CHAPTER 1

INTRODUCTION

1.1 RADIO SPECTRAL LINES

Radio spectral lines of astronomical interest can be broadly classified into three major types. The 21cm neutral hydrogen line, centimeter and millimeter wavelength molecular lines and recombination lines which extend over the entire radio frequency range. These lines were predicted and discovered chronologically in that order. The ground state hyperfine transition of hydrogen which gives rise to the 21cm line was predicted by Van de Hulst(1945). This line was subsequently detected by two groups almost simultaneously (Ewen and Purcell 1951 and Muller and Oort 1951). The possibility of detecting molecular lines from interstellar space was first predicted by Shklovsky(1949). He suggested the possibility of detecting spectral lines due to transitions between the Λ-doublet ground state rotational levels of OH and CH. Weinreb, Barrett, Meeks and Henry (1963) first detected the close pair of OH lines in absorption. Since then a host of lines arising from transitions in more than 50 molecular species have been detected (see for example list by Lovas et al 1979) and the study of these has become a major branch of radio astronomy. Some of the lines from molecules like OH, H_2O, SiO etc are intense and they arise from exotic phenomena like masers.

Kardashev(1959) first predicted the possibility of observing recombination lines of hydrogen and helium in the radio frequency range, from ionized regions in interstellar space. The prediction was subsequently confirmed by Dravskikh and Dravskikh(1964) who detected the recombination line arising due to the transition from n=105 to n=104 in the direction of M17 and the Orion nebula.

The above three types of spectral lines come from three different types of objects in interstellar space. The 21cm line arises in the ubiquitous neutral hydrogen which occurs in the form of cold clouds and also as a hot intercloud medium Most of the molecular lines are observed from what are known in the literature as giant molecular clouds. These clouds or cloud complexes are believed to be sites of star formation. The recombination lines arise in clouds which are more or less completely ionized by young and hot stars which are embedded in them These are known as HII regions. These three types of objects correspond to, in a sense, three evolutionary stages of interstellar matter. The giant molecular clouds are believed to be formed due to collisions and coalescence of neutral hydrogen clouds or due to compression of interstellar matter in a density wave through the Galaxy. Stars will be born in such cloud complexes and they ionize the matter surrounding them giving rise to HII regions. The HII regions will eventually become neutral clouds once the exciting stars inside them move out of their hot phase and become incapable of supporting continuous ionization. The star may eventually explode as a supernova and throw much of the interstellar matter from which it was made back into interstellar space.

1.2 RADIO RECOMBINATION LINES

Since their first detection by Dravskikh and Dravskikh (1964) observation and interpretation of radio recombination lines has become an important branch of radio astronomy. These lines have been observed over a wide frequency range from 86GHz to 26MHz corresponding to transitions from principal quantum numbers n=42 and n=630 respectively. The recombination lines are designated as $Xn\alpha$, $Xn\beta$ etc where X is the chemical symbol of the emitter (H, He, C etc) and n is the quantum number of the lower level. α, β, etc represent changes Δn in n of 1, 2 etc due to the transition. The population of these high principal quantum number states is usually by recombination of electrons and protons (or ions) in an ionized region and hence the name recombination lines.

The lowest frequency recombination line which correspond to a transition from the highest principal quantum number observed so far is the C630α by Konovalenko and Sodin (1981). The highest transition observed from hydrogen is the H300α by Casse and Shaver (1977). Most of the recmbination lines observed so far are from galactic objects, mainly HII regions. In a few cases these lines have been detected from external galaxies (Bell and Seaquist 1978,1980, Shaver et al 1978).

Observations of radio recombination lines are useful in understanding the properties of ionized regions in the galaxy. The measured intensity and width of the lines can be used together with a theory of formation of these lines to derive the temperature, and in some cases the densities of the line emitting regions. The doppler shift in the frequency of the emitted line can be used to infer the velocity of the object along the line of sight. This observed velocity together with a model for the galactic rotation can lead to the determination of the position of the ionized region in the Galaxy. Comparison of the observed velocities with those of other objects like molecular clouds lying along the same line of sight can be used to study the association of ionized gas with such objects. The relative intensity of recombination lines from two elements such as hydrogen and helium, can in principle lead to the determination of their relative abundance.

1.3 HII REGIONS

As mentioned earlier, most of the observed recombination lines come from HII regions. These are gaseous nebulae which are more or less completely ionized by the ultra-violet radiation from hot stars which are embedded in them In addition to radio recombination lines, HII regions emit continuum radio radiation through thermal bremsstrahlung, optical continuum through free-bound transitions and a number of optical lines. The properties of HII regions have been widely studied using both the optical and radio radiation from them The radio radiation has the advantage that obscuration by interstellar dust is not important, and therefore it allows one to study properties of distant HII regions in the Galaxy

Most of the HII regions are known to be associated with giant molecular clouds (cf Israel 1978) which are also birth sites for stars (cf. Lada 1980). HII regions are also good tracers of the spiral arms of the Galaxy (Georgelin and Georgelin 1976). It is now established that HII regions have a gradient in electron temperature as a function of their distance from the galactic centre (Churchwell and Walmsley 1975, Churchwell et al 1978). This is attributed to a gradient in the abundance of heavy elements like Oxygen, Nitrogen, Neon etc which essentially control the temperature of HII regions (Shaver et al 1983).

1.4 GALACTIC RIDGE RECOMBINATION LINES :

In radio maps of the sky, the galactic plane appears as a ridge of strong radio emission with an angular width of 1 to 2 degrees. The ridge has a strong background radiation which at low frequencies is known to be mostly non-thermal synchrotron emission. Superposed on this background are a number of strong and weak disrete sources which are largely either HII regions or supernova remnants. This narrow strip of strong radio emission in the sky is sometimes referred to as the galactic ridge.

As mentioned earlier, radio recombination lines are observed mainly from HII regions. These objects are large in number and they appear as discrete sources on the galactic ridge. However, weak recombination lines were observed at centimeter wavelengths from many positions along the galactic ridge which are free of discrete continuum sources (Gottesman and Gordon 1970, Gordon and Gottesman 1971, Jackson and Kerr 1971, Gordon and Cato 1972, Mathews et al 1973, Jackson and Kerr 1975, Mebold et al 1976). These are now known in the literature as the galactic ridge recombination lines. These lines are observed at almost every position having galactic longitude <40° and latitude ± 0°.5. The origin of the galactic ridge recombination lines has been a puzzle since their first observation by Gottesman and Gordon (1970). They were initially thought to be coming from the general interstellar medium itself. Interpretations were given by some in terms of a hot medium (Gordon and Gottesman 1971) and by others in terms of partially ionized cold clouds (Cesarsky and Cesarsky 1971, Lockman et al 1973). These interpretations could not explain many of the observed properties of the ridge lines, like for example their absence at longitudes > 40°.

Subsequent interpretations have all been in terms of hot ionized gas (Mathews et al 1973, Jackson and Kerr 1975, Shaver 1976, Lockman 1980) which are presumed to be weak HII regions or outer envelopes of normal HII regions. There still appears to be no full consensus among the workers in the field as to the origin of the galactic ridge recombination lines. For example Lockman(1980) has concluded that at least near longitude l=36°, the lines appear to come from an extended medium The physical properties of the gas responsible for the ridge lines are not yet fully determined. This is mainly because the above observations were made only at centimeter wavelengths and the frequency dependence of the ridge line emission is not known. There are no low frequency (<1GHz) observations of the galactic ridge towards regions free of discrete sources.

1.5 SCOPE OF THE PRESENT WORK

In this thesis we present observations and interpretation of recombination lines at 325MHz which correspond to a transition from principal quantum number n=273 to n=272. The observations were made using the Ooty radio telescope towards 53 directions in the galactic plane. Of these, one was towards the galactic centre, 34 were towards HII regions, 12 towards SNRs and 6 towards 'blank' regions free from discrete continuum sources. These are the first major recombination line observations of the galactic plane at a frequency less than 1GHz (see Wilson 1980 for a list of existing surveys). Prior to this work, there were only a handful of low frequency observations made towards a few discrete sources in the galactic plane (see Pedlar and Davies 1980).

The present observations also constitute the first major spectral line study using the Ooty radio telescope. Chapters 3 and 4 of this thesis are devoted to a description and discussion of the equipment built and installed for this purpose, the procedure used for the observations and the data reduction methods.

Observations of recombination lines at different frequencies are sensitive to different types of ionized gas. Observations at high frequencies are weighted towards dense HII regions, whereas at low frequencies they are more sensitive to low density and large angular size regions. This is because recombination lines from high density gas are suppressed at low frequencies due to pressure broadening and high continuum optical depth (Griem 1967, Brocklehurst and Seaton 1972, Brown et al 1978). On the other hand, the intensity of recombination lines at low frequencies is enhanced in low density regions due to stimulated emission by background radiation (Shaver 1975), which itself is also stronger at lower frequencies due to its non-thermal nature.

We show in this thesis that most of the recombination lines at 325MHz observed in this study are not produced within the HII regions which are prominent continuum sources in the galactic plane; they will be shown to be coming from low density outer envelopes of the HII regions.

We shall combine the parameters of the lines observed here towards blank regions and SNRs with other measurements at higher frequencies to deduce the physical properties of the gas responsible for the observed lines. For the lines seen towards HII regions, we shall use the observed velocity agreement with higher frequency lines and invoke geometrical considerations to deduce the properties of the outer low density envelopes.

Based on these results we suggest towards the end of this thesis that most, and probably all, of the galactic ridge recombination lines come from extended outer low density envelopes of conventional HII regions which are prominent in the radio continuum maps of the galactic plane. It will be shown that conventional HII regions are so large in number in the galactic longitude range $l \leq 40^\circ$ 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. These outer envelopes can therefore account fur all of the galactic ridge recombination lines which are observed only in this longitude range. The present observations will be shown to have the unique advantage that the observed lines have practically no contribution from conventional HII regions, and that they have detected only that gas which is responsible for the galactic ridge recombination lines i.e. outer envelopes of normal HII regions.