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ASTRONOMY AND ASTROPHYSICS

HI Observations Towards the Sagittarius Dwarf Spheroidal Galaxy

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Abstract. We have measured the λ21 cm line of Galactic H I over more than 50 square degrees in the direction of the Sagittarius dwarf spheroidal galaxy. The data show no evidence of H I associated with the dwarf spheroidal which might be consider analogous to the Magellanic Stream as it is associated in both position and velocity with the Large Magellanic Cloud. Nor do the H I data show evidence for any disturbance in the Milky Way disk gas that can be unambiguously assigned to interaction with the dwarf galaxy. The data shown here limit the H I mass at the velocity of the Sagittarius dwarf to < 7000 M$_\odot$ over some 18 square degrees between Galactic latitudes $-13°$ and $-18\overset{\circ}{.}5$.

1. Introduction

The Sagittarius dwarf spheroidal galaxy appears as a stream of stars covering several hundreds of square degrees around $l = 5°$, $b = -15°$. It is elongated perpendicular to the Galactic plane and apparently is in the process of plunging through the Milky Way some 25 kpc from the Sun and 17 kpc from the Galactic center (Ibata et al. 1994, 1997; Mateo et al. 1998). This encounter is probably not the first for this system. It seems reasonable to search for effects which such an encounter might plausibly produce on the Milky Way, including distension of the H I layer in the direction of the dwarf galaxy, and, depending on the dwarf's mass, creation or enhancement of a Galactic warp (Lin 1996, Ibata & Razoumov 1998). Previous λ21 cm measurements have detected no H I at three positions near the center of the Sgr dwarf (Koribalski et al. 1994), making this system typical of nearby dwarf spheroidals, although the dSph galaxy Sculptor is an interesting exception (Carignan et al. 1998, Carignan 1999).

We have measured the λ21 cm emission line of neutral hydrogen over a large area which includes the central region of the Sgr dwarf in a search for neutral gas associated with or entrained by the dwarf galaxy, for a perturbation in Galactic gas resulting from the first phases of an encounter, or for evidence for other phenomena such as a tidal tail or an analogue to the Magallenic Stream as it is associated with the Large Magellanic Cloud.

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2. Observations

Galactic H I spectra were taken toward the Sagittarius dwarf galaxy using the 140 Foot Telescope of the NRAO in Green Bank, WV, which has an angular resolution of $21'$ at the 21cm wavelength of the H I line. Each spectrum covers about 1000 km s^{-1} centered at a velocity of +50 km s^{-1} with respect to the LSR. The channel spacing is 2.0 km s^{-1}. The data were obtained by switching against a reference frequency +5 MHz above the signal band. The temperature scale was calibrated using laboratory measurements of a noise diode. Spot checks show that the spectra do not deviate by more than 10% from the calibrated intensity scale of the Leiden/Dwingeloo H I survey of Hartmann & Burton (1997). The system temperature at zenith was about 20 K; a typical rms noise level in a spectrum is about 30 mK. This noise is equivalent to a column density uncertainty $\sigma(N_{\rm HI}) = 1.8 \times 10^{17}$ cm^{-2} over a 20 km s^{-1} band. At the 25 kpc distance of the Sagittarius Dwarf Spheroidal, this noise level allows a 3σ detection of 200 M$_\odot$ of H I in a single 140 Foot pointing.

Spectra were taken every $0\overset{\circ}{.}5$ in Galactic longitude and latitude over the region bounded by $4\overset{\circ}{.}0 \le l \le 8\overset{\circ}{.}0$ and $-4\overset{\circ}{.}0 \le b \le -15\overset{\circ}{.}5$, with an extension to $b = -18\overset{\circ}{.}5$ over $4\overset{\circ}{.}0 \le l \le 6\overset{\circ}{.}5$. In all, more than 250 H I spectra were measured.

We also examined H I spectra that were available over a more extended region, albeit taken at lower sensitivity, from the Leiden/Dwingeloo survey which covers the sky north of declination $-30°$ at half–degree spacing, and from the observations of Liszt & Burton (1980), which cover the area within about 10° of the Galactic center, also at half–degree intervals.

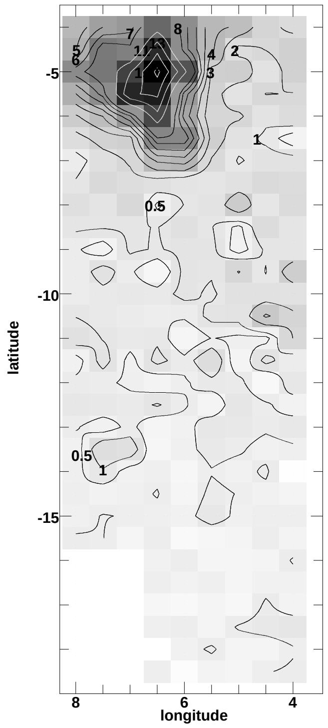

Fig. 1. Contours and grey scale of neutral hydrogen integrated over $+130$ km s^{-1} to $+170$ km s^{-1} over the region of our observations. The H I column descreases smoothly from the Galactic plane, and there is no indication of significant H I associated with the Sagittarius dwarf spheroidal galaxy in these data. The contours are labelled in units of K km s^{-1}, each equivalent to 1.8×10^{18} cm^{-2}.

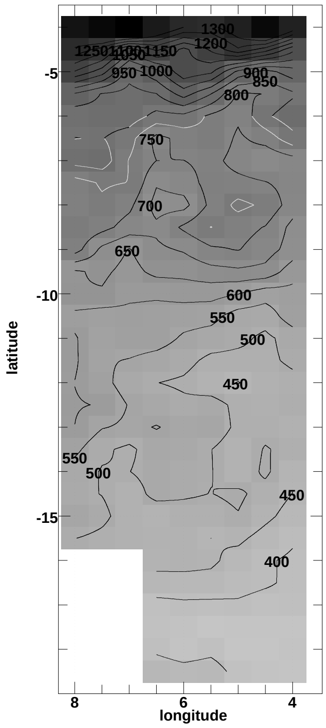

Fig. 2. Contours and grey scale of neutral hydrogen integrated over the range -400 km s^{-1} to $+500$ km s^{-1}. The H I column descreases smoothly from the Galactic plane. There is no indication of significant H I associated with the Sagittarius dwarf spheroidal galaxy over this extended velocity range. The contours are labelled in units of K km s^{-1}, each equivalent to 1.8×10^{18} cm^{-2}.

3. Expected Location of HI Emission

The brightest parts of the Sagittarius dwarf spheroidal galaxy are near $l = +5°, b = -15°$; stars associated with this system have been found from latitudes $-4°$ to perhaps $-40°$, and its true extent is still uncertain (Alard 1996, Alcock et al. 1997, Mateo et al. 1998). The mean stellar velocity over the central region is within a few km s^{-1} of $+170$ km s^{-1} with respect to the Galactic Standard of Rest, which, at the center of the dwarf, corresponds to $+150$ km s^{-1} with respect to the Local Standard of Rest (Ibata et al. 1997). At such a low Galactic longitude, conventional Galactic rotation is almost entirely perpendicular to the line of sight, so unperturbed Milky Way disk gas at the location of the dwarf galaxy would have an LSR velocity of order -10 km s^{-1}. The longitude of the Sgr dwarf spheroidal passes, however, close to the Galactic nucleus where gas in the bulge regions displays both high positive– and negative–velocity motions within about 6° of the Galactic plane (e.g. Liszt and Burton 1980). Any H I that is related to the Sagittarius dwarf would be expected to be either at the velocity of the dwarf (in the Galactic Center Frame) or to be spatially extended in relation to the dwarf. The former possibility can be tested simply, because there is not expected to be Galactic H I at the velocity of the dwarf; the later possibility requires comparison of the Galactic H I toward the dwarf with the situation in directions away from it.

4. Results

Figure 1 shows the H I intensity integrated over $+130$ to $+170$ km s^{-1} (LSR); this velocity range extends $\pm 2\sigma$ about the mean stellar velocity of the Sagittarius dwarf spheroidal (Ibata et al. 1997). The amount of Galactic H I decreases smoothly with latitude over this area; there is no evidence for a concentration at the latitude of the central part of the Sagittarius dwarf within this velocity range. A comparable view of the H I is given in Figure 2, which shows contours of H I intensity integrated over all observed velocities. Again, there is no significant con-

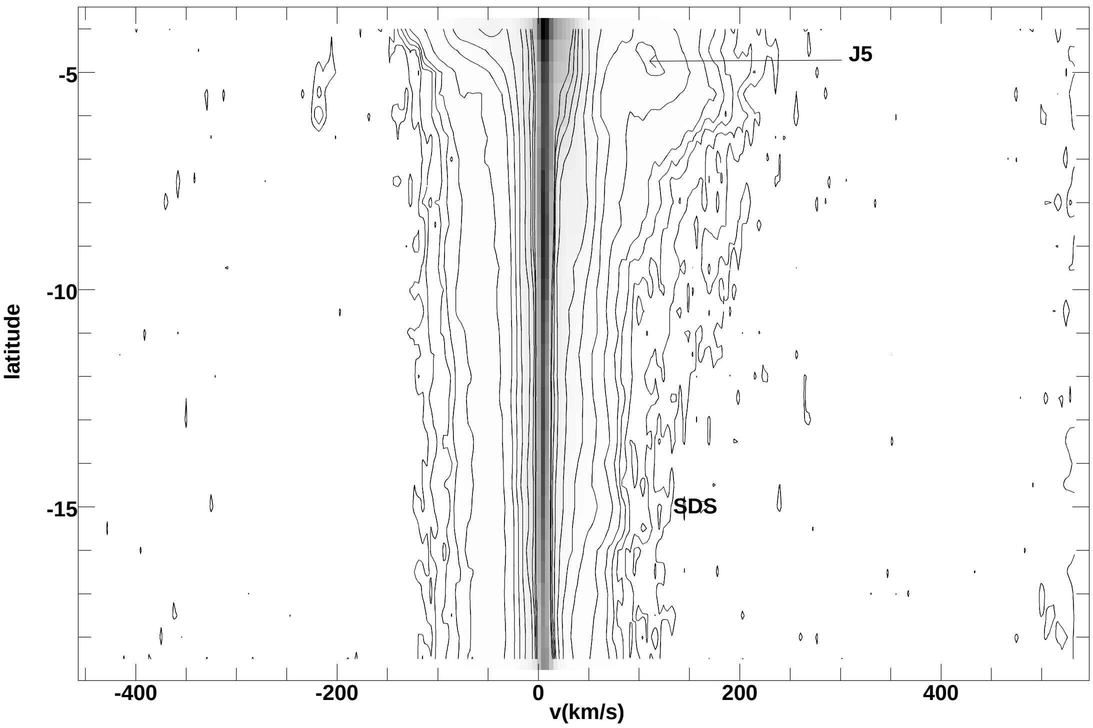

Fig. 3. Latitude–velocity diagram showing contours of HI brightness temperature averaged at each latitude over longitudes 4° to 8°. The LSR velocity and position of the brightest stellar component of the Sagittarius Dwarf Spheroidal galaxy is marked by the initials SDS. The width spanned by the initials is plus and minus twice the velocity dispersion of the stellar component; the height of the initials corresponds approximately to the angular resolution of the 140 Foot Telescope. The H I cloud marked J5 (Cohen 1974) is likely associated with gas patterns associated with the Galactic bulge region (Liszt & Burton 1980). Contours are drawn at brightness–temperature emission levels of 0.015, 0.03, 0.05, 0.07, 0.1, 0.2, 0.5, 1.0, 2.0, 4.0, 6.0, 8.0, and 10.0 K.

centration of H I at the location of the Sagittarius dwarf spheroidal within that extended velocity range.

Figure 3 shows a latitude–velocity map of the HI made after spectra at constant latitude have been averaged over the longitude range of our observations. The centroid of the Sagittarius dwarf spheroidal galaxy is marked by the letters 'SDS'.

For comparison, Figure 4 shows a similar display of data for directions *above* the Galactic plane from the Leiden/Dwingeloo survey of Hartmann & Burton (1997). Note that the positive–latitude figure is plotted with the latitude scale inverted to facilitate comparison with the data toward the dwarf galaxy.

These figures show again that there is no bright H I feature at the location and velocity of the dwarf galaxy. Moreover, at the latitude of the Sagittarius dwarf spheroidal the appearance of the H I contours at all velocities is quite similar above and below the Galactic plane, showing no indication of a disturbance in the Milky Was disk gas stemming from the proximity of the dwarf.

The feature labeled J5 in Figure 3 is a cloud found by Cohen (1975) that has previously been interpreted as one of the observational vagaries stemming from the projection of kinematics associated with the barred potential of the inner few kpc of the Galaxy (see Burton & Liszt 1978, Liszt & Burton 1980, Burton & Liszt 1983). J5 has a velocity with respect to the Galactic center of $+140$ km s^{-1}, while at its latitude the Sagittarius dwarf spheroidal has a velocity of about $+170$ km s^{-1} in the same coordinate system. Because of the velocity difference and lack of any evident spatial coincidence, and because feature J5 fits naturally into models of the Galactic barred potential, we believe that an association of this H I feature with the Sagittarius dwarf spheroidal galaxy is unlikely. The Liszt & Burton model of the Galactic core also accounts for the small H I feature at $b \sim +5°$, $v \sim -75$ km s^{-1} seen in Figure 4 at the location and velocity mirror–symmetric to the J5 feature. Feature J5 and its mirror–symmetric counterpart are a single pair of more than the dozen apparently anomalous paired H I features lying within the Galactic core discussed by Burton & Liszt (1978). All important geometrical aspects of the barlike model of the inner–Galaxy gas distribution proposed by Liszt & Burton (1980) whose consequences subsume the individual anomalous H I fea-

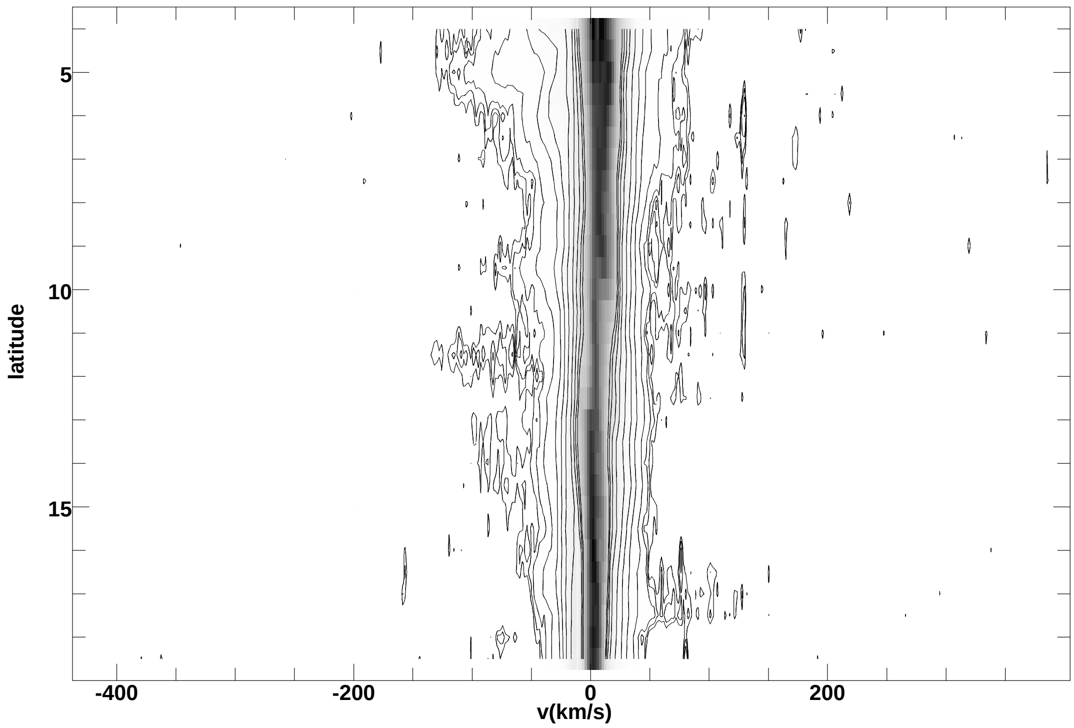

Fig. 4. Latitude–velocity diagram showing contours of HI brightness temperature averaged at constant latitudes over longitudes 4° to 8° for regions *above* the Galactic plane. The data are from the Leiden/Dwingeloo survey. For easier comparison with Figure 3 the latitude scale has been inverted. Contours are the same as for Figure 3, but the lowest two contours have been omitted because the noise level of the data is higher here.

tures, have subsequently been confirmed by the direct evidence for a stellar bar in the Milky Way shown by the near–IR surface photometry (see review by Fux 1999 and references there, in particular Blitz & Spergel 1991, Dwek et al. 1995, and Binney et al. 1997). The larger context into which J5 and its mirror–symmetric counterpart fit in a natural way makes a suggested association with the Sagittarius dwarf particularly unconvincing.

There is an additional HI cloud visible in the data at $(l, b, v) = +8°, -4°, -212$ km s^{-1}. This is a compact high–velocity cloud (see Braun & Burton 1999) discovered by Shane (see Saraber & Shane 1974), with no evident connection either to the Milky Way or to the Sagittarius dwarf.

We can place a limit on the H I mass at the velocity of the Sagittarius dwarf spheroidal galaxy of $\sim$ 200 M$_\odot$ (3σ) in a single beam of the 140 Foot Telescope, assuming that the H I would have the velocity centroid and velocity dispersion ($\sim$ 10 km s^{-1}) observed in the stellar component (Ibata et al. 1997). With the same assumpton, a limit on the total mass of HI associated with the system in the region covered by the current observations was derived by averaging all H I spectra with $b \leq -13°$ and $4.^\circ0 \leq l \leq 8.^\circ0$. The average H I spectrum thus obtained shows some emission above the noise level over the velocity range $+140 < v < +160$ km s^{-1}, in an amount which would be equivalent to 7000 M$_\odot$ of H I at the 25 kpc distance of the Sagittarius dwarf spheroidal, but Figure 3 shows that most of this emission is coming from the lowest latitudes, and it is neither centered on, nor increasing in intensity toward, the position of the Sagittarius dwarf spheroidal galaxy. Indeed, the amount of H I in the velocity interval is doubled if the average is taken over an area extending to $b = -11°$ rather than to $-13°$. We conclude that the rather small amount of emission detected in the large-area average is most likely contributed by gas in the Galactic core (possibly via the antenna sidelobes) rather than by gas associated with the Sagittarius dwarf spheroidal galaxy.

5. Discussion

There is no bright H I associated with the Sagittarius dwarf spheroidal galaxy, either at the velocity of the galaxy itself, or signaling a perturbation to the Milky Way. There is no indication of a train of gas analogous to the Magellanic Stream (see Mathewson et al. 1974) which is focussed at the position and velocity of the Large Magellanic Cloud.

The absence of H I in the dwarf spheriodal is consistant with earlier, more limited, H I measurement (Koribalski et al 1994) and with observations of similar systems. In general, the dwarf spheroidal companions of the Galaxy and of M31 do not have a detectable amount of HI. The one exception is the Sculptor dwarf galaxy, which has $> 3\times10^4$ $M_\odot$ of H I located in two clouds each about 500 pc from the center of that galaxy (Carignan et al 1998, Carignan 1999). These clouds have peak column densities in excess of a few times 10^{19} cm^{-2}, an order of magnitude greater than any feature in our data at the position and velocity of the Sagittarius dwarf spheroidal galaxy (Figure 1).

The brightest part of the Sagittarius dwarf spheriodal galaxy is now about 5 kpc below the plane of the Milky Way, and some stars associated with it may be within 2 kpc of the disk. It appears that it will strike the Milky Way at a location near the line of nodes of the Galactic warp, where the disk H I is expected to be distributed approximately symmetrically about $z = 0$. The H I at a galactocentric distance of 17 kpc has, on average, a scale-height of about 400 pc (Burton 1992). The main part of the Sagittarius dwarf is thus unlikely to be encountering the Milky Way gaseous disk gas as of yet, consistent with our finding that the Sagittarius dwarf has not yet affected the Milky Way H I in any significant way.

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