LETTERS TO THE EDITOR

ASTROPHYSICS

A Sensitive Test for the Presence of Atomic Hydrogen in Intergalactic Space

FIELD[1] has stressed the importance of the scattering of Lyman-α quanta on hydrogen atoms in determining the spin temperature of intergalactic hydrogen. The purpose of this communication is to point out that the scattering itself provides an extraordinarily sensitive indication of the presence of atomic hydrogen.

According to Field[1] (equation 11) radiation emitted at wave-lengths shorter than Lyman-α is scattered:

$$N = 2{\cdot}4 \times 10^{10}\ n_{\text{H}}$$

times while it is red-shifted through the Lyman-α line. (Field assumed that Hubble's constant is 180 km/sec Mpc, but the order of magnitude of N should be correct in any case.) Thus, with a typical 'cosmological' density of $n_{\text{H}} = 10^{-5}$ atoms cm^{-3}, a quantum emitted with a wave-length shorter than Lyman-α is scattered 10^5 times, and has a negligible chance of continuing in its initial direction. Even a density of 10^{-9} atoms cm^{-3} would very effectively scatter such radiation. Thus, if any radiation is observed from a discrete extragalactic source in the range of wave-lengths between the local and the red-shifted Lyman-α wave-lengths, the density of hydrogen atoms in intergalactic space is $\leqslant 10^{-9}$ cm^{-3}.

Ultra-violet spectroscopy by rocket or satellite-borne telescopes cannot, as yet, reach the galaxies one would wish to examine. However, Schmidt[2] has shown that the optical object associated with the radio source 3*C* 9 has a red-shift $z = 2{\cdot}012$, and its Lyman-α emission line is red-shifted into the visible spectrum. Schmidt's paper is concerned only with the two emission lines of 3*C* 9, and there is no explicit mention of a continuum. The Lyman-α line is some tens of Å units wide, and the fact that the centre of the line is not noticeably displaced might already be considered as evidence that there is no noticeable scattering within the first Mpc around 3*C* 9. However, it is quite possible that 3*C* 9 has a peculiar velocity of a few 100 km/sec, and it is also possible that intergalactic hydrogen in the vicinity of 3*C* 9 is exceptionally highly ionized. Thus a decision must await a new examination of Schmidt's spectrum.

If the scattering were appreciable, then the radiation emitted at a particular frequency would be scattered from a spherical shell around the source, the radius of which is proportional to the difference between the emitted wave-length and Lyman-α. Observation of such scattered light would, in principle, yield Hubble's 'constant' as a function of z, and hence provide a history of the expansion of space. Unfortunately, the detection of such faint radiation distributed over disks many minutes of arc in diameter is beyond the reach of observation.

If it turns out that 3*C* 9 has a continuum below 3660 Å, then either the mean density of hydrogen is exceedingly low, or its ionization is very complete. The conditions required to produce such complete ionization will be examined elsewhere. A third possibility, that the red-shift of 3*C* 9 is not cosmological[3], cannot be ruled out at present.

Note added in proof. I understand from Dr. Schmidt that work on the lines suggested in the foregoing letter has been carried out independently by Gunn and Peterson (*Astrophys. J.*, in the press).

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[1] Field, G. B., *Astrophys. J.*, **129**, 536 (1959).

[2] Schmidt, M., *Astrophys. J.*, **141**, 1295 (1965).

[3] Terrell, J., *Science*, **145**, 918 (1964).

RADIOPHYSICS

Ordinary Mode Whistlers observed in Satellites

SMITH *et al.*[1] recently published dynamic spectra of a very interesting phenomenon observed in the satellites *Alouette I* and *Injun III*. One of these is reprinted here as Fig. 1*A*. This shows a whistler (rapidly falling part) produced by (extraordinary mode) dispersion of an atmospheric propagated upwards to the satellite. The whistler is followed by a rising trace which flattens out at a frequency which could correspond to the ion gyrofrequency.

Although such a sequence of events may suggest a 'triggering' process for the rising trace[1], I would like to show that the spectral (frequency-time) shapes of both traces can be closely matched if both are interpreted as dispersed forms ('whistlers') of the original atmospheric. Thus the falling trace is an extraordinary mode whistler and the rising part an ordinary mode whistler.

The ordinary mode can propagate only below the ion (proton) gyrofrequency. For frequencies very much less than the electron gyrofrequency, the refractive indices (for longitudinal propagation) become[2]:

$$n^2 = a(g \pm f)^{-1}$$

where g is the proton gyrofrequency, f the wave frequency, and a the scale frequency (ratio of plasma frequency squared to the gyrofrequency, for either protons or electrons). The plus and minus signs correspond to the extraordinary and ordinary modes respectively ($f < g$ for the latter). I have assumed a neutral plasma of electrons and protons only. The group refractive indices are then (signs as above):

$$n_G = a^{1/2}(g \pm \tfrac{1}{2}f)\,(g \pm f)^{-3/2}$$

The travel times of waves in the two modes can be calculated from this with an appropriate model. Fig. 1*B* shows the result of such a calculation using parameters (a,g and path length) to fit the observed dynamic spectrum in Fig. 1*A*.

The agreement for both modes is quite reasonable. Effectively only two independent parameters can be chosen to obtain a fit. These determine the time and frequency scale. The shape is mainly determined by the refractive index expression given here and only slightly by the model or form of the plasma density and magnetic field variation. The effects of other ions do not appear to be important.

Jacobs and Watanabe[3] have suggested that certain types of micropulsations which have dynamic spectral shapes like the rising part shown in Fig. 1*A* might be such ordinary mode whistlers (they used the term