HI SHELLS AND SUPERSHELLS

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I. HI SURVEY DATA

A. Existing Survey Data

The entire sky has now been surveyed in the 21-cm line with an angular resolution of about 0.5 degree. In the north, above declination -20° or so, the "galactic plane" $|b|<10°$ has been completely sampled Weaver and Williams (1973; 1974). Above declination -30° or so, the sky outside the galactic plane has been almost completely sampled (Heiles and Habing, 1974; Heiles, 1975).

In the south Kerr, Kerr, and Bowers have surveyed the galactic plane; the data are in an advanced state of reduction and will soon be available. Outside the galactic plane, both Cleary, Haslam, and Heiles (1979) and Colomb, Poppel, and Heiles (1980) have surveyed the sky outside of the galactic plane. There is reason for two surveys, not just one, in the southern sky: the Magellanic Stream (Mathewson, Cleary, and Murray, 1974). HI in the Magellanic Stream is, in some regions, brighter than the ordinary gas in our galaxy, and widely separated in velocity. The Cleary et al. survey, with its wide velocity coverage, allows one to determine accurate column densities--not just within the local gas, but within the Magellanic Stream as well (Heiles and Cleary, 1979). The other survey has better velocity resolution and is necessary for mapping the kinematics of the gas.

B. The Stray Radiation Problem

There is a significant systematic error in some of the high-latitude data. This arises from "stray radiation," which is the response of a telescope to radiation coming from directions other than that where it is pointed. It makes observed column densities larger than they should be. The effect is particularly serious at high latitudes, where the 21-cm line is weaker than it is everywhere else in the sky. The derived column densities can be too high by factors of

J. Danziger and P. Gorenstein (eds.), Supernova Remnants and their X-Ray Emission, 367–372.

order two (Heiles, Stark, and Kulkarni, 1981). This makes a very significant difference for low-energy X-ray observations, and particularly for extragalactic studies.

Stark, Heiles, and others have used the Bell Labs horn reflector at Crawford Hill, Holmdel, New Jersey, to make a new survey of the northern sky. This telescope is the same one used for the original discovery of the cosmic background radiation and is essentially free of stray radiation. This survey will be available on magnetic tape from me in a few months.

II. MORPHOLOGICAL AND PHYSICAL PROPERTIES OF HI SHELLS AND SUPERSHELLS

A. Morphological Properties

When HI data are presented as photographic maps of HI column density in small velocity ranges, a spherical expanding shell appears as circles of different diameter at different velocities. Easily visible shells include one around Radio Loop I (the North Polar Spur), visible in the photographs of Colomb et al. (1980) and the Eridanus shell, discussed by Heiles (1976); the interiors of these shells are the classical high-latitude sources of diffuse X-ray emission. The only other HI shell that exhibits X-ray emission is the Monogem ring (Nousek et al., 1981); this HI shell is discernable only with great difficulty. A number of large shells and supershells are easily visible in the galactic plane; an excellent example is GS096+04-113 in Figure 2 of Heiles et al. (1979). Larger structures are visible in the HI photographs that combine HI data from both the galactic plane and high latitude Hat Creek surveys. These photographs are presented in Heiles (1982b), who also gives a new list of shells and filaments.

There are many curved HI filaments that do not change size with velocity. None have significant X-ray emission. The proper interpretation of such filaments is not certain. They may be portions of shells that have evolved to the point where they are no longer expanding; in a homogeneous interstellar medium, such a shell would be complete and the filament would be that part of the shell seen tangentially. On the other hand, they may be filamentary condensations within a larger shell--or might be simply condensations in the ambient medium, and not parts of formerly expanding shells at all. Detailed analysis of HI data, not yet performed, should enable these questions to be resolved.

Some shells are huge. Diameters range above 2 kpc, and observed kinetic energies of the largest shells range above 10^{53} erg. These "supershells" tend to be located at fairly large galactic radii, outside the solar circle. Although this preferential location might be an observational bias, reflecting the fact that shells are easier to recognize outside the solar circle, it is likely to be real. Large HI shells have been observed in external galaxies--in M101 by Allan, Goss, and van Woerden (1973), and Allan and Goss (1979), and in M31 by Brinks (1982)--and the same tendency is observed.

Expanding shells tend to show only one hemisphere. That is, only the approaching or the receding hemisphere is seen, and in those few cases in which both are seen one of the two hemispheres is very much weaker and more difficult to recognize. The implication is that most shells are not fully complete, a point which also emerges from the simple fact that the circular filaments on the sky are usually only partial circles and not equally discernable over their full circumferences.

B. Magnetic Fields in Shells

A puzzling feature about expanding HI shells is the relatively large thicknesses. Consider the gas pressure in the shell, given by the product of density and temperature, nT. Temperatures in shell structures are generally low, less than about 200K; the shells are in fact the low temperature "cloud" component of the interstellar medium seen in the 21-cm line (Heiles, 1982). Volume densities in shell structures are much lower than those we have come to accept as characteristic of the cloud component; the shell geometry forces a change in the derived densities. For the Eridanus shell, for example, the HI volume density is less than 3 cm^{-3} at the distance of 500 pc (see Reynolds and Ogden, 1979 and Heiles, 1976).

Therefore, the gas pressure in the shell is only about 300 cm^{-3} K. This is much lower than the ram pressure of the shell expansion, and also much lower than generally-accepted values for the pressure of the interstellar medium (see Cox's paper in this volume). How can the shell maintain such a low gas pressure in the presence of such high external pressures?

The answer is the shell magnetic field, measured using Zeeman splitting of the 21-cm line to be 7 μGauss in two cases by Troland and Heiles (1982). A measurement of Zeeman splitting yields only the longitudinal component of the field, i.e. that component oriented along the line of sight to the observer. From geometrical considerations alone, with a probability of 1/2, the field is at least twice as large as the measured value. Suppose the field strength is really 10 μGauss; then the equivalent magnetic pressure is 3×10^4 cm^{-3} K, 100 times larger than the gas pressure. Clearly the magnetic field plays a crucial role in the gas dynamics of the shell.

C. Unusual and Peculiar Morphology in Apparent Shell Structures

There are some cases in which the velocity structure does not mimic that expected for an expanding shell. Two spectacular examples are discussed in more detail in Heiles (1982b). One shell, about 30 degrees in diameter and located in the galactic anticenter, can be discerned over a velocity range of 100 km/sec or more. There is no systematic change of filament diameter with velocity. There is velocity structure, but it exhibits no systematic trends. The other consists of large-diameter HI filaments that overlap radio loops II and III. In the vicinities of these loops are curved HI filaments with comparable angular scales. These filaments exist in velocities ranging from +20 to -170 km/sec. Some filaments with widely different velocities are superimposed or lie parallel to each other. In one case, the end of a long filament abuts the end of another filament whose velocity is 70 km/sec different. A final example is the peculiar structure discovered by Lockman and Genzel (1982).

The juxtaposition of HI filaments at widely differing velocities is not expected if the filaments are parts of expanding shells. It seems to me that these structures are intrinsically different from the usual shells. They have velocity structure, but it is not simple expansion and they are visible over very wide velocity ranges. Therefore, even though some of the filaments appear roughly to be circular on the sky, they might not be parts of shells.

III. ORIGIN OF SHELLS AND SUPERSHELLS

Many shells are of moderate size and energy, and some are clearly associated with star clusters. In these cases it is most reasonable to assume that the source of energy is stellar winds and supernovae from the stars. Bruhweiler et al. (1980) have developed a theory that nicely accounts for the properties of many HI shells using this idea.

It is natural to try to extend the application of this idea to all shells and supershells. However, for the largest supershells this meets with difficulty because of the energy requirements. Five supershells in Heiles (1979) are estimated to have kinetic energies of more than 10^{53} erg, with radii ranging up to 1.3 kpc and expansion velocities up to 24 km/sec. Such shells are much too energetic to have been produced by a "typical" OB associated with 28 B0 stars and earlier (equivalent to the Sco OB1 association); a much, much larger association would be required. However, there is no independent evidence that such large star clusters exist in our galaxy, particularly outside the solar circle where most supershells reside and where star formation activity is presumably quite moderate. Similarly, the structures with peculiar kinematic morphology are quite possibly not expanding shells at all. And if they are, the very large velocity spreads and peculiar juxtapositions of filaments at widely different velocities imply that peculiar, unknown physical processes are at work.

There seems to be little reason to assume that such structures are produced by the "conventional" energy source, stellar winds and supernovae in star clusters. The most prominent alternative is collisions of high-velocity clouds with the galactic disk, a possibility explored theoretically by Tenorio-Tagle (1980, 1981). An infalling cloud transfers a large fraction of its kinetic energy to the ambient gas in the disk; energy requirements are met fairly easily for clouds similar to those observed. The fact that only one hemisphere of the expanding supershells is observed is a prediction of the theory. The juxtaposition of gas filaments at widely different velocities can be modelled in terms of colliding gas clouds (see Cohen, 1981). However, the presence of adjacent gas filaments at different, widely-spaced velocities does not seem to be a natural consequence of this model. More detailed theoretical and observational studies--perhaps using X-rays--may clarify the explanation of these interstellar gas structures.

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DISCUSSION

GOSS: In the Westerbork HI observations of M101 (an ScI galaxy), we observe one or two large HI holes. The diameters are 2 to 4 kpc. Can these be related to your large galactic shells?

HEILES: I would think that they are the same type of object. It is comforting to see them in other galaxies, because their appearance in our own galaxy is severely influenced by the presence of unrelated HI along the line of sight. Do you see expansion motion around the HI holes in other galaxies?

GOSS: We observe no large systematic velocities in the M101 holes, but they would be difficult to detect because this galaxy is very face-on.

GULL: Partial shells are notable in other regions of the spectrum. About half a dozen SNR's show complementary structure in the form of a [OIII] half ring and the remainder in a Hα, [NII], [SII] half ring. Other SNR's show only half a shell. Around OB associations it is rare that more than half to two-thirds of the shell is visible. This may be explained by differences in shock velocities, densities, and especially nonuniformities in the interstellar medium.