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HII REGIONS IN ABSORPTION AT LOW FREQUENCIES

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ABSTRACT

This paper reviews the information provided by the analysis of low radio frequency observations of HII regions seen in absorption against the Galactic background radiation. Man-made terrestrial interference and effects of the earth's atmosphere/ionosphere make the far-side of the moon the ideal location for such observations. The technique is illustrated by analysis of 30.9 MHz observations of the W51 Giant HII complex.

INTRODUCTION

The absorbing property of ionized gas in the Interstellar Medium (ISM) at low radio frequencies is a powerful tool for Galactic astrophysics. Dulk and Slee (1972, 1975) and Kassim (1989) have used the low frequency turnovers in the spectra of Galactic Supernova Remnants (SNRs) to constrain the distribution of ionized gas in the ISM responsible for the absorption. Kassim and Weiler have used the appearance of an HII region in absorption against the SNR G8.7-0.1 to set a lower limit to its distance and thus suggest a possible association with the very young pulsar PSR18-00-21 (Kassim and Weiler 1990). In this paper we explore the information obtained from observing HII regions in absorption against the Galactic background, applicable to observations in the 10-100 MHz regime. We review an analysis of 30.9 MHz observations of W51 by Kassim (1987,1988) as an example of the application of the technique. Reynolds (1990) has suggested that the techniques we describe below may also be used to explore the properties of the Warm Ionized Medium (WIM) component of the ISM at even lower radio frequencies (<5 MHz).

Unfortunately, low frequency observations from the surface of the earth are severely hampered by man made terrestrial interference, and below 10 MHz are impossible because of the opacity of the earth's ionosphere. Observations from a low frequency telescope located on the far-side of the moon would be free of such interference and opacity effects. Thus the far-side of the moon presents the ideal location for carrying out observations capable of exploiting the techniques described below.

OBSERVATIONS

Figs. 1 and 2 show 30.9 MHz continuum maps from the Clark Lake Galactic plane survey (Kassim 1988). Notice the large number of deep absorption regions (black holes) located towards the inner Galaxy, and note how their effects decrease with increasing Galactic longitude. Rarely would such absorption regions be seen in areas other than towards either the first or fourth Galactic quadrants.

GEOMETRY

Fig. 3 is a simple diagram which illustrates the relevant geometry. The telescope is pointed towards the inner Galaxy, and a foreground (i.e. nearby compared to the distance to the Galactic center) HII region is located along the line-of-sight.

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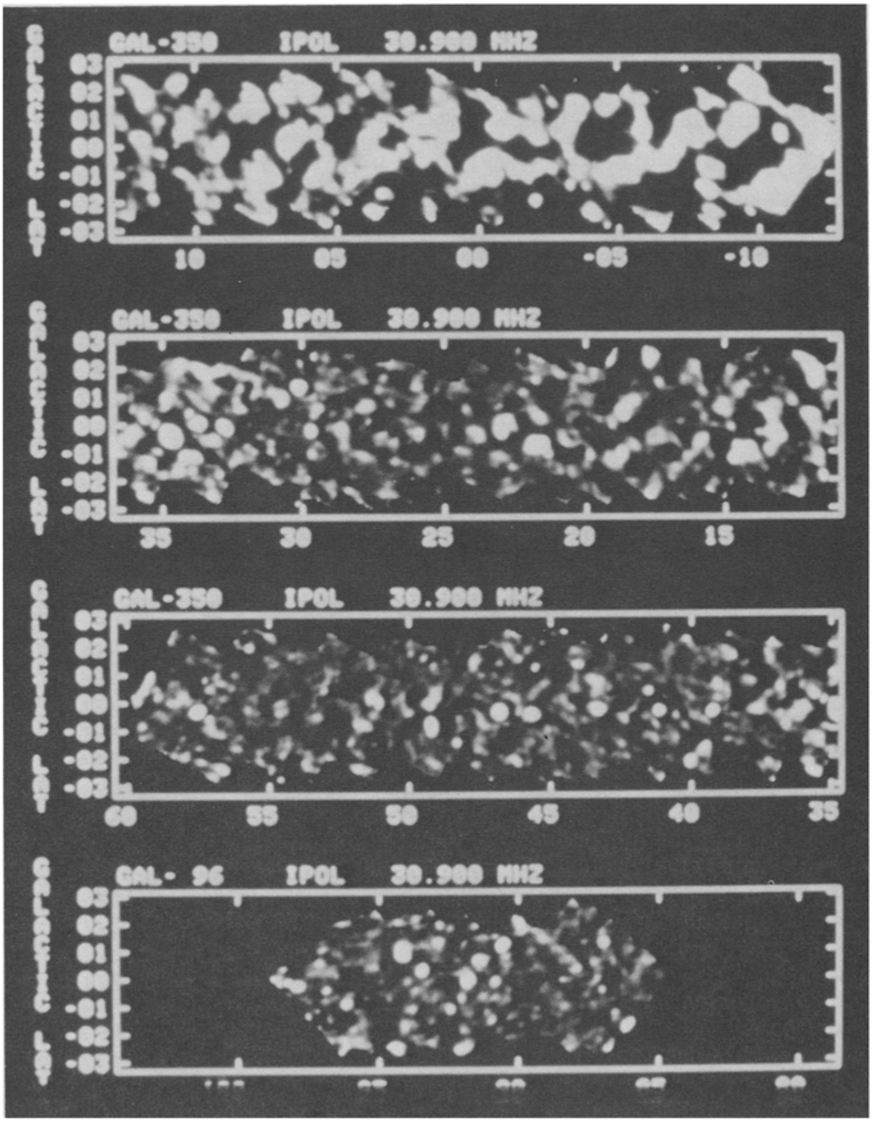

Fig. 1: Grey scale photograph of 30.9 MHz continuum maps of the inner Galaxy taken from the Clark Lake Galactic Plane Survey (Kassim 1988). Each strip is centered on the Galactic equator and extends over Galactic latitude ~b = ±2.5°. Galactic longitude increases from right to left and each strip covers approximately as follows: Strip #1: l=-12° to +12°; Strip #2: l=10° to 36°; Strip #3: l=35° to 60°; Strip #4: l=85° to 98°. The resolution of the "T" shaped array used to make the maps is approximately 15 arcminutes at the zenith. Dark "holes" concentrated towards the lowest longitudes are discrete absorption holes produced by foreground HII regions. The W51 HII region complex appears as a depression near l=49°, b=-0.5° on Strip #3.

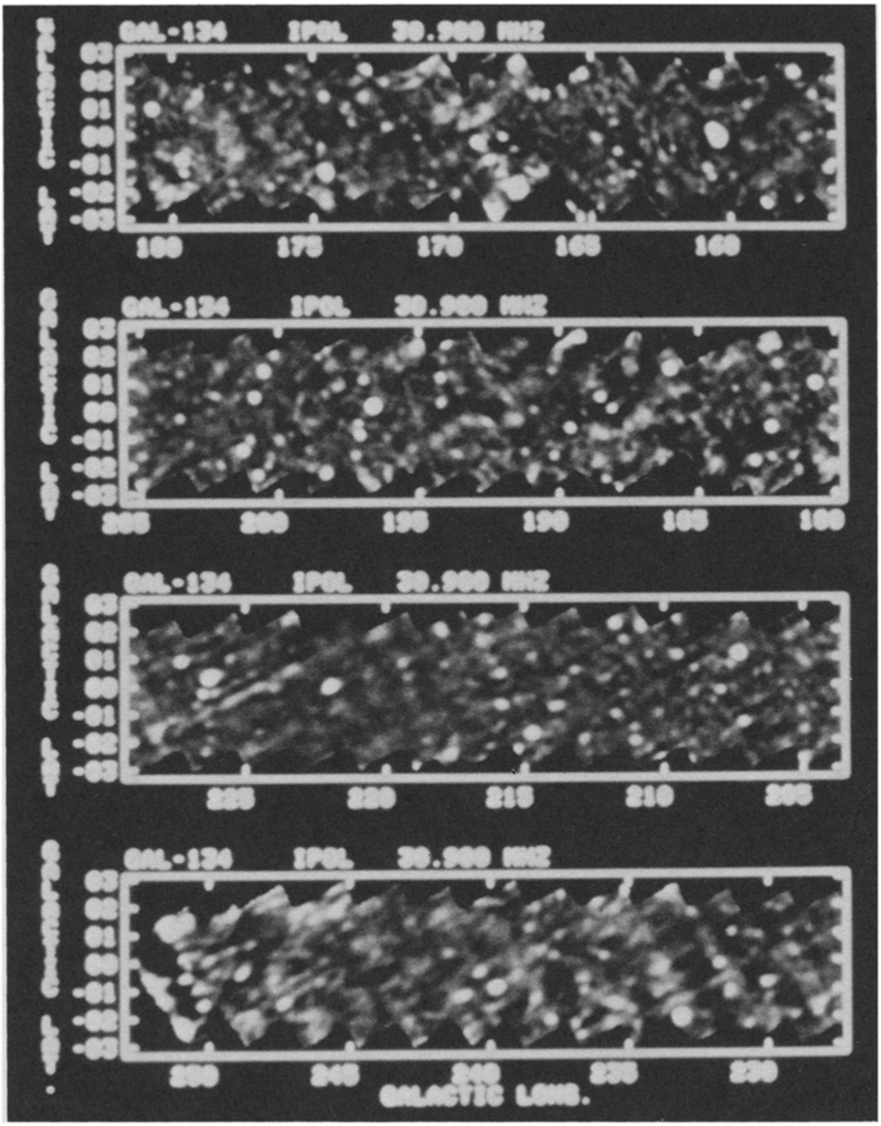

Fig. 2: Grey scale photograph of 30.9 MHz continuum maps made towards the outer Galaxy taken from the Clark Lake Galactic Plane Survey (Kassim 1988). Strip scans are the same as in Fig. 1 except that the coverage in Galactic longitude is as follows: Strip #1: l=155° to +181°; Strip #2: l=180° to 205°; Strip #3: l=204° to 229°; Strip #4: l=227° to 252°. Source counts (Kassim 1987) confirm that most of the sources seen here are extragalactic, i.e. the view is essentially the extragalactic sky. (The small region beyond l=250° is distorted by edge effects and should be ignored.)

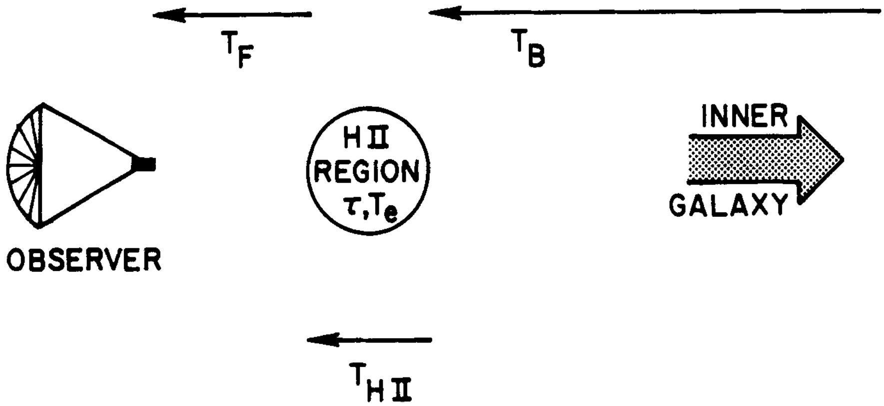

Fig. 3: Simplified HII Region Absorption Geometry

The following quantities are defined as follows:

T_{HII} = observed brightness temperature of the HII region
T_e = electron temperature of the HII region
τ = free-free optical depth of the HII region
T_B = component of the Galactic synchrotron emissivity originating on the far side of the HII region.
T_F = component of the Galactic synchrotron emissivity originating on the near side of the HII region.
$T_T \equiv T_B + T_F$

SIMPLE ANALYSIS

Consider the simplest case of a large, optically thick HII region with optical depth $\tau \gg 1$, i.e. $T_{HII} = T_e$. If this HII region is a foreground object observed along the line-of-sight towards the inner Galaxy with a single-dish telescope with infinite resolution, then Fig. 4 illustrates the picture that emerges as one scans the telescope beam across the Galactic plane.

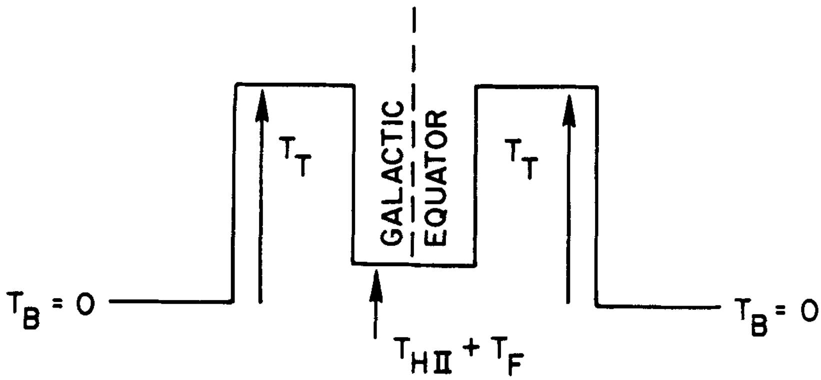

Fig. 4: Simplified illustration of single-dish scan across HII region.

Now, at 30.9 MHz we have roughly:

$$T_T \sim 100{,}000 \text{ K},\ T_{HII} = T_e \sim 10{,}000 \text{ K},\ T_F \sim 10{,}000\text{K} \tag{1}$$

Therefore:

$$T_{HII} + T_F \sim 20{,}000\text{K} < T_T \tag{2}$$

and so the HII region appears as a depression on the map. If the same observation were conducted with an interferometer which has no zero-spacing, i.e it cannot measure T_T, then the scan would like Fig. 5.

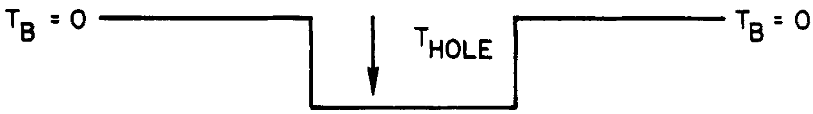

Fig. 5: Simplified illustration of interferometer scan across HII region.

In this case the HII region actually appears as a "HOLE" on the map. This is because:

$$T_{HOLE} = T_{HII}+T_F-T_T = T_{HII}+T_F-[T_F+T_B] \tag{3}$$

and therefore

$$T_{HOLE} = T_{HII}-T_B < 0 \tag{4}$$

THEORY

In general, the depth of the depression T_D observed towards an optically thick HII region at some position in the sky (α,δ) at some low frequency f is given by the following relationship:

$$T_D(\alpha,\delta,f) = T_T - [T_F + T_B e^{-\tau} + T_e(1-e^{-\tau})] \tag{5a}$$

$$= (T_e-T_B)\{1-e^{-\tau}\} \tag{5b}$$

or in the most general case where T_x is the brightness contribution from the extragalactic background and $P(\alpha,\delta)$ is the normalized polar diagram of the antenna power pattern:

$$T_D(\alpha,\delta,f) = [T_e-T_B(f)-T_x(f)] \times \int\{1-\exp[-\tau(\alpha+\alpha',\delta+\delta',f)]\} \times P(\alpha',\delta')d\alpha' d\delta' \tag{6}$$

For simplicity, if we ignore the antenna pattern of the telescope (i.e. assume infinite resolution) and ignore T_x, we arrive at the following basic (simplified) relationship:

$$T_D=[T_e-T_B] \times (1-e^{-\tau}) \tag{7}$$

TECHNIQUE WITH MEASUREMENTS AT ONE (LOW) f

Simplest Case: Assume $\tau >> 1$, assume T_e

If we measure T_D >>>>>>>>>>>>>>>>>>>> Solve for T_B

If we can measure T_D and T_T >>>>>>>>>> Solve for T_B and T_F
(i.e. if we can measure a zero spacing flux)

If we can measure T_D and T_T, >>>>>>>> Solve for T_B, T_F, and the Galactic
and we know the distance to Emissivity
the HII region

Next Simplest Case: Assume T_e but estimate τ from higher frequency measurements:

Estimating τ:
>>>>> From Recombination line observations
or
>>>>> From optically thin continuum maps where the approximation $T_{brightness} \sim \tau T_e$ is valid.

TECHNIQUE WITH MEASUREMENTS AT MORE THAN ONE f

If we can make measurements of T_D at 2 sufficiently spaced low frequencies (say 30 and 60 MHz), then:

If we can measure T_D and T_T, >>>>>>>> Solve for T_B, T_F, the foreground
and we know the distance to Galactic emissivity AND T_e
the HII region i.e. need only get τ from higher frequency data.

GENERALIZATION: HII region absorption "HOLES" observed at low frequencies depend on a number of interesting parameters. With only a single measurement most of these must either be assumed or estimated from higher frequency data and, if appropriate, be extrapolated to the lower frequency. If one is able to make more than one low frequency measurement then the dependance on either assumptions or results obtained from higher frequency data is decreased.

APPLICATION TO 30.9 MHZ OBSERVATIONS OF W51

The HII region W51 appears as a depression on Fig. 1 near l=49°, b=-0.5°. The following simplified analysis summarizes results originally presented by Kassim (1987).

1) Measure T_{HOLE} = -35,000 K @ 30.9 MHz towards W51.
2) Assumption of $\tau >> 1$ is supported by both recombination line data and optically thin continuum measurements.
   Therefore: $T_{HOLE} = T_e - T_B - T_x = -35{,}500$ K
3) $T_e \sim 7{,}500$ K from recombination line observations.
4) $T_x \sim 3{,}700$ K from the model by Bridle (1967).

SOLVE FOR : $T_B = 39{,}300 \text{ K} \pm 4{,}000 \text{ K}$

This result compares well with results of Desphande and Sastry (1986) based on 34.5 MHz observations using the Garibidinauer telescope of T_B (@30.9 MHz) = 37,100 K ±3,000 K.

5) Use estimate of T_T from "old" low frequency surveys:

$T_T \sim 14{,}800$ K from [Milogradov-Turin and Smith 1974; Parish (1972); Cane (1978)]

SOLVE FOR $T_F = 14{,}800$ K

6) If W51 is at 6.5 kpc (Beiging 1975):
   SOLVE FOR: Line-of-sight Synchrotron Emissivity=2.3 K/pc

Comparison with results of others:
Deshpande and Sastry (1986): 2K/pc
Milogradov-Turin (1974): 2-3 K/pc
GOOD AGREEMENT (i.e. we must be doing something right)

SUMMARY

At low radio frequencies, foreground HII regions seen in absorption towards the inner Galaxy will make the Galactic Plane look like "Swiss Cheese". Measurements of these holes can be combined with a variety of higher frequency data to constrain the following physical parameters:

T_e = Electron Temperature of the HII Region
τ = Optical Depth of the HII Region
T_B = Brightness Temperature Component of the Distributed Galactic Synchrotron Emission from behind the HII region
T_F = Same as T_B but from in front of the HII Region
E = Synchrotron Emissivity originating along the line-of-sight to the HII region;
IMPORTANT TO COSMIC RAY PHYSICS because:
COSMIC RAYS+GALACTIC B FIELD = DISTRIBUTED GALACTIC SYNCHROTRONEMISSION

Distances: HII Region distance ambiguities can also be resolved since only "near" (i.e. foreground) HII regions would appear in absorption.

From earth the low frequency observations required to exploit the techniques we have described are hampered by man made terrestrial interference and the opacity of the earth's ionosphere.

THEREFORE THE BEST PLACE TO MAKE THE OBSERVATIONS DISCUSSED IN THIS PAPER WOULD BE FROM THE FAR SIDE OF THE MOON

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