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New results from Galactic ISM surveys: The frothy ISM

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The past 10 years have seen a resurgence in studies of the Milky Way's interstellar medium (ISM) driven by new surveys of the Galactic plane at wavelengths from 4 microns to 20 cm. These surveys, which include the H I International Galactic Plane Survey, the Spitzer GLIMPSE and MIPSGAL surveys, the recently commenced Herschel HI-GAL survey, and several surveys of CO J = 1–0, are allowing us to trace the evolution of the ISM on scales of parsecs and sub-parsecs from warm and diffuse through to cold, dusty molecular gas. Together with hydrodynamical simulations of ever-increasing sophistication our understanding of the ISM in the disk of the Milky Way has evolved from the 1970's simplistic models of cold clouds surrounded by warm gas to a complex mixture of phases intertwined and interconnected, whose cooling is driven by colliding flows. Here I focus on the "frothy" ISM, where structure and evolution is impacted by bubbles, shells and supershells. I discuss the role of these objects in cooling, the formation of molecules and even the transfer of matter out of the disk of the Galaxy.

1 Introduction

If we are to understand how galaxies evolve, we must first understand the physics of their evolution in environments we can observe in detail. Our own Galaxy, the Milky Way, provides us with the closest laboratory for studying the evolution of gas in galaxies, including how galaxies acquire fresh gas to fuel their continuing star formation, how they circulate gas and how they turn warm, diffuse gas into molecular clouds and ultimately, stars. Without the answers to these questions our ability to understand and model the evolution of the Universe as a whole is blocked.

The Milky Way is a very complex ecosystem. Just as ecosystems on Earth involve many elements linked together by a common source of nutrients and energy flow, the Milky Way ecosystem consists of stars fuelled by a shared pool of gas in the interstellar medium (ISM) and energy that flows back and forth between the stars, the ISM and out of the Galactic disk. Though only a small fraction of the total mass of a galaxy, the ISM is the essential element in its ecosystem. Once thought to be a simple, quiescent medium, the ISM is now known to include a number of diverse constituents, which exhibit temperatures and densities that range over eight orders of magnitude. The ISM is composed of gas in all its phases (ionised, atomic and molecular), dust, high energy particles and magnetic fields, all of which interact with the stars and gravitational potential of a galaxy to produce an extraordinary, dynamic medium. We know that the life cycle of the Milky Way and most galaxies involves a constant process of stars ejecting matter and energy into the interstellar mix, from which new stars then condense, continuing the cycle. This cycle is represented in the diagram shown in Fig. 1. Somehow matter makes the transition from hot, ionised stellar by-products, cooling and condensing through the atomic phase, to become cold molecular clouds from which new stars are formed, which in turn pump energy and mass into the ISM. How warm, diffuse gas cools and condenses is not yet clear. Furthermore, the Galaxy is a gradual consumer of gas (e.g. Rocha-Pinto et al. 2000). Some fraction of the ISM converted into stellar matter is never returned to the interstellar soup and another fraction is expelled from the Galaxy disk by highly energetic stellar winds and supernovae.

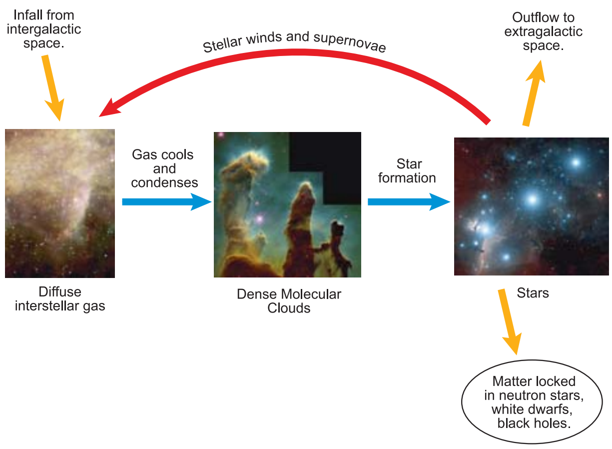

Fig. 1 The evolutionary cycle of matter in the ISM.

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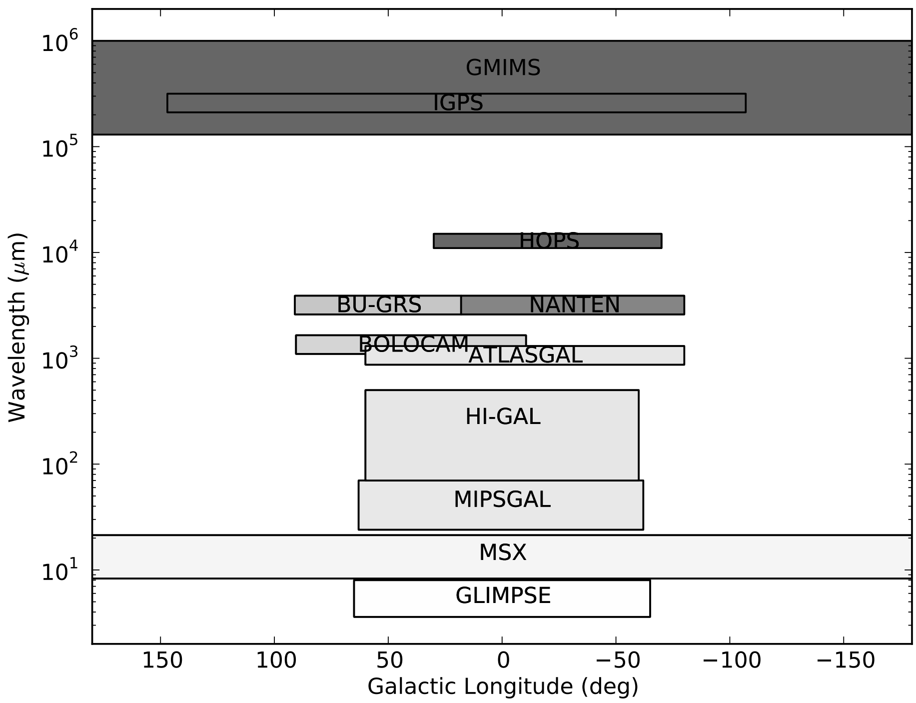

Fig. 2 Coverage in longitude and wavelength of recent Galactic Plane Surveys. The greyscale of the boxes represents the angular resolution of the surveys with the best being $\sim 1\farcs5$ in white and the worst being $>1'$ in dark grey. Modelled after a figure on HI-GAL website (https://hi-gal.ifsi-roma.inaf.it/higal/).

2 Overview of new ISM surveys

Surveys of the ISM have undergone a renaissance over the past ~10 years at all wavelengths from 3.6 μm to 20 cm, pushing the sky coverage and angular resolution of these surveys to new levels. Many of the new surveys, particularly those in the infrared and sub-millimetre, have angular resolutions of almost $1''$, allowing spatial resolution of less than a parsec in many cases. Figure 2 summarises some of the recent and on-going ISM surveys by sky coverage and observing wavelength. At the short wavelength end of the spectrum lies the Spitzer Galactic Legacy Infrared Survey Extraordinaire (GLIMPSE) survey (Benjamin et al. 2005) at 3.6, 4.5, 5.8, and 8 μm with a resolution of $\sim1''$. GLIMPSE improved in angular resolution on the previous Midcourse Space Experiment (MSX) survey at 8.5, 12.1, 14, and 21 μm and a resolution of $20''$(Price et al. 2001). Spitzer's longer wavelength survey MIPSGAL (Carey et al. 2009) complements GLIMPSE with 24 and 70 μm data at $6''$ and $18''$. The Herschel HI-GAL survey (Molinari et al. 2010), extends the infrared coverage to 70, 170, 250, 350, and 500 μ m, with angular resolutions of $4''$–$40''$. Recent bolometer surveys cover portions of the inner Galaxy: BOLOCAM at 1.1 mm (Aquirre et al. 2010) with $30''$ resolution and ATLASGAL at 870 μm (Schuller et al. 2009) with $19''$ resolution. Meanwhile the Boston-University Galactic Ring Survey (BU-GRS; Jackson et al. 2006) and NANTEN (Mizuno & Fukui 2004) surveys probe the CO $J = 1$–0 emission over most of the inner Galaxy. The recent H2O Galactic Plane Survey (HOPS) covers H_2O, NH_3, and HCCN emission in the Southern Galactic Plane at $2'$ resolution (Walsh et al. 2011). Moving into the centimetre regime, the International Galactic Plane Survey (IGPS) project is made up of constituent surveys the Canadian Galactic Plane Survey (Taylor et al. 2002), the Southern Galactic Plane Survey (McClure-Griffiths et al. 2005) and the VLA Galactic Plane Survey (Stil et al. 2006). These surveys are multi-wavelength, covering atomic hydrogen (H I) emission and 20 cm radio continuum. Finally, polarized radio continuum surveys probe the magneto-ionic medium include the Canadian and Southern Galactic Plane Surveys and the large-scale, on-going Global Magneto-ionic Medium Survey (Wolleben et al. 2009) covering the whole sky between 20 cm and 1 m.

Most parts of the interstellar cycle shown in Fig. 1 are probed by current Galactic plane surveys. For example, H I and mid to long-infrared emission trace the diffuse interstellar gas. As it cools, H I absorption probes moderate densities ($n \sim 100\ \mathrm{cm}^{-3}$). Optically thick infrared clouds and molecular gas tracers such as CO and NH_3 trace dense, cold gas ($n \sim 10^3$–$10^4\ \mathrm{cm}^{-3}$). The bolometer surveys at ~1 mm probe dense star-forming clumps with molecular hydrogen column densities of $n \sim 10^4$–$10^5\ \mathrm{cm}^{-2}$. The effects of massive star-formation on the ISM are traced once

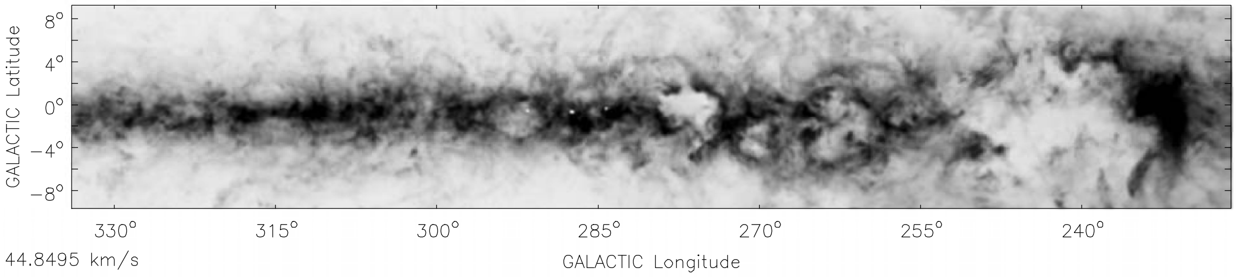

Fig. 3 Image of Galactic H I in the Southern Galactic Plane at a velocity of $v_{\rm LSR} = 44.85$ km/s from the Galactic All-Sky Survey (GASS) (McClure-Griffiths et al. 2009; Kalberla et al. 2010). The velocity slice of one of many filled with shells and voids.

again in the diffuse interstellar gas, through polycyclic aromatic hydrocarbon (PAH) emission surrounding H II regions, and H I shells and chimneys around stellar clusters. Even the elusive effects of magnetic fields are beginning to become clear through the radio continuum surveys of the diffuse magneto-ionic medium.

3 The frothy ISM

Def: frothy, adj., consisting of froth or light bubbles, of the nature of or resembling foam, spumous; (OED).

One of the most striking aspects of the new Galactic Plane Surveys is the dominant "frothy" structure in the diffuse gas. Even a cursory glance of random subsections of the GLIMPSE/MIPSGAL or International Galactic Plane H I Surveys reveals a medium filled with bubbles. These images, such as the H I image of a single velocity slice at $v_{\rm LSR} = 44.85$ km s^{-1} in Fig. 3, show multiple large bubbles, often growing into each other. These aggregations of bubbles give the ISM its characteristic frothy appearance.

The frothy structure of the ISM is largely due to the effects of massive stars. The ISM of disk galaxies like the Milky Way are significantly impacted by massive stars which, through their stellar winds and supernovae, create a variety of structures referred to alternately as bubbles, shells, holes, superbubbles, supershells and giant holes. Stellar winds and supernovae plough into the interstellar medium surrounding the progenitor stars, creating large cavities of hot, diffuse, ionised gas surrounded by walls of cooler, ionised and/or atomic gas (see Tenorio-Tagle & Bodenheimer for a review). These objects are responsible for re-shaping disk galaxies and playing a significant role in the evolution of the ISM through their heating and compressing of gas. Furthermore, the largest objects, superbubbles and supershells, can grow large enough to exceed the scale height of the disk and play a role in the interaction of the disk and halo. Here I discuss the role of these objects in both the overall evolution of the ISM and the disk-halo interaction.

The terminology of bubbles, shells, holes, superbubbles, supershells and giant holes can be confusing at best. Before proceeding I will try to outline a consistent language in hopes of clarifying the definitions. Most of these objects derive from a similar origin but their names often reflect the method of detection. In general, the terms bubbles, shells and holes are used to referred to objects formed by one or a few stellar winds and supernovae and exist on scales less tens of parsecs. *Bubbles* are often found around single stars or H II regions with recent spectacular examples coming from the GLIMPSE project (Churchwell et al. 2006, 2007). Bubbles are most often detected in the optical and infrared bands. *Shells* are usually detected in H I and generally found around supernova remnants and occasionally Wolf-Rayet stars (e.g. Giacani & Dubner 2004), although it is not unusual to have no detectable stellar component. *Holes* are also usually detected in H I, but more often in external galaxies, and the term is used when the origin is not obvious. On slightly larger size scales are *superbubbles* and *supershells*, which have sizes from hundreds of parsecs to kiloparsecs and implied formation energies of 10^{52} erg to 10^{54} erg. Although these are also generally assumed to be the fossils of stellar winds and supernovae it is often difficult to confirm the stellar progenitor of these objects.

3.1 Bubbles around H II regions

Through the GLIMPSE and MIPSGAL surveys it has become clear that the Galaxy's interstellar medium is filled with thousands of bubbles giving it the frothy characteristic that is so clear in the images created by these surveys. Working with GLIMPSE data alone, Churchwell et al. (2006, 2007) catalogued nearly 600 new infrared bubbles. In the inner galaxy these have a surface density of $\sim 5\ {\rm deg}^{-2}$. The bubbles are identified by bright rings of $8\ \mu{\rm m}$ PAH emission, often surrounding H II regions detected through $24\ \mu{\rm m}$ and/or 20 cm radio continuum emission. Clearly the H II regions are dusty, as traced by $24\ \mu{\rm m}$ emission, but the PAHs are destroyed inside bubbles by the soft UV radiation fields inside the H II region ionization front (Watson et al. 2008).

Between 12 and 25 % of the Churchwell et al. (2006, 2007) bubbles are associated with known H II regions and those authors estimate that at least two-thirds of the bubbles are associated by late-type B stars that do not produce a detectable H II region. For bubbles with associated H II regions or other distance indicators measurements of physical sizes suggest radii of 1–10 pc.

Recently "Citizen Science" has been applied to the task of cataloguing bubbles in GLIMPSE and MIPSGAL through the Milky Way Project (Simpson et al. 2012). More than 35 000 volunteers examined the GLIMPSE/MIPSGAL surveys to produce a catalogue of 5106 bubbles, which independently confirmed 86 % of the Churchwell et al (2006, 2007) catalogues. The sources from the Simpson et al. (2012) catalogue with known distances include some larger objects with radii up to 30 pc. From the Simpson et al. (2012) catalogue it seems that the the Galactic plane is even more frothy than we thought.

The structure of the most resolved bubbles is remarkable, showing dense globules and filamentary walls down to subparsec scales. Many of these features have the appearance of hydrodynamic instabilities, such as the classic Rayleigh-Taylor instability. Recent magnetohydrodynamic (MHD) simulations by Arthur et al. (2011) of H II regions around O and B-type in a turbulent magnetized medium have reproduced many of these same features, as well as the characteristic PAH emission exterior to H II regions traced by radio continuum emission (see Fig. 7 of Arthur et al. 2011).

3.2 Shells and supershells

The preponderance of H I shells and supershells in the Milky Way has been known for many years from the pioneering work of Heiles (1979, 1984) to more recent catalogues stemming from the H I Southern Galactic Plane Survey (McClure-Griffiths et al 2002) and many in between. H I shells are characterised as voids in the H I distribution surrounded by dense walls of swept-up gas. These objects have radii from tens to hundreds of parsecs and are often observed with expansion velocities of 10–20 km s^{-1}. The radii and expansion velocities imply formation energies of 10^{51-53} erg. For the most energetic supershells we must assume that they were formed by the action of many tens of massive stars. With lifetimes on the order of tens of millions of years, H I shells survive much longer than the radiative lifetimes of their parent stars and therefore provide a lasting record of the impact of massive stars on the ISM.

The contributions of the recent H I Galactic Plane (Taylor et al. 2002; McClure-Griffiths et al. 2005; Stil et al. 2006) and even H I all-sky surveys (i.e. GASS; McClure-Griffiths et al. 2009) has been to resolve parsec scale structure on kiloparsec scale supershells. The data reveal loops, filaments and globules along the edges of all well-resolved supershells. Morphologically the supershells are similar to their smaller infrared counterparts the bubbles. The H I velocity channel shown in Fig. 3 shows several of the most impressive examples of resolved H I shells, including the GSH 277+00+36 shell at Galactic longitude, $l = 277°$, and latitude, $b = 0°$, a distance of ~ 6.5 kpc. This object was the topic of an in-depth study, which found evidence for Rayleigh-Taylor formed arcs and drips all along the edges of the shell. The giant hole centered at $l = 242°$, $b = 0°$ and extending over 15° in longitude and 10° in latitude shows remarkably similar structure along the walls.

3.3 Magnetized shells and bubbles

Even the magnetized, ionic medium is beginning to reveal its frothy nature. The magneto-ionic medium as a constituent of the ISM is only just starting to reveal its full impact, partially due to the new data reduction technique of Faraday rotation measure synthesis (Brentjens & de Bruyn 2005), which allows us to slice the ISM in Faraday rotation measure space, separating the parts of the ISM with magnetic fields pointed towards us from the parts with magnetic fields pointed away.

Both the Canadian and Southern Galactic Plane Surveys were complemented by observations of diffuse polarized radio continuum emission. These data revealed magnetic fields associated with H II regions (e.g. Gaensler et al. 2001) detected through their almost complete lack of polarized emission following the contours of H II regions. The high electron density in H II regions, combined with a magnetic field, has a depolorizing effect on the polarized synchrotron Galactic background. Depolarization occurs when the polarization angle is rotated by a significant amount between vectors contributing to a single measurement. In an H II region this can occur because the polarization angle differs in adjacent lines of sight sampled by a single telescope resolution element (beamwidth depolarization) or because the polarization angle varies along the path length through the H II region (depth depolarization).

Using Canadian Galactic Plane Survey data West et al. (2007) provided some of the first observations of magnetic fields in a much larger (>100 pc) bubble, the W4 H I chimney. Like the H II regions observed in the Galactic plane, the chimney is detected through its depolarization of the Galactic polarized background resulting in a lack of polarized emission coincident with the H I chimney (see Fig. 8 in West et al. 2007). These authors were able to use the polarization images to estimate a magnetic field strength of 3–5 μG.

Using data from the on-going GMIMS survey, Wolleben et al. (2010) have used rotation measured synthesis to trace the three-dimensional magnetic field structure of an nearby ~ 150 pc diameter H I shell. Figure 4 shows filaments of diffuse polarized emission that are detected at several rotation measures. The different rotation measures indicate that the magnetic field is pointed towards the observer on one side of the shell and away from the observer on the other side of the shell. The filaments match spatially with H I filaments forming the large H I shell (see Fig. 4). Wolleben et al. (2010)

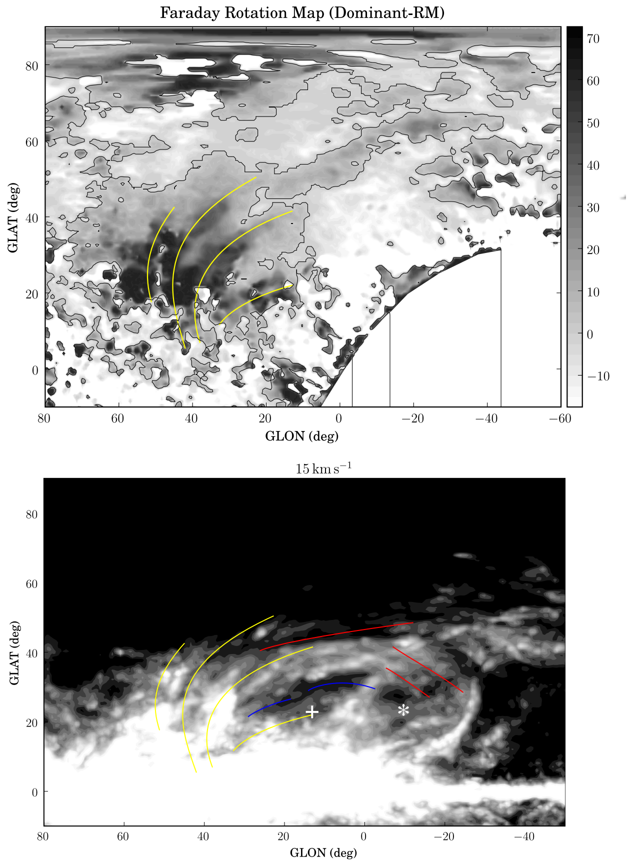

Fig. 4 A magnetic bubble found in the ISM. The *top panel* shows the rotation measure of the dominant polarized emission in each pixel (the position of the peak in the RM-synthesis spectrum for each pixel). The grey scale is chosen to show features with positive rotation measure. Four yellow lines indicate the location of the four filaments that can be identified in this map, and which are located in the eastern part of the system of H I shells. The *bottom panel* shows the H I brightness temperature at $v_{\rm LSR} = 15$ km s^{-1} in a logarithmic grey scale. The same yellow lines from the top panel plus the positions of several negative rotation measure polarized filaments are shown. Reproduced with permission from M. Wolleben.

developed a model in which the shell expanded asymmetrically, constrained by the dense wall of the Local Bubble, compressing and redirecting the ambient magnetic field outwards with its expansion. Simulations show that magnetic fields have a significant impact in the evolution of supershells, changing the instability processes that lead to their break-out and dissolution (e.g. de Avillez & Breitschwerdt 2005). And yet, observational knowledge of magnetic fields in supershells and superbubbles is limited. As surveys like GMIMS progress we can expect to see many more magnetic bubbles.

4 Impact of bubbles in Galaxy evolution

H I shells and bubbles play several very important roles in the evolution of the ISM. Our knowledge about these roles has increased dramatically over the past decade due to the preponderance of outstanding new Galactic plane surveys giving us high resolution imaging of shells and bubbles throughout the Milky Way. We are now able to resolve parsec and subparsec scale structure on objects up to a kiloparsec in scale. Comparing these observations with simulations like Arthur et al. (2011) and de Avillez & Breitschwerdt (2005) is allowing us to finally probe the physics of shell and bubble evolution and their role in the ISM.

Amongst their many roles in disk galaxies, shells likely play a role in driving the turbulent structure of the ISM. Structure in the ISM of the Milky Way is observed over more than twelve orders of magnitude in spatial scale, from AU scale to kiloparsec scale features (Spangler 2001). Most of this structure is turbulent in nature, having no clear origins but following a power law of density fluctuations with size scale. However, on scales larger than about ten parsecs a large fraction of the observed ISM structure is deterministic in nature, and apparently related to bubbles, shells and supershells. These objects inject energy into the ISM on scales of parsecs to hundreds of parsecs. Shells eventually break down by various instability processes in the ISM and join the turbulent cascade.

Shells play a role in shaping the large-scale structure of galaxies, too. The H I structure of some galaxies, for example the Large Magellanic Cloud, is dominated by H I shells (Kim et al. 1999). In other spiral disk galaxies, such as NGC 6946, the number of large H I shells dominates the structure, producing a semi-flocculent effect on the spiral arms (see Fig. 7 of Boomsma et al. 2008). One problem that has plagued studies of H I shells and holes is that the number of large holes in some galaxies is seemingly inconsistent with the amount of star formation activity in those galaxies or at least the evidence of for stellar progenitors is lacking. For example, many of the shells in the LMC lack the internal Hα emission that would be expected for stellar wind formed shells and the number of large shells is surprising given the star formation of the galaxy. Similarly, although the NGC 6946 shells match the star formation energy budget many of the holes have no progenitor remnants (Boomsma et al. 2008), leading to questions about their origin. Within the Milky Way the surface density of energetic shells exceeds the density of massive star clusters (McClure-Griffiths et al. 2002), raising concerns about how the large shells were formed. Examples such as these have been used to motivate a need for more exotic origins to the formation of shells such as collisions of high velocity clouds with the disk (Tenorio-Tagle et al. 1986), gamma ray bursts (Loeb & Perna 1998) or disk instabilities (Wada, Spaans & Kim 2000). There are, however, very few indications of these processes operating on large scales in galaxies and it is more likely that we have over-estimated the amount of energy required to form some of the shells and over-estimated the number of holes in some galaxies, including perhaps the Milky Way.

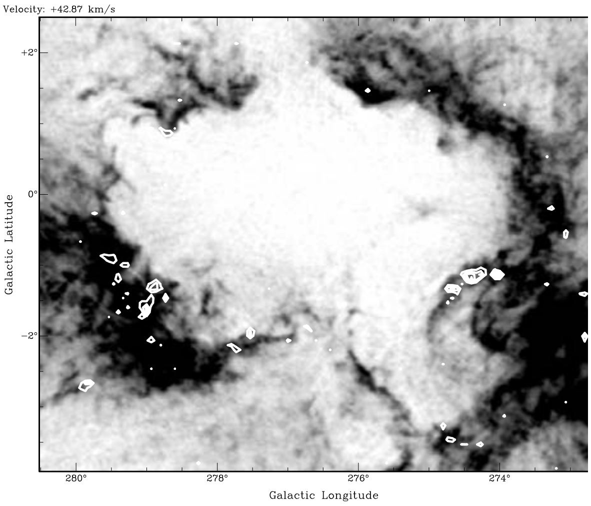

Fig. 5 H I emission of the Galactic supershell GSH 277+00-
overlaid with contours of CO emission.

Perhaps most importantly shells and bubbles play a r
in both the heating and cooling of the interstellar mediu
We know that superbubbles are often filled with extrem
hot, X-ray emitting gas (e.g. Chu et al. 1990; Callaway
al. 2000). High resolution imaging of H I shells reveals
extent of their role in compressing gas over small scal
An excellent example of this role is seen in the Galactic supershell GSH 277+00+36 (McClure-Griffiths et al. 2003). The walls of this supershell show a jump in density of about a factor of ~ 10 over ~ 18 pc (see Fig. 8 of McClure-Griffiths et al. 2003).

Dawson et al. (2011) compared the H I and CO emission in the supershells GSH 277+00+36 and GSH 287+04-17. Figure 2 shows an image of GSH 277+00+36 overlaid with CO emission from the NANTEN 4m telescope. Dawson et al. (2011) found an enhanced level of molecularization over the volumes of both supershells, providing the first direct observational evidence of increased molecular cloud production due to the influence of supershells. They showed that the walls of these supershells are dominated by cold gas with estimated temperatures and densities of $T \sim 100\,\mathrm{K}$ and $n \sim 10\,\mathrm{cm}^{-3}$, respectively. The rich substructure of filaments and drips previously seen in H I was matched with CO emission elongated along the inner edges of the atomic walls, or embedded within the H I filaments and clouds, or taking the form of small CO clouds at the tips of tapering atomic "fingers". The enhanced molecularization raises the question of whether the supershells condense gas along their walls enough that it cools and molecular gas forms in situ or simply collect small clouds as they expand. If molecular gas were formed in situ, it is possible that we see in one object the evolution from very hot stellar by-products inhabiting the centre of shells, through warm diffuse ISM, to cold atomic material and finally molecular gas. As such, shells seem to be catalysts for the evolution of the ISM.

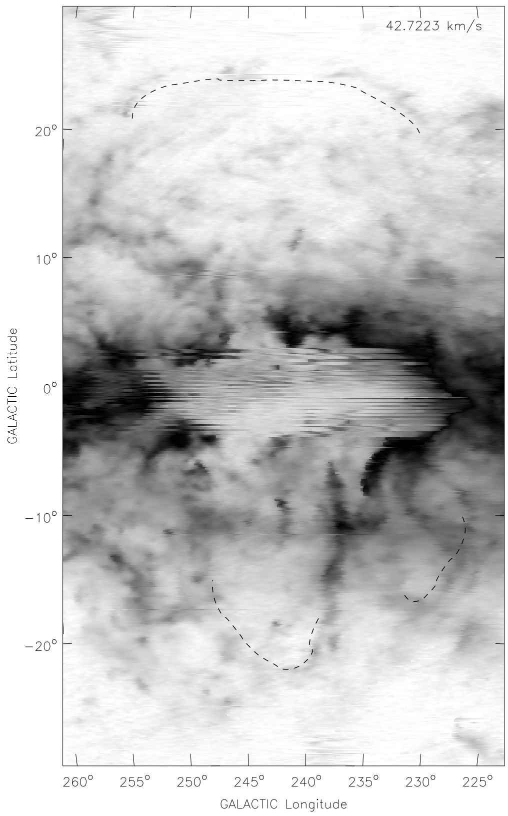

Fig. 6 H I emission of the Galactic supershell GSH 242-03+42 (from Fig. 6 in McClure-Griffiths et al. 2006).

4.1 Role of supershells in the disk-halo interaction

It has long been suspected that supershells and superbubbles may play a role in the interaction of the disk and halo in galaxies. Theories predict that gas might escape from the disk to the halo by superbubbles growing so large that they exceed the scale-height of the disk gas. As the continue to expand along the density gradient towards the halo they effectively run away unimpeded to "pop" in the lower halo (e.g. Norman & Ikeuchi 1989). This is the so-called "chimney model". An alternate method of supplying gas to the halo is via the classic "fountain" model in which gas heated by multiple supernovae rises buoyantly towards the halo (e.g. Bregman 1980).

Regardless the method of transport the necessity of moving gas between the disk and halo in clear. This gas is needed both as a source of heating and support for the halo, as well as a method for distributing metals about the disk. Furthermore, as evidenced at this meeting, disk gas may play an important role in the creation of neutral and molecular structures in the lower halo of the Milky Way and other galaxies.

Recent models of superbubble evolution have focused on where and how shells break into the halo, suggesting that supershells reach z heights of several hundred parsecs before their caps become Rayleigh-Taylor unstable, causing them to break and release their hot interior gas to the halo (de Avillez & Berry 2001; de Avillez & Breitschwerdt). The observations seem to reveal a variety of breakout morphologies. For example, the Galactic chimneys GSH 277+00+36 and GSH 242-03+42, as shown in Fig. 6, breakout via multiple channels at $z = 250$–300 pc each presumably releasing gas (McClure-Griffiths et al. 2003; McClure-Griffiths et al. 2006). By contrast, the W4 chimney breaks out with the classical cone shape (West et al. 2007) at a slightly lower z height. It is not clear whether these differences represent different evolutionary stages or conditions in the ambient medium.

There is some evidence that supershells not only supply hot gas to the halo, but that they can also pull cool gas into galaxy halos. Some of the best examples are in the edge-on galaxies, NGC 4217 (Thompson, Howk & Savage 2004) and NGC 891 (Howk & Savage 2000), which show dust loops apparently extending from the disk to $z = 1$ kpc. Presumably these have been pulled into the halo by disk activity, but the challenge with edge-on galaxies is tracing the high-latitude dust loops back into the disk. In this respect, the Milky Way offers a better vantage point for tracing high latitude structures back into the disk.

Although there are no clear examples in the Milky Way of dusty loops at high latitude, there is plenty of evidence for moderately cool H I at high latitude that connects back with structures in the disk. A nice example is the Ophiucus superbubble (Pidopryhora et al. 2007). This gigantic superbubble has both H I and Hα traced up to $z = 3.4$ kpc connected to the plane by "whiskers" of H I emission. Another good example of an H I chimney creating structure in the lower halo is supershell GSH 242-03+42 shown in Fig. 6. GSH 242-03+42 has a in-plane radius of $\sim$560 pc but appears to break out as a multi-channel chimney and exhibits looping caps of H I at $z \sim 1.5$ kpc. These caps appear to be breaking into small clumps with sizes of a few tens of parsecs, linewidths of $\sim$10 km s^{-1} that suggest temperatures of $T \sim 10^3$ K, and number densities of $n \sim 1\,\mathrm{cm}^{-3}$. These properties are strikingly similar to the lower halo clouds discovered by Lockman (2002) and explored by Ford et al. (2008, 2010). This similarity in clump properties led McClure-Griffiths et al. (2006) to suggest that broken caps of chimneys may be the origin for the Lockman type clouds. This option was explored more thoroughly by Ford et al. (2008), who came to a similar conclusion. Ford et al. (2010) went on to show that in fact the distribution of lower halo cloudlets correlates well with areas of active star formation in the Galaxy. So, although theory suggests that lower halo clouds could form either from broken tops of supershells or from cooling condensation of expelled hot gas (de Avillez 2000), the observations suggest that broken caps may be a dominant mechanism.

5 Conclusions

The past 10 years have seen a positive explosion in the availability of high quality, high resolution surveys of the Galactic plane. These surveys extend in wavelength coverage from 4 μm to 20 cm and cover most of the Galactic plane. The surveys cover most parts of the evolutionary cycle of matter in the interstellar medium, probing warm diffuse gas as it cools into star forming molecular clouds and the outflowing effects of massive stars. The new Galactic plane surveys with their angular resolutions of $\sim 1'$ (IGPS) up to $1''$ (GLIMPSE) provide us with the ability to study the physical processes effecting ISM evolution with spatial resolutions of parsecs to sub-parsecs. Using these data the overwhelming picture that arises of the ISM is that of its frothy nature. The ISM is replete with bubbles, shells and supershells that dominate the deterministic structure of the Milky Way, act as catalysts for gas cooling and drive gas out of the disk.

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References

Arthur, S.J., Henney, W.J., Mellema, G., de Colle, F., Vázquez-Semadeni, E.: 2011, MNRAS 414, 1747
Aguirre, J.E., Ginsburg, A.G., Dunham, M.K., et al.: 2011, ApJS 192, 4
Benjamin, R.A., Churchwell, E., Babler, B.L., et al.: 2005, ApJ 630, L149
Boomsma, R., Oosterloo, T.A., Fraternali, F., van der Hulst, J.M., Sancisi, R.: 2008, A&A 490, 555
Bregman, J.N.: 1980, ApJ 236, 577
Brentjens, M.A., de Bruyn, A.G.: 2005, A&A 441, 1217
Callaway, M.B., Savage, B.D., Benjamin, R.A., Haffner, L.M., Tufte, S.L.: 2000, ApJ 532, 943
Carey, S. J., Noriega-Crespo, A., Mizuno, D.R., et al.: 2009, PASP 121, 76
Chu, Y.-H., Mac Low, M.-M.: 1990, ApJ 365, 510
Churchwell, E., Povich, M.S., Allen, D., et al.: 2006, ApJ 649, 759
Churchwell, E., Watson, D.F., Povich, M.S., et al.: 2007, ApJ 670, 428
Dawson, J.R., McClure-Griffiths, N.M., Kawamura, A., et al.: 2011, ApJ 728, 127
de Avillez, M.A.: 2000, MNRAS 315, 479
de Avillez, M.A., Berry, D.L.: 2001, MNRAS 328, 708
de Avillez, M.A., Breitschwerdt, D.: 2005, A&A 436, 585
Ford, H.A., McClure-Griffiths, N.M., Lockman, F.J., et al.: 2008, ApJ 688, 290
Ford, H.A., Lockman, F.J., McClure-Griffiths, N.M.: 2010, ApJ 722, 367
Gaensler, B.M., Dickey, J.M., McClure-Griffiths, N.M., et al.: 2001, ApJ 549, 959
Giacani, E., Dubner, G.: 2004, A&A 413, 225
Heiles, C.: 1979, ApJ 229, 533
Heiles, C.: 1984, ApJS 55, 585
Howk, J.C., Savage, B.D.: 2000, AJ 119, 644
Jackson, J.M., Rathborne, J.M., Shah, R.Y., et al.: 2006, ApJS 163, 145
Kim, S., Dopita, M.A., Staveley-Smith, L., Bessell, M.S.: 1999, AJ 118, 2797

Lockman, F.J.: 2002, ApJ 580, L47
Loeb, A., Perna, R.: 1998, ApJ 503, L35
McClure-Griffiths, N.M., Dickey, J.M., Gaensler, B.M., Green, A.J.: 2002, ApJ 578, 176
McClure-Griffiths, N.M., Dickey, J.M., Gaensler, B.M., et al.: 2005, ApJS 158, 178 196
McClure-Griffiths, N.M., Ford, A., Pisano, D.J., et al.: 2006, ApJ 638, 196
McClure-Griffiths, N.M., Pisano, D.J., Calabretta, M.R., et al.: 2006, ApJS 181, 398
Mizuno, A., Fukui, Y.: 2004, in: D. Clemens, R. Shah, T. Brainerd (eds.), *Milky Way surveys: the structure and evolution of our Galaxy*, ASPC 317, p. 59
Molinari, S., Swinyard, B., Bally, J., et al.: 2010, A&A 518, L100
Norman, C.A., Ikeuchi, S.: 1989, ApJ 345, 372
Pidopryhora, Y., Lockman, F.J., Shields, J.C.: 2007, ApJ 656, 928
Price, S.D., Egan, M.P., Carey, S.J., Mizuno, D.R., Kuchar, T.A.: 2001, AJ 121, 2819
Schuller, F., Menten, K.M., Contreras, Y., et al.: 2009, A&A 504, 415
Simpson, R.J., Povich, M.S., Kendrew, S., et al.: 2012, astro-ph/1201.6357
Spangler, S.R.: 2001, Space Sci. Rev. 99, 261
Stil, J.M., Taylor, A.R., Dickey, J.M., et al.: 2006, AJ 132, 1158
Taylor, A.R., Landecker, T.L., Willis, A.G.: 2002, *Seeing through the dust: the detection of HI and the exploration of the ISM in galaxies*, ASPC 276, Astronomical Society of the Pacific, San Francisco
Tenorio-Tagle, G., Bodenheimer, P.: 1988, ARA&A 26, 145
Tenorio-Tagle, G., Bodenheimer, P., Rozyczka, M., Franco, J.: 1986, A&A 170, 107
Thompson, T.W.J., Howk, J.C., Savage, B.D.: 2004, AJ 128, 662
Wada, K., Spaans, M., Kim, S.: 2000, ApJ 540, 797
Walsh, A.J., Breen, S.L., Britton, T., et al.: 2011, MNRAS 416, 1764
Watson, C., Povich, M.S., Churchwell, E.B., et al.: 2008, ApJ 681, 1341
West, J.L., English, J., Normandeau, M., Landecker, T.L.: 2007, ApJ 656, 914
Wolleben, M., Landecker, T.L., Carretti, E., et al.: 2009, in: K.G. Strassmeier, A.G. Kosovichev, J.E. Beckman (eds.), *Cosmic magnetic fields: from planets, to stars and galaxies*, IAU Symp. 259, p. 89
Wolleben, M., Fletcher, A., Landecker, T.L., et al.: 2010, ApJ 724, L48