A STUDY OF RADIO RECOMBINATION LINES FROM THE GALACTIC PLANE AT 325 MHz

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By

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DECLARATION

I declare that the work presented in this thesis has been conducted by me in the Raman Research Institute, Bangalore, India. No part of this work has been submitted for the award of any other degree, diploma, associateship, fellowship or any similar title.

(K.R. ANANTHARAMAIAH)

CERTIFIED

(V. RADHAKRISHNAN, GUIDE)

(P. PARAMASIVIAH, GUIDE)

CERTIFICATE

We certify that this thesis has been composed by K.R. Anantharamaiah based on investigations carried out by him at the Raman Research Institute, Bangalore, India, under our supervision. The subject matter of this thesis has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar title.

(V. RADHAKRISHNAN, GUIDE)

(P. PARAMASIVIAH, GUIDE)

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SYNOPSIS

Studies of radio recombination lines are useful in understanding the distribution, kinematics and thermodynamic .properties of the ionized gas in the galaxy. Recombination lines mainly of hydrogen and helium, and to some extent of carbon have earlier been observed over a wide range of frequencies from 86GHz to 26MHz corresponding to the transitions from principal quantum number levels n=42 and n=630 respectively. From many such studies it has now become clear that there is a whole hierarchy of ionized regions with different densities, temperatures and sizes distributed in different ways in the galaxy.

In a heterogeneous medium, recombination line observations at different frequencies sample different components of the ionized gas. In particular, recombination line emission at low frequencies (<1GHz) is expected to be dominated by low density ionized regions. Those at high frequencies originate in high density ionized gas typical of HII regions prominent in most radio continuum surveys. This is because low frequency line emission from high density gas is suppressed due to opacity and pressure broadening, while from low density regions it is enhanced by stimulated emission in the presence of strong background continuum sources or even the nonthermal galactic background. Frequencies below 500MHz are best suited to study conditions in cold partially ionized gas and in large low density ionized regions. For the latter, beam dilution due to the poorer angular resolutions available at low frequencies is also not important.

Most existing large scale recombination line surveys of the galaxy have been carried out at frequencies higher than 1 GHz. Below 500 MHz, there are only a handful of observations made towards a few selected sources in the galactic plane. Weak recombiation lines have been detected at centimetric wavelenghts at several pdsitions along the galactic ridge. These lines, which are known as 'galactic ridge recombination lines', were initially thought to be coming from cold partially ionized clouds in the interstellar medium but are now believed to be due to low density hot gas, presumably weak HII regions. However, there are no comparable observations at frequencies below 500MHz to help understand these galactic ridge recombination lines.

In this thesis we present observations and interpretaion of recombination lines from the galactic plane at a frequency of 325 MHz corresponding to a transition from principal quantum number n=273 to n=272. This study is based on observations made towards 53 directions in the galactic plane using the Ooty radio telescope which operates at a nominal centre frequency of 326.5 MHz.

The present observations made over a period of 3 years constitute the first major spectral line study carried out using the Ooty telescope. In the first part of this thesis we describe in detail the equipment, observing procedure, the precautions necessitated by the use of such a phased array telescope for line studies and the data reduction methods .

The 53 directions in the galactic plane chosen for this study consist of 34 directions corresponding to well known HII regions, 12 corresponding to supernova remnants and 6 directions of continuum minimum which we call as 'blank regions'. The majority of the observed directions lie in the first quadrant of the galaxy but a few sources were selected in the anticentre direction where the nonthermal galactic background is considerably weaker. Observations towards the HII regions were used to study the properties of low density ionized gas associated with them, and those towards SNRs and blank regions to study any low density ionized gas along the line of sight.

In this thesis we present the results of these observations. Hydrogen recombination lines (H272α) were detected in 47 of the 53 directions observed and possibly carbon recombination lines

(C272α) in 12 of these directions. The intensity of the recombination lines detected in this study were found to correlate well with the total continuum intensity in all directions observed irrespective of whether the direction corresponds to that of an HII region, an SNR or a blank region. As the continuum radiation at this frequency is mainly nonthermal in origin, the correlation observed indicates that most of the lines arise due to stimulated emission by the background radiation.

We show in this thesis that most of recombination lines observed here are not produced within the HII regions which are prominent continuum sources in the galactic plane; they are shown to be coming from low density outer envelopes of the HII regions. Applying the theory of formation of recombination lines to the line parameters observed here and in other observations at different frequencies available in the literature, we have deduced the density, temperature and sizes of the ionized regions in the direction of blank regions and SNRs. For the lines seen towards HII regions we have used the observed velocity agreement with higher frequency lines and invoked geometrical considerations to deduce the properties of the outer low density envelopes. We find that the gas responsible for the lines has an electron density of 1–10 cm^{-3}, an electron temperature of 3000–8000K and that it extends over 50–300 pc along the line of sight.

We have compared the observed velocities of these low density regions with those of HII regions observed in high frequency recombination line surveys and find that there is generally a very good agreement suggesting a physical association in most cases. Further, we have used the longitude–velocity diagram of the observed lines together with a model of the galactic rotation to deduce the distribution of these low density regions in the galactic disk. A comparison is then made of this distribution with those of other components of the interstellar medium like the neutral hydrogen, HII regions, giant molecular clouds, and SNRs. We find that this gas is not distributed like the neutral hydrogen thereby ruling out the possibility that the lines arise in partially ionized cold HI gas. Its distribution shows a peak between 4 kpc and 8 kpc from the galactic centre and is similar to those of HII regions, giant molecular clouds and SNRs.

Based on the result of this study we suggest in this thesis that most, and probably all, of the galactic ridge recombination lies come from extended outer low density envelopes of conventional HII regions which are prominent in the radio continuum maps of the galactic plane. We show that conventional HII regions are so large in number in the galactic longitude range $1 \lesssim 40^{\circ}$ that given the kind of envelope sizes derived from the present observations, their outer regions will intersect practically every line of sight within this range thereby giving rise to the observed ridge lines. The present observations are shown to have the unique advantage that they are practically insensitive to line emission from conventional HII regions and that they have detected only that gas which is responsible for the galactic ridge recomibination lines.

We have also appended to the thesis the results of two other investigations carried out during the course of the above study. Although not central to the main theme of the thesis they relate to an understanding of the composition and state of the interstellar gas, probed by the recombination line investigations. The first of these is the most sensitive yet attempt to observe the ground state hyperfine transition of interstellar deuterium No positive detection was made but a limit to the atomic deuterium to hydrogen ratio was obtained consistent with ultraviolet observations from satellites in the directions of bright nearby stars.

The second investigation concerns the velocity distribution of interstellar hydrogen, in particular the non-circular motions which appear as peculiar velocities. The method involved a comparison of the velocities obtained in a given direction from recombination line and neutral hydrogen (21cm) observations. The results provided strong support for a picture in which the interstellar hydrogen clouds could be categorized into two populations with very different velocity dispersions.

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CONTENTS