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# ARCMINUTE SCALE HI AND IRAS OBSERVATIONS TOWARD HIGH LATITUDE CLOUD G86.5+59.6

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## ABSTRACT

G86.5+59.6 is a degree-sized high latitude cloud originally selected for investigation by Heiles, Reach, & Koo (1988) on the basis of its appearance on the IRAS Skyflux images at 60 and 100 $\mu$m. Because of the interesting possibility that this is an intermediate velocity cloud colliding with HI in the Galactic plane, we have examined this region further, both at low resolution over an extended field to provide some context and at higher (arcminute) resolution within the cloud.

## INTRODUCTION

IRAS images of infrared cirrus present an all-sky picture of an interstellar environment made up of extended regions each comprising smaller scale substructure. HI 21-cm emission and infrared emission by interstellar dust are correlated over large angular scales (Boulanger & Pérault 1988), and on the finer scale afforded by IRAS images too (Joncas, Dewdney, & Boulanger 1992). There is

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some cosmic scatter, perhaps the result of variations in grain emissivity, illumination, the dust-to-gas ratio, and unaccounted-for molecular, ionized, or atomic gas. Thus HI and infrared emission provide complementary information to address many interesting questions like: How does the degree of HI – infrared correlation change with angular resolution? How well mixed is the interstellar environment, particularly dust and gas? Do interstellar environments approach homogeneity at some large angular scale?

G86.5+59.6 is a degree-sized high latitude cloud originally selected for investigation by Heiles, Reach, & Koo (1988; hereafter HRK) on the basis of its appearance on the IRAS Skyflux images at 60 and 100 $\mu$m. Such regions of bright infrared cirrus might be the result of superposition of unrelated structures separated along the line of sight. However, in the position-velocity plots of the Heiles & Habing (1974) HI survey, HRK found G86.5+59.6 to be a relatively isolated feature in intermediate velocity gas (IVG: $\sim -40$ km s$^{-1}$) along with significant "local" low velocity gas (LVG: $\sim 0$ km s$^{-1}$) and a connection by a fainter "bridge" (BVG), suggesting that the IVG and LVG components are interacting.

The velocity information available for the gas can be used to "deproject" the effects of superposition implicit in the infrared cirrus; i.e., morphological comparison of observations of dust and gas at sufficient angular resolution might establish the association of dust with particular velocity components of the gas. Interpretation of infrared or HI features seemingly isolated in space and/or velocity can also benefit from the wider context of extensive angular and velocity coverage. Our study illustrates and addresses some of these issues.

## STEPPING BACK: THE BIG PICTURE

To provide some context for the G86.5+59.6 degree-sized feature, we have examined a 25° surrounding region using cirrus mosaics of infrared surface brightness ($I_{60}$ and $I_{100}$) based on the 5′resolution IRAS Sky Survey Atlas (ISSA; Wheelock et al. 1994). G86.5+59.6 is a relatively bright central feature (still, $I_{100}$ < 5 MJy sr$^{-1}$), superimposed on more extensive IRAS cirrus of even lower surface brightness. We also made a data cube from the Heiles & Habing HI survey (beam sampled at 36′) for the same field and projection, and more recently resurveyed (fully sampled) a 16° field with the DRAO 26-m telescope. The integrated column density, $N_{\rm HI}$, is also not very large, typically a few times $10^{20}$ cm$^{-2}$.

### Integrated Column Density

The cirrus mosaics were degraded to the same resolution as the HI surveys. A plot comparing $I$ and $N_{\rm HI}$ pixel by pixel shows an obvious linearity (e.g., $I_{100} = 0.85 N_{\rm HI} - 1.4$) whose slope is typical of this relationship at high latitudes (Boulanger & Pérault 1988). This correlation was used to create consistent "colour tables" with which to display the cirrus and $N_{\rm HI}$ images, making the morphological correspondence between infrared brightness and $N_{\rm HI}$ all the more striking. In addition to the central G86.5+59.6 feature, many "arm" and "ring" features appear in each with identical "colours". Below we shall investigate whether there is as good (or better) correspondence at higher resolution.

## Radial Velocity Slabs from the Survey Data

To seek an association of the infrared cirrus with particular velocity systems (deprojection), we made images from the HI survey data cubes integrated over three velocity slabs (IVG, -70 to -29 km $s^{-1}$; BVG, -29 to -13 km $s^{-1}$; and LVG, -13 to 35 km $s^{-1}$). The colour representation was kept identical to show correctly the relative importance of different features.

G86.5+59.6 is clearly the brightest (largest column density) feature in the IVG, but it is not totally isolated; there are other IVG features with clear counterparts in the infrared cirrus, for example the NW part of the ring to the E and several arms to the W.

The LVG is much more widespread, as might be expected for the "local" material, and is actually brighter at positions other than G86.5+59.6. It too has structure seen in the cirrus, for example, defining the S part of the cirrus ring with extensions to the SE. There is a slight brightening at G86.5+59.6, but perhaps a more interesting feature is a ridge of emission running to the NE. This ridge lies parallel to bright IVG which lies just to its NW.

The BVG is the least spectacular component, but very interesting. Because the division into three slabs is rather arbitrary, it naturally blends in some regions with features of the IVG and in others with the LVG. In particular, it contributes to the N and S of the cirrus ring. At G86.5+59.6, however, it is less bright than in other parts of the ring, and therefore seems less likely to be the result of an interaction.

The BVG also helps illustrate the effects of superposition on the perception of features in the infrared cirrus (or total $N_{HI}$). Although the features in the BVG are generally weak they can be identified in the cirrus; this is because they add to any smooth pedestal present from other velocity components; in particular, a bright patch of cirrus to the SE of the ring is created by BVG on a much smoother background of LVG. In this context, it is interesting that G86.5+59.6 is situated near the conjunction of three arms in the IVG. Thus in addition to the LVG contribution (pedestal), the G86.5+59.6 bright feature that stands out might be the result of superposition of different systems within the IVG. This can be investigated at higher (arcminute) resolution.

## 60/100 $\mu$m Brightness Ratio

HRK measured the overall 60/100 $\mu$m brightness ratio to be about 0.3, higher than (0.2) for most of the other clouds in their study; this diagnostic suggested that grains in this line of sight have been modified by shocks. From the mosaics we found that although there is some range in the ratio in the larger field (0.25 – 0.34) quite similar ratios occur for dust associated with IVG and LVG. The ratio at G86.5+59.6, near 0.32 overall, is not unusual in comparison to its surroundings. This value 0.32 is like the Galactic average for atomic gas (Deul 1988) and that found on a large scale in the northern Galactic cap (Boulanger & Pérault 1988; $b > 50°$, which encompasses G86.5+59.6). There are regions in the Galaxy where the brightness ratio is lower (closer to 0.20), including much of the HRK sample, but this ratio is more typical of molecular clouds (Deul 1988). While there is no persuasive evidence from this broad perspective that indicates that G86.5+59.6 is a special region of interaction, there are suggestions of local colour changes near G86.5+59.6 related to different velocity components. The sense of these appears to be a somewhat lower ratio for LVG and higher ratio for IVG; whether this distinction is generally true is still being investigated.

## ZOOMING IN ON G86.5+59.6 WITH DRAO ST AND HIRES

To pursue the issue of interaction a 2° field has been observed with the DRAO Synthesis Telescope, with velocity resolution 0.8 km $s^{-1}$ and with angular resolution 1′. This angular resolution is about 35 times better than in the survey data and about 5 times that in the ISSA plates. We have reprocessed the IRAS data with the IPAC HiRes software, to enhance the resolution to as small as 1′ (as measured on test data and actual point sources in this field).

### Integrated Column Density

As mentioned above, the column density and infrared surface brightness at G86.5+59.6 are quite low, and so this is an interesting test of observational and processing capabilities in *faint* diffuse fields. By simple inspection of Figure 1, it can be seen that the morphological similarity of the cirrus and integrated $N_{HI}$ images down to about 2′ is quite remarkable. *At this finest scale yet achieved, this agreement is quite quantitative.* There is a good pixel by pixel correlation between $I$ and $N_{HI}$ and the slope of this linear relationship is similar to that found in the above and other studies at larger angular scales. This suggests that there is dust associated with each of the two major velocity components (even without velocity slicing of the cube) and that there is a general absence of $H_2$. Emission in CO has not been detected at positions within G86.5+59.6 (HRK; W. Reach, private communication).

### Radial Velocity Slabs from the DRAO ST Data

To investigate the association of velocity structure in HI with cirrus morphology on this finer scale, the DRAO ST data have been integrated over the same velocity ranges as defined for the survey data radial velocity slabs. The HI images were displayed for comparison with the HiRes images, again using a consistent colour table.

A striking discovery is that the IVG provides most of the detailed morphological structure seen in this infrared cirrus. *This deprojection analysis therefore shows definitively that there is dust in the IVG component*, of note because the dust has either survived the acceleration to −40 km $s^{-1}$ or more or has reformed since (dust destruction is predicted in shocks of sufficiently high velocity).

As in the survey data, the LVG is more diffuse; but it has a hook-like feature (with NE spur) which can be located in the cirrus too. This hook and spur do not align exactly with a similar pattern in the IVG. Nor does the LVG appear at the ends of the SE-NW bar in the IVG.

The BVG has weak features that perhaps correlate (with modest lateral displacement) most with the IVG. Again, the division between velocity slabs is somewhat arbitrary. There are no obvious bridges between common features in both the IVG and LVG as would provide circumstantial evidence for interaction.

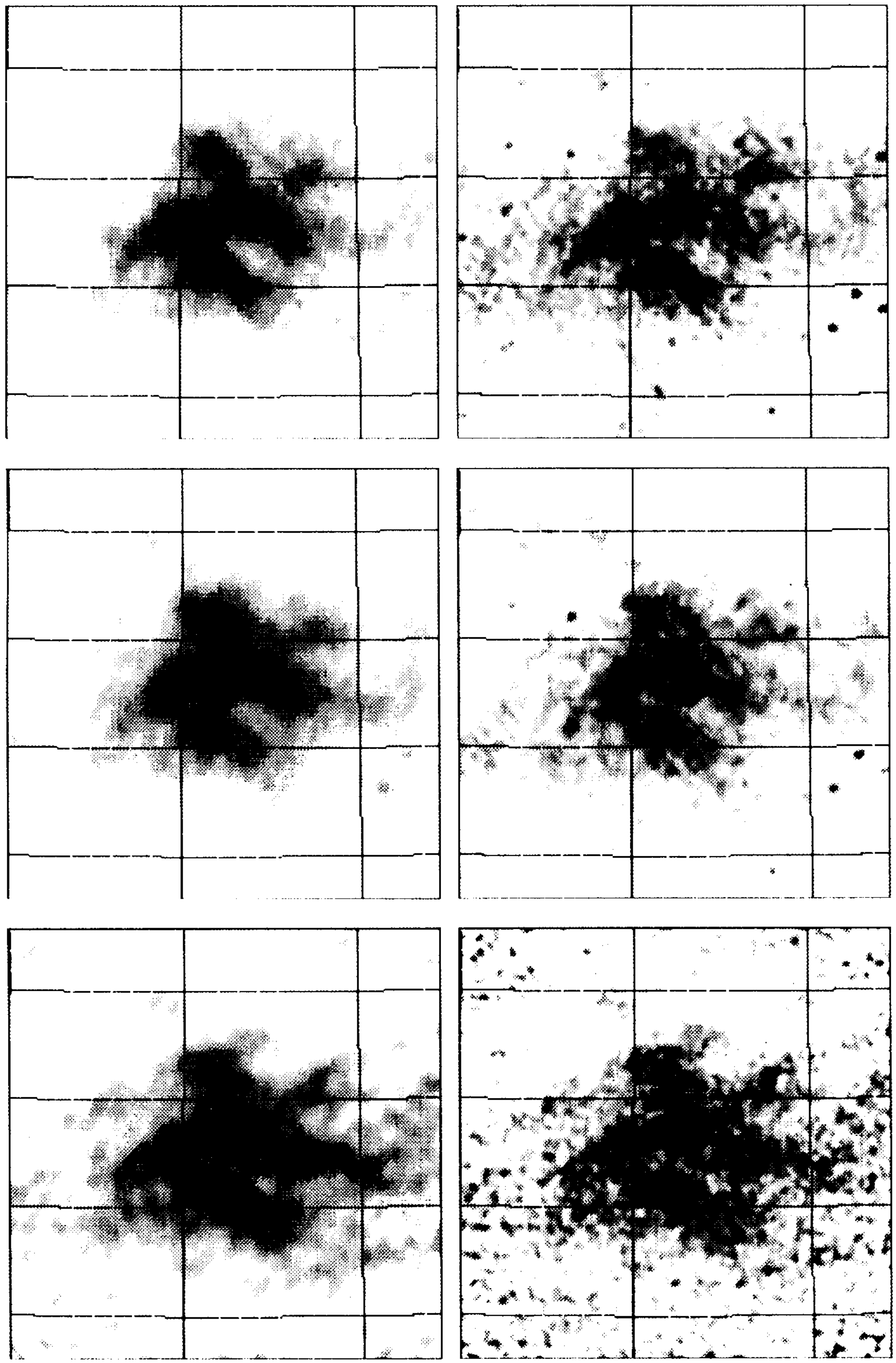

FIGURE 1 2° images of G86.5+59.6. Top row, 60 $\mu$m; middle, 100 $\mu$m; bottom, $N_{\rm HI}$. Left column, ISSA resolution ~4.5′; right, resolution improved to ~2.3′. Images printed with consistent grey scales to assess the correspondence in morphology.

## EXAMINATION OF THE HI DATA CUBES

The detailed relationships between HI and infared cirrus are arguably best studied by examining the images of individual velocity channels. This work is still in progress on both the survey data and ST data and no final conclusions will be presented. An unresolved question is whether the three velocity components are interacting now or whether they interacted in the past. Because the relative velocity vector would not necessarily be lined up along our line of sight, then potential connections between the morphologies in the different velocity components need not be exactly superimposed. Instead, the patterns in each slab might be translated versions of one another (translating the LVG pattern to the W does seem to line up the structures better with the IVG) or one pattern could be embedded in another. Investigation of velocity gradients and fine velocity structure in the cube is important.

### Volume Rendering

One analysis tool with which we are working is volume rendering of the HI data cube. In the ST cube the tapering by the 9-m primary beam pattern is not removed so that noise near the cube edges is not amplified. While this permits a clear view of the interior of the cube, it does tend to heighten the perception of central concentration in all velocity ranges. The 26-m cube emphasizes how the LVG is more widely distributed while the IVG is concentrated. Near G86.5+59.6 the LVG and IVG components of $N_{\mathrm{HI}}$ appear as clearly separated components (whether there is spatial separation is another question). These renderings also reveal that there are different morphological features in the different velocity components, as was described above using the three coarse velocity slabs. Here one has the potential of observing the "three-dimensional" structure, including any systematic velocity gradients. This approach can in principle be used to deproject, or at least interpret, the infrared cirrus image. For example, the relatively sharp NE boundary in the infrared cirrus image of G86.5+59.6 reflects that of the IVG; to the SW the IVG boundary is itself less sharp and in the integrated cirrus it is even less apparent because of the underlying diffuse LVG.

### Animation

We have also found it instructive to make an animation showing successive velocity slices of the data cubes (0.8 km $s^{-1}$ per slice). The directional orientation of the velocity gradients near G86.5+59.6 within the LVG and IVG components can be noted: toward negative radial velocities, LVG runs from the NE to the SW, while IVG appears (in broad brush) to have subcomponents running from NE and SE to the W. We also have experimented with a false-colour animation in which the LVG and IVG components appear simultaneously against a background image of $I_{100}$. This is an effective means of intercomparing the morphologies of the different velocity components and infrared emission at small angular scales and with better velocity resolution than in the broad velocity slabs. *The animation shows several striking correspondences of features in the infrared image with features in HI which appear over only a few velocity channels* (thus these features have small line widths). Also the LVG slice with maximum column density (peak in the integrated line profile toward G86.5+59.6) appears to bisect and fill in a spatial gap present in the IVG slice at its peak velocity; the opportunity to investigate such potentially interesting interrelationships is washed out in the radial velocity slabs.

## REFERENCES

Boulanger, F., & Pérault, M. 1988, *ApJ*, **330**, 964

Deul, E. 1988, Ph.D. thesis, Leiden

Heiles, C., & Habing, H. 1974, *A&AS*, **14**, 1

Heiles, C., Reach, W.T., & Koo, B-C. 1988, *ApJ*, **332**, 313 (HRK)

Joncas, G., Dewdney, P.E., & Boulanger, F. 1992, *ApJ*, **397**, 165

Wheelock, S., et al., 1994, *Explanatory Supplement to the IRAS Sky Survey Atlas*, (Pasadena:JPL), in press