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RADIO ASTRONOMY AND THE ORIGIN OF COSMIC RAYS

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At present we can *observe* the origin of only the solar component of cosmic rays. The sun emits cosmic rays in connexion with flares and probably also continuously on a smaller scale. Thus the emission of cosmic rays appears to be connected much more closely with non-thermal radio emission than with thermal radiation of light and heat.

The large cosmic ray bursts are often not exactly coincident with the H_α flare itself, but are retarded by about half an hour and more. The coincidence is much better with the 'second part' of the radio outburst, e.g. at 200 Mc./s. Both are evidently connected with streams of high-speed particles penetrating the outer parts of the solar atmosphere. Expressing the flux of the radio-frequency radiation for 100 Mc./s. in w.m.$^{-2}$ (c./s.)$^{-1}$ and of cosmic rays (energy range $\sim 0{\cdot}5$ to 5 BeV) in units of the total cosmic radiation we obtain the observed ratio as given in the Table.

Ratio of radio frequency radiation to cosmic radiation

Flare of 25 July 1946: Major burst	$3{\cdot}0 \times 10^{-18}$	
Second part	$0{\cdot}1 \times 10^{-18}$	2×10^{-18}
Moderate flares (Firor, neutron pile)	$1{\cdot}7 \times 10^{-18}$	
Solar component (Firor, Simpson, Treiman)	$1{\cdot}8 \times 10^{-18}$	
Galactic radio-frequency radiation/total cosmic radiation		$3{\cdot}6 \times 10^{-21}$

In the last line the 'isotropic component' or 'halo radiation' of the galactic radio-frequency radiation has not been included. Assuming it to be galactic too would increase the ratio by about a factor two, which is still within the range of uncertainty.

We should be aware that in our Galaxy the (charged) cosmic-ray particles are stored in an interstellar magnetic field of $\sim 5 \times 10^{-6}$ gauss. Their mean free path Λ (measured along the coiled orbits) must be somewhat shorter than that for the destruction of heavy nuclei by collisions with interstellar protons. In this way Morrison, Olbert and Rossi obtain

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$\Lambda \approx 1{\cdot}2 \times 10^6$ parsecs. The average distance from which light or radio waves reach us is only $l \approx 500$ to 1000 parsecs. This means, the cosmic-ray particles are 'stored' in the Galaxy by a factor $\Lambda/l = (1 \text{ to } 2)\, 10^3$ and the ratio for the *production* of the two non-thermal radiations in the Galaxy,

$$\text{radio-frequency radiation/cosmic rays} = 1{\cdot}5 \times 10^3 \,.\, 3{\cdot}6 \times 10^{-21} = 5 \times 10^{-18},$$

is practically *equal* to that found for the sun. Furthermore, the radio-frequency spectra of the non-thermal galactic radiation and of the average non-thermal solar radiation are very similar, the radiation temperature T_ν varying as $\nu^{-(2\cdot7 \text{ to } 2\cdot5)}$ and $\nu^{-2\cdot3}$ in the two cases.

On the other hand we know from the radio-spectrum observations by Wild *et al.* that the non-thermal radio-frequency radiation on the sun is produced by plasma oscillations which are excited by fast-moving matter, or—one might just as well say—corpuscular radiation. As we have seen already, cosmic-ray particles are accelerated in the same medium, probably by induction effects of fast-moving magnetized matter. Although neither the physical processes producing the radio-emission nor those producing the high-energy particles are known in detail, the observations presented above are best summarized by the hypothesis that:

On the sun as well as in galactic sources non-thermal radio-frequency radiation and cosmic rays (at least up to 5 BeV) are produced together in the same ratio in violently moving plasma, probably having also magnetic fields.

The question, whether particles of energies up to 10^{18}–10^{19} eV. in the general cosmic radiation are produced from the BeV particles by interstellar acceleration or by step-wise acceleration in the powerful sources themselves, might be left open for the present. Since already the 1 to 5 BeV-particles on the sun are probably produced by acceleration of less energetic particles which in turn have been accelerated magnetically, the latter possibility appears not unreasonable.

Looking for galactic sources which might account *simultaneously* for the major part of the non-thermal radio-frequency radiation and of the cosmic rays we realize that the types of radio sources which have so far been identified with optical objects do not come into account.

As to more or less *interstellar sources* one might first think of supernova shells, but with present data this leads into difficulties concerning the energy of cosmic rays. About one supernova with $\sim 10^{49}$ ergs every 300 years would produce all over the Galaxy $\sim 10^{39}$ ergs/sec. On the other hand a volume of $\sim 2 \times 10^{11}$ parsecs^3 (a cylinder of 10 kiloparsecs radius and 600 parsecs thickness) ought to be refilled with cosmic radiation of

$\sim 10^{-12}$ ergs/cm. every $\sim 4 \times 10^{6}$ years, thus requiring $\sim 4 \times 10^{40}$ ergs/sec. With ordinary novae one finds a similar discrepancy.

In spite of this result, the following considerations show that the hypothesis of an interstellar origin still merits further investigation. (*a*) Present estimates of the frequency of supernovae of type I and especially those of type II (resembling violent ordinary novae) might be too low. (*b*) In the central parts of the Galaxy the interstellar hydrogen—according to recent work of the Dutch group—has high velocities whose mechanism is not yet understood. (*c*) The 'galactic halo', supposedly producing the nearly isotropic radio-frequency radiation, is still quite enigmatic.

Looking for *stellar sources* we have called attention to the extremely cool dwarf stars which are very numerous and show many signs of solar-type 'activity' on a very enhanced scale (bright H + K lines as in the plages faculaires; huge spots producing light-variation; violent flares). Also theoretically we should expect that the hydrogen convection zone, which ultimately drives all these mechanisms, is more strongly developed in these stars than in the sun. The requirements that such sources produce the observed radio emission per parsec^3 *and* that individual sources of this type have not been identified with the largest existing radio telescopes can be accounted for by postulating about 7×10^{-2} radio stars per parsec^3 with $M_{\mathrm{phot.}} \approx 18$, $M_{\mathrm{vis.}} \approx 14$ and $M_{\mathrm{bol.}} \approx 9$.

The volume density fits very well with the luminosity function for the nearest stars. The cosmic-ray output would have to be about 4 % of the total light plus heat radiation. Since all our assumptions are astrophysically very reasonable, the hypothesis that the galactic radio-frequency radiation *and* cosmic rays originate in enormous numbers of extremely faint, cool stars has much to recommend itself. It is obviously not essential to postulate only *one* type of galactic objects involving highly turbulent and magnetic plasmas.

The alternative hypothesis, that the galactic radio-frequency radiation be produced by high energy electrons spiralling in magnetic fields, cannot be discussed here in detail. But it should be clear that on this hypothesis the agreement of the radio spectra and of the ratio of radio frequency to cosmic ray emission between the active sun and the Galaxy would be only a matter of chance.

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