Colloque de l'Union Astronomique Internationale
N° 37 – DECALAGES VERS LE ROUGE ET EXPANSION DE L'UNIVERS

A SEARCH FOR NEUTRAL HYDROGEN IN PRIMORDIAL PROTOCLUSTERS

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Résumé :

La prévision de Sunyaev et Zel'dovich que les proto-amas peuvent passer par une phase d'hydrogène neutre pendant leur formation a été testée par la recherche de leur émission de la raie d'hydrogène décalée vers le rouge. Des limites supérieures comprises entre 0.07 et 0.17 °K ont été obtenues dans une bande de 2.5 MHz à 327 MHz ce qui correspond à un décalage vers le rouge de z = 3.33. Ces résultats indiquent qu'il ne peut pas exister plus de proto-amas d'hydrogène que la quantité calculée par ces auteurs.

I . INTRODUCTION

It is generally assumed that galaxies have formed out of neutral gas. A residuum of this promordial neutral gas is still seen in the nearby (low redshift) late type galaxies. It is of particular interest to discover this neutral gas phase in galaxy formation which occurs between the hot Big Bang (in the conventional picture) and the present luminous galaxy epoch. This neutral phase evidently occurs before $z \sim 1$, the epoch of the furthest detected normal galaxies. Indeed the quasars which may also be taken as indicators of galaxy formation, are found out to $z \sim 4$.

This suggest that not all material would be in the hot gas phase at this epoch. A search for H-line emission from neutral protogalaxies at such an epoch would appear to be worthwhile. In order for this line emission to be detectable with present day techniques it is necessary to consider clusters rather than individual galaxies.

A quantitative assessment of the hydrogen line emission from protoclusters has been made by Sunyaev and Zel'dovich (1972, 1975). They predict that protocluster emission would be detectable in the range z = 3-10 from a neutral hydrogen mass of $\sim 10^{14}$ $M_\odot$ at a temperature of $\lesssim 10^4$K.

II . THE OBSERVATIONS

The present search for protoclusters was made at a frequency of 328 MHz in a bandwidth of 2.5 MHz. This band also included the 271 α radio recombination line ; the detection of recombination lines from a number of galactic sources provided a check on the performance of the observing system. The Mark IA radio telescope (diameter = 76m) was used for this experiment ; it has a beamwidth of 50 arcmin at this frequency. Simultaneous observations were made of the emission in orthogonal linear polarizations in order to improve sensitivity. 512 channels of the Jodrell Bank 1024 channel autocorrelation spectrometer were used on each polarization. The resulting frequency resolution was 8.8 kHz. The use of such a high frequency resolution relative to the predicted astronomical signals (100 to 1200 kHz) enabled continuous wave interference to be identified and eliminated from the analysis. Interfering signals could also be distinguished from protocluster emission because the former are polarized and latter are unpolarized.

The observations were made by switching the beam between pairs of fields separated by 2° in the sky. The difference in signal from each pair of fields was recorded, so that the emission from a protocluster in one or other field would be detected as a positive or negative feature in the 2.5 MHz bandwidth spectrum. Regions chosen for observation were in areas of low background continuum brightness ($\sim$ 30K) lying at intermediate galactic latitudes. One group was centred at ℓ = 110°, b = -40° and the other at ℓ = 170°, b = 50°. Periods of 3 to 7 hours clear of confusing interference were spent on observations of each of 10 beam pairs (i.e. 20 beam areas in total). Upper limits of 0.07 to 0.17K were set on the emission from various beam areas. These upper limits referred to line emission features whose widths were in the range 100 to 1200 kHz (which correspond to ΔV=90 to 1100 km s^{-1} and $\Delta z = 1.3 \times 10^{-3}$ to 1.5×10^{-2}). More details of the observations are given in a paper to be submitted to the Monthly Notices of the RAS.

III. DISCUSSION

The predictions of the Sunyaev and Zel'dovich model can be compared directly with the observations. A protocluster mass of 3×10^{14} $M_\odot$ and a diameter of 2 Mpc, as deduced for nearby (low z) clusters are appropriate parameters for the early epochs considered in the model. Half the total mass is taken to be neutral gas of which 70% by mass is hydrogen and 30% is helium. The neutral hydrogen line integral through such a cluster (assumed spherical) is

$$n_H \ell = 6.4 \times 10^{21} \text{ atoms cm}^{-2}$$

https://doi.org/10.1017/S0252921100053690 Published online by Cambridge University Press

The velocity dispersion of the protocluster can be estimated on the basis that it is gravitationally stable. This leads to an upper limit of the observed velocity dispersion of $1100/\sqrt{3} = 660$ km s^{-1}. A total velocity width (ΔV) would be a reasonable upper limit for a stable cluster where $\Delta V = 660$ km s^{-1}.

The brightness temperature T_b expected from the cluster is related to the neutral hydrogen line integral by

$$T_b = 5.44 \times 10^{-19} \; (\Delta V)^{-1}.\; n_H \ell \;=\; 3.5 \times 10^3 \;\; (\Delta V)^{-1}$$

Where ΔV is in km s^{-1}. The brightness temperature actually seen by the observer is $T_b{}^1 = T_b/1 + z$. At the 328 MHz ($z = 3.33$) observing frequency this becomes

$$T_b{}^1 = 1.2 \text{ K for } \Delta V = 660 \text{ km s}^{-1}$$

$$\text{or } 2.5 \text{ K for } \Delta V = 330 \text{ km s}^{-1}$$

The aerial temperature observed will depend upon the relative size of the protocluster and the aerial beam. Sunyaev and Zel'dovich estimate a typical diameter of 10 arcmin at this value of z ; the precise value depends upon the cosmological model chosen. With the present observing beamwidth of 50 arcmin the expected aerial temperature is

$$T_a = 0.05 \text{K for } \Delta V = 660 \text{ km s}^{-1}$$

$$\text{or } 0.10 \text{K for } \Delta V = 330 \text{ km s}^{-1}$$

The probability of observing a protocluster in the beam within a given bandwidth depends upon their lifetime in the neutral state Sunyaev and Zel'dovich assume to be 10% of their cosmological age. the total number of such protoclusters is $\sim 2 \times 10^5$ and accordingly in the annular shell sampled by the bandwidth there will be 1500 over the whole sky.

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This corresponds to one protocluster per 27 $(\deg)^2$. The present survey has covered 14 $(\deg)^2$ at a sensitivity greater than the half power response and 26 $(\deg)^2$ at greater than the quarter power response. Thus the predictions indicate that with the present sensitivity one protocluster would have been seen in the 20 beam areas searched. If a protocluster in a beam contained more than 2×10^{14} $M_{\odot}$ of neutral hydrogen or its velocity width were less than 600 km s^{-1} it would have been readily detectable.

We thus conclude that there are not significantly more protoclusters than the numbers estimated by Sunyaev and Zel'dovich. A sensitive search for protoclusters at larger values of z is planned. Such an extension is necessary since the epoch of condensation into the neutral phase is not known with any precision.

REFERENCES

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DISCUSSION

B.M. LEWIS: The z = 3.35 epoch is rather late to see HI protoclusters for most cosmologies, is it not, and in more extreme cosmologies such as those with ($\rho \sim t^{-1}$), galaxy formation in proto-clusters is likely to be completed by about 2×10^8 years after the beginning of the expansion.

R.D. DAVIES: As judged by the cut-off in the numbers of observed QSOs at $z \sim 4$, it would seem that a study of protoclusters at z = 3-4 would be justified. Further searches at larger values of z are planned; the era of protocluster formation (particularly the neutral phase) is clearly very uncertain since it depends upon the particular cosmology assumed.

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B.J.T. JONES: Was the 10' angular diameter calculated for a $q_o = 0$ cosmological model?

R.D. DAVIES: A value of about 10' arc is obtained for a range of cosmological models investigated by Sunyaev and Zel'dovich, including the $q_o = 0$ case.

S. SHOSTAK: Can you comment on the sensitivity of your experiment to broad velocity features? Protogalaxies might be expected to have velocity dispersions of thousands of kilometers per second. At what level can broad features be distinguished from instrumental baseline effects?

R.D. DAVIES: The 2·5 MHz bandwidth used in this experiment is equivalent to a velocity range of 2000 kms^{-1}. The estimated velocity widths of the protoclusters is less than 1000 kms^{-1} to ensure the necessary gravitational binding. A beam switching technique was used with two 512 channel receivers as described in the text. The limits given were for broad features. Noise fluctuations in the band were much less (a factor of 3 to 10) than the tabulated limits.

J.-C. PECKER: What would be the number of protoclusters predicted in the case of a completely static universe? Would it be compatible with your upper limit?

R.D. DAVIES: Yes, the number would be similar. Details of the calculations are given in the Sunyaev and Zel'dovich papers.

G. DE VAUCOULEURS: Why not use a larger disk to better match the beam width to the expected size of the HI clouds?

R.D. DAVIES: Indeed a smaller beam would be an advantage, however more beam areas have to be covered to make a detection. The prediction is that the protoclusters cover only 0.1 percent of the sky in the bandwidth used. Further, a receiver with a large number of channels (~ 1000) is required to eliminate continuous-wave interference propagated via the ionosphere. Long integrations are also needed.

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