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Bright Prospects: Comparing the Hα Survey with Large-scale Radio Continuum Emission

A. R. Duncan[1] and R. F. Haynes[2]

[1] Physics Department, University of Queensland, St Lucia, Qld 4072, Australia
duncan@physics.uq.edu.au

[2] Australia Telescope National Facility, CSIRO, PO Box 76, Epping, NSW 2121, Australia

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Abstract: Prospects for comparisons between the AAO/UKST Hα survey and large-scale radio continuum emission are considered, with particular reference to the recently completed Parkes 2·4 GHz survey of the southern Galactic Plane. Both these surveys have a high sensitivity to thermal emission, and comparisons between the Parkes work and previous Hα surveys show many objects in common. Possibilities for new detections include: a number of new supernova remnants; the faint extensions and envelopes surrounding 'classical' H II complexes, and other faint regions of thermal emission; several active H II complexes, including an outflow of ionised gas from IC 4628 and a number of bi-polar 'plumes' of low-density, thermal material apparently associated with H II complexes on the Carina spiral arm.

Keywords: H II regions — radio continuum: general — surveys

1 Introduction

It has long been known that radio continuum emission is a tracer of star formation in galaxies, both on global (i.e. galaxy-wide) scales and on the relatively local scales of individual star-forming regions (e.g. Day, Caswell & Cooke 1972; Klein 1982). Indeed, in our own galaxy, H II and star forming regions (such as the Orion and η Car complexes) are some of the brightest sources of radio emission.

In addition to radio continuum emission, Hα emission is also produced by these regions of hot, ionised gas. Both the Parkes 2·4 GHz survey (Duncan et al. 1995, 1997b) and the AAO/UKST Hα survey (Masheder, Phillipps & Parker 1998, present issue p. 5) are very sensitive to these thermal emissions. Preliminary comparisons of the two surveys show that they will detect many objects and structures in common. As such, the Parkes survey is complementary to the Hα imaging now being undertaken, and detailed comparisons of the two should prove very worthwhile.

2 The Parkes Survey

New, high-resolution radio surveys of the southern Milky Way, such as the Molonglo Observatory Synthesis Telescope (MOST) survey (Whiteoak et al. 1989), show the fine structure and detail of H II and star-forming regions well. However, as the recently completed Parkes 2·4 GHz survey has shown, a great deal of thermal structure exists on large angular sizes (of the order of 1° and greater). Emission on such large angular scales cannot generally be detected by synthesis instruments.

The Parkes survey is a sensitive, polarimetric, radio continuum survey of the southern Milky Way that has produced high-quality images with a minimum of instrumental artefacts. This work covers 127° of Galactic longitude ($238° \leq l \leq 5°$) and latitudes out to $b = \pm 5°$, although in some regions this has been extended to $b = +7°$ and $b = -8°$.

At 10·4 arcmin, the angular resolution of the radio images is rather low, certainly much lower than the resolution of most synthesis telescopes. However, this large beamwidth allows impressive brightness sensitivity to be achieved (see also Cram, Green & Bock 1998, present issue p. 64). The rms noise of the Parkes survey corresponds to a brightness sensitivity of approximately 1500 Jy sr^{-1} (17 mJy/beam area), which is approaching the confusion limit of the telescope at this wavelength. Indeed, for optically-thin thermal emission (at a temperature of 8×10^3 K), this brightness sensitivity implies a limiting emission measure of approximately 10 cm^{-6} pc. Whilst the limiting emission measure of the Hα survey is not yet known, the earlier work of Sivan (1974) quotes a value of 30 cm^{-6} pc. The new AAO/UKST Hα survey could be expected to better this somewhat. As a result, the radio and Hα surveys should have comparable sensitivities to thermal emission.

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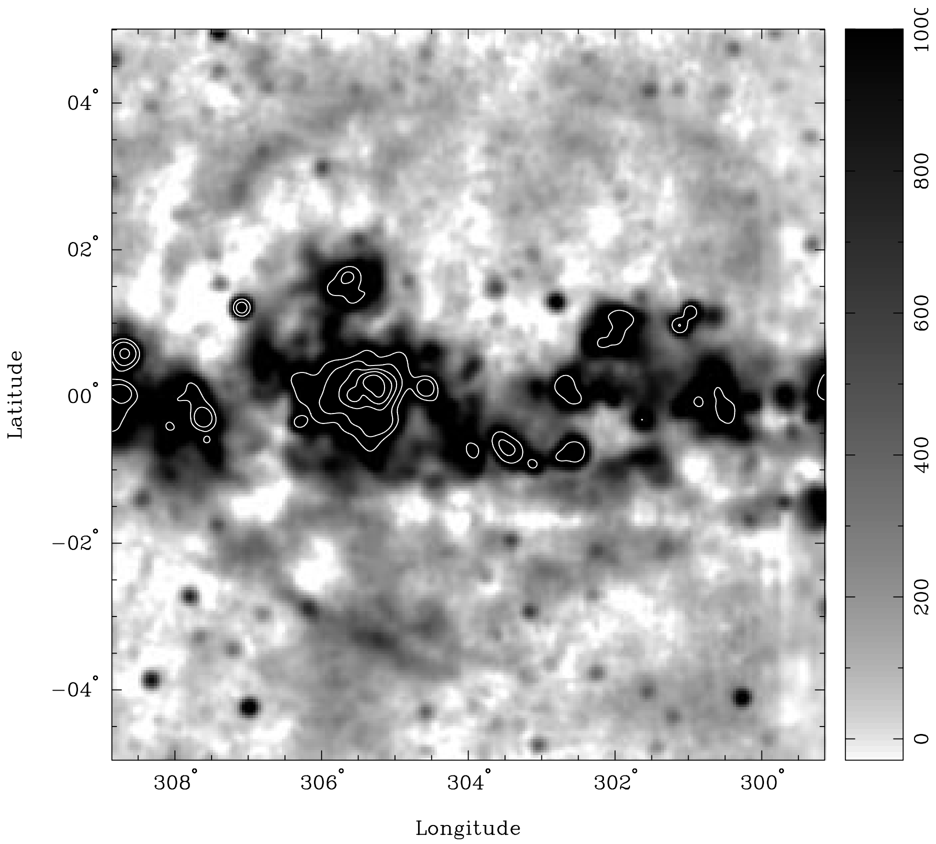

Figure 1—Total-power image of a region of the Galactic Plane, between longitudes of 299° and 309°. This image clearly shows the faint, diffuse emission seen close to the Plane (generally between latitudes of $b = \pm 2°$), which is apparently associated with H II complexes (see Section 4·1). Such faint emission often exhibits considerable structure. Towards higher latitudes, the faint ring arcs of a large supernova remnant can be discerned. This remnant is approximately 8·5° in angular diameter (see Section 4·3). The resolution of this image is 10·4 arcmin, and the rms noise is approximately 17 mJy (beam area)$^{-1}$. The grey-scale wedge is labelled in units of mJy (beam area)$^{-1}$. Contour levels are: 2, 4, 10, 20 and 40 Jy (beam area)$^{-1}$.

3 Comparisons

The essential objective of comparisons between radio and Hα emission is to determine as much as possible about the presence, morphology and physical conditions of the ionised gas.

However, although the limiting emission measures of the Parkes and Hα surveys are similar, there are several significant differences between the two types of emission in general, and between these two surveys in particular. A few of the more important similarities and differences will be noted now.

First, we reiterate that both Hα and radio continuum emission are tracers of ionised gas, with temperatures of several times 10^3 K. Both types of surveys can therefore assist in detailing the structure and morphology of ionised regions, although the low resolution of our Parkes observations restricts the radio data to investigations on scales of 10 arcmin or greater. Hence, the Hα survey can provide high-resolution information on many objects identified from the radio data. Note also that the radio continuum, unlike optical observations, is not affected by extinction.

Second, in contrast to Hα, the radio continuum contains large quantities of non-thermal emission. This can be of benefit when investigating certain objects (such as supernova remnant shocks) but can complicate studies of large-scale, diffuse thermal emission.

Third, the comparison of Hα with radio continuum data can assist in determining line-to-continuum ratios, which allows the temperature of the ionised gas to be estimated.

4 Prospects

In this section, results from the Parkes 2·4 GHz work of relevance to the AAO/UKST Hα survey will be examined. These are areas in which interesting comparisons between the radio and Hα data may be made.

4.1 Diffuse Thermal Emission

A section of the Parkes 2·4 GHz survey can be seen in Figure 1, showing a region of the Galactic Plane centred on longitude 304°. Even though this section of the survey is relatively devoid of bright

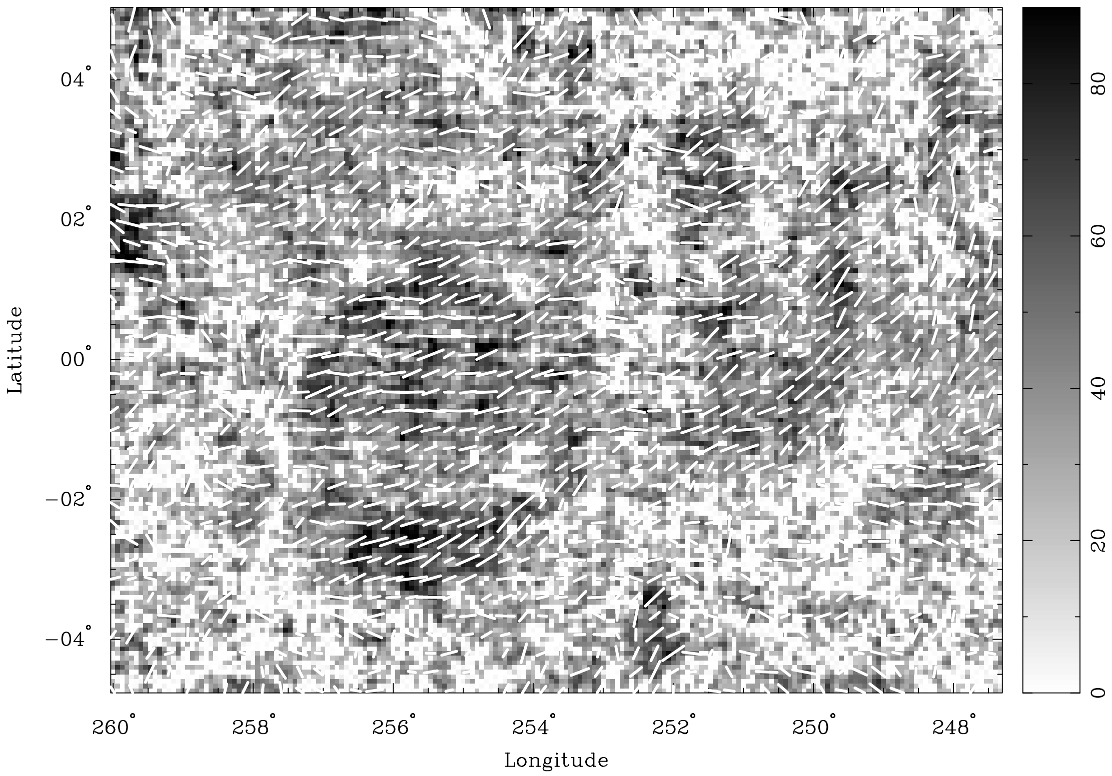

Figure 2—This image shows the polarised intensities detected over a section of the 2·4 GHz survey, dominated by the Gum nebula (see Section 4·2). The orientation of the polarisation vectors (electric vector of the received radiation) are also superposed on the image; note the uniformity in the vector angles over this large region. A vector is plotted every 16 arcmin. The resolution of this image is 10·4 arcmin, and the rms noise is approximately 11 mJy (beam area)$^{-1}$. The grey-scale wedge is labelled in units of mJy (beam area)$^{-1}$.

objects, the image nevertheless shows the Plane to be a confused and complex place, with bright H II regions (e.g. the complex at 305°–306° longitude), supernova remnants (e.g. G299·2–1·5; see Duncan et al. 1997a) and extragalactic sources (e.g. G307·0–4·2) superposed on fainter, extended emission.

This diffuse emission is very extensive, generally appearing between latitudes of $b = \pm 2°$ and over all longitudes of the survey coincident with bright spiral arms. The images reveal condensations and other structure within this emission, much of which is known to be thermal. Both the positioning and structural characteristics of this faint component suggest an association with the brighter, 'classical' H II regions, such that these objects are probably embedded within the more extended (and presumably lower-density) regions of faint emission.

The presence of this diffuse, thermal component over most of the longitude range covered by the Parkes survey suggests that this 'core–halo' structure is a common morphology for many H II complexes in the Galaxy (see also e.g. Lockman 1976; Anantharamaiah 1985, 1986).

4.2 The Gum Nebula

The western end of the Parkes survey, between longitudes of approximately $260° > l > 240°$, covers an area of the Plane occupied by the Gum nebula (Gum 1952, 1956). In this region, part of which is shown in Figure 2, we have detected radio emission from the Gum's faint emission nebulosities (see Duncan et al. 1996 for further detail). Interestingly, this emission also contains a non-thermal, polarised component which exhibits strikingly uniform vectors over many degrees of sky. The vector orientations are also plotted on Figure 2, showing the electric vector of the received radiation. These vector orientations exhibit an rms variation in position-angle of only ±30°. This is a very uniform distribution for an area of the Plane approximately $10° \times 12°$ in extent, and is unlike any other area of the Parkes survey. It is the uniformity of the vector angles over this region of the Plane that leads us to conclude that the survey is detecting large-scale, uniform, magnetic field structure associated with the Gum.

Although not shown here, the survey has also revealed another example of magnetic fields associated with Hα emission, near longitude 271° (see Figure 5 of Duncan et al. 1996). The alignment and uniformity of the vectors over this latter region again suggest that we are tracing magnetic field structure associated with this Hα feature, and also show that the rotation measures over this area are rather low ($|\mathrm{RM}| < 20$ rad m^{-2}).

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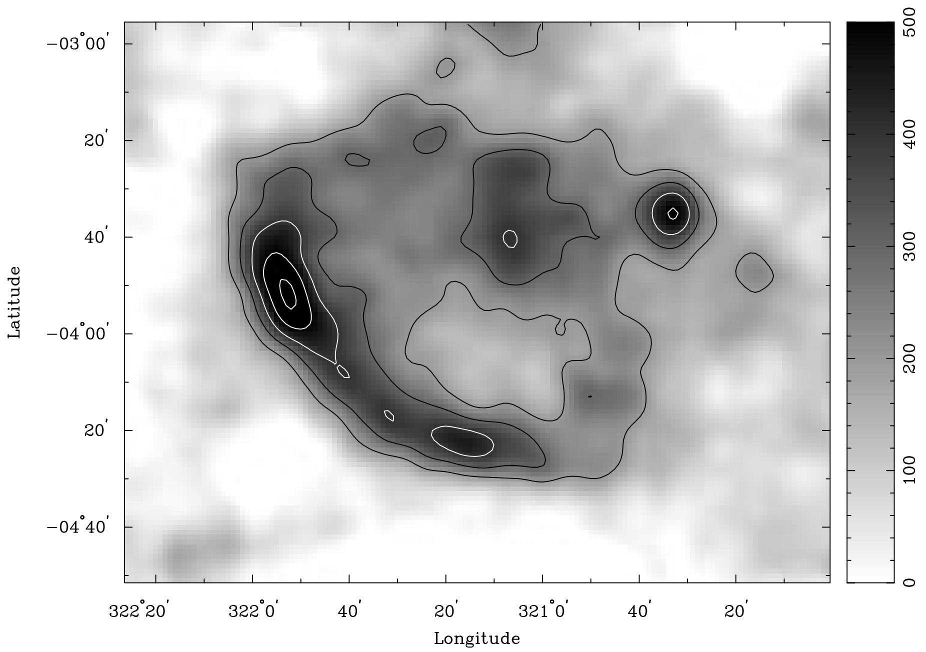

Figure 3—Total-power image of one of the new supernova remnants, G321·3–3·8. This SNR appears as an elliptical region of emission, with a central minimum. The south-east side of the remnant is considerably brighter than the rest of the shell. This image has a resolution of 10·4 arcmin, and an rms noise of 17 mJy (beam area)$^{-1}$. The grey-scale wedge is labelled in units of mJy (beam area)$^{-1}$. Contour levels are: 200, 300, 400, 500 and 600 mJy (beam area)$^{-1}$.

Of course, such detections are only possible for nebulae with very low emission measures, otherwise the polarised radio emission will be destroyed by the depolarising effects of the ionised gas.

4.3 New Supernova Remnants

A large number of new supernova remnants (SNRs) and SNR candidates have been uncovered by the Parkes 2·4 GHz survey. A total of 22 such objects were discovered as a result of this work, ranging in angular diameter from approximately 20 arcmin to 18° (see Duncan et al. 1997a for more information). There are many possibilities for Hα detections from these objects. Several examples of SNR discoveries from the survey are shown in the accompanying figures.

In addition to the diffuse, thermal emission discussed in Section 4·1, Figure 1 shows the large remnant G304+0 (8·5° in diameter), which appears as a series of faint ring arcs lying symmetrically about the centre of the figure. These arcs are mainly seen towards higher Galactic latitudes, away from the bright Plane emission.

Another new SNR, G321·3–3·8, appears in Figure 3 as an ellipse approximately 1·3° × 1·8° in diameter. The southeast boundary of this SNR appears as a well-defined arc of emission, whilst the northwestern side is fainter and more diffuse. Although not shown here, the south-eastern edge of the remnant appears strongly polarised (Duncan et al. 1997a).

As many of these new SNRs are of large angular size, they are probably quite nearby. In particular, the largest remnants (of approximately 4° diameter and greater) must lie on the local arm. As such, there is a high probability that many of these objects may be detected by the AAO/UKST survey. Indeed, some initial results presented by Walker & Zealey (1988, present issue p. 79) appear to show an Hα counterpart to a section of the G304+0 remnant.

We are proceeding with radio investigations of many of these objects, including high-resolution observations of a number of the smaller SNRs with the Very Large Array (VLA) and the Australia Telescope Compact Array (ATCA).

4·4 Outflows from H II *Complexes*

The Parkes survey has identified a number of H II complexes along the southern Plane which seem to be associated with outflows of thermal material. The most spectacular example is the H II complex G345·0+1·5 (IC 4628). Ionised material appears to be sourced from this region, which is located some 50 pc above the Galactic Plane (Caswell & Haynes 1987), in a well collimated outflow which reaches heights of approximately 200 pc from the Plane. This feature is clearly seen in both the radio data (Figure 4, top) and previous optical observations (Laval 1972).

In other regions of the Plane (Figure 4, bottom) a number of bipolar outflows of low-density, ionised gas are visible. Figure 4 shows an area of the survey dominated by several bright H II complexes. To the north and south of these regions, faint, bipolar features are visible, which correspond to decreases in the level of diffuse, background po-

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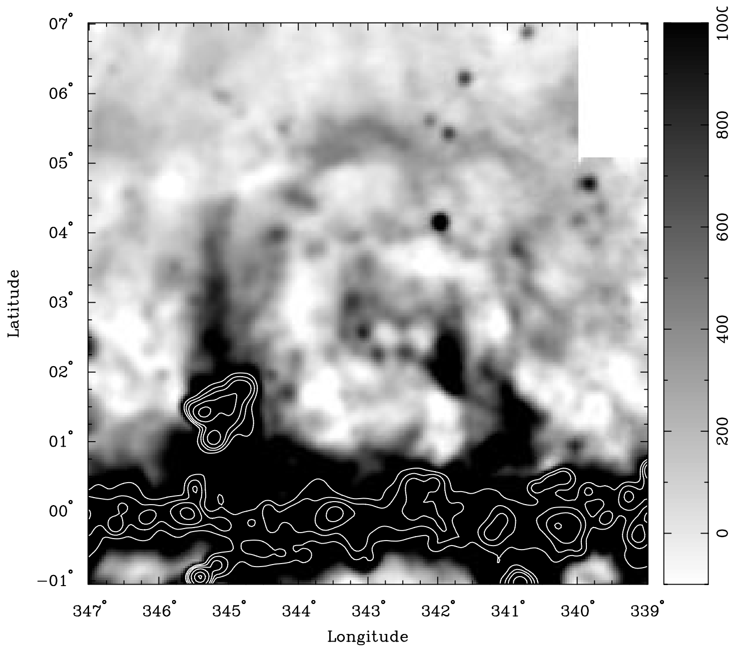

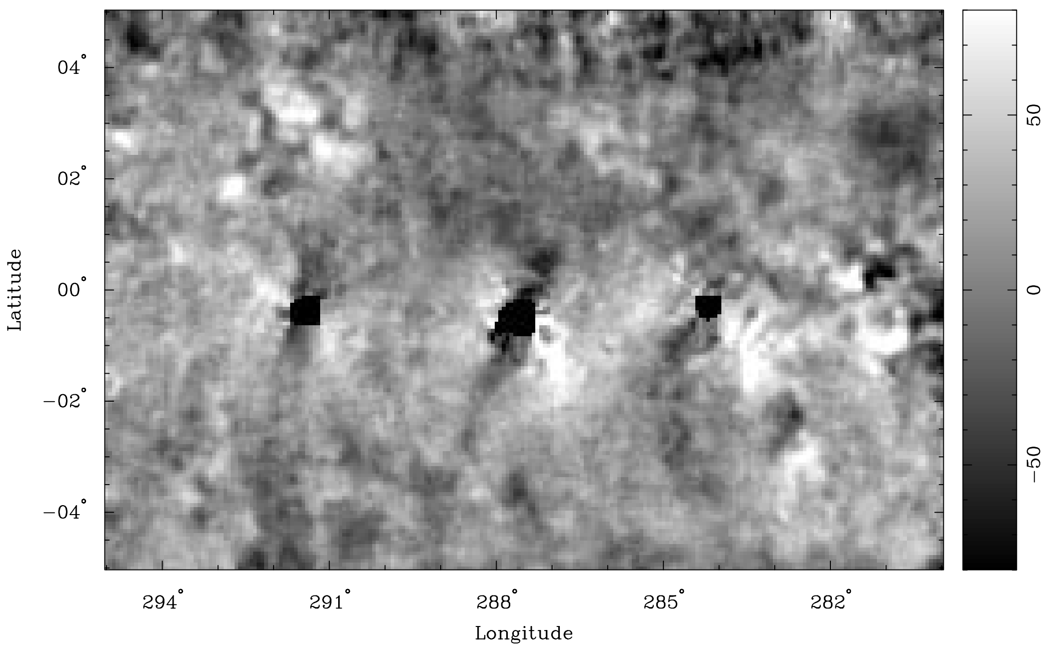

Figure 4—Examples of H II complexes exhibiting possible 'outflow' morphologies, discovered from the Parkes survey (see Section 4·4). At top the bright H II region IC 4628 (G345·0+1·5) appears to be producing a conspicuous outflow of ionised gas, which reaches up to a latitude of $b = +6°$. The bottom image shows a Stokes-Q map of a region of the Plane containing several bright H II complexes. Data in the vicinity of the complexes have been blanked, and appear black. Note the dark 'channels' stretching from the H II complexes towards higher Galactic latitudes; we believe these to be indicative of faint, bipolar outflows of low-density, thermal gas. Both of these images have a resolution of 10·4 arcmin. The rms noises are approximately (top) 17 mJy (beam area)$^{-1}$ and (bottom) 10 mJy (beam area)$^{-1}$. The grey-scale wedges are labelled in units of mJy (beam area)$^{-1}$. The contour levels at top are: 2·0, 3·2, 5, 10, 20 and 30 Jy (beam area)$^{-1}$.

larisation. We interpret these features as resulting from depolarisation of the more distant polarised emission (originating from distances greater than those of the H II complexes), by passage through low-density, thermal material. If this interpretation is correct, then the regions that show the strongest depolarisations (closest to the H II complexes) contain thermal electrons at densities of 1–10 cm^{-3} (see

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Duncan et al. 1997b for more information). At such low densities, and in the presence of other thermal emission in the vicinity, it is questionable whether these bipolar structures could be detected by the Hα survey; nevertheless, this remains an exciting possibility.

Finally, we note that the improved angular resolution of the AAO/UKST Hα survey may uncover evidence for more outflows and unusual morphologies associated with H II regions.

5 Conclusions

The sensitivity and image quality of the Parkes 2·4 GHz survey have led to many discoveries pertaining to the thermal component of the southern Galactic Plane. As such, this work will complement the upcoming AAO/UKST Hα survey well, and we look forward to exciting discoveries and collaborations in the future. Note that the Parkes survey data are all available on-line, at the URLs below:

http://www.physics.uq.edu.au/people/duncan

http://www.atnf.csiro.au/people/duncan.

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