Changing parameters along the path to the Vela pulsar

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Summary. Recent observations of the Vela pulsar, PSR 0833-45, confirm that the rotation measure of the source is increasing, and show that at the same time the dispersion measure is decreasing. The observations are interpreted in terms of a magnetized cloud moving out of the line-of-sight to the source.

1 Introduction

Hamilton et al. (1977) have reported polarization measurements of the Vela pulsar, PSR 0833-45, which show that between 1970 and 1976 the rotation measure increased by 14 per cent, while over the same period there may have been a slight decrease in dispersion measure. We have made further measurements which show that the rotation measure continues to increase, and we confirm that this is accompanied by a decrease in dispersion measure. The latest results support the hypothesis that a magnetized filament of the interstellar medium is moving out of the line-of-sight to the pulsar. These measurements are the first to be made with a new type of polarimeter spectrometer based on surface acoustic wave (SAW) dispersive filters.

2 Observations

The new observations were made in 1984 October using the 14-m steerable paraboloid at the University of Tasmania observatory near Hobart. A disk feed (Howell 1975) was used, with outputs responding to orthogonal linear polarizations. The centre frequency of the system was 629 MHz.

A block diagram of the polarimeter spectrometer is given in Fig. 1, and a detailed description has been published by Hall, Hamilton & McCullough (1982, 1983). A dispersive filter is excited with an impulse to give a chirp (or swept-frequency) local oscillator signal. The RF input band is mixed with the chirp, so input signals separated in frequency produce product chirps which are also offset in frequency. The product chirps enter a second dispersive filter, the group delay slope of which is such that chirp inputs emerge as compressed, impulse-like output signals. Product chirps due to different input frequencies enter the compressor passband at different times, so the compressed outputs are separated in time. A spectrum thus emerges serially from the compressor in response to each impulse excitation of the local oscillator. The SAW filters are matched through being fabricated in a common process and this, together with the common oscillator, ensures that signals which are coherent at the inputs remain coherent through the system.
In-phase and quadrature correlators together with detectors then yield the full polarization properties of the signal. The spectrometer operation is similar to that of a sweeping spectrum analyser except that there is no time-sharing, and frequency resolutions of the order of the reciprocal chirp duration can be obtained independent of the local oscillator sweep rate. It is possible to observe the whole passband all the time, with information being stored temporarily in acoustic waves in the filters. The performance of the system is therefore equivalent to that of two filter banks, one in each RF channel, with a set of correlators and detectors at each filter frequency. However, the SAW system is much simpler to align and maintain in correct phase-adjustment.

The polarimeter is capable of processing a total bandwidth of 32 MHz with a frequency resolution of 650 kHz and a time resolution of 2 μs. A high-speed digital integrator is used to reduce the data rate from a spectrum every 2 μs to a value acceptable to a computer. Limitations associated with the receiver front-end restricted the observing bandwidth to 20 MHz. During the observations, successive spectra from the polarimeter were averaged synchronously with the pulsar to give averages over 4000 pulses. These data were then combined to give an average over 4 hr of observing. Subsequent processing gave pulse arrival time as a function of frequency and thence dispersion measure, and position angle of the linearly polarized component as a function of frequency leading to rotation measure. The rotation measure was corrected for Faraday rotation in the Earth’s ionosphere using concurrent measurements of the critical penetration frequency \( f_0 \)F2; typical corrections were 0.6 rad m\(^{-2}\), with an estimated uncertainty of less than 10 per cent.

3 Results

Using the data from the new polarimeter we obtain values of 68.2 ± 0.2 cm\(^{-3}\)pc for the dispersion measure, and 46.1 ± 1.6 rad m\(^{-2}\) for the rotation measure (2σ errors). These results are given in Fig. 2 together with the data from Hamilton et al. (1977) and some unpublished measurements at 400 and 950 MHz made in 1979 August by Hamilton. The variations from point to point show that RM and DM are related, with high values of RM corresponding to low values of DM. The general trends are shown by the straight lines which represent weighted least-squares fits to the data; the slopes are 0.040 cm\(^{-3}\)pc yr\(^{-1}\) and 0.73 rad m\(^{-2}\)yr\(^{-1}\).

It is clear that the increase in rotation measure noted in 1977 has continued and that the decrease in dispersion measure is real. The decrease in DM shows that a region of excess electron density is moving out of the path to the pulsar. Since the rotation measure has increased, the mean
Figure 2. Rotation measure and dispersion measure of PSR 0833-45 at different epochs. Error bars are 2σ. The lines represent least-squares fits to the data.

line-of-sight component of the magnetic field in this region must be directed towards the pulsar, giving a negative contribution to the rotation measure. This is in the opposite sense to the mean interstellar field in this direction.

Hamilton et al. (1977) discuss the possible locations of this region, and conclude that the observed effects are probably the result of the line-of-sight changing through movement of the pulsar. If, following them, we adopt 500 km s⁻¹ as a reasonable upper limit on the transverse velocity of the source, we obtain a transverse scale length of 5.1×10⁻⁴ pc or 166 AU per year. Assuming a comparable line-of-sight dimension, the average change in dispersion measure of 0.040 cm⁻³ pc per year implies an excess electron density in the region of about 78 cm⁻³. We can estimate the weighted mean line-of-sight component of the magnetic field in this dense region by

\[ \langle B_0 \rangle = 1.23 \times \frac{(dRM/dt)}{(dDM/dt)} \]

where RM and D are in the usual units and B is in μG. For \( (dRM/dt) = 0.73 \) rad m⁻² yr⁻¹ and \( (dDM/dt) = 0.040 \) cm⁻³ pc yr⁻¹, we obtain \( \langle B_0 \rangle = 22 \) μG. If individual values of RM and DM are considered rather than the average rates of change, higher values of \( \langle B_0 \rangle \) are obtained. These numbers are not unreasonable for magnetized filaments observed in the region of supernova remnants.

At lower frequencies the pulse from the Vela pulsar shows a marked increase in duration, and it has been shown (Ables, Komesaroff & Hamilton 1970; Komesaroff, Hamilton & Ables 1972) that this is due to scattering of the radiation by electron density inhomogeneities in the interstellar medium. We have considered the possibility that the irregularity responsible for the change in RM and DM is associated with the scattering region. Ables et al. (1970) suggest that the most likely position of the scattering screen is in the Gum nebula, situated approximately midway between the pulsar and the Earth. They estimate that the upper limit on the scale size of irregularities in the region is \( 4 \times 10^7 \) km (1.3×10⁻⁶ pc) and that the relative velocity of the medium is about 10 km s⁻¹, at least an order of magnitude less than the assumed velocity of the Vela pulsar. We would thus expect DM or RM changes due to changing conditions at the scattering screen to occur on a time-scale of days rather than years. It is most likely therefore that the observed variations are the result of relative motion of the pulsar and the supernova remnant.
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References