LETTERS TO THE EDITORS

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Rotating Universe ?

ONE of the most mysterious results of the astronomical studies of the universe lies in the fact that all successive degrees of accumulation of matter, such as planets, stars and galaxies, are found in the state of more or less rapid axial rotation. In various cosmogonical theories the rotation of planets has been explained as resulting from the rotation of stars from which they were formed. The rotation of stars themselves (in particular that of *B*-stars) can be presumably reduced to their origin from the rotating gas-masses which form the spiral arms of various galaxies. But what is the origin of galactic rotation ?

If, according to the current theories, we consider the galaxies as the result of gravitational instability of the originally uniform distribution of matter in space, we will find it very difficult to understand why such condensations are in most cases found in the state of rather fast rotation. In fact, on the basis of statistical distribution of angular momentum, we would rather expect such condensations to show no more rotation than the water droplets in a fog formed from oversaturated vapour. Barring the possible explanation of the rotation of galaxies on the basis of the alleged irregular turbulent motion of the masses of the universe, we can ask ourselves whether it is not possible to assume that *all matter in the visible universe is in a state of general rotation around some centre located far beyond the reach of our telescopes ?*

The answer to such, at first sight fantastic, question need not wait until much larger telescopes shall have been built. It can be, in fact, settled by present means of observation. We know that the rotation of the stars of our system around the galactic centre can be proved by the study of the so-called Oort-effect in the radial velocities of comparatively near stars. In fact, due to the phenomenon of differential rotation, the mean radial velocities of stars located along the galactic plane show a double-sine periodicity with nodal axes directed parallel and perpendicular to the line connecting the sun with the centre of rotation. Thus if the realm of galaxies as seen through Mt. Wilson telescope represents only a small part of a much larger system (a 'super-galaxy' in the super-Shapley sense) rotating around a distant centre, careful observations of mean radial velocities of galaxies located in different regions of the sky should reveal similar periodicity.

The existence of this effect would prove general rotation of the universe and indicate the direction towards the rotation centre without, however, giving us its distance. Thus, it seems that the answer to the problem of universal rotation lies within the grasp of modern astronomical technique.

It must be added in conclusion that in the language of the general theory of relativity such a rotating universe can be probably represented by the group of anisotropic solutions of the fundamental equations of cosmology.

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Conditions of Escape of Radio-frequency Energy from the Sun and the Stars

IN several communications in *Nature*[1,2,3,4] and elsewhere, various British, Australian and New Zealand workers have described experiments carried out during the War which prove conclusively that during times of solar disturbance there are large outbursts of radio-frequency energy from the sun. The wave-lengths measured vary from 1·5 metres to 30 metres (10 Mc. to 200 Mc.). On a rough estimate, the intensity of emission appears to be, as Appleton[1] has shown, 10^4 times the value calculated from the black-body formula taking $T = 6{,}000°$ K. If we assume that the radiation proceeds only from the active areas, as appears to be corroborated by the experiments now in progress at the Cavendish Laboratory, Cambridge*, the emissivity of these regions for the range mentioned is increased nearly 10^7–10^8 times the black-body radiation.

There are certain difficulties in the escape of these radiations from the sun to which attention may be directed. It has been found that the quiescent sun has, like the earth, a magnetic field of the order of 50 gauss, but the spots show a field of much higher range, from 100 gauss in the case of tiny spots to 4,000 gauss for the largest ones[5]. If the radio waves are generated anywhere within the outer layers of the sun, then they must follow the physical laws of electromagnetism. According to the magneto-ionic theory of Appleton, an electromagnetic wave of frequency f, generated anywhere on the earth's surface, can escape vertically from the earth only when the frequency of the waves exceeds certain limits, depending upon the maximum electron concentration above. The exact mathematical relations are

$$f_0^2 > \frac{4\pi Ne^2}{m} > 8{\cdot}0 \times 10^7 . N$$

$$f_e(f_e + f_h) > \frac{4\pi Ne^2}{m} > 8{\cdot}0 \times 10^7 . N.$$

Here N is maximum number of electrons per c.c. in the ionosphere, f_0 is frequency of the o-wave, f_e is frequency of the two extraordinary waves, f_h the characteristic gyro-frequency of the electrons under the total field H, $f_h = eH/4\pi$ cm. $= 1{\cdot}32\ H$ Mc. These conditions set a lower limit to the frequency of the radiations which can escape from the earth, and their validity has been verified by innumerable experiments.

If we apply these conditions to the sun, and also to the stars, we find at once that severe physical conditions have to be imposed on the emission of radio-waves from these bodies. Taking first the o-wave, we should have

$$\begin{aligned} N &< 1{\cdot}25 \times 10^{-8} . f^2 \\ &< 1{\cdot}25 \times 10^6 \text{ for } f = 10 \text{ Mc.} \\ &< 5 \times 10^8 \text{ for } f = 200 \text{ Mc.} \end{aligned}$$

The concentration of electrons in the different layers of the sun has been found by well-tried astrophysical methods[6] to have the mean values of 10^{13} per c.c. for the reversing layer, 4×10^{11} per c.c. for the mean chromosphere, and 4×10^8 per c.c. for the base of the inner corona. It is, therefore, obvious that o-radiations of radio-frequency range which we obtain from the sun cannot have their origin either in the reversing layer or the chromosphere, but only in the corona, and that also progressively in the outer layers as the wave-length is increased. But the corona has been shown to be a purely 'electron atmosphere' without any heavier atomic particles, excepting very small concentrations of heavily ionized Fe, Ni and Ca which produce the coronal lines. The mechanism of origin contemplated by Greenstein, Henyey and Keenan[7] which ascribes the radio-waves to recombination between protons and electrons therefore appears to fall to the ground in the case of the sun.

The e-waves. For the e-waves, the value of f_h is decisive, and this varies from 66 Mc. for the quiescent sun to roughly 4,000 Mc. for the spot, taking $H = 3{,}000$. These are frequencies of an order which are not contemplated in Appleton's theory, but a little work shows that whatever has been said regarding the o-wave also applies to *that* e-wave which corresponds to the condition $f_e(f_e - f_h) > 8{\cdot}10^7 \times N$ with greater emphasis. In fact, this wave cannot escape unless f_e has very high values, $>$ 66 Mc. The e-wave corresponds to the condition $f_e(f_e + f_h) > 8 \times 10^7\ N$.

The possibility of reception of this wave on the earth has generally been ignored by European and American workers, but it has been obtained distinctly on several occasions by Toshniwal[8] at Allahabad, and his findings have been confirmed by Leiv Harang[9]. Recently, Saha and B. K. Banerjee[10] have shown that any radio-wave generated on the earth would be decomposed into three waves as in inverse Zeemann effect, the p-component corresponding to the o-wave, and the S-components to the e-waves. If this deduction be accepted, we at once see that for the spots, the e-wave of this type has a far greater probability of escape ; for now we should have

$$\begin{aligned} N &< 1{\cdot}25 \times 10^8\ f_e(f_e + f_h) \\ &< 1{\cdot}25 \times 10^8\ f_e f_h, \text{ taking } f_h \gg f_e \\ &< 5 \times 10^8 \text{ for } 10 \text{ Mc. waves, and } < 10^{10} \text{ for } 200 \text{ Mc. waves ;} \end{aligned}$$

taking $f_h = 4{,}000$ Mc., corresponding to the field-strength of 3,000 gauss. For a quiescent sun, the figures are $N < 8 \times 10^6$ and $1{\cdot}4 \times 10^8$ respectively. Hence the probability of escape of these waves from the quiescent sun continues to be very small, if the wave originates in the deeper layers. For larger spots, the field generally increases and has been known to reach values as high as 4,000 gauss.

From these arguments, it is fair to draw the conclusion that the large spots are just the regions whence the e-waves of the frequency range 10–200 Mc. can escape. The value of the fields given above corresponds to the level where the atomic lines originate, but Chapman[11] thinks that fields might increase to even 10,000 gauss in the deeper layers. If this be true, the e-waves can originate even from much deeper layers. Further, it is well known that the spot is a region of far lower temperature, and the electron concentration in the spot is much lower than on the general surface of the sun ; this circumstance also helps the escape of the e-waves.

If these considerations be on the right line, the radio-waves received on the earth when a big spot is in the centre of the sun's disk should be circularly polarized, and its sense of polarization will be determined by the sign of the field.

These considerations apply equally well to the stars composing the Milky Way region, from which waves in the metre range have been observed[3]. They cannot be emitted from the surface of the hotter stars, but from cooler stars of G-, K- and M-type, and probably the escape of the radiation is facilitated by the development of spots in these stars, analogous to the case of the sun. The difficulties of the dilution factor pointed out by Greenstein *et al.*[7] are therefore eased to a large extent, as, according to Dunham[12], the disk area covered by K- and M-stars is nearly 10^4 times that of B-stars.

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[2] Hey, Phillips, Parsons, *Nature*, **157**, 297 (1946).
[3] Hey, *Nature*, **157**, 47 (1946).
[4] Pawsey, Payne-Scott, and McCready, *Nature*, **157**, 158 (1946).
[5] Nicholson, *Pub. Astro. Soc. Pacific*, **45**, 51 (1933).
[6] See for reference, Unsold, "Sternatmosphare", 82, 436, 440.
[7] Greenstein, Henyey, Keenan, *Nature*, **157**, 806 (1946).
[8] Toshniwal, *Nature*, **135**, 471 (1935).
[9] Harang, *Terr. Mag.*, **41**, 143 (1936).
[10] Saha and Banerjee, *Ind. J. Phys.*, **19**, 159 (1945).
[11] Chapman, *Nature*, **124**, 19 (1929).
[12] Dunham, *Proc. Amer. Phil. Soc.*, **81**, 277 (1939).