POLARIZATION IN THE MAGELLANIC CLOUDS

R.F.HAYNES [1], S.WAYTE [4], J.I. HARNETT [5], U.KLEIN [2,3], R.WIELEBINSKI [2], U.R.BUCZILOWSKI [2], E.BAJAJA [2], D.MALIN [6], J.D.MURRAY [1], A.J.HUNT [1], R.WARK [1], L.SCIACCA [1]

1. Australia Telescope National Facility#, 2. Max-Planck-Institut für Radioastronomie
3. University of Bonn, 4. Mount Stromlo and Siding Spring Observatories
5. University of Sydney, 6. Anglo-Australian Observatory

ABSTRACT. We present new results from a number of deep radio polarization surveys of the Magellanic Clouds at 2.3 GHz, 4.75 GHz and 8.55 GHz. Extended linearly polarized radio emission has been found at 2.3 and 4.75 GHz from both galaxies.

1. Introduction

The Magellanic Clouds provide the closest view we have of external galaxies and as such are ideal astrophysical laboratories for galaxy studies. We have therefore embarked on a program to accomplish sensitive radio continuum surveys of the Clouds at four frequencies. This study happens to be accompanied by investigations in other spectral regimes by various groups (far-infrared, Hα, UV, and X-rays).

Our first major survey of the Magellanic Clouds at Parkes was made in November 1984 at 1.4 GHz (Haynes *et al.*,1986). Subsequently, a new generation 4-frequency, dual-channel receiver was integrated to a *very* phase-stable polarimeter at Parkes for this research program (Haynes *et al.*,1989a). This polarimeter provides full Stokes parameter data acquisition at 1.42, 2.3, 4.75, and 8.55 GHz with T_S values between 20-50 K and instantaneous bandwidths between 350-500 MHz. The first of the new surveys using this facility was made at 2.3 GHz in November 1987, followed by the 4.75 GHz one in March 1988 and, very recently, the 8.55 GHz survey in November 1988.

2. Results and Discussion

As an example, Figure 1 shows preliminary results for the LMC at 4.75 GHz. The other survey results will be published shortly (Haynes *et al.*, 1989b).

The radio survey results we now have available at 1.4, 2.3, 4.75 and 8.55 GHz provide a unique dataset for studying the Magellanic Clouds. The radio-emitting region of both galaxies is very extensive. At 1.4 GHz emission is found over a $\approx 10^o \times 10^o$ field around the LMC (Klein *et al.*,1989) and a $\approx 4^o x 4^o$ field around the SMC (Loiseau *et al.*,1987). At our highest observing frequency of 8.55 GHz thermal free-free-emission dominates, especially in the vicinity of HII regions, while non-thermal emission is increasingly present at lower frequencies (Klein *et al.*, 1989, Haynes *et al.*, 1989b).

In the 2.3 and 4.75 GHz maps we find polarized radio emission from both the LMC and the SMC. In the LMC two extended bands of polarization south of the 30-Doradus region were

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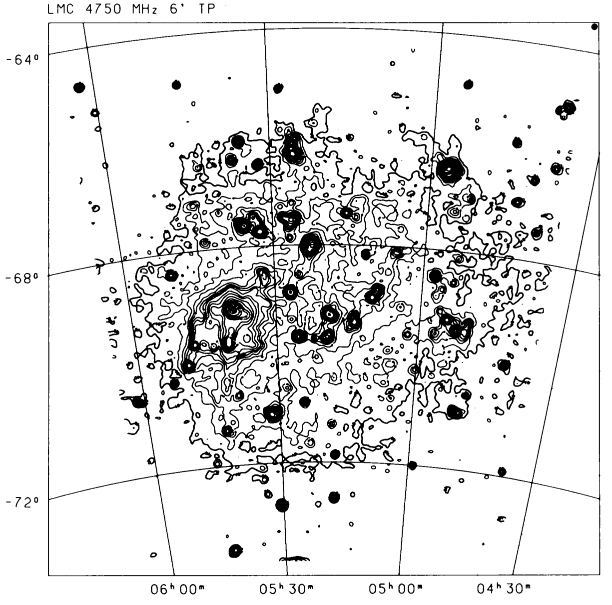

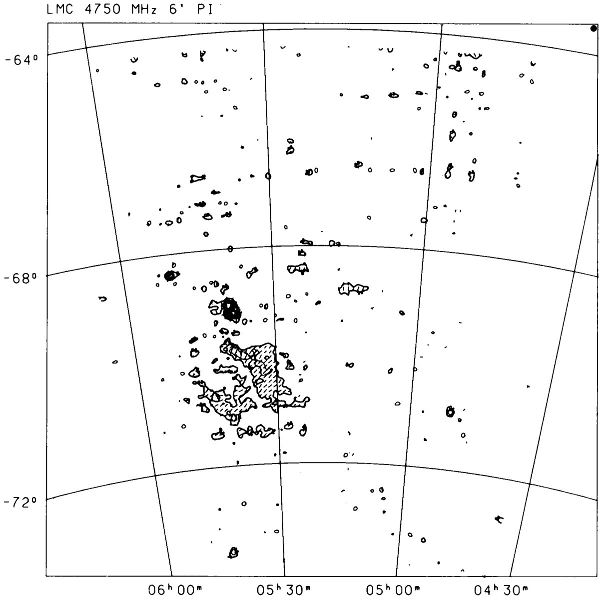

Figure 1 The Large Magellanic Cloud at 4.75 GHz
Preliminary results of a survey with the Parkes telescope.
Above:- total intensity.
Below:- polarized intensity with E vectors superimposed.
Note that the polarized intensity near 30-Doradus is due to instrumental effects.

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detected at each frequency (Fig.1), while in the SMC polarized radiation originates in the two regions near $\alpha_{1950} = 00^h45^m$, $\delta_{1950} = -73^o30'$ and $\alpha_{1950} = 01^h20^m$, $\delta_{1950} = -73^o50'$.

The two LMC ridges of polarized radio emission correspond closely to the filaments we found at 1.4 GHz (Haynes *et al.*, 1986) and which we labelled B & C (Feitzinger et al., 1987). Using estimates for the Faraday rotation of 24 ± 6 rad m^{-2} (Broten et al., 1988) we might expect that in these regions the 4.75 GHz B-polarization vectors (drawn at 90^o to the E-vectors) are likely to be not more than $5^o \pm 1^o$ away from the intrinsic magnetic field directions (Haynes et al.,1989b). The indicated vector orientations in Figure 1 thus correspond quite well to alignment along these southerly, filamentary structures running away to the south and south-west of 30–Doradus.

Further, we find that the most intense radio emission at all four frequencies comes from the 30–Doradus region and the area immediately to the south of the 30-Doradus complex. The greatest concentration of radio, CO (Cohen *et al.*,1987), FIR (Schwering, 1988) and HI (Rohlfs *et al.*, 1984) emission thus all occur near, and due south of, the 30–Doradus complex. We see filaments and strings of star-forming regions emanating from near 30–Doradus, and radio images map out these filamentary structures.

All of our radio images of the LMC appear also to show a sharp eastern boundary and a peak emissivity near 30–Doradus. To the west, and particularly the south–west of the LMC the radio luminosity dies away gradually in the direction towards the SMC without any such feature (Klein *et al.*, 1989).

Our radio polarization results have recently been nicely corroborated. Wayte(1989) finds that by smoothing star-light polarization data from a decade ago (Visvanathan, 1966; Mathewson & Ford, 1970; Schmidt, 1976) to cell sizes comparable to the resolutions of our radio surveys, there is good correlation between vectors indicating that intrinsic Magellanic Cloud magnetic fields from star–light are polarized by the Davis-Greenstein(1951) effect and that magnetic field directions are consistent with the radio polarization data.

The polarized star-light also shows a magnetic field direction in the south-west corner of the LMC field that is roughly pan-Magellanic (Wayte, 1989). Moving closer to 30–Doradus the field smoothly blends in with the field around 30–Doradus sweeping around in an anti-clockwise sense to the south of 30-Doradus. Three regions of optical polarization show vectors (Wayte,1989) corresponding well to the filaments labelled A, B and C which appear to emanate from 30-Doradus (Feitzinger *et al.*,1987). In the B and C regions especially the optical vectors mimic polarization B-vectors found at 4.75 GHz extremely well. If the magnetic field in the so-called pan-Magellanic direction smoothly blends into the fields around 30–Doradus the question arises as to whether the creation of both fields, and the filamentary features have a common cause, namely the interaction of the SMC with the LMC and both galaxies with the Milky Way.

In the SMC a similar agreement applies. The radio emission is neither so widely nor so uniformly distributed as for the LMC, but is confined to the so-called bar-region and the HII complexes. The polarized emission at 4.75 GHz comes from a region south of the southern complex of the SMC near $\alpha_{1950} = 00^h45^m$, $\delta_{1950} = -73^o30'$. An even weaker polarized region near $\alpha_{1950} = 01^h20^m$, $\delta_{1950} = -73^o50'$ probably also exists. Figure 4 of Schmidt(1976), showing the corrected intrinsic polarization of the SMC in the same region, agrees extremely well with our radio polarization vectors (Haynes *et al* ., 1989 b).

Both the distribution of the radio continuum and the structure of the linearly polarized emission suggest a distinguished role of the star-forming complex 30-Doradus.

It appears that the centre of gravity of the LMC lies closer to the centre of the optical bar of old and red stars (de Vaucouleurs, 1964) but that position certainly does not define the centre of currently active star formation and peak intensity of radiation from dust, CO, HI and radio-emitting material. A perhaps controversial suggestion would be that 30-Doradus is the current centre of activity of the LMC. Perhaps the dust, HI, CO and radio emission are all concentrated away from the gravitational centre of the LMC as a result of the gravitational interaction of the Clouds with our Galaxy or as a result of the interaction of the Magellanic Clouds with the halo of the Milky Way. The older star population seems less influenced by such interactions.

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BECK: The close correlation between radio continuum and far infrared emission you found in the LMC is highly important because of your high linear resolution: If the correlation is solely due to the enhanced production of cosmic-ray electrons in star-forming regions, you have to explain why the cosmic rays do not leave these regions; if the correlation is mainly due to enhanced field strength in star-forming regions, you have to find an enhancement mechanism which can operate locally.

HAYNES: Yes, I agree to both statements. Presumably since we see non-thermal radio emission over a total size of ~2-3 kpc with a smooth distribution of the field and polarized emission at a scale size of 70 pc the cosmic rays could be constrained by the field over at least those regions. A question that follows though is more related to the hot dust and hence the 60 μm IR emission. It is not entirely clear that we do see the polarized radio emission in regions where there is very active star formation. There is obviously warm dust aligned with the magnetic field orientation but we do not see star-burst activity in the same regions south of 30 Dor - this can be seen by a careful view of the relationship between the regions of polarized radio emission and the IRAS images.

HELOU: The magnetic field may be more extended than the radio maps indicate: if the cosmic-ray electrons are produced in the 30 Doradus region, they will "light up" the magnetic field only near their sources and escape before they have diffused very far.

HAYNES: Yes, I fully agree. But the point still remains. We have to align the magnetic fields along the filamentary structures we see to the south and south-west of 30 Doradus. All the 4.75 GHz E vectors indicate (assuming Faraday rotation corrections of, as we believe, $< 4^\circ$) alignment of the field over scale sizes of ~4 kpc in the same direction as the extreme population I material in these filaments.

BROWNE: Might not there be motion of field and plasma relative to stars? When $B^2/8\pi \gtrsim 1/2\, \rho v^2$ (B: field strength, ρ: mass density, v: fluid velocity) motion of field lines drops plasma and gas, but stars which form from the gas decouple from the field and are left behind. It seems to happen in spirals and the Milky Way.