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Search for HI in Dwarf Spheroidal Galaxies

Claude Carignan

Département de Physique and Observatoire du Mont Mégantic, Université de Montréal, CP 6128, Succ. centre ville, Montréal, Québec H3C 3J7, Canada
carignan@astro.umontreal.ca

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Abstract: After reviewing the HI content and distribution in extreme dwarf irregular (dIrr) and dwarf elliptical (dE) galaxies, previous searches for HI in dwarf spheroidal (dSph) galaxies will be discussed. I will report on the recent detections of HI probably associated with the Local Group (LG) dSph Sculptor and dIrr/dSph Phoenix, obtained with the ATCA, along with a similar detection in the Centaurus Group dSph CEN_41. Data obtained for Sculptor, using the Parkes Multibeam system, will also be presented and the advantage of the wide field for such nearby objects will be emphasised. Finally, the possible origin of the gas and the general problem of the missing ISM in dSph galaxies will be discussed.

Keywords: Local Group—galaxies: ISM—galaxies: individual (Sculptor)—galaxies: irregular—galaxies: structure—ISM: clouds

1 Introduction

Twenty years ago, Knapp, Kerr & Bowers (1978) published the results of a systematic search for HI in dSph galaxies using NRAO 91 m and 41 m single dish observations centred on the optical position. They reported that no HI had been detected within their single beam, single pointing observations, setting upper limits in the range of $10^2 - 10^4$ $\mathcal{M}_\odot$. More recent observations (Mould et al. 1990; Koribalski, Johnston & Otrupcek 1994) using the Parkes 64 m telescope yielded very similar results. Since then, those papers are often cited as evidence that no ISM is present in dSph galaxies and that, because of their shallow potential well, they probably lost all their gas during their first episode(s) of star formation (SF) which took place many billions of years ago.

However, without knowing it, Knapp, Kerr & Bowers (1978) were the first to detect HI in the LG dSph galaxy Sculptor. In fact, in their paper, they mention a peak in their spectrum around 100 km s^{-1}, but discarded the possibility that this gas could be associated with Sculptor because of the wrongly determined optical velocity at the time of ~200 km s^{-1}. The optical velocity is now known to be $110 \pm 1{\cdot}5$ km s^{-1} (Queloz, Dubath & Pasquini 1995), very close to the gas detected by Knapp, Kerr & Bowers (1978) at the Sculptor position.

2 HI Distribution in Extreme dIrr and dE

Before looking at the ISM in dSph galaxies, it is instructive to look at what is known on the HI distribution in low luminosity dE and dIrr galaxies. For the dE, the best study is the one of Young & Lo (1997*a*), where they looked at the HI content and distribution of NGC 185 and NGC 205. In both cases, they found HI masses $\sim 10^5$ $\mathcal{M}_\odot$, with the peak of the distribution having a slight offset ($\sim 1'$ S for NGC 205 and $\sim 10''$ NE for NGC 185) from the optical centre.

For the low-luminosity ($M_{\rm B} \leq -14$) dIrr, mainly two kinds of HI distributions are found: first, there are systems like GR8 (Carignan, Beaulieu & Freeman 1990) and Sextans A (Skillman et al. 1988) where most of the HI is in a few clouds just outside the optical and, second, those such as Leo A (Young & Lo 1996), SagDig (Young & Lo 1997*b*) and M81dwA (Figure 1) where the HI is distributed in a complete ring, again just outside the optical. In fact, it is possible that we may see the same distribution in GR8 and Sextans A when higher spatial resolution data become available. Those systems have HI masses around $10^6 - 10^8$ $\mathcal{M}_\odot$.

Puche & Westpfahl (1994) gave a good summary of the situation. Large expanding cavities, surrounded by dense shells are found in the ISM of the dwarfs they observed at high resolution. Energy arguments suggest that they are created by stellar winds and supernova explosions. In the smallest dwarfs, one large, slowly expanding shell usually dominates the ISM. The expansion and contraction of the entire HI component is interpreted as being associated with bursts of SF. They speculated that in extremely low mass dwarfs, the initial burst of SF could deplete the galaxy of almost all its gas. This scenario suggests a search for HI emission outside the optical disk in galaxies which may have evolved in this way, such as dSph's. This is the program we started a few years ago.

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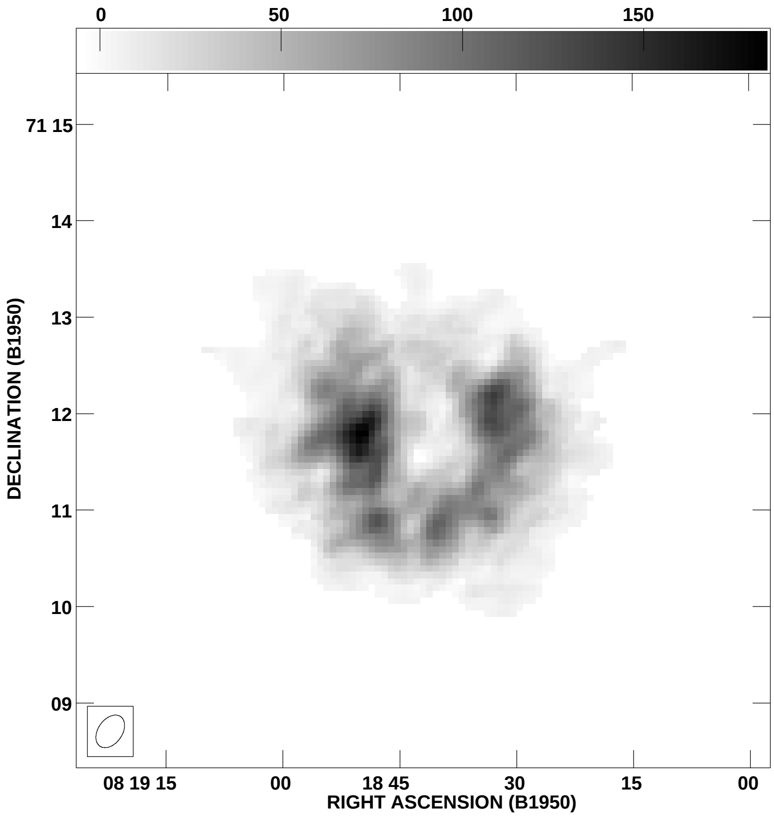

Figure 1—HI surface densities of M81dwA from VLA observations. (Courtesy of E. Brinks & F. Walter.)

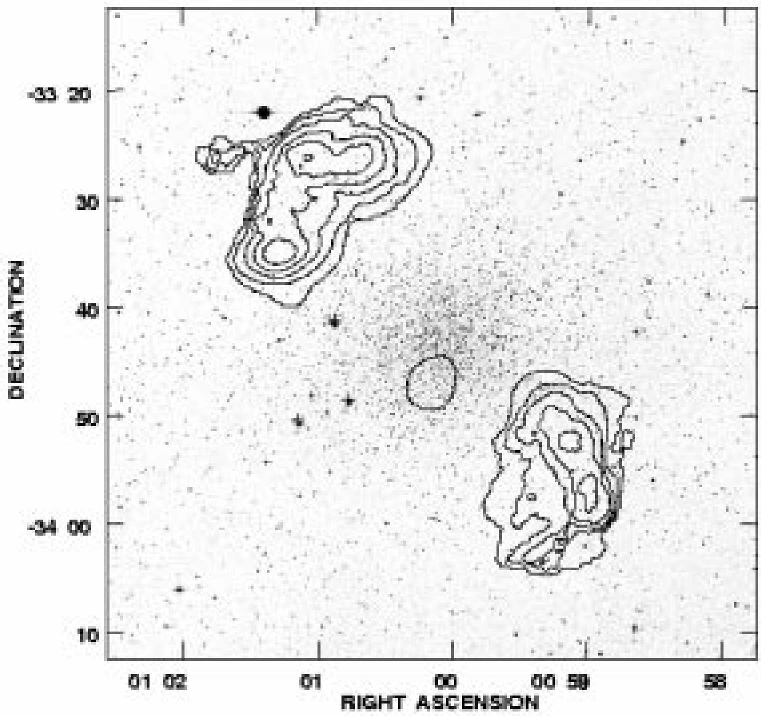

Figure 2—HI surface densities of Sculptor, primary beam corrected, superposed on an STScI Digitized Sky Survey optical image. The contours are 0·2, 0·6, 1·0, 1·4, 1·8 and 2·2 $\times 10^{19}$ cm^{-2}. The moment maps were derived for the velocity range [72·3, 151·7] km s^{-1}.

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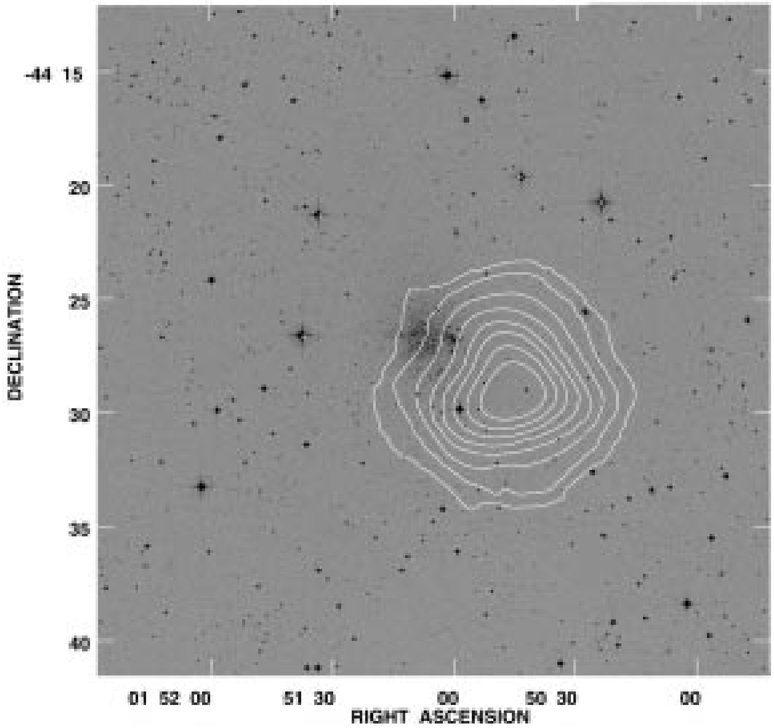

Figure 3—HI surface densities for the component at $\sim$−23 km s^{-1} in the field of Phoenix, superposed on an STScI Digitized Sky Survey optical image, for a mosaic of nine pointings obtained with the ATCA. The contours are 0·5, 1·0, 1·5, 2·0, 2·5, 3·0, 3·5 and 4·0 $\times 10^{19}$ cm^{-2}. The moment maps were derived for the velocity range [−43·4, −7·1] km s^{-1}.

3 Previous HI Observations of dSph Galaxies

The first claim that HI could be associated with a dSph-like system was for the dIrr/dSph system Phoenix (Carignan, Demers & Côté 1991). They identified a component, corresponding to $\sim 10^5\ \mathcal{M}_\odot$, around 50 km s^{-1}, between the Galactic HI $\sim$0 km s^{-1} and gas $\sim$150 km s^{-1}, associated with the Magellanic Stream (MS: Mathewson, Cleary & Murray 1974; Haynes & Roberts 1979). More recently, Young & Lo (1997*b*) identified another velocity component $\sim$−23 km s^{-1}, nearly superposed on the optical.

The other system, in the field of which HI was detected, is the more distant ($\Delta \simeq 900$ kpc) dSph Tucana (Oosterloo, Da Costa & Staveley-Smith 1996). However, since most of the HI is located $\sim 15'$ (~ 4 kpc) east of the optical and since the detected gas, if associated with Tucana, would imply a mass in excess of $10^6\ \mathcal{M}_\odot$, they discarded this possibility and suggested that it was most probably gas associated with the Magellanic Stream. Unfortunately, in both cases, no optical velocities are yet available to disentangle which velocity component could be truly associated with those galaxies.

4 HI associated with Sculptor and Phoenix

The recent ATCA observation of Sculptor (Carignan et al. 1998) is the best case, so far, of HI probably associated with a bona-fide dSph galaxy. As can be seen in Figure 2, not only is the detected gas symmetrically distributed on each side of the optical, but it is also at the same systemic velocity as the optical. However, we know that the $\sim 10^4\ \mathcal{M}_\odot$ of HI is only a lower limit since most of the detected HI lies outside the HPBW of the ATCA antennae. Moreover, the size of the clouds ($\sim 20' = 0{\cdot}5$ kpc) corresponds to the largest scale that could be seen with the 375 m configuration used (see Section 6).

Better observations are now available for the dIrr/dSph Phoenix (St-Germain, Carignan & Oosterloo 1998). It consists of a mosaic of nine pointings obtained with the ATCA. Figure 3 shows that the component around −23 km s^{-1} now clearly overlaps the optical image. Moreover, this is the only velocity component that shows well ordered motion, with clear rotation $\simeq 5$ km s^{-1}, while the other components only show random motions. However, optical velocities are clearly needed to make sure that this gas is truly associated with Phoenix.

Already, some conclusions can be derived from those observations. First, the HI distribution, seen in Sculptor, with a concentration in two clouds just outside the optical is very similar to what is seen in the dIrr galaxy Sextans A (Skillman et al. 1988). Second, the slight offset of the HI distribution seen in Phoenix is more reminiscent of what is seen in the dE galaxies NGC 185 & NGC 205 (Young & Lo 1997*a*). Finally, the HI content around

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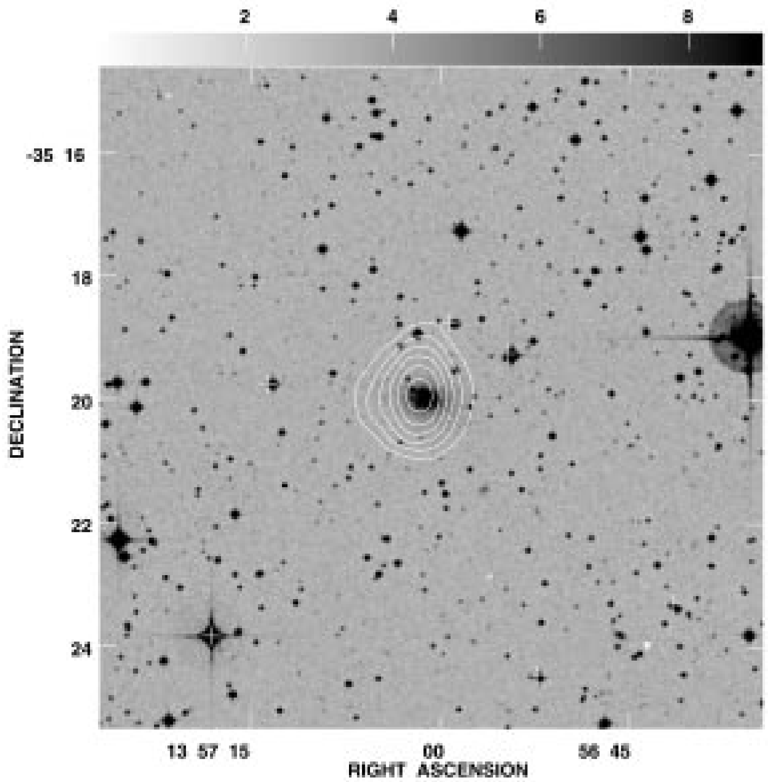

Figure 4—HI surface densities of CEN_41, superposed on an STScI Digitized Sky Survey optical image, for a single field ATCA observation. The contours are $0 \cdot 5$, $1 \cdot 0$, $1 \cdot 5$, $2 \cdot 0$, $2 \cdot 5$ and $3 \cdot 0 \times 10^{19}$ cm^{-2}.

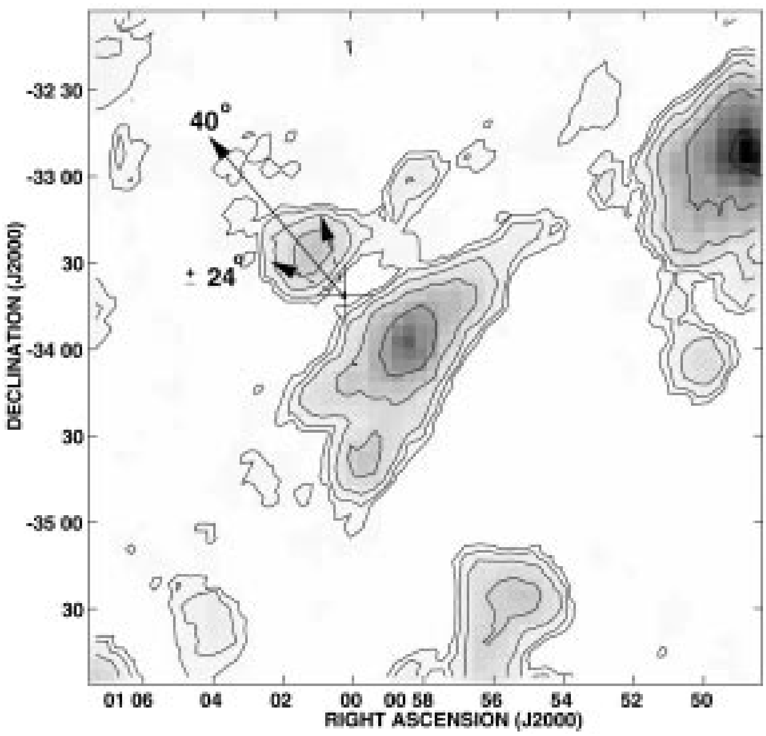

Figure 5—A $4^\circ \times 4^\circ$ field around Sculptor from the HIPASS survey. The contours are $1 \cdot 5$, $3 \cdot 0$, $6 \cdot 0$, $12 \cdot 0$ and $24 \cdot 0 \times 10^{18}$ cm^{-2}. The arrow indicates the position angle of the measured proper motion. The moment maps were derived for the velocity range $[59 \cdot 3,\ 138 \cdot 4]$ km s^{-1}.

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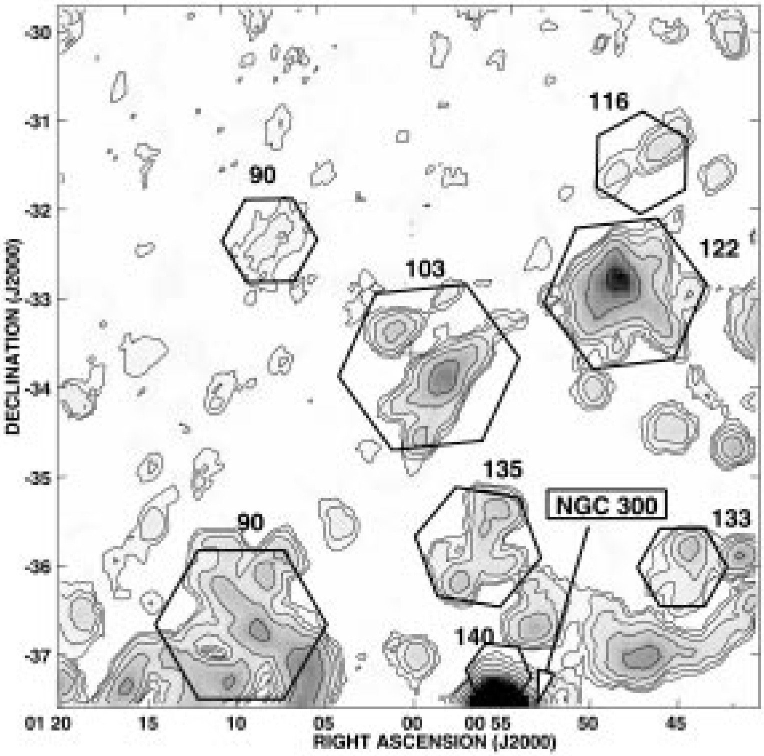

Figure 6—A $8^\circ \times 8^\circ$ field around Sculptor from the HIPASS survey. The contours are $0{\cdot}2$, $0{\cdot}4$, $0{\cdot}8$, $1{\cdot}6$ and $3{\cdot}2 \times 10^{19}$ cm^{-2}. Velocities of the different HI components are indicated.

$10^4 - 10^5$ $\mathcal{M}_\odot$ compares to what is seen in dE's but is a factor $10^2 - 10^3$ less than what is seen in dIrr galaxies. Those similarities suggest possible *evolutionary links* between those three types of dwarfs.

5 HI associated with the Centaurus Group dSph CEN_41

Recently Beaulieu et al. (1999) have started to look for HI in dSph-like systems associated with the Sculptor and Centaurus Groups. So far two out of four objects observed were detected, namely the dS0 NGC 59 in the Sculptor Group and the dSph CEN_41 (Figure 4) in the Centaurus Group. Contrary to what is seen for the LG dSph Sculptor, the HI is well centred on the optical in both cases, which means that we should expect to find relatively young stellar populations in those systems.

6 New HIPASS Data on Sculptor

As was discussed in Section 4, single field synthesis observations (or single dish observations centred on the optical) are most likely missing some (if not most) of the gas present in such nearby systems where the gas is expected to cover a large area (∼ few degrees) on the sky. As was demonstrated with the study of the Magellanic System (Putman et al. 1998), the Parkes 21 cm Multibeam System (PMS: Staveley-Smith et al. 1996) is best suited for this kind of study. Figure 5 shows a $4^\circ \times 4^\circ$ field around Sculptor obtained with the PMS. It can be seen that the detected gas is very extended with, for examples, the SW cloud extending over more than 2° while only the central 20′ could be seen in the synthesis observations (Figure 2). In fact, the gas nearly encircles the optical with the two main concentration aligned with the direction of the proper motion.

Since the detected gas covers a very large area and since it is at low velocities, very close to the velocities seen for high velocity clouds (HVC) and for MS gas, it is important to be able to view a very large area if one wants to disentangle those different velocity components. Figure 6 shows an even larger area of $8^\circ \times 8^\circ$ around Sculptor, again obtained with the PMS. The first striking feature is the large amount of gas to the south of Sculptor. The gas to the SW is the HI disk of the Sculptor Group late-type spiral NGC 300 (Puche, Carignan & Bosma 1990), while the gas to the SE is believed to be a long HI tail also associated with NGC 300 since it connects very smoothly with the eastern section of the main body of HI surrounding NGC 300. Mathewson, Cleary & Murray (1975) claimed that this could be the remains of the original concentration of gas from which NGC 300 formed. A larger area will be needed to see if the clouds at 116 and 122 km s^{-1} to the west are part of a larger complex.

So, in the region of Sculptor, it is clear that large areas have to be looked at with an instrument

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sensitive to the large scales if one wants to be able to disentangle the gas associated with the dSph from the Local gas (HVC's), the MS gas, and from the Sculptor Group gas which all have very similar radial velocities. This is not only the case for Sculptor but also for most LG dSph galaxies.

7 Discussion and Conclusions

What is the origin of the detected gas? Where is the missing gas in dSph galaxies? As discussed for the case of Sculptor in Carignan et al. (1998), the origin of the gas could be internal as well as external. For the internal case, it can be shown that stellar mass loss in normal giants could easily account for the observed neutral gas. As summarised by Mould et al. (1990), the total mass loss rate expected from normal evolution is about $0{\cdot}015\ \mathcal{M}_\odot\ \mathrm{yr}^{-1}$ per $10^9 L_{\odot,B}$. For Sculptor ($L_B \sim 10^7 L_\odot$), this implies a total return of $1{\cdot}5 \times 10^5\ \mathcal{M}_\odot$ per Gyr. Since most of the SF seems to have taken place between 8 and 10 Gyr in Sculptor (Da Costa 1984), it would have produced a gas reservoir of $\sim 3{\cdot}0 \times 10^5\ \mathcal{M}_\odot$. So, only 10% of this need be retained in its neutral form to account for the HI detected by the present observations.

On the other hand, there is circumstantial evidence supporting the notion that dSph galaxies may be accreting gas of external origin. In Carina, Smecker-Hane et al. (1994) argued for a large age spread yet a surprisingly small spread in abundance. This is in striking contrast to Leo I which has a complex SF history (Lee et al. 1993) and a broad giant branch indicative of a large abundance spread. This behaviour makes somewhat more sense if the gas that formed distinct generations of stars in these galaxies was accreted or captured from distinct clouds with their individual—and therefore random—mean abundances. Wakker and van Woerden (1997) reviewed the observations of HVC in the halo; their summary of past surveys suggest that many small, low-column density, and distant clouds could still be hidden throughout the Galactic halo.

As for the missing gas, the reason why HI was not detected before, especially with single dish observations having typically $\sim 15'$ beams, is probably because we were not looking at the right place, as suggested by Puche & Westpfahl (1994). This is why, in the coming months, we intend to search large areas around the LG dSph galaxies ($\delta \leq 0°$) observed by the HIPASS (HI Parkes All-Sky Survey), namely: Sculptor, Phoenix, Fornax, Carina, Antlia, Sextans, DDO 210, and Tucana.

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