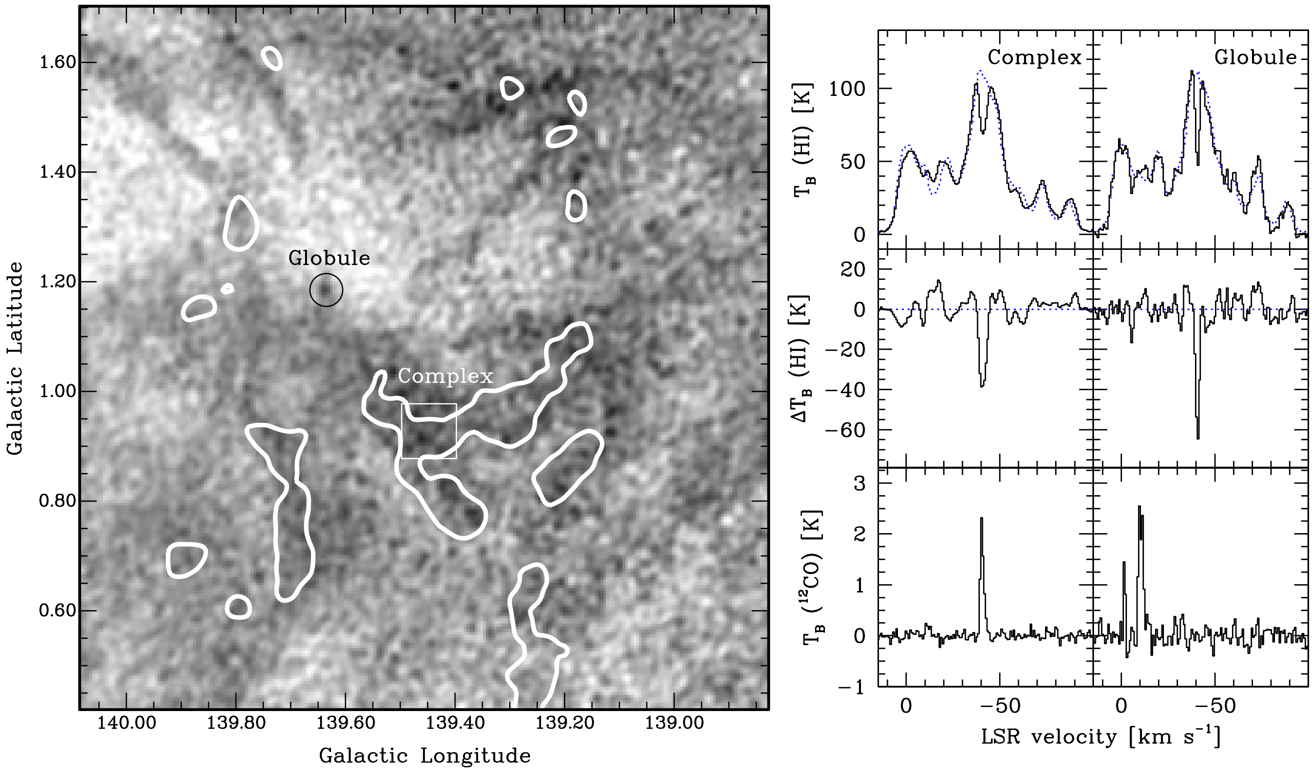
Outline of Current Research

I have a range of research interests, but my current projects all involve different aspects of the interstellar medium (ISM) of the Milky Way, our home galaxy. I describe each of these projects below.

1. Cold Atomic Hydrogen

My main focus is the cold ($T < 100$ K) interstellar gas traced by the 21cm hyperfine transition of neutral atomic hydrogen (H I). Cold atomic gas represents $\sim 30\%$ of the ISM mass in our part of the Galaxy (Reynolds 1992). Since hydrogen is the most abundant element in interstellar gas, the H I 21cm line is a natural probe of the cold atomic phase, the coldest parts of which ($T < 50$ K) can be detected as H I self-absorption (HISA) against brighter background H I emission.

1.1. HISA in the Canadian Galactic Plane Survey

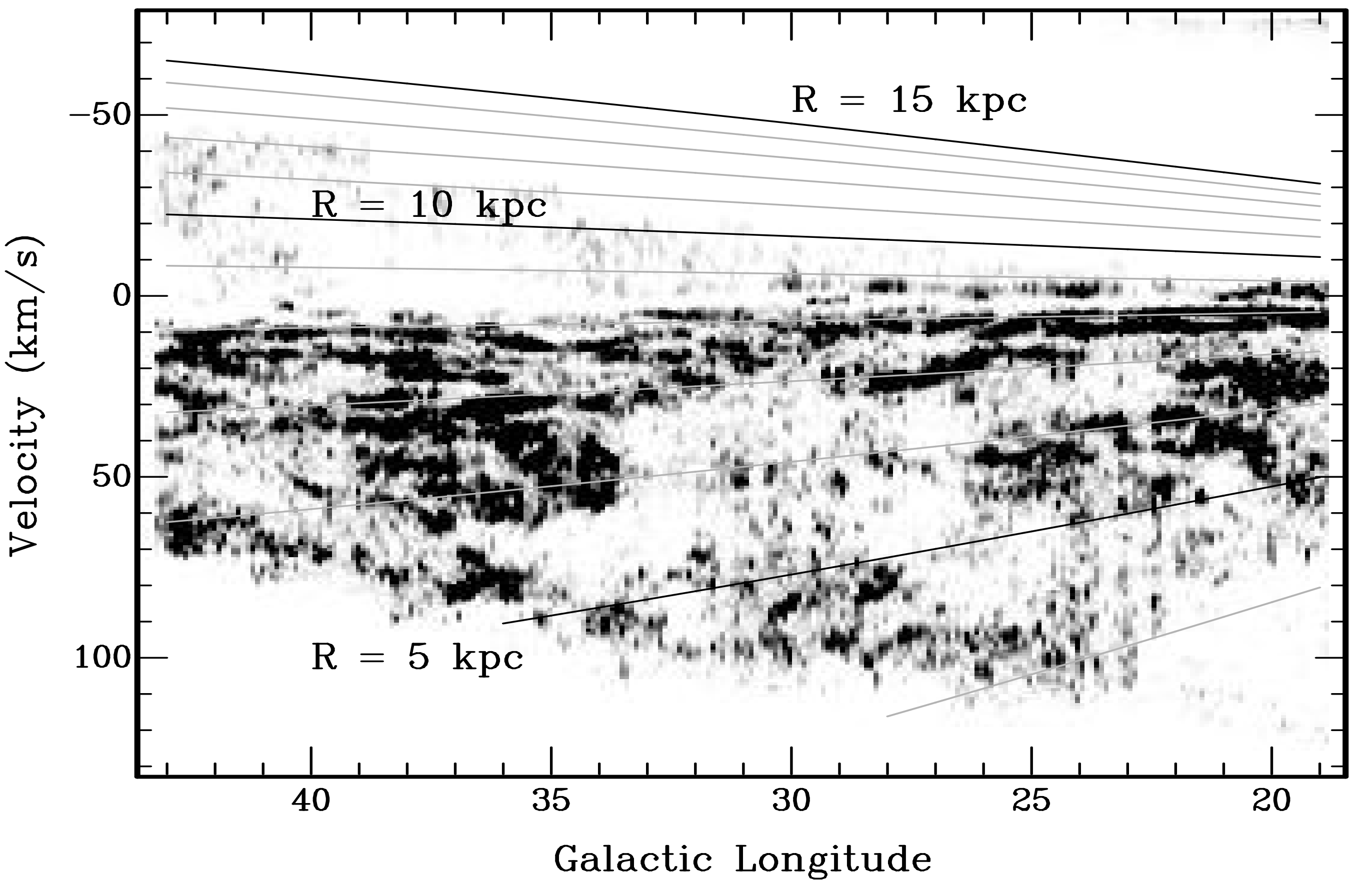


Left: Dark HISA clouds in the CGPS. Some HISA features have CO emission (contours), but some do not. *Right:* Spectra of two HISA features at $v = -40$ km s^{-1}, with total H I emission (top), ON-OFF absorption strength (middle), and CO emission (bottom).

Until recently, HISA studies of cold H I were hampered by low angular resolution, limited sky coverage, or both, making it difficult to measure the absorption properly and chart the cloud population in an unbiased way. But these problems have been overcome with new large-scale, arcminute-resolution 21cm radio synthesis surveys of the Galactic disk. Since 1998, I have led a broad-based HISA investigation using the Canadian Galactic Plane Survey (CGPS; Taylor et al. 2003) of the second quadrant (longitudes $74^\circ - 147^\circ$). Our first paper (Gibson et al. 2000) showed that (1) a rich and varied HISA population can be seen at high angular resolution, and (2) most of these cold H I clouds have no obvious counterparts in the standard 2.6mm CO $J = 1 - 0$ line tracer of molecular gas. The latter contradicts traditional expectations that HISA gas traces the small fraction of molecular cloud gas that is atomic, unless the CO proxy for H_2 is itself suspect.

Our group has since developed algorithms to identify and analyze the many CGPS HISA features systematically, and two new papers describing our results are nearing completion (Gibson et al. 2004a,b; see also Gibson 2002). We have found faint, intricate HISA wherever the background is sufficently bright. By contrast, strong HISA is clustered near radial velocities predicted for the density wave of the Perseus spiral arm (Roberts 1972). Indeed, the strong outer-Galaxy HISA we see in the CGPS *requires* spiral arm velocity perturbations in order to exist; otherwise, the velocity-distance relationship is monotonic, and no organized H I emission background can occur at the same velocity as the HISA foreground. HISA thus probes the spiral structure of our galaxy from the inside. We've also found that, statistically, most CGPS HISA does not correspond with significant CO emission. This does not rule out H_2 untraced by CO, a possibility we are investigating in a separate project (see §1.3). Or, some HISA may lack molecular gas entirely. Equilibrium cloud models have difficulty explaining the low HISA temperature without molecular cooling, but equilibrium may not apply. Instead, the HISA may trace cold H I before or after a phase change. In the standard spiral shock picture, gas is compressed downstream of the shock, where it forms molecular clouds and then the massive stars that define the spiral arm. If this is correct, HISA is tracing evolving gas as well as spiral structure.

1.2. HISA across the Galactic Disk



HISA line strength integrated over latitude for a 25° section of the VGPS, with darker features being stronger. Many HISA features run almost parallel to lines of constant Galactocentric radius R (overplotted for a flat rotation curve with $R_0 = 8.5$ kpc and $v_0 = 220\ \mathrm{km\,s^{-1}}$), which is consistent with the HISA tracing spiral structure in the inner Galaxy.

The original CGPS longitude coverage is being extended to 65° − 175°, and we are writing a proposal for a second extension to 190°. In addition, the VLA Galactic Plane Survey (Taylor et al. 2002) has been observed over 18° − 67° longitude, and the Southern Galactic Plane Survey (McClure-Griffiths et al. 2001) covering 252° − 358° is being extended through the Galactic center region to 20°. Collectively, these and other projects to map molecular gas and dust in the same areas are now known as the International Galactic Plane Survey (IGPS). When the IGPS data are complete, they will allow HISA mapping over most of the Galactic disk. Already, these efforts are bearing fruit: a preliminary analysis of part of the VGPS (Gibson et al. 2004c) shows HISA is even more common here than in the CGPS. The inner-Galaxy sightlines of the VGPS should be more favorable for HISA, since gas on the near side of the Galactic center always has a far-side emission background at the same velocity. The VGPS HISA also shows an improved though still imperfect CO correspondence, perhaps because of the same geometric effect. Most intriguing is the prominent concentration of HISA along a number of velocity features that look suspiciously like spiral arms. Spiral structure has traditionally been more difficult to discern in the inner Galaxy, but HISA may help with this situation.

1.3. Constraining Molecular Counterparts

Two side projects are currently using other observations to constrain the relationship between molecular gas and HISA in specific clouds. A series of ultraviolet spectra toward OB stars behind several CGPS HISA features was taken with the *Far-Ultraviolet Spectroscopic Explorer* satellite to assess the quantity of H_2 absorption, if any, in these objects (PI: P. E. Dewdney). Preliminary analysis indicates that H_2 absorption has been detected, and a quantitative assessment is underway. At the same time, Caltech Submillimeter Observatory spectra were observed toward some other prominent HISA features to look for 1.3mm CO $J = 2-1$ and 0.6mm [C I] emission in these locations (PI: R. Plume). No [C I] was found, but CO $J = 2-1$ measurements toward one object are providing useful additional constraints on the gas properties in this area, which may lead to a better understanding of the fraction of the gas in the HISA cloud that is molecular (Klaassen et al. 2004).

1.4. Cold H I in Emission

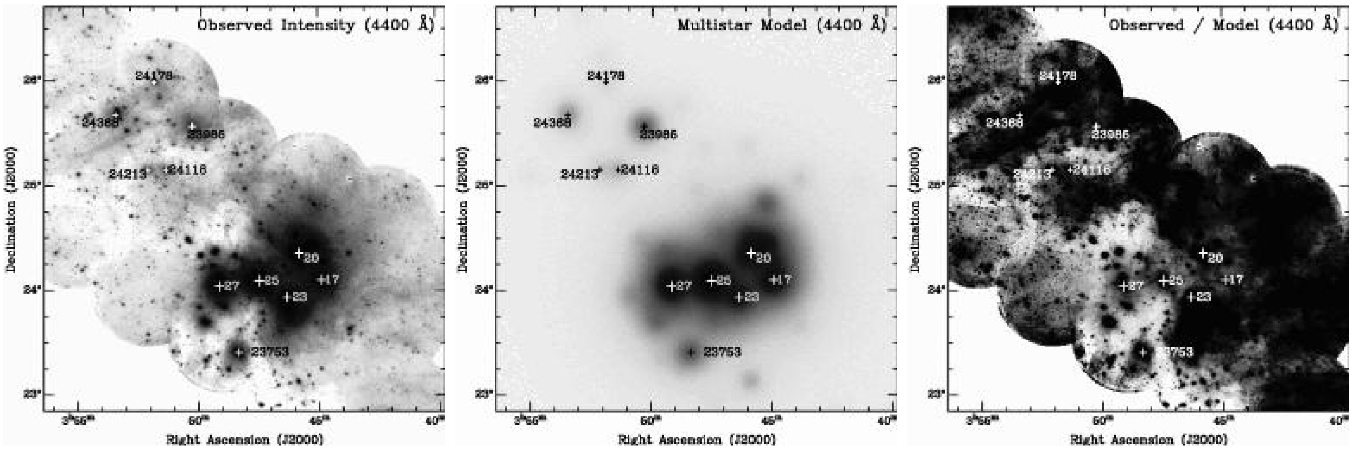
Most sightlines in the sky lack sufficiently bright backgrounds to produce the HISA effect, and since the population of cold H I clouds should be randomly distributed with respect to such backgrounds, the majority of cold H I features should manifest as narrow-line H I emission (NHIE) rather than HISA (one famous example is Verschuur's Cloud A; see Knapp & Verschuur 1972). The algorithms used to detect HISA in the CGPS dataset can also be run in an inverse mode to identify NHIE features. Early tests of this facility on CGPS data show considerable promise, with a great many NHIE features appearing as organized structures on the sky and in velocity. The CGPS NHIE feature population outnumbers the CGPS HISA population considerably, as might be expected. Further work is planned to explore the spatial distributions of the NHIE features and to attempt to constrain their properties with additional data.

1.5. Sky Surveys

Also on the horizon for cold H I studies are new surveys of large parts of the sky. One of these involves the GALFA consortium to use the Arecibo L-band Feed Array (ALFA), under current design and construction, to map all the Galactic H I emission visible with the Arecibo telescope – about 30% of the entire sky (see http://alfa.naic.edu/galactic for more details). Arecibo's 305m dish is the largest in the world. The signal-to-noise it affords makes it superbly suited to the study of narrow-line H I features at high (3 arcminute) angular resolution. Thus, GALFA will enable a large-scale survey of both HISA in the Galactic plane and NHIE off the plane. I have led a recent drive within the GALFA consortium to do just this when the instrument becomes available. The NHIE survey is especially important, because very little is known about the NHIE cloud population at present, and this is likely to dominate the total population of cold H I features over the sky. Farther on the horizon, the Large Adaptive Reflector project will yield a steerable "northern Arecibo" in a few years' time that can be used to survey the entire northern hemisphere for cold H I clouds.

Complementing these HISA/NHIE sky surveys is the Spectroscopy of Plasma Evolution from Astrophysical Radiation (SPEAR) satellite telescope (PI: J. Edelstein), which will observe a variety of UV line emission over the entire sky, including H_2 fluoresence in response to local UV radiation from stars. SPEAR was launched successfully a few weeks ago and is currently undergoing testing. I am very interested in comparing SPEAR observations of H_2 against the narrow-line H I detections the GALFA project will produce, to see what the molecular-atomic phase relationships are like out of the plane.

2. Scattering by Interstellar Dust

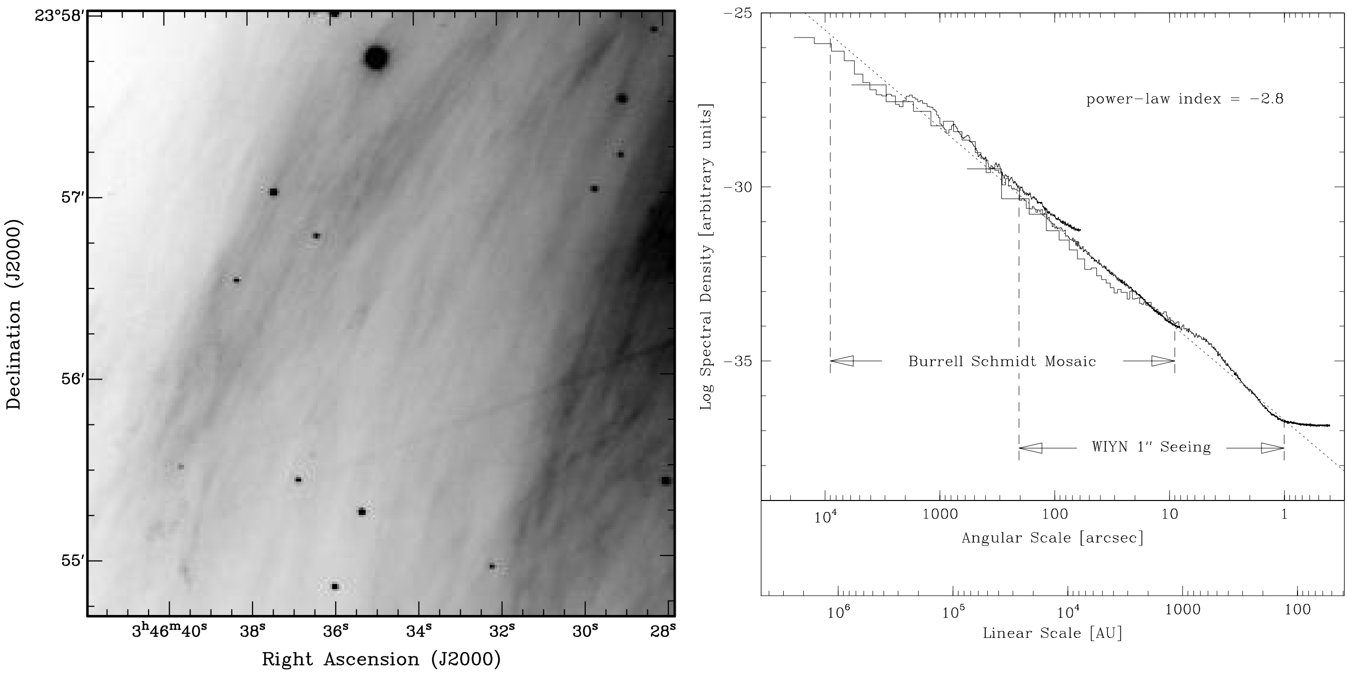


Left: Optical (4400 Å) brightness of the Pleiades reflection nebula. *Center:* Best-fit scattering model for a uniform slab of dust. *Right:* Ratio of observed intensities / model intensities showing nebular structure (Gibson & Nordsieck 2003b).

A second focus of mine for many years has been the scattering and absorption of starlight by interstellar dust. The appearance of dusty environments, from local star-forming regions to galaxies in the distant universe, is strongly affected by dust scattering. The physical conditions inside interstellar clouds also depend upon the penetration of photon energy from outside. Dust scattering effects can be examined in reflection nebulae, whose brightness and color are functions of the optical properties and spatial distribution of the dust they contain. In my dissertation on the Pleiades reflection nebula (Gibson 1997), I initiated a detailed study of these effects using vacuum-ultraviolet imaging photometry from the sounding rocket borne *Wide-field Imaging Survey Polarimeter (WISP)* telescope (Nordsieck & Harris 1999), plus complementary ground-based optical images from the Burrell Schmidt telescope and thermal radiation maps from the *Infrared Astronomical Satellite.* My collaborator and I recently completed a detailed analysis to constrain both the UV properties of the dust and the 3-D scattering geometry in this region (Gibson & Nordsieck 2003a,b). We found that, in contrast to some previous analyses, most of the observed scattering comes from two dust layers in front of the stars. The dust albedo also appears to be less in the UV ($a \sim 0.2$) than many authors have found, and the degree of UV forward-scattering is quite high ($g \sim 0.7$), although both of these measurements could be biased by clumpiness in the dust distribution.

I have been involved in two other dust investigations. I assisted with the target selection and early data analysis for the *WISP* observation of the west side of the Large Magellanic Cloud, which successfully obtained UV polarimetry to aid in the scattering analysis (Cole et al. 1999). I also performed Mie scattering simulations to compare to more sophisticated finite-element models of "fluffy" grains, to determine the circumstances under which the latter are necessary (Wolff et al. 1998).

3. Structure of Interstellar Clouds



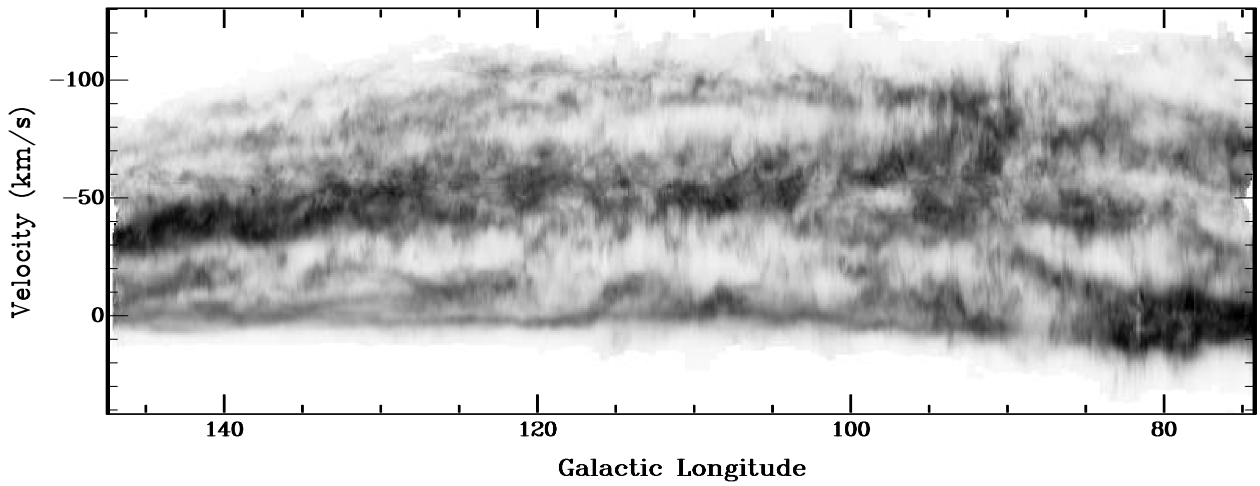
Left: Intricate filamentary structure in the Pleiades reflection nebula. *Right:* 2-D angular power spectrum of the Pleiades dust structure, which follows a power law of slope −2.8 over four decades of angular scale (Gibson 2004).

In addition to the role of 3-D geometry in dust scattering, I have a general interest in the shape and structure of interstellar clouds. In my dissertation, I constrained the Pleiades nebula's placement in space by observing its neutral atomic gas in H I 21cm emission and Na I 5890 & 5896 Å absorption toward bright stars along the cluster sightline. At velocities consistent with those of the absorbing gas in front of the cluster, my collaborators and I found detailed correspondences between the dust and gas filaments in the nebula at our 21cm resolution of $1' = 0.04$ parsecs, dramatically illustrating the nature of small-scale structure in local interstellar gas clouds (Gibson, Holdaway, & Nordsieck 1995).

This structure is traced to even smaller scales by the optical reflection nebulosity, reaching 0.006 pc in the Schmidt optical maps and 0.0006 pc (130 astronomical units) in more recent higher-resolution ground-based WIYN images (Gibson 2004). A Fourier analysis of the Schmidt+WIYN data yields a 2-D angular power spectrum that follows a power-law of slope −2.8 over an unprecedented four orders of magnitude in angular size. Such a result may help theorists to constrain models of turbulent energy cascades in the ISM (e.g., Lazarian & Pogosyan 2000).

4. Fine Structure in the Galactic Disk

Another project of mine explores the detailed structure of the Galactic disk revealed by IGPS H I data. My collaborator and I fit smooth functions through low-resolution all-sky H I survey longitude-latitude-velocity (ℓ, b, v) cube data to model the "midplane" surface $b_{mid}(\ell, v)$ where the H I emission brightness is greatest. This surface should correspond to the bottom of the gravitational potential through the disk, and it reproduces the basic shape of the well-known warp in the outer parts of the disk. We then extracted high-resolution CGPS longitude-velocity slices parallel to our smooth $b_{mid}(\ell, v)$ surface. Because these cuts through the CGPS data follow the true gas distribution better than an ordinary (ℓ, v) slice at constant latitude, they enable a more complete picture of the gas dy-



CGPS H I emission brightness in the midplane surface $b_{mid}(\ell, v)$, showing large-scale spiral arm features and considerable smaller-scale structure from objects in the Galactic plane (Gibson & Stil 2002).

namics in the disk (Gibson & Stil 2002; see also http://www.ras.ucalgary.ca/~gibson/himp). On large scales we see major spiral features, while on smaller scales we see many instances of gas displaced from the spiral arms into interarm velocities or even velocities forbidden by ordinary Galactic rotation. The $b_{mid}(\ell, v)$ slices thus allow us (1) to identify parcels of Galactic gas where a simple spiral arm model breaks down, and (2) to look for associations of such features with known objects, such as expanding shells of gas around young, energetic stars. Work on this project is proceeding.

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