is smaller. The difference is such as to remove the electrons that have velocities nearly perpendicular to the lines of force. The net effect is exactly opposite to that proposed by Mrs. Tunmer.

Smith: Certainly the angular distribution of electron velocities depends greatly on their position and mode of origin. Very likely there are many electrons with velocities along the arm, and these would contribute to the more nearly isotropic emission mentioned by Mills.