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Galactic Bowshock ? A Cross Section of the 5-kpc Arm

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Abstract

A bowshock structure has been found on a 10-GHz radio continuum map toward the 5-kpc arm which is seen tangentially at G 30.5+00. The bow appears as an arc-shaped ridge of a thermal radio emission concave with respect to the W43 complex at G 30.8−00 and extends from the galactic plane up to $b=0\overset{\circ}{.}6$ and $-0\overset{\circ}{.}9$, respectively. A ridge of the CO gas at the same velocity as that of the W43 complex, or $V_{\rm LSR}=90$–$100\ {\rm km\ s^{-1}}$, is associated with the radio ridge. This fact indicates that the bow is physically associated with the complex and its distance is about 7 kpc. Such a bowshock will be formed by a supersonic flow of the interarm gas against the compressed gas and magnetic field around W43 caused by the galactic shock wave in the 5-kpc arm.

Key words: Galactic shock; Galaxy; Spiral arms; Star formation.

1. Introduction

The galactic shock wave theory has been established for the formation of gaseous arms in spiral galaxies (Fujimoto 1966; Roberts 1969; Tosa 1973). Evidence for the shock in our Galaxy has been given through analyses of velocity fields of H I gas and H II regions in the spiral arms (Roberts and Yuan 1970). Tosa (1973) has taken into account the magnetic pressure and treated the variation of disk thickness across a shocked region. He has shown that the thickness of a gas layer increases in the shocked region compared to a pre-shocked interarm region due to the magnetic pressure. More recently Nelson et al. (1984) studied the vertical structure of a shocked spiral arm by their extensive numerical computations.

Such a structure in the arms can be observationally investigated by looking at the tangential points of the inner spiral arms of our Galaxy (see Sofue 1973, 1976). In the present paper we study a cross section of the 5-kpc arm, or the Scutum arm, through radio continuum observations at 10 GHz. We discuss a possible bowshock structure associated with the W43 complex region.

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2. Observations and the Maps

A radio continuum mapping of a region of area 3°×3° centered on G 31+00 was made in the course of a 10-GHz radio continuum survey at NRO using the 45-m telescope. The observations were made in April 1983 and September 1984. The center frequency was 10.05 GHz and the bandwidth was 500 MHz. The system noise temperature was about 150 K. We used a cooled parametric amplifier with Dicke switching referring to a cooled dummy load at the 20-K stage. The HPBW of the antenna was 2!7.

We mapped the region by scanning perpendicular to the galactic plane. Both sides of each scan were taken as the zero level. Figure 1 shows the obtained 10-GHz map for a 1°5×1°5 area centered on G 30.5−0.1. In this figure a large-scale structure with a scale size greater than 0°5 has been removed by applying the BGF (background filtering) method with a filtering beam of 0°5 HPBW (see Sofue and Reich 1979) in order to enhance finer structures. Figure 2 is the same but in a gray-scale representation.

The strongest source near the map center at G 30.8−00 is W43. There are many discrete sources around this source. Downes et al. (1980) have given LSR radial velocities for some of the sources from their H 110α recombination-line and H_2CO absorption-line observations. Most of them are H II regions and have $V_{LSR}=90$ to 100 km s^{-1}, which are close to that of W43 ($V_{LSR}=90$ km s^{-1}). They may form a large complex in the 5-kpc arm involving the giant H II region W43. The kinematical distance of the complex is estimated to be about 7 kpc at the tangential point of the 5-kpc arm. The measured V_{LSR} are indicated in figure 3 as V_{LSR}(H 110α)/V_{LSR}(H_2CO) in units of km s^{-1}.

3. A Radio Bow Structure at G30.5+00

3.i. *Radio Continuum Features*

We call attention to an arc-shaped ridge in figures 1 and 2 which extends from the galactic plane at G 30.5+00 towards positive and negative latitudes, respectively, as

Table 1. Spectral index of the surface brightness between 2.7 and 10 GHz at several points along the bow-shaped ridge.

Object	Position	Spectral index α*	Object	Position	Spectral index α*
Radio-bow south ...	G 30.51−0.20	−0.1	Radio-bow north ...	G 30.66+0.14	−0.1
	G 30.50−0.30	−0.2		G 30.70+0.20	−0.1
	G 30.50−0.40	−0.2		G 30.75+0.30	−0.1
	G 30.55−0.52	−0.1		G 30.77+0.36	−0.1
	G 30.60−0.60	−0.2		G 30.85+0.46	−0.1
	G 30.71−0.66	−0.3			
	G 30.82−0.73	−0.1			
	G 30.92−0.85	−0.3			

* The errors are typically ±0.1 corresponding to a ±10% error in the surface brightness measurements. Here α is defined as $\Sigma \propto \nu^{\alpha}$.

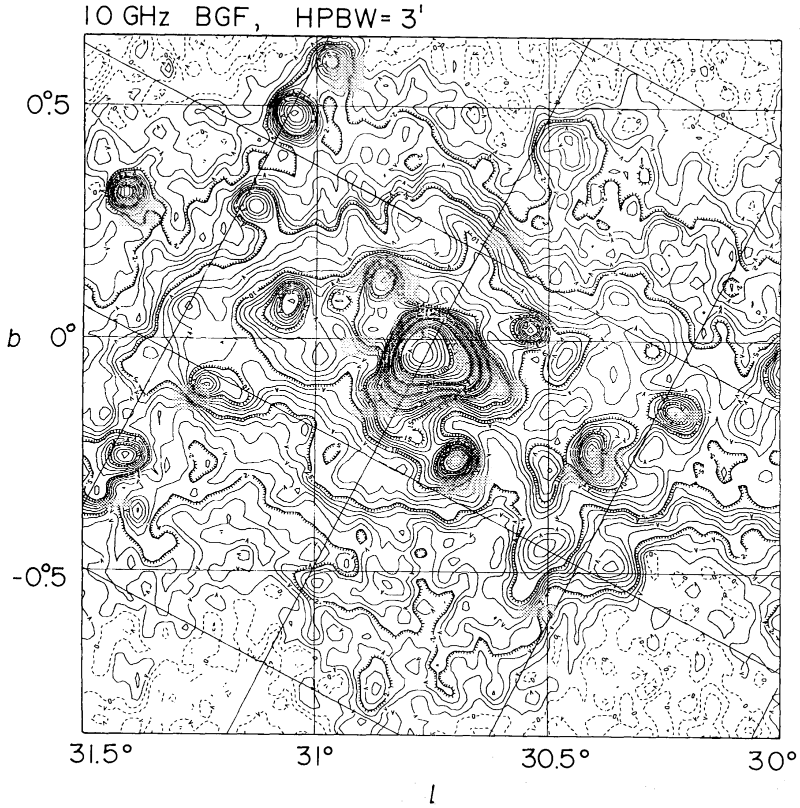

Fig. 1. A 10-GHz radio continuum map of G 30.5+00 region around W43 observed with the 45-m telescope at NRO. The background, a large-scale structure with a scale size greater than 0°5, has been removed (see the text). The map has been smoothed to a 3′ resolution (originally 2′7) in order to increase the S/N ratio to see faint, extended structures. The unit of the numbers on the contours is 10^{-21} W m^{-2} sr^{-1} Hz^{-1} in surface brightness.

illustrated in figure 3 with the thick line. The northern ridge reaches almost to G 31+00.6, and the southern ridge extends to G 30.9−00.9. Both the ridges form a large bow-shaped arc concave with respect to W43. The radio intensity along the arc increases toward the galactic plane. The arc has no counterpart to form a loop, which, if existed, should appear at around G 31.8+00. The arc is also recognized on the Bonn 2.7-GHz map (Reich et al. 1985) and on the Bonn 5-GHz map (Altenhoff et al. 1978). If we assume that the arc is associated with the W43 complex and its distance is about 7 kpc (see subsection 3.ii), the extent of the arc from the bottom to top (1°5 in angular size) is about 200 pc and the width (0°1) is about 20 pc.

Figure 4 shows a cross section of figure 1 at a constant latitude, $b=0°2$. The figure shows that the radio intensity increases suddenly at the ridge ($l=30°6$) with increasing longitude, and gradually decreases toward $l=31°5$. Such a cross section suggests a shock-compressed front against a supersonic gas flow directed toward increasing longitude (from right to left in the figure). It should be emphasized that this flow direction is in coincidence with that of the interarm gas relative to the galactic shock wave pattern at the 5-kpc arm when projected on the sky.

Radio spectra between 2.7 and 10 GHz of the ridge at several points, avoiding

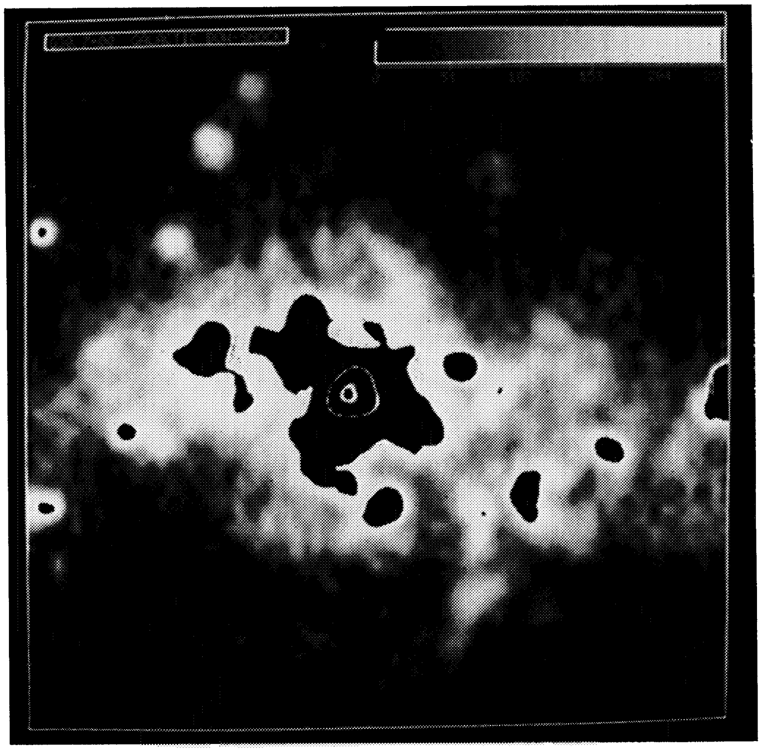

Fig. 2. The same as figure 1 but in a gray-scale representation.

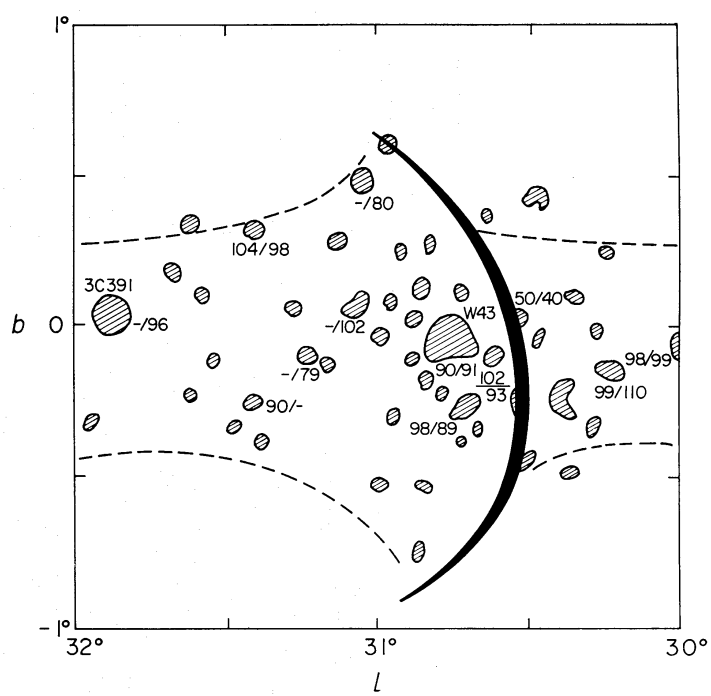

Fig. 3. A schematic illustration of the radio bow at G 30.5+00, which may be a bowshock in front of the W43 complex in the 5-kpc arm. H II regions and discrete sources are hatched. Note a concentration of the sources behind (or in the left-hand side of) the bow shock. For some sources their radial LSR velocities are indicated as V(H110α)/V(H_2CO) after Downes et al. (1980).

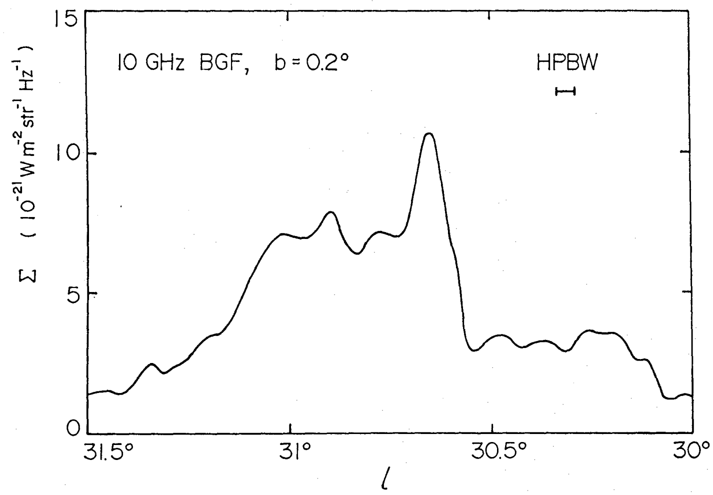

Fig. 4. The brightness distribution across the radio bow along a constant latitude, $b=0^\circ\!.2$, obtained from figure 1. The distribution suggests a shock-compressed structure by a flow from right to left in the figure.

discrete sources, were obtained using the present observations and the Bonn 2.7-GHz galactic plane survey data of Reich et al. (1984). Table 1 lists the derived spectral indices. The spectral indices are typically $\alpha=-0.1$ along the northern ridge at $b=0^\circ\!.1$ to $0^\circ\!.5$, and $\alpha=-0.1$ to -0.2 along the southern ridge at $b=-0^\circ\!.2$ to $-0^\circ\!.8$. The spectra along the ridge are almost the same as those of H II regions. This fact indicates that the emission from the bow is thermal radiation, due to the ionized H II gas. We should also note that the arc is very unlikely to be a part of an old shell-type supernova remnant because of its flat spectrum.

We here estimate an emission measure, *EM*, toward the arc. Using an approximate equation given by Mezger and Henderson (1967), we obtain

$$EM(\mathrm{pc\ cm^{-6}})=39.6(T_e/\mathrm{K})^{0.35}(\nu/\mathrm{GHz})^{0.1}(\Sigma/10^{-21}\ \mathrm{W\ m^{-2}\ sr^{-1}\ Hz^{-1}})\ . \quad (1)$$

We assume further that the electron temperature is about 10^4 K. Since the excess surface brightness on the ridge at $b\sim0^\circ\!.2$ (figure 4) is about 5×10^{-21} W m^{-2} sr^{-1} Hz^{-1}, we obtain $EM\approx7000$ pc cm^{-6}. It is difficult to estimate the line-of-sight depth of the bow. However, if we assume that the depth is of the order of 100 pc, which is a typical scale length of a coherent structure in the interstellar gas, we obtain an electron density of 8 cm^{-3}. As the arc width is about 20 pc, we may roughly estimate the total mass of the ionized gas as several times $10^4\ M_\odot$.

3.ii. CO Line Emission

To examine if the radio arc is really associated with W43 complex, we have studied the CO gas distribution. Figure 5 shows the distribution of the peak temperature of the CO line emission between $V_{\rm LSR}=90$ and 100 km s^{-1} inferred from the Columbia survey with the 1.2-m telescope (Dame 1984). Although the resolution and data sampling are not good enough to see the details, we can recognize two spurlike features extending from G 30.5+00 towards both positive and negative latitudes, respectively,

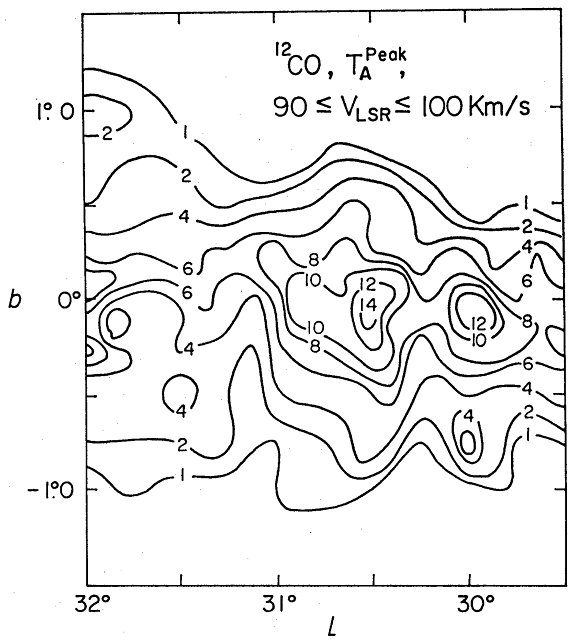

Fig. 5. The distribution of the peak temperature (T_A) of the ^{12}CO line emission in the V_{LSR} range between 90 and 100 km s^{-1} as derived from the Columbia survey (Dame 1984). The angular resolution is 12′ and sampling interval is 7′.5. Two spurlike features are associated with the radio bow.

in positional coincidence with the radio continuum arc. This fact may indicate that the CO gas is associated with the arc at the same velocity as that of W43 complex, and therefore, that the arc is physically associated with W43.

The mean excess temperature in the CO line emission along the arc is about 2 K for an extent of $\sim 0^\circ.2 \times 1^\circ.5$ or 25 pc × 180 pc in figure 5. A rough idea about the total amount of H_2 gas in the bow can be obtained by applying the empirical relation between H_2 column density and ^{12}CO line intensity which was derived by Young and Scoville (1982) for galactic objects: $N(H_2)=4\pm2\times10^{20} I_{CO}$ (cm^{-2}) with I_{CO} (K km s^{-1}) the line intensity. Assuming that the velocity range is about 10 km s^{-1} and inserting known quantities, we obtain the total mass of molecular hydrogen associated with the bow as $M \sim$ a few times $10^5\ M_\odot$.

We also examined H I gas distributions in the region using the H I-line survey data of Westerhout and Wendlandt (1982). However, no prominent association was found, being disturbed by complex absorption features against the strong background continuum emission at 1.4 GHz. We find no associated H I shell in the catalogs of Heiles (1979) and Hu (1981) [see also Sofue and Nakai (1983)].

3.iii. A Galactic Bowshock?

We suggest the following mechanism for the origin of the bow. According to the galactic shock wave theory, a shock is produced by a supersonic passage of an interstellar gas through a spiral density wave. The shock compresses the gas together with the magnetic field to form a dense magnetized shocked arm (Tosa 1973) in which the star formation is enhanced to produce many H II regions like the W43 complex.

If the interarm gas further encounters such a magnetized arm at a supersonic velocity, a bowshock is formed in front of the arm. Namely we are just looking at a cross section of a wave front of the galactic shock occurring in the 5-kpc arm as the radio bow. We emphasize that the discrete sources surrounding the W43 complex, mostly star forming sites or H II regions, are found in the down-stream side of the bow (figure 3). We finally emphasize that the observed radio structure of the 5-kpc arm resembles the vertical structure of a shocked spiral arm as predicted from the extensive numerical computations by Nelson et al. (1984).

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