VII. RADIO FREQUENCY RADIATION

https://doi.org/10.1017/S007418090017977X Published online by Cambridge University Press

LOW FREQUENCY RADIO ASTRONOMICAL OBSERVATIONS FROM ROCKETS AND SATELLITES

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RÉSUMÉ. — *On passe en revue les observations obtenues à bord de véhicules spatiaux, concernant les ondes de basse fréquence en les confrontant aux observations faites sur la Terre. On montre qu'au-dessous de 5 MHz le rayonnement est principalement d'origine extragalactique et que les brillances mesurées sont compatibles avec les valeurs obtenues par extrapolation des mesures faites aux fréquences élevées.*

Au-dessous de 2 MHz, on observe une absorption qui semble isotrope et due à une région H II centrée sur le Soleil et de mesure d'émission égale à 5 pc cm^{-6}. *Si cette région est contenue dans la Galaxie, elle doit avoir un effet notable pour l'émission synchrotron dans le plan galactique et sur la polarisation des sources discrètes.*

ABSTRACT. — *Observations from space vehicles of low frequency radio waves are discussed in relation to the observations made at higher frequencies from ground based observatories. It is shown that at frequencies below about 5 MHz the radiation is primarily extragalactic in origin, and that the observed values of sky brightness are consistent with the extrapolated values.*

An absorption effect observed at frequencies below 2 MHz appears to be isotropic and suggests that the Sun is at the centre of an H II region with emission measure 5 pc.cm^{-6}. *It is shown that if this region is contained in the Galaxy it will have a significant effect on the synchrotron radiation from the plane and on the rotation measure of polarisation of discrete sources.*

Резюме. — Просмотрены наблюдения полученные на борту пространственных транспортеров, относящиеся к низкочастотным волнам, сравнивая их с наблюдениями сделанными на земле. Показано, что ниже 5 Мгц излучение имеет, главным образом, внегалактическое происхождение и что измеренные блески совместимы со значениями полученными экстраполированием измерений сделанных в высоких частотах.

Ниже 2 Мгц наблюдается поглощение по-видимому изотропное и происходящее в области H II центрированной на направлении Солнца и с измерением эмиссии равным 5 парсек/см^{6}. Если эта область содержится в Галактике, она должна иметь значительное действие для синхротронной эмиссии в галактической плоскости и на поляризацию дискретных источников.

It is fortunate that the terrestrial atmosphere allows radio waves to reach the ground virtually unobstructed over a wavelength range of height octaves. With the wide possibilities of observation in this range as yet only partially explored we must enquire carefully into the advantages of going beyond either at the microwave or long wavelength extremes. The difficulties need no emphasis. Apart from the practical problems common to all space experimentation, the basic difficulties in space radio observations are to obtain sensitivity at microwaves, and to obtain directivity at kilometric wavelengths. The microwave problem is so acute that we conclude immediately that our studies are confined to the solar system, and I shall pursue this line no further. At the long wavelength end there is adequate signal strength for at least a measurement of average sky brightness over a considerable frequency range and I enquire first about the significance of this simple measurement. The achievement of angular resolution is a possibility as yet almost unexplored, but this of course would be a very great advantage even if it were confined to beamwidths no smaller than 30°.

Observations made so far have had to contend with the difficulties presented by the ionosphere, both in its effects on the signals we observe and in its effects on our aerial systems. There is a risk in many observations that what intended as an astronomical observation becomes instead geophysical, as will be seen from the very interesting incidental results of all the experiments to be described later. The calibration of equipment must be arranged to take account of any ionospheric effects, both in the relation of receiver output to field strength, and in the relation of field strength to sky brightness.

The expected sky brightness

Accepting the view that satellite-based observations will never give the detailed results available from ground-based observations at higher frequencies, we must interpret our results by the use of models based on existing information. Under some special circumstances the ionosphere permits observations down to about 20 MHz over most of the earth, and down to 2 or 3 MHz for the particularly fortunate, such as Ellis in Tasmania. Those observers who have made particular efforts to obtain accurate spectra of different areas of sky, and from these to separate the spectra of galactic and extragalactic components, have not so far published any results below 26 MHz (Turtle *et al.*, 1962). This work is very important to us, for it indicates firstly that in the coldest parts of the sky the extragalactic component and the galactic component are roughly equal at 26 MHz and secondly that the extragalactic component has a steeper spectrum than the galactic. At 1 MHz if these spectra continue, the extragalactic component will dominate many times over, and our observations will only relate to the Galaxy because of its absorption rather than its emission.

Taking the separation made by Turtle, and extrapolating according to the latest spectral information, we can assign values to the various components of sky brightness expected at low frequencies. These I quote in units of flux density since this relates most simply to the measured quantity of field strength. To obtain sky brightness a division by 4 π is required. I have divided the sky into four typical regions :

A) Halo minimum, for example near α = 10 h, δ = 40 °N, where the extragalactic component will certainly predominate over the halo ;

B) Halo maximum, for example near α = 17 h, δ = 50 °N ;

C) Galactic Plane, where H II absorption is known to be overwhelmingly important ;

D) Anticentre, where a plane component of emission, H II absorption, and an attenuated extragalactic component may all be present.

I hope to publish details in a paper to be submitted to the Royal Astronomical Society, and I quote only the results here in a table.

We note particularly the importance of the extragalactic component. Near the plane I have excluded the effects of H II except that which has already been observed at higher frequencies, as given in the model derived by Westerhout from combining radio observations at high and low radio frequencies.

TABLE

The flux density, in units of 10^{-19} w.m.$^{-2}$ Hz^{-1}, expected from typical regions of the sky.

Frequency MHz	0.5	1.0	2.0	3.0	5.0
Extragalactic	3.2	2.0	1.2	0.9	0.65
Region A	3.9	2.5	1.6	1.25	0.95
» B	4.6	3.2	2.2	1.76	1.37
» C	0.31	0.25	0.20	0.18	0.16
» D	3.2	2.2	1.5	1.3	1.0

We note further that the theory of synchrotron emission does not lead us to expect any great departures from these flux densities, since the emission mechanism is very broad band and even drastic discontinuities in the energy spectrum of the cosmic electrons will not have much effect.

To sum up so far : we expect a flux density of about 2×10^{-19} at about 2 MHz, following the extragalactic spectrum $\nu^{-0.7}$. Let us look at the experiments.

Experimental values of flux density

There are two main experimental results available to me so far, those from Michigan and those from Cambridge. This is to some extent a result of the luck of the draw, as both Harvard and Jodrell Bank have flown experiments which have been unlucky in some way. (New results from Harvard will be presented at this meeting.) There is also Alouette, which although it is primarily an ionospheric experiment has given a spectrum down to 1.5 MHz and some specially interesting results on solar and Jovian emission. It did not, of course, set out to measure absolute values.

The Michigan results were presented by Walsh and Haddock at COSPAR in 1963. Their rocket flight gave for one region of sky the following main results :

(i) Flux density at

$$2.0 \text{ MHz} = 2.4 \times 10^{-19} \text{ w.m.}^{-2} \text{Hz}^{-1}.$$

https://doi.org/10.1017/S007418090017977X Published online by Cambridge University Press

(ii) **Flux density at**

1.225 MHz $= 1\ 2 \times 10^{-19}$ w.m.$^{-2}$ Hz^{-1}.

(iii) Large signals of ionospheric origin at 750 kHz, 1.225 MHz and 2.0 MHz when $1 < x < 1 - Y^2$ and $Y < 1$ and at 750 kHz when both $X > 1$ and $Y > 1$.

There was also some very good confirmation of dipole impedance theory. These results are now confirmed and supplemented by satellite Ariel II, with a receiver designed by Hugill and myself. The orbit Ariel II is at 52° inclination, perigee 200 kms, apogee 1400 kms. In our receiver the frequency sweeps continuously from 650 kHz to 3.5 MHz. The electric dipole aerial is 40 m tip to tip, providing signals large compared with receiver noise from an impedance which is low compared with the receiver input impedance. Measurement is therefore a direct measurement of electric field strength. The bandwidth is 20 kHz and the centre frequency sweeps linearly at about 120 kHz per second, with sweeps repeating at intervals of 28 seconds.

A series of frequency sweeps received by direct telemetry from near apogee is presented at this meeting by M. Harvey. The drop in flux density at frequencies below 2 MHz is evident, even allowing for a cut-off of the extraordinary wave near 1-2 MHz. We also see the large noise levels, reaching well into the logarithmic range of the receiver, and limited here to $1 < X < 1 - Y^2$. Harvey will speak about these, and particularly about the polarization which he has been able to determine from his work on satellite attitude

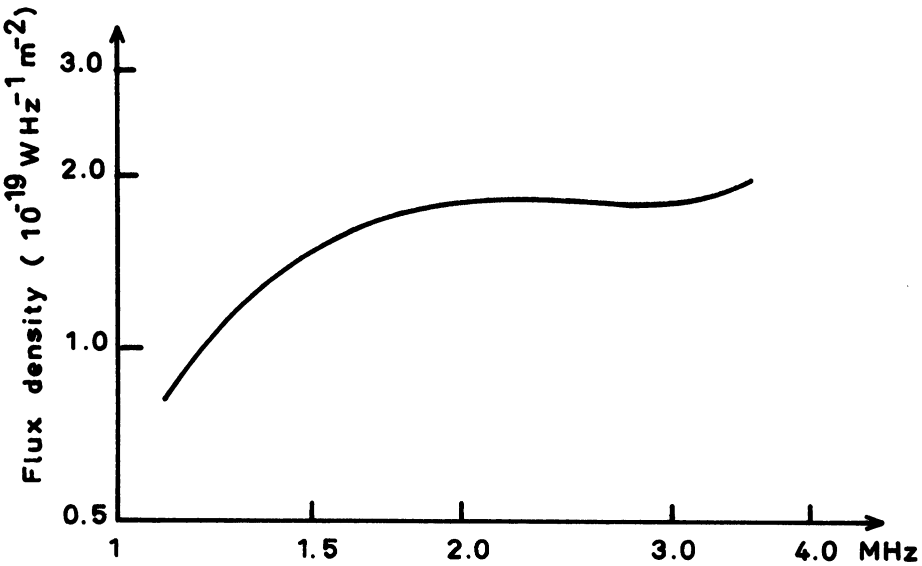

Fig. 1. — The average flux density recorded in a first series of measurements by Ariel II.

The provisional flux density values we obtain, without proper correction for ionospheric effects, are shown in the graph. This refers, as do the Michigan results, to one hemisphere of sky. We are looking for variations over different regions but not much variation is to be found or indeed to be expected from such a wide polar diagram.

The Low Frequency fall.

The fall in flux density may be accounted for by a deficiency in emission from the source, by an absorption in or near the source, or by absorption closer to the observer. In the source a sharply curved spectrum may be expected from the effect first discussed by Tsytovich (1951) in which synchrotron emission is reduced at low frequencies by the presence of ionized hydrogen. Ionised hydrogen can also absorb at low frequencies, and either of these processes can be invoked to explain the observed fall in the spectra of some discrete sources (Williams 1963). However, for the whole sky brightness to be reduced so steeply, all sources must be so affected together, and it seems necessary to turn to a local effect.

We conclude, as has already been concluded by Walsh *et al.* (1963), that the low frequency fall represents absorption in ionized hydrogen in the vicinity of the Sun. The fall would be explained by putting optical depth $\tau = 1$ in all directions

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at 1.4 MHz, so that we are situated in an H II region in which $n\sqrt{L} \simeq 0.07$. (Measuring n = cm^{-3}, L in Kpc). For example, L might be 0.2 Kpc, giving $n = 0.15$ cm^{-3}. The emission measure along a line of sight is approximately 5 cm^{-6} pc.

A similar result was obtained by HOYLE and ELLIS (1963), using the results of ELLIS *et al.* (1962) from ground-based observations The details of their argument are questionable, since they do not take account of the extragalactic component which becomes very important at the frequencies they considered, but the general result of such an analysis is bound to be similar to the present values.

The effects of this distribution of ionized hydrogen are very interesting. Not only does it absorb extragalactic radiation, but it may inhibit the emission of galactic radiation in the plane. The Tsytovich effect gives a cut-off at about 15 $\frac{n}{B}$ MHz where B is in microgauss, so that if for example $n = 0.15$ cm^{-3} and B = 1 we have no emission from the plane below about 2.5 MHz.

FOCUSSING

The crude calculations just made refer to an average sky brightness. If we could resolve detail to 30° or so, we could distinguish plane, halo, North Galactic Spur, and perhaps other features.

Ionospheric focussing is far from the simple matter suggested for example by SMITH (1961). At the O-wave focus a band of noise appears, wiping out the sky background. The E-wave focus is still possible, although the signal is confused by the presence of the O-wave It is important to analyse the actual shape of the polar diagram obtainable under reasonable conditions, and also to try in practice the effects of ionospheric irregularities in distorting the ideal beam.

FIELDS AND IMPEDANCES IN THE IONOSPHERE

Interpretation of any measurement of voltage or power at a receiver input requires an analysis of the effect of the ionosphere on the noise field (BUDDEN and HUGILL, 1963) and on the impedance of the antenna (KAISER, 1962, WEIL and WALSH, 1964). These are not trivial matters of receiver calibrations ; they require very detailed analysis in magneto-ionic theory. They have as much part in our discussions today as has the basic astronomy, but they do illustrate my thesis that low-frequency astronomy from satellites is always in danger of being a geophysical rather than an astronomical enterprise.

Manuscrit reçu le 27 septembre.

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Discussion

R. C. JENNISON. — In our work on focussing we became somewhat suspicious of the fickle conditions which might influence the narrow beams obtainable with the receiver operating close to the ambient plasma frequency. I therefore proposed the alternative technique of earth occultation on which a satellite orbit considerably further from the the earth is chosen. The edge of the directivity pattern resulting from the occultation and used to perform the spatial survey is much less likely to be severely affected by irregularities or ionospheric noise. I see no reason to retract this proposal in the light of the evidence which Prof. SMITH suggested might render narrow angle focussing of little use. I shall be glad of comments.

D. W. SCIAMA. — If Dr. SMITH is correct in attributing most of the low frequency background radiation to extragalactic space, then the absorption may also be occurring in extragalactic space. According to some cosmological theories the emission measure of the intergalactic gas has about the required value of 4 cm^{-6} *pc.* On this view the isotropy of the absorption would be naturally accounted for.