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# H I Emission and Absorption in the Southern Galactic Plane Survey\*

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**Abstract:** We present preliminary results from the Southern Galactic Plane Survey (SGPS) Test Region and Parkes data. As part of the pilot project for the Southern Galactic Plane Survey, observations of a Test Region ( $325.5^\circ \leq l \leq 333.5^\circ$ ;  $-0.5^\circ \leq b \leq 3.5^\circ$ ) were completed in December 1998. Single-dish observations of the full survey region ( $253^\circ \leq l \leq 358^\circ$ ;  $|b| \leq 1^\circ$ ) with the Parkes Radio Telescope were completed in March 2000. We present a sample of SGPS H I data, with particular attention to the smallest- and largest-scale structures seen in absorption and emission, respectively. On the large scale, we detect many prominent H I shells. On the small scale, we note extremely compact, cold clouds seen in H I self-absorption. We explore how these two classes of objects probe opposite ends of the H I spatial power spectrum.

**Keywords:** Galaxy — ISM: bubbles, clouds, structure

## 1 Introduction

The Southern Galactic Plane Survey (SGPS) is an H I spectral-line and  $\lambda 21$  cm continuum survey of the fourth quadrant of the plane of the Milky Way (Dickey et al. 1999). The survey covers the region  $253^\circ \leq l \leq 358^\circ$ ;  $|b| \leq 1^\circ$ . The dataset, which is a combination of data from the Australia Telescope Compact Array (ATCA) and the Parkes Radiotelescope, is sensitive to angular scales larger than  $\sim 1\text{--}2'$ . The ATCA data comprise a mosaic of 2212 pointings. The Parkes data, which were obtained with the inner seven beams of the multibeam receiver, have extended coverage to  $|b| \leq 10^\circ$ . The final data product includes H I datacubes with a spectral resolution of  $0.8 \text{ km s}^{-1}$  and continuum maps in all four Stokes parameters.

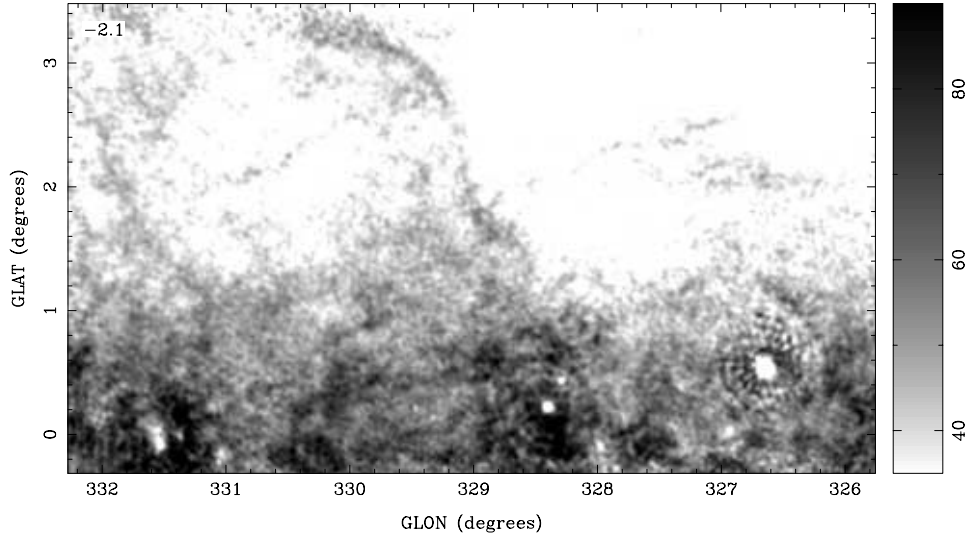
Observations for the SGPS are expected to be finished in late 2000, with a full data release in early 2001. Currently the Parkes observations are complete, as are observations of the SGPS Test Region ( $325.5^\circ \leq l \leq 333.5^\circ$ ;  $-0.5^\circ \leq b \leq 3.5^\circ$ ). This paper is based on a talk given at the ASA Annual Meeting in July 2000 (ASA2K). Here we present a representative sample of the SGPS H I data, including low-resolution data from Parkes and full-resolution data for the Test Region. The continuum emission has been subtracted from these H I data. A full description of the observations and data analysis are provided in detail elsewhere (McClure-Griffiths et al. 2000, 2001).

\* Given as an oral presentation at ASA2K, Hobart, Tasmania, Australia, July 2000

In this introduction to the data, we explore how the SGPS can contribute to our understanding of the interstellar medium (ISM) over a large range of size scales. The SGPS data span several orders of magnitude in angular size, allowing us to probe opposite ends of the H I spatial power spectrum over a significant portion of the inner Galaxy. On the large scale we are studying H I emission structures, particularly shells and supershells to understand the effects of these shells on the structure and dynamics of the ISM. The SGPS data may help us to understand how these deterministic structures are ‘pumping’ the spatial power spectrum. On the small scale, we are using H I self-absorption (HISA) to probe the coldest, smallest clouds in the ISM. We seek to understand the ISM on all scales in between, but the clues may be at the furthest extremes.

## 2 H I Shells

We present here a small gallery of H I shells detected in the Test Region and the Parkes data. These shells represent a selection of the broad range of structures displayed by shells. They range in diameter from about 30 to 600 pc. H I shells provide an interesting environment in which to study the ISM because they are among the largest structures visible in the Galaxy. In addition, they are among the few discrete objects which are apparently deterministic in nature. They result from relatively well understood phenomena, such as a supernova explosion for the smallest shells, or the combined effects of stellar winds and many supernovae for the largest shells. As the fossils of extremely energetic events, they allow us to study how



**Figure 1** Grayscale image of an H I channel map at  $v = 2.12 \text{ km s}^{-1}$  showing an apparent H I shell approximately  $2.5^\circ$  in diameter in the local ISM at  $l = 330.5^\circ$ ,  $b = 2.2^\circ$ . The grayscale is logarithmic to emphasise the shell walls. The brightness temperature scale in Kelvin is displayed in the wedge on the right.

energy is injected into the ISM, and subsequently how that energy affects the ISM as it undergoes the transition from deterministic to turbulent in nature.

### 2.1 Local Shell

One of the smallest shells visible in the Test Region is extremely local. Figure 1 shows a grayscale of a large-angular-diameter shell centred at about  $l = 330.5^\circ$ ,  $b = 2.2^\circ$ ,  $v_{\text{LSR}} \approx 2.1 \text{ km s}^{-1}$ . Because of its local velocity, distance estimates are extremely uncertain. However, we used a standard rotation curve for the Galaxy (Fich, Blitz & Stark 1989) to estimate the kinematic distance to this shell to be in the range 350 pc to 1 kpc. At these distances the diameter is between 15 and 50 pc. There is also tentative evidence for slow expansion on the order of  $4 \text{ km s}^{-1}$ , although no front or back caps are detected. It should be noted, though, that random H I cloud motions are on the order of  $6 \text{ km s}^{-1}$ , making it difficult to place much confidence in the expansion velocity estimate. The small size of this shell suggests that it may be an old supernova remnant (SNR) which no longer radiates in the continuum. It is interesting to note, however, that the shell is extremely circular, far more so than a typical SNR.

### 2.2 Terminal Velocity Shell

There is another small shell at the terminal velocity of  $v = -110 \text{ km s}^{-1}$ . This shell, as shown in Figure 2, is centred on  $l = 329.9^\circ$ ,  $b = 0.4^\circ$  and is at a kinematic distance of  $\sim 7.4 \text{ kpc}$ . This distance translates into a physical diameter of  $\sim 51 \text{ pc}$ . The shell stands out as the only feature in the H I channel maps near the terminal velocity that persists over many velocity channels. It is detectable from beyond the terminal velocity at  $v = -120 \text{ km s}^{-1}$ , where there is very little gas, to  $v = -105 \text{ km s}^{-1}$ , where it appears as a void

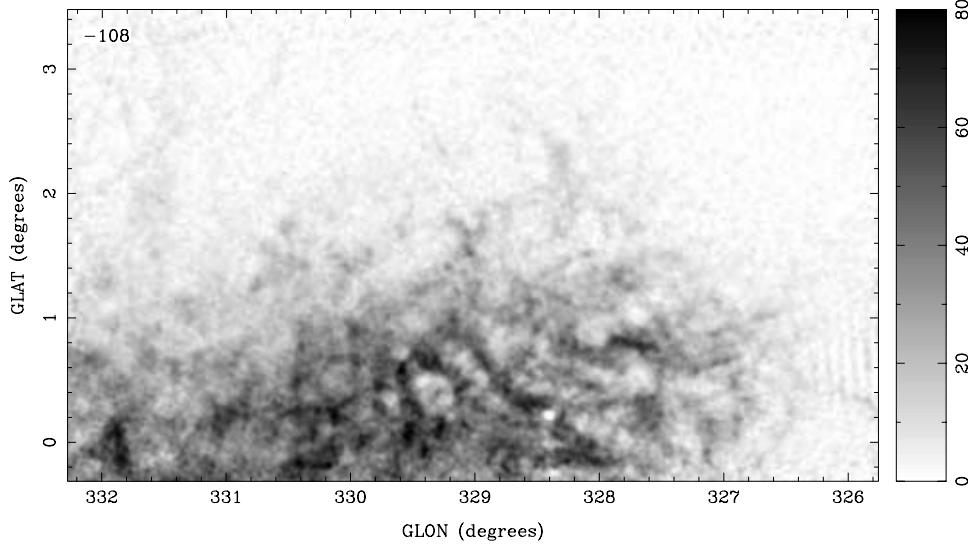
surrounded by a great deal of H I emission. The structure changes very little over the entire velocity range. There are no obvious front or back caps and there is no evidence of continued expansion. With no obvious expansion it is difficult to hypothesise about the origins of the shell. Its size indicates that it too may be an old supernova remnant, but its curious position at the terminal velocity suggests that it could be gas displaced from circular rotation by any number of possible influences.

### 2.3 RCW 94 Shell

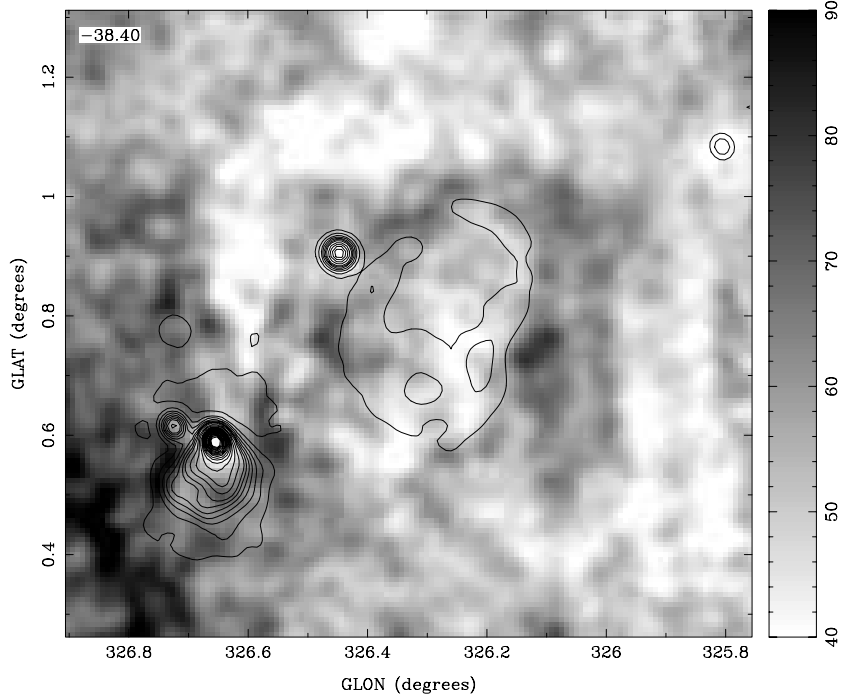
There is an H I shell surrounding the H II region RCW 94 at  $l = 326.3^\circ$ ,  $b = 0.8^\circ$ . The shell is itself surrounded by a ring of H I depletion. Figure 3 shows the H I channel map at  $v = -38 \text{ km s}^{-1}$  with continuum contours overlaid. The H I absorption distance for this H II region is  $\sim 3.0 \text{ kpc}$ , which agrees well with a distance of  $\sim 3.1 \text{ kpc}$  determined by Caswell & Haynes (1987) using recombination line velocities. The distance implies a shell diameter of  $\sim 25 \text{ pc}$ . There is evidence for a small expansion velocity of  $\sim 5 \text{ km s}^{-1}$ . We speculate that this shell was formed in a molecular cloud, where the molecular hydrogen was dissociated by the H II region RCW 94. The depletion ring exterior to the shell is most likely an effect of the high molecular gas densities.

### 2.4 Supershells

Another class of H I shells are the so-called ‘supershells’, with diameters on the order of hundreds of parsecs. Two large supershells have been discovered in the Parkes data (McClure-Griffiths et al. 2000). These shells, GSH 277+0+36 and GSH 280+0+59, have diameters of 620 and 430 pc, respectively, in addition to showing evidence of break-outs above and below the Galactic plane (see



**Figure 2** Grayscale image of an H I channel map at  $v = -108 \text{ km s}^{-1}$  showing an apparent H I shell in the ISM. A small shell, of diameter  $\sim 0.4^\circ$  is located at  $l = 329.3^\circ$ ,  $b = 0.4^\circ$ . This shell is identified by the bright ring of emission surrounding an H I void. The grayscale is linear and is shown in the wedge on the right.

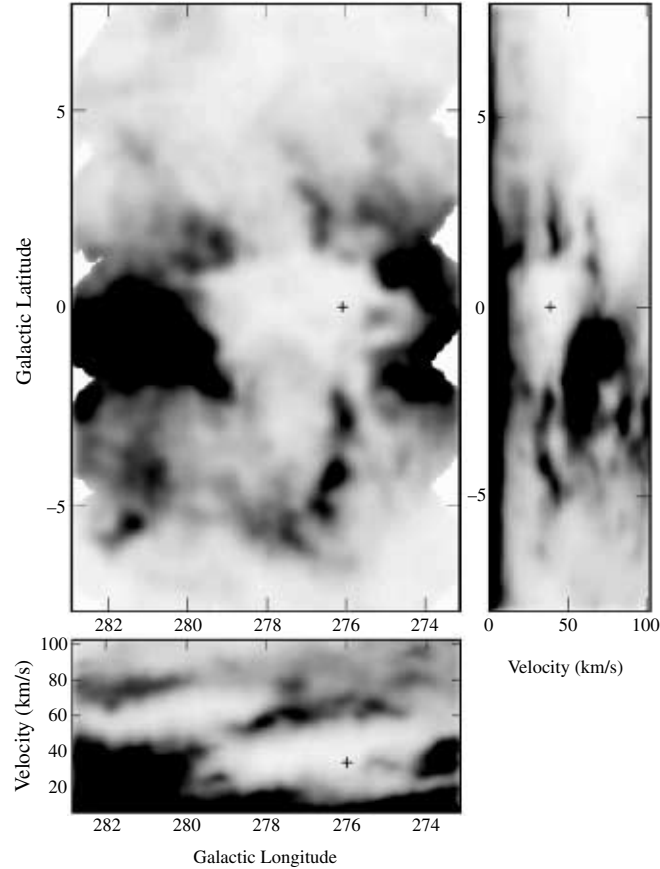


**Figure 3** Grayscale plot of an H I channel map at  $v = -38 \text{ km s}^{-1}$  with 21 cm continuum contours overlaid. The grayscale is linear and runs from 0 to 80 K, while the contours are at 10 K intervals from 20 to 400 K. The small shell, centred at  $l = 326.3^\circ$ ,  $b = 0.8^\circ$ , is identified by the ring of emission around the H II region. The grayscale is linear and is shown in the wedge on the right.

Figures 4 and 5). These shells appear to lie on the far edge of the Carina arm in the inter-arm region. The energy required to form a shell of this size is extremely large, on the order of  $10^{52}$ – $10^{53}$  erg. At that level of energy input, it is clear that supershells are one of the driving sources of energy in the ISM and have a significant impact on the structure of the Galaxy.

### 3 H I Self-Absorption (HISA)

On the other end of the H I spatial power spectrum we are using H I self-absorption (HISA) to study the cold neutral medium (CNM). HISA occurs when cold foreground gas absorbs H I emission from warmer background gas at the same velocity. The correspondence of one velocity to two distances interior to the solar circle



**Figure 4** Grayscale image showing three orthogonal slices through the H I cube containing the supershell GSH 277+0+36. The grayscale is linear and runs from 0 K (white) to 35 K (black). The largest panel is a channel map at  $v = +36 \text{ km s}^{-1}$ . The panel to the right is the  $b$ - $v$  slice at the position marked by the cross-hair in the  $l$ - $b$  slice. Similarly, the bottom figure is the  $l$ - $v$  slice at the same position. Several chimney-like extensions to high latitudes are visible in both the channel map and  $b$ - $v$  slice (McClure-Griffiths et al. 2000b).

provides a prime opportunity for studies of HISA. HISA is characterised by extremely narrow velocity width ( $\sim 1$ – $2 \text{ km s}^{-1}$ ) absorption features seen against the warmer background hydrogen emission. The small, cold clouds are also seen in the H I channel maps as in Figure 6. New high-resolution H I studies, such as the Canadian Galactic Plane Survey (Taylor 1999), are revealing large numbers of cold clouds through HISA (Gibson et al. 2000). Because HISA does not require background continuum sources, it is an excellent way to study the CNM throughout the Galaxy.

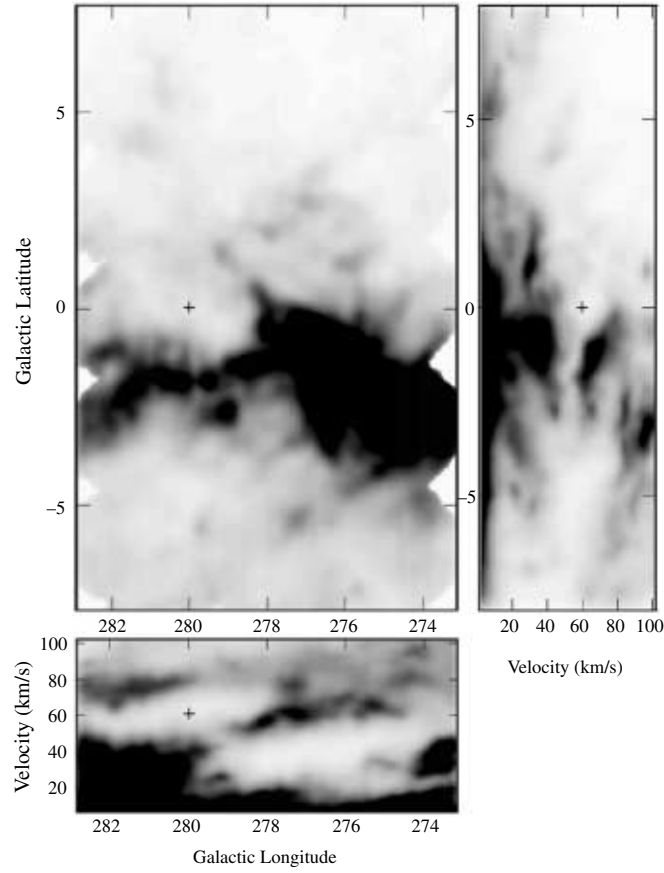
There are numerous HISA features in the SGPS Test Region. These cold clouds can be seen in the channel map shown in Figure 6. An absorption profile towards the cloud at  $l = 330.35^\circ$ ,  $b = 0^\circ$  shows a characteristically narrow profile with a spin temperature of  $\sim 30 \text{ K}$  (Figure 7). Most of these HISA features are in the velocity range  $-50 \text{ km s}^{-1} \leq v \leq -40 \text{ km s}^{-1}$  which, at these longitudes, corresponds to the edge of the Scutum-Crux spiral arm. We suggest that these cold clouds may mark the compressed gas at the edge of the spiral shock, where molecular clouds are likely to form. While some HISA does clearly trace molecular emission, other HISA features are isolated,

suggesting cold gas that has not yet been compressed enough to form molecules (Gibson et al. 2000).

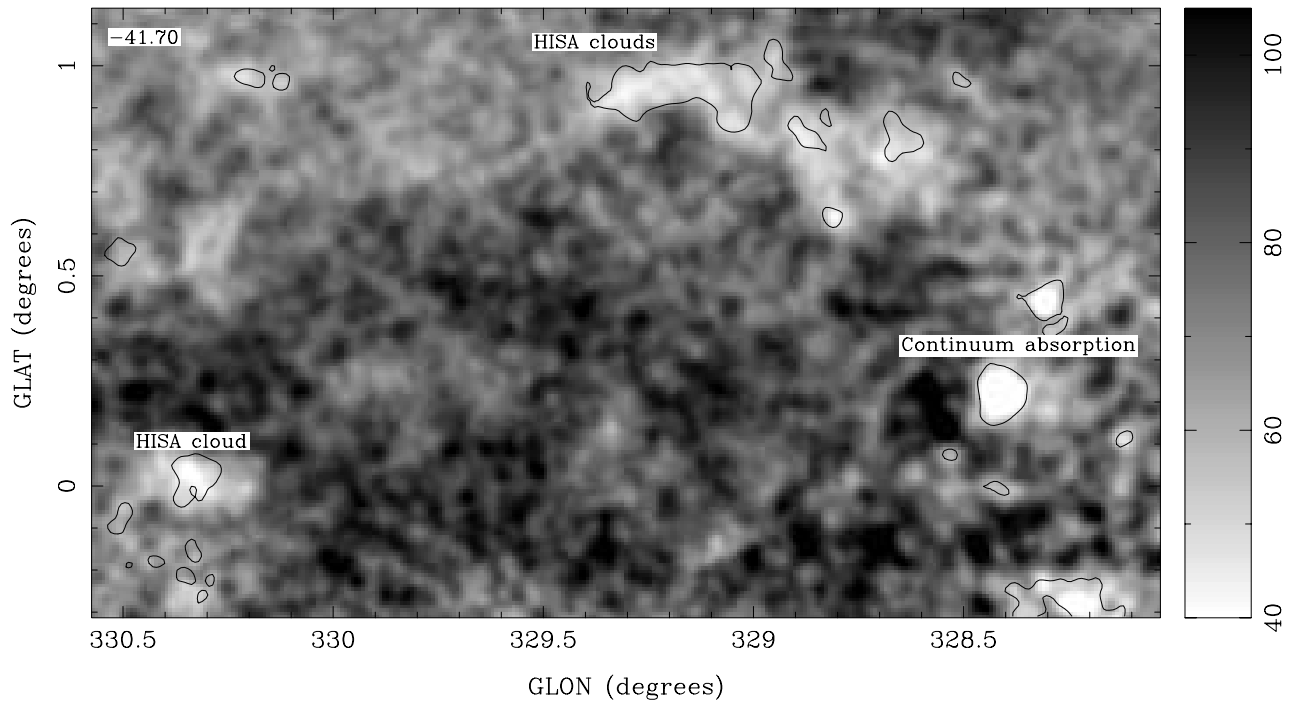
The smallest and most dramatic features tend to stand out in initial searches for HISA. In order to study the HISA in a statistically significant way, it will be necessary to develop non-subjective searching techniques. Such techniques have been developed for the CGPS data by Gibson et al. (2000). Similar techniques are being developed for the SGPS data. The many cold clouds detected in the CGPS and SGPS suggest excess emission fluctuations on the small side of the spatial power spectrum. It is possible that there are many warmer, less dense clouds that we are not detecting.

#### 4 Questions and Future Work

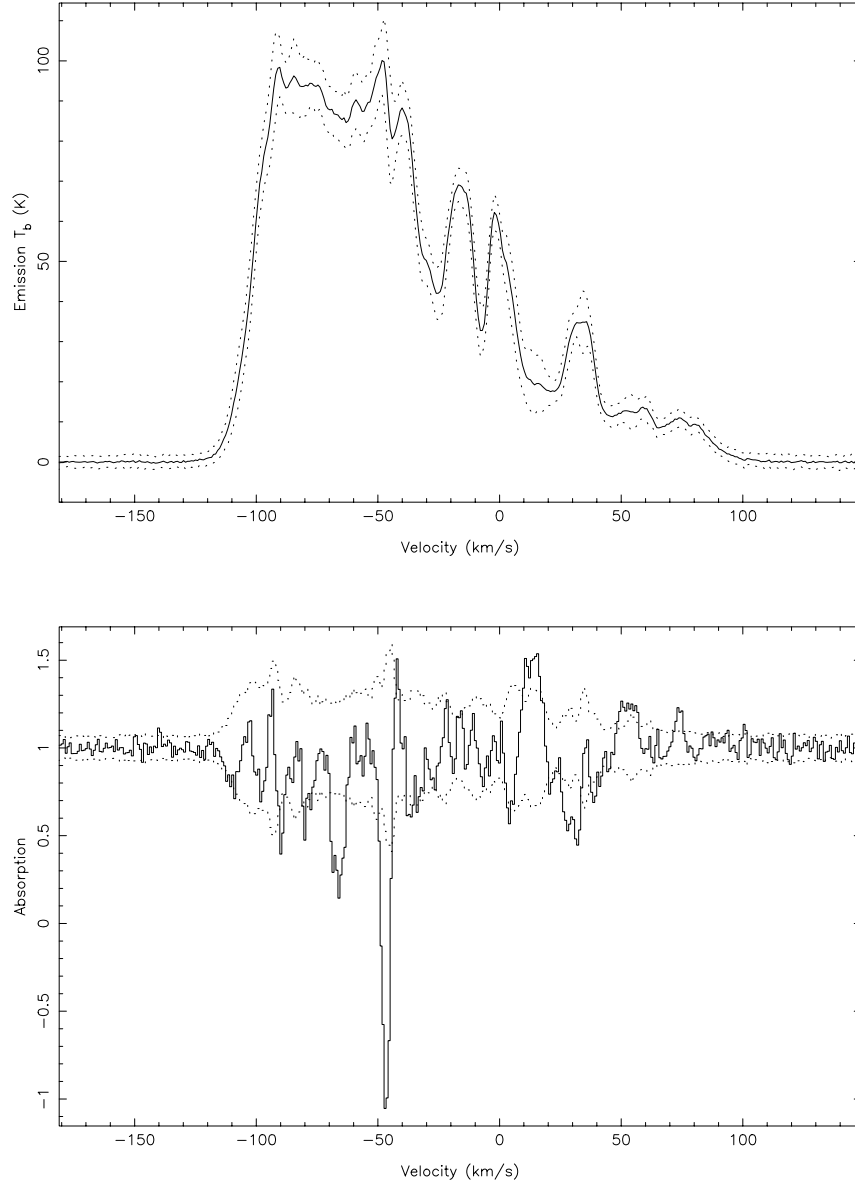
There are several questions to be answered about the H I shells and H I self-absorption as we proceed with the SGPS. With the SGPS dataset, we expect to catalogue many new shells. How are these shells distributed in the Galaxy? Do they lie along spiral arms, like GSH 277+0+36 and GSH 280+0+59, or is their distribution seemingly random, as in the Large and Small Magellanic Clouds (Kim et al. 1998; Staveley-Smith et al. 1997)? How



**Figure 5** A similar image to that in Figure 4, showing orthogonal slices through the centre of the supershell GSH 280+0+59.



**Figure 6** This grayscale plot is an H I channel map at  $v = -41.7 \text{ km s}^{-1}$  with a 55 K contour of the same channel overlaid. The grayscale is linear and runs from 40 to 105 K, as shown in the wedge on the right. The contours outline several prominent sources of absorption, including a supernova remnant. The extended areas marked as HISA are cold clouds seen in absorption.



**Figure 7** The top panel is the emission profile near  $l = 330^\circ$ ,  $b = 0^\circ$ . The bottom panel shows the absorption profile for the cold cloud seen at  $l = 330.35^\circ$ ,  $b = 0^\circ$ . The dotted lines trace the  $1\sigma$  error envelope. The narrow width of the absorption feature is one of the defining characteristics of HISA.

large an impact do shells have on the global ISM? Will the Milky Way resemble the LMC and SMC, which are dominated by shells?

With respect to the small-scale structure, we ask: How are the HISA features distributed? Do they lie predominantly along spiral shocks or are they ubiquitous? How do they relate to the molecular clouds? What fraction of the ISM is in the CNM? Are there larger, warmer clouds that we are missing? How small are the numerous clouds that remain unresolved by the SGPS?

## 5 Conclusions

New large-scale, high-resolution H I surveys like the SGPS and CGPS finally make it possible to study simultaneously the small- and large-scale structure of the ISM. We hope

that the SGPS dataset will allow us to understand how the large- and small-scale structures relate to each other throughout the inner Galaxy. The SGPS should be able to catalogue the majority of H I shells in the inner Galaxy and determine exactly how they shape the ISM. It is likely that we are currently seeing only the most dramatic cold clouds with HISA; however, further studies may lead to a complete understanding the distribution of the CNM.

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