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VLBI observations of magnetic fields during high-mass star formation

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VLBI observations of maser emission offer unique insights in the environment of massive star formation at extremely high resolution. Maser polarimetric observations are currently the only probe of the magnetic field in high density regions, and the different maser species OH, H_2O and methanol masers probe an enormous density regime. Here I present recent results of interferometric maser polarization observations, specifically those of H_2O and methanol masers, and discuss their importance for studying the role of magnetic fields during massive star formation.

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1. Introduction

Star forming regions, and especially those forming massive stars, often contain a wide variety of maser species tracing many different density and temperature regimes. Most information on the small scale magnetic fields comes from maser polarization observations, dominated by OH maser measurements but also with an increasing number of H_2O and methanol maser observations. An extended review of important considerations regarding maser polarization observations is given in Vlemmings (2007), and besides H_2O and methanol masers also includes a discussion on OH and SiO masers.

2. H_2O masers

After the first discovery of interstellar H_2O maser Zeeman splitting by Fiebig & Güsten (1989) using single dish observations, there have been an increasing number of higher spatial resolution circular polarization observations confirming the earlier results (e.g. Sarma et al. 2001, 2002). These observations typically reveal *B*-field strengths between 15 and 150 mG at densities of $n_{\mathrm{H}_2} = 10^8 - 10^{11}$ cm^{-3}. The largest field was recently found in a proposed protostellar disk around one of the several protostars in the Cepheus A HW2 region, with a field strength of ~ 650 mG (Vlemmings et al. 2006a). Such high *B*-field strength implies a nearby source enhancing the magnetic field. Considering the size of the disk this implies a *B*-field strength of ~ 2.5 G near the embedded protostar. Alternatively, the observations indicate much higher densities then current H_2O maser theory allows in the shockwave where the masers are excited (Elitzur et al. 1989, and references therein).

In addition to the circular polarization, low levels of linear polarization (typically $< 2\%$) are also observed in star forming regions. While often structure in the *B*-field direction is detected, the observations show rapid changes of direction over small scales.

3. Methanol masers

Although the 6.7 and 12 GHz methanol masers are some of the most abundant masers in massive star forming regions, polarization observations have been rare. Ellingsen (2002) presented ATCA linear polarization measurements of the 6.7 GHz masers, with a typical polarization fraction $m_l \sim 1.5\%$, while Koo et al. (1988) presented similar polarization fractions for the 12.2 GHz maser. Finally, Wiesemeyer et al. (2004) claim up to 40% linear polarization of the millimeter methanol masers. Only recently has the first 6.7 GHz methanol maser polarization map been made of the star forming region W3(OH), as shown in Fig. 1(left) (Vlemmings et al. 2006b). These observations show that the *B*-field is aligned with the large scale methanol maser filament and are consistent with previous OH maser observations. Importantly, the observations show that because they are less influenced by both internal and external Faraday rotation, methanol masers are better probes of the overall *B*-field structure than OH masers. Since the Zeeman splitting of methanol is small and circular polarization measurements are often hindered by dynamic range problems, the first tentative detection of a *B*-field strength from methanol observations has only recently been made (Green et al. 2007).

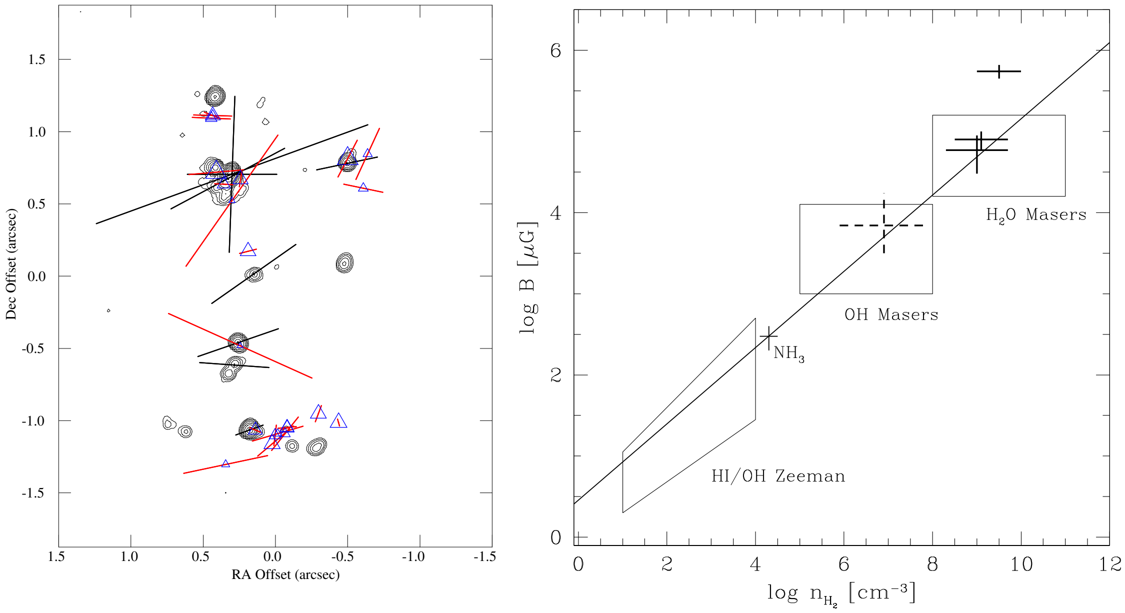

Figure 1: (left) The methanol masers of W3(OH) (contours) including the polarization vectors (black) scaled linearly according the fractional linear polarization (for a complete description of the figure see Vlemmings et al. 2006b). (right) The magnetic field strength B in massive star forming regions measured from Zeeman measurements as a function of n_{H_2}, the number density of neutral hydrogen. The boxes indicate the literature values for HI/non-masing OH, OH maser and H_2O maser Zeeman splitting observations. Also indicated are the H_2O maser measurements (thick solid crosses) and OH maser measurements (thick dashed cross) in the star forming region Cepheus A (Vlemmings et al. (2006a), Bartkiewicz et al. 2005) as well as an NH_3 measurement for the same source from Garay et al. (1996). The solid line is the empirical relation $B \propto n^{0.49}$ determined by Crutcher (1999) fixed to the NH_3 magnetic field measurement.

4. Summary

Fig. 1(right) shows the B-field measurements of both masers and non-maser observations as a function of number density. The figure seems to indicate that (with the exception of regions such as the above mentioned protostellar disk), the B-field follows the density scaling law over an enormous range of densities, implying that the magnetic field remains partly coupled to the gas up to the highest number density. However, the shock excited H_2O maser are short-lived (with a typical lifetime $\tau_m \sim 10^8$ s) compared to the typical adiabatic diffusion timescale at the highest densities ($\tau_d \sim 10^9$ s), implying that in the non-masing gas of similar densities, magnetic field strengths are likely lower due to the adiabatic diffusion. Still, the maser B measurements strongly imply a dynamical importance of magnetic fields during the massive star formation process, especially in shaping outflows and jets.

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