CHAPTER I

INTRODUCTION

1.1 Background and Rationale of the Study

Masers are the best tool to investigate magnetic fields in star-forming regions, especially on milliarcsec scales, where they will help our understanding of the physical processes of star formation. OH and methanol masers are mainly found in high-mass star- forming regions where they are seen to be associated with each other. By studying the positions, velocities, intensities and distribution of masers in star-forming regions, the physical conditions in these regions, such as temperatures, densities and magnetic fields can be probed. Examples of previous work are the Multi-Element-Radio-Linked- Interferometer-Network (MERLIN) observations of the 18-cm transitions (or ground state energy level transitions) of the OH molecules to study the strength and direction of the magnetic field in sources associated with bipolar molecular outflow and in cometary HII regions (Nammahachak et al., 2006; Hutawarakorn and Cohen, 1999; Hutawarakorn et al., 2002; Hutawarakorn and Cohen, 2003; Gray et al., 2003; Gasiprong et al., 2002). Full polarization observations of the massive star-forming region, ON1, in the OH maser lines have also provided a case study for modelling of OH maser emission (Green et al., 2007). The excited state energy levels of OH masers, which give rise to the lines at 6 GHz, are particularly useful for Zeeman investigations. For these transitions the Lande g-factors lead to typical Zeeman splittings comparable with the OH maser linewidths, so that full 'Zeeman patterns' develop as the maser radiation propagates. For example, Desmurs and Baudry (1998) have shown that 56 of the 61 OH-6035 MHz masers in W3(OH) formed 28 Zeeman pairs. As a comparison, only 10 of the 81 OH-1665 MHz masers formed 5 Zeeman pairs (Garcia-Barreto et al., 1988). The value of the 6.0-GHz line is that such a high fraction of Zeeman pairs are usually visible, and hence a large number of magnetic field strength measurements are possible (Caswell, 1997; Caswell, 2003; Etoka et al., 2005).

Although the excited state OH-6 GHz masers have great potential as probes of star- forming regions, very few radio facilities are equipped to observe them. In the Northern Hemisphere the European VLBI Network (EVN) and MERLIN are the only interferometer networks capable of mapping these masers at high angular resolution. The EVN provides an angular resolution of ~5 milliarcsec, but without phase-referencing it can only provide absolute positions to an accuracy of ~200 milliarcsec. The upgraded MERLIN at 6 GHz has an angular resolution of ~40 milliarcsec and can provide absolute positions for OH masers to an accuracy of up to ~3 milliarcsec, although significantly less for sources at low declination. The 40 milliarcsec beam of MERLIN is sufficient to resolve the structure of individual clusters of masers on all but milliarcsec scales. Furthermore, the few milliarcsec positional accuracy resulting from phase-referencing observations enables accurate registration of the 6-GHz masers on maps at other wavelengths, in particular

MERLIN phase-referenced maps of other maser transitions of OH, of methanol and water, as well as maps of the radio continuum emission.

There are two principle requirements for using masers as tools in star-forming regions to derive the physical conditions such as the density, kinetic temperature, motions and magnetic fields. First, they need to be observed at as many frequencies as possible to better constrain the conditions responsible for the emission; second, one must ensure that the masers observed at the differing frequencies originate from material that is co- propagating through the same body of gas. This second requirement means absolute positions of the maser spots to an accuracy comparable with the resolved size of the spots themselves in the different observing bands must be obtained. This is only possible with phase-referenced observations. The MERLIN facility is ideal for such measurements. Previous work by the author has been the determination of some of the physical properties of the ON1 star-forming region from an analysis of the OH masers resulting from the J = 3/2 rotational levels (Asanok, 2005). This thesis presents part of an investigation into the properties of OH masers, such as their energies (intensity of signals), positions and velocities, and hence also the magnetic fields in a number of massive star- forming regions. It is hoped to obtain agreement between observations and theoretical data for the OH masers at 18-cm (1.6 GHz) and 5-cm (6.0 GHz).

1.2 Objectives of the Study

MERLIN observational data have been obtained from 5 star-forming regions:- S140- IRS1, DR20, W51, 19120+1103 and W49 A. The main aims of the work reported in this thesis are:-

1. The calibration of the 'raw' data from two of these sources, S140-IRS1 and W49 A, and the further processing and analysis of it to determine the kinematic and physical properties of the ground-state 1.6-GHz and excited state 6.0-GHz OH masers.

2. To investigate magnetic field structure using the OH polarization data.

3. To study the full polarization properties and the degree of polarization of individual 6.0-GHz masers.

4. To compare the positions of individual maser spots, the number of maser features and Zeeman pairs in the same star-forming region, and to search for coincidence between ground-state (1.6 GHz) and excited state (6.0 GHz) OH masers.

1.3 Equipment, Observations and Data Processing

MERLIN is a U.K. National Facility operated by the University of Manchester on behalf of the Science and Technology Facilities Council. It is a network of radio telescopes across central England which are linked together to form a high-resolution synthesis radio telescope. The individual telescopes of the network were

Table 1.1 The pointing position of star-forming regions S140-IRS1 and W49 A.

Source Name	Right Ascension (2000) hh mm ss.sssss	Declination (2000) $\pm 00^\circ\, 00'00''.0000$
S140-IRS1	22 19 18.21853	63 18 46.7568
W49-UM	19 10 15.30775	09 06 08.4822

equipped with receivers at L-Band and C-Band to cover the OH 18-cm ground-state and the 6-cm excited state OH spectral lines, and also the 5-cm methanol lines. A majority of the observations were made during the period May - June 2005 to February 2006, although some additional 6-GHz observations were made in February 2008 because some of the earlier data had been affected by interference. The observation of the $6_{16} - 5_{23}$ H_2O transition (rest frequency 22.235079 GHz) were observed in two epochs on February 1998 and April 2004. The 'raw' data from these observations were initially processed (edited and calibrated) at Jodrell Bank Observatory and also at the Jodrell Bank Centre for Astrophysics using local software - the d-programmes. The ouput FITS files from these programmes provided input to the Astronomical Image Processing System (AIPS) software. Using this, further calibration was undertaken and the intensities, positions and frequencies of the masers were determined. From an accurate measurement of the frequency of each maser, its velocity relative to the 'Local Standard of Rest' (LSR) was obtained. Some of the later stages of the data processing were also carried out at Khon Kaen University using a remote access facility to the computers at Jodrell Bank.

1.4 Outline of the Thesis

Literature reviews are presented in Chapter 2. Data reduction and the method of analysis of the data are presented in Chapter 3. The results of an analysis of the OH masers in the S140-IRS1 star-forming region and the structure of its magnetic field are presented in Chapter 4. The results of an analysis the satellite line 1.6 GHz of OH masers in the W49 star-forming region and the structure of its magnetic field are presented in Chapter 5. Finally, Chapter 6 gives a summary of the results presented in this thesis and suggestions for future work.