Anisotropic interstellar scattering of OH masers in W51

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We present the results of VLBI observations of OH masers in the direction of the Galactic star forming region W51. The aim of this exercise was to measure the distribution of the apparent angular broadening of these maser sources. The maser spots lie in two patches covering some $8''$ NS. Individual spots are extended by up to 50 m.a.s., with axial ratios of typically 1 – 3. Unlike OH masers observed in other parts of the Galaxy, we find no preferred direction of orientation of the major axes.

1. Introduction

The role of large scale magnetic fields in the Galaxy in mediating the transfer of energy from large to small scales has been discussed by Higdon (1984) and Goldreich & Sridhar (1995). They argued that irregularities in the interstellar medium (ISM) should be elongated in the direction of the ambient magnetic field, producing anisotropic scattering: greater scattering would be expected perpendicular to the magnetic field. Such an effect was observed in the maser emission from OH/IR stars near the Galactic Center (Frail et al. 1994). Similarly, Desai et al. (1994) observed OH masers in the direction of W49N, and found that their scattering disks were also elongated, with the distribution preferentially oriented perpendicular to the Galactic plane. They interpreted this as being caused by anisotropic scattering, with the Galactic magnetic field presumably directed along the plane.

To further investigate the phenomenon of anisotropic scattering, we have observed the structure of OH masers in another star-forming region, the giant molecular cloud and HII complex W51 (main). Some of the properties of W51 (main) are summarized below:

- Galactic coordinates: $l \simeq 50^\circ$, $b \simeq 0^\circ$
- Distance: $\simeq 7.5$ kpc
- Contains: OH and H_2O masers, NH_3 emission
  IR hotspots, compact HII regions
- Kinematics: $v_{\rm OH} = +58\ {\rm km\,s^{-1}}$

Previous VLBI observations of OH masers in W51 were made by Benson et al. (1984), and showed the distribution of the many maser spots and determined magnetic field strengths from Zeeman splitting. Although their maps did indicate some structure in the maser spots, this aspect was not investigated in detail. Our observations improve upon the angular resolution of Benson et al. (1984) by about an order of magnitude.

2. Observations and data reduction

The observations were made at 18 cm using all ten antennae of the NRAO's[1] VLBA. The source was observed for a total of about 5 hours, and the data were calibrated with

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regular observations of the standard sources 3C 345 and 3C 454.3. All four OH lines were measured in both right- and left-hand circular polarization, over a 500 kHz band centered on the expected OH frequency. The data were correlated at the AOC in Socorro, with 128 frequency channels and a time constant of 5 s to enable mapping of the entire field of view.

The distribution of baselines, given the low declination of W51 ($\delta = 14°$), provides us with spacings in $u \times v$ of up to $40\,\mathrm{M}\lambda \times 20\,\mathrm{M}\lambda$. We only detect maser emission at 1665 and 1720 MHz, as was the case with the previous observations (Benson et al. 1984). The right-circularly polarized emission is generally stronger than left, and the source extent is clearly seen in the strong decline of visibility with increasing baseline. The data were calibrated with standard routines in AIPS, and maps were made to determine the regions showing emission, and the source extent.

3. Results

Channels showing the strongest line emission were mapped in AIPS. The resulting brightness distributions reveal the presence of many tens of compact sources over a region of some $8''$. The distribution of spots is rather similar to what was found before (Benson et al. 1984): there are two patches extended NS by $1''$–$2''$, and separated NS as well; 1720 MHz emission is seen from the more northerly region only, 1665 MHz from both. However, we find that the centroid of the former is shifted about $1''$ NW of the latter, and that the centroid of the southern region lies about $1''$ N of what was found previously (Benson et al. 1984). Although there is some overlap between the regions producing 1665 MHz and 1720 MHz emission, none of the individual spots actually coincide.

Inspection of the brightest spots in the maps shows that they are all clearly extended well beyond the expected beamsize. In Fig. 1, we show bright spots from a region near the center of the 1720 MHz patch. The spots are clearly extended, with no obvious preferred orientation, which is typical of the data at both 1665 and 1720 MHz. Consequently, for the analysis presented here, we have simply fitted two-dimensinal gaussians (using the AIPS routine IMFIT) to 19 of the brightest spots in our maps. We find source sizes ranging from 5 to nearly 50 m.a.s. The distribution of source major axis ($\theta_{\rm maj}$) is shown in a histogram (Fig. 2). Values of the axial ratio, $\theta_{\rm maj}/\theta_{\rm min}$, range from 1 to nearly 4, with a median value of 1.7. This is similar to what has been observed in the other OH masers (Frail et al. 1994; Desai et al. 1994).

Although the OH masers seen in the direction of W51 are not unlike the W49 and Galactic Center masers, there are some differences. In W49 (Desai et al. 1994) the sources are extended by up to 200 m.a.s., and in the Galactic Center the extent even reaches $1''$ (Frail et al. 1994): the amount of scattering in W51 is relatively modest in comparison. But the major difference is that there appears to be no preferred direction or pattern in the case of the W51 masers, while there certainly is in the other two. The W49 masers are largely elongated perpendicular to the Galactic plane, while those in the direction of Sgr A tend to be oriented radially about the Galactic Center.

To illustrate the situation in the direction of W51, Fig. 3 shows a histogram of the position angle (PA) of the major axis of each of the spots included in our analysis. It is clear that there is no preferred direction. At best, there are two rather broad ranges of PA, around 60° and 150°. A source oriented at right angles to the Galactic plane would have $PA \simeq 120°$.

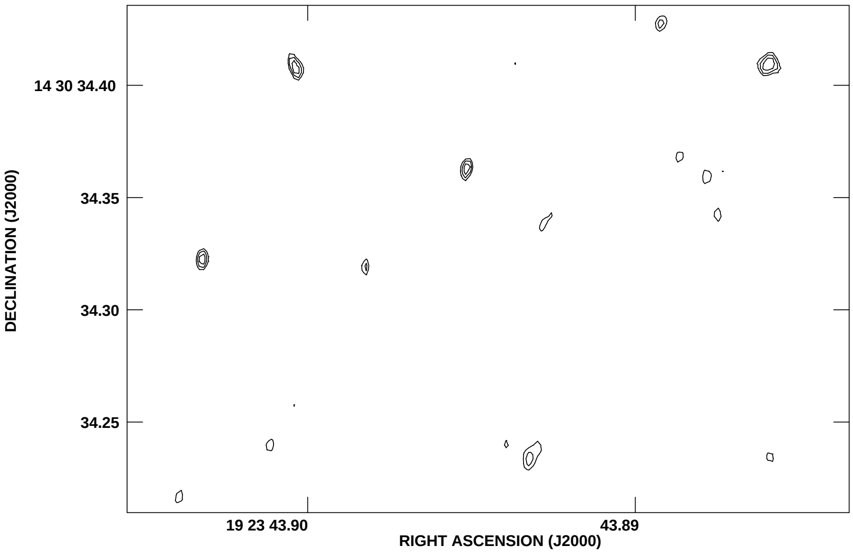

FIGURE 1. Part of the field observed at 1720 MHz

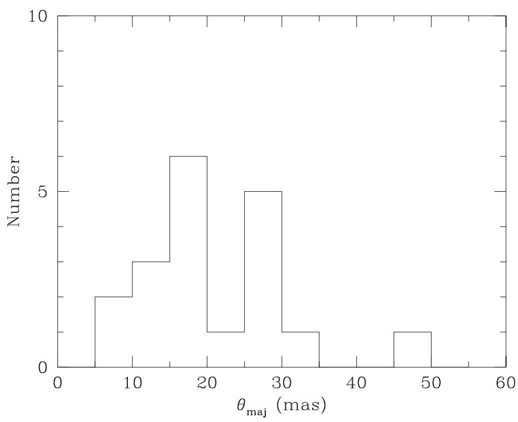

FIGURE 2. Distribution of the extent of maser spots, θ_{maj}

4. Conclusions

The results of this VLBI investigation of OH masers in W51 are that we have mapped the small-scale structure of several tens of maser spots at 1665 and 1720 MHz, and

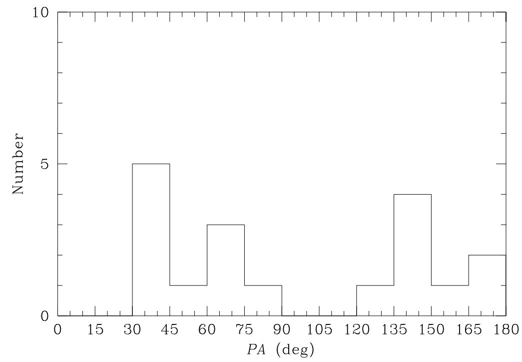

FIGURE 3. Distribution of the major axis, PA, for maser spots

find them all significantly extended, though somewhat less than those in W49. The axial ratios found are similar to what has been observed in the past, and we conclude that we are seeing the effects of anisotropic scattering in the ISM. The anisotropy is presumably caused by the ambient magnetic field. However, while the field appears to have a preferred orientation in the other two cases, running parallel to the Galactic plane in the direction of W49, and circumferential about the Galactic Center, we discern no pattern in the case of W51. Indeed, not only is the distribution in PA rather broad (Fig. 3), but even adjacent sources in the sky can display quite different values of PA (cf. Fig. 1). This suggests a magnetic field with a large degree of disorder on small (projected) linear scales. More extensive and detailed analysis of our data is continuing.

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