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MAGNETIC FIELD MEASUREMENTS IN TWO EXPANDING H I SHELLS

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ABSTRACT

We report the first measurements of the magnetic field in expanding H I shells. At one position in each of two shells, the measured line-of-sight field components are both about 7 microgauss. We discuss in some detail the physical nature of one of these shells located in Eridanus. The magnetic field severely limits the density enhancement in the cool postshock gas, and it probably has some effect on the overall dynamics of the shell.

Subject headings: interstellar: magnetic fields — magnetic fields — nebulae: supernova remnants — radio sources: 21 cm radiation — shock waves — Zeeman effect

I. INTRODUCTION

Much of the interstellar H I gas is distributed in curved filamentary structures that appear to be parts of large shells. These are evident in photographic presentations of H I data both in the galactic plane (Heiles 1979) and away from the plane (Colomb, Pöppel, and Heiles 1980). Shell radii range up to 1 kpc, masses to $10^8\ M_\odot$, and expansion velocities up to 30 km s^{-1}. Presumably, the products of supernovae or stellar-wind–induced shocks, or of both, the expanding shells should sweep up magnetic field lines in the original undisturbed medium. The enhanced field strengths in the shells can, in turn, severely limit the factor by which gas densities in the shells exceed densities in the undisturbed medium.

In this *Letter*, we describe the first Zeeman effect measurements of the magnetic field in two expanding shells of atomic gas. One of these is the Eridanus H I shell, which is centered near $(l, b) = (198°, 40°)$ (Heiles 1976); the other is an expanding shell that lies inside of and seems to be associated with radio loop II (see Colomb *et al.* and Heiles 1982*a*, *b*).

II. OBSERVATIONS

The Zeeman effect measurements discussed here were made at the same time as those reported by Heiles and Troland (1982) using identical techniques. In Figures 1 and 2 we present spectra obtained at $(l, b) = (206.°9, -49.°6)$, a position on the extreme negative-latitude edge of the Eridanus H I shell, and at $(156.°8, -49.°3)$, a position in the radio loop II H I shell. These spectra are identical in format to those of Heiles and Troland, with the conventional frequency-switched spectrum on top and the polarization-switched V spectrum on the bottom. Shown also at the bottom of each figure (*dashed line*) is a least squares fit of the V spectrum to the derivative of the frequency-switched spectrum. These fits yield values for $B_{\rm II}$, the magnetic field parallel to the line of sight, of -6.7 ± 1.5 microgauss and -6.9 ± 1.2 microgauss in Figures 1 and 2 respectively. These errors, derived from the least squares fit, are 3 σ. The negative signs indicate that the fields point toward the observer.

We have computed the effects of instrumental circular polarization in the manner described by Troland and Heiles (1982), and we find these effects to be negligible.

III. DISCUSSION

a) Magnetic Field at $(l, b) = (206.°9, -49.°6)$

The properties of this shell are discussed by Heiles (1976). The variation in size of the shell with radial velocity implies that it is expanding at about 23 km s^{-1}. Heiles, having no means to estimate the distance to the shell center, assumed a value of 150 pc. Subsequently, Reynolds and Ogden (1979) presented a convincing case for a distance of 400–500 pc, based on optical observations of Hα and [N II] λ6584 emission from ionized gas associated with the shell. With this distance, the shell diameter is about 300 pc, its mass about $10^6\ M_\odot$, kinetic energy of expansion about 4×10^{51} ergs, and kinematic age about 6×10^6 years. If the mass was once uniformly distributed within the present shell volume, then the preshock ambient density was 1.1 cm^{-3}. The density within the shell itself does not appear to be enhanced by more than a factor of 2 or so above this ambient density

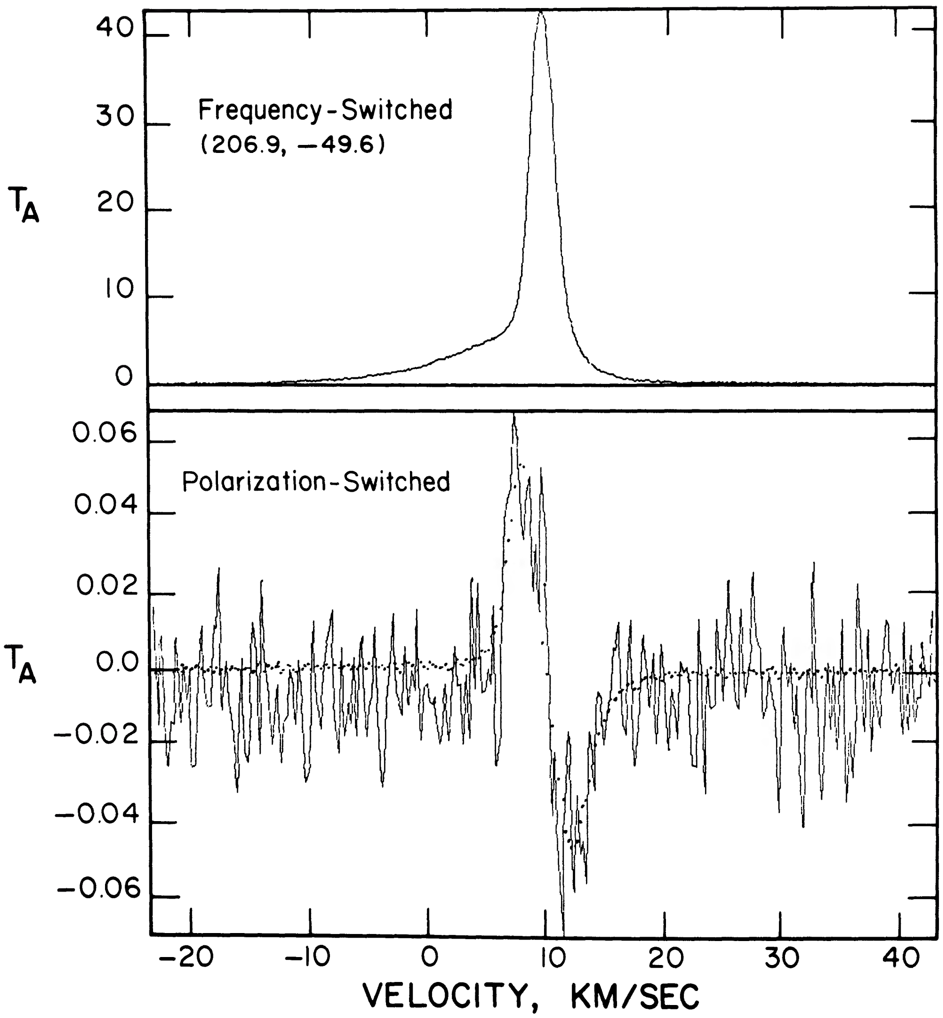

FIG. 1.—Frequency-switched and polarization-switched profiles for the position $(l, b) = (206\overset{\circ}{.}9, -49\overset{\circ}{.}6)$

because the shell is thick and has no apparent small-scale structure.

The conclusion that the shell properties have been significantly affected by the interstellar magnetic field seems inescapable. In the absence of a magnetic field, the density enhancement expected in the radiatively cooled postshock region is $(V_{sh}/C_0)^2$, where V_{sh} is the shock velocity and C_0 the speed of sound in the undisturbed medium (see Spitzer 1978 for the shock equations both with and without magnetic fields). Given $V_{sh} = 23$ km s^{-1}, we expect a density enhancement of about 500. This is certainly much higher than the actual enhancement in the shell. One might surmise that such a large density enhancement would have produced a dense molecular shell which would not be apparent in the 21 cm line; however, studies of OH absorption (Kazès, Crovisier, and Aubry 1977; Dickey, Crovisier, and Kazès 1981) and CO emission (Kazès and Crovisier 1982) against the extragalactic sources 3C 75, 3C 78, and 3C 88, which lie behind the shell, show that there are no definite detections of molecules in these directions. Therefore, we conclude that the amount of compression in the postshock gas is very much less than expected from an isothermal nonmagnetic shock with velocity of 23 km s^{-1}.

However, if the undisturbed medium were permeated by a modest magnetic field, then the expected compression factor would be greatly reduced. For example, with an ambient field of 6 microgauss, the Alfvén velocity is about 11 km s^{-1} and the compression factor is only about 2.5. The magnetic field behind the shock would be 15 microgauss; on geometrical grounds, the probability of our measuring a line-of-sight component of 6.7 microgauss or less is equal to 0.45, which is entirely reasonable.

The magnetic field is probably beginning to have a dynamical effect on the shell. If we apply the virial theorem to the shell, the only significant terms are those

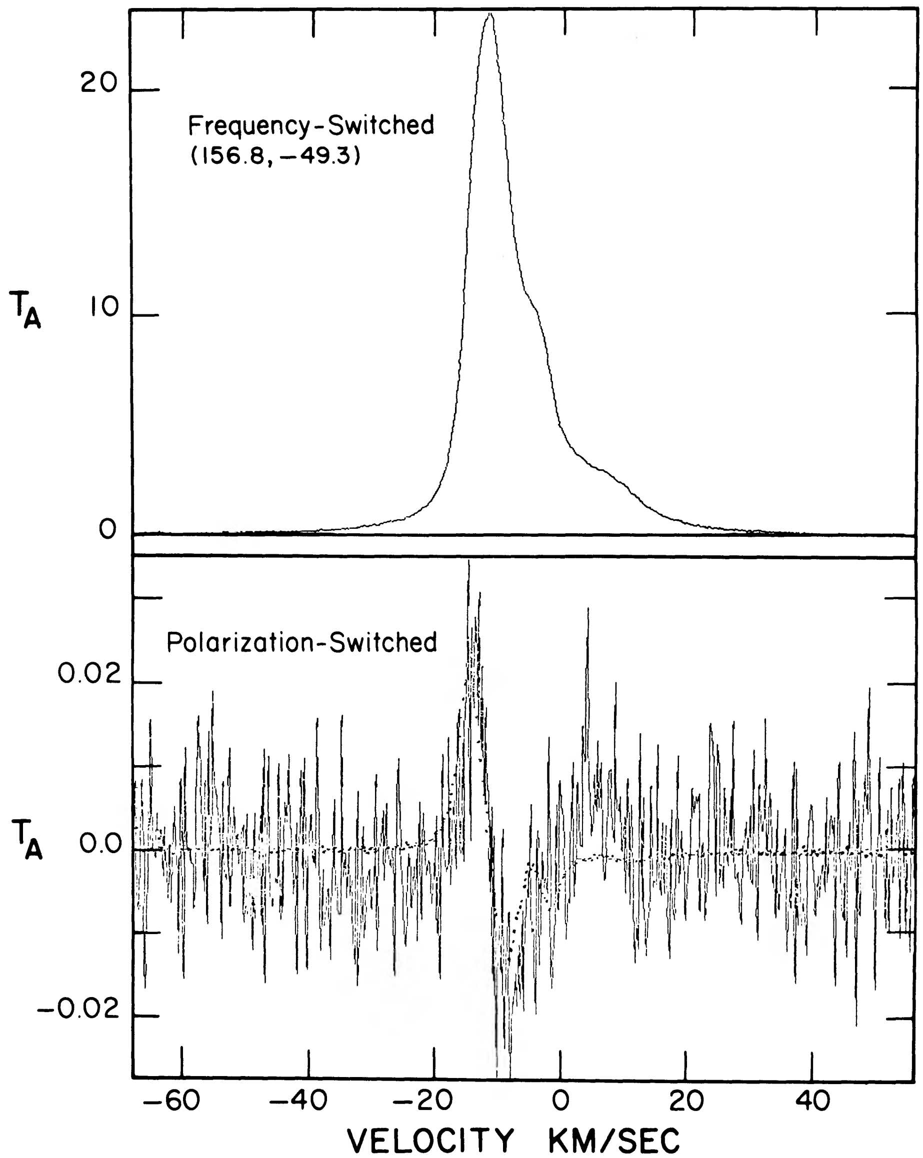

FIG. 2.—Frequency-switched and polarization-switched profiles for the position $(l, b) = (156^\circ.8, -49^\circ.3)$

involving the kinetic energy of expansion and the magnetic field. For a field of 15 microgauss, a density of 1.1 H atoms cm^{-3}, and an expansion velocity of 23 km s^{-1}, the kinetic energy and magnetic terms are about equal in the volume of the shell itself (about 10^{-11} ergs cm^{-3}). If the shell swept up an initially uniform B, then the magnetic surface term is larger than the magnetic volume term, and it acts to retard the expansion of the shell. The actual significance of the magnetic field depends on whether the total field is really as large as twice the measured line-of-sight value, since magnetic terms in the viral theorem are proportional to B^2.

Faraday rotation data are consistent with the idea that the total field is roughly twice the measured line-of-sight component. In an expanding shell, the original undisturbed field lines are swept up and concentrated in the shell itself. At $l = 207$ the galactic longitudinal field makes an angle of about 50° to the line of sight (Simard-Normandin and Kronberg 1980). If this angle has any relevance to the present direction of the field in the shell (as it may for fields near the magnetic equator of the shell), then our Zeeman effect measurement accounts for only 65% of the total field strength. The polarization data of Mathewson and Ford (1970) provide weak evidence for a swept-up field in the shell since there appears to be some tendency for polarization vectors to lie parallel to the edge of the shell. Unfortunately, the number of suitably placed stars is too small to make this conclusion certain. A much better example of this phenomenon is the H I shell associated with radio loop I. In this shell, optical polarization vectors clearly indicate that the field lies parallel to the shell surface over its entire projected extent (Heiles and Jenkins 1973).

b) *Magnetic Field at* $(l, b) = (156\overset{\circ}{.}8, -49\overset{\circ}{.}3)$

This position lies within an expanding H I shell that runs parallel to and lies inside of radio loop II. This shell is best seen in the photographic maps of Colomb, Pöppel, and Heiles (1980) for radial velocities -13 and -8 km s^{-1}; its expansion velocity is difficult to estimate, but it is probably about 10 km s^{-1}. Optical polarization vectors of Mathewson and Ford (1970) appear to show some alignment with the shell for stars at distances between 200 and 400 pc. Heiles (1982*a*, *b*) estimates the volume density within the shell to be 2 cm^{-3}.

Very roughly speaking, this shell is similar in bulk characteristics to the Eridanus shell and has nearly the same value of the magnetic field strength. The physical discussion for the Eridanus shell should apply in a qualitative way to this shell, also; differences in physical properties are too uncertain to make a second quantitative discussion for this shell worthwhile.

IV. SUMMARY

In these two H I shells, which are expanding and associated with prominent features at either X-ray or radio wavelengths, the measured longitudinal field strengths are about 7 microgauss. We picture the H I in each shell to be the result of a nearly isothermal shock that is associated with the expansion. With no magnetic field, the gas density in an isothermal shock increases by factors of several hundred. However, the field is strong enough to severely limit the density increase to much less than a factor of 10. The field, which has been swept up from the interior volume and compressed, may even be strong enough to affect the overall dynamics of the shell's expansion.

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