Unravelling the kinematic structure of infrared cirrus

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Abstract. Infrared cirrus dust features at high \(|b| > 15^\circ\) galactic latitudes show structural forms similar to those of associated gas features observed in emission from neutral atomic hydrogen. We examine this correlation in detail for 7 cirrus fields, typically some \(10^\circ \times 10^\circ\) in size. Effects caused by non-negligible \(\text{H}\i\) optical depth, by variations of the interstellar radiation field within individual regions, and by the presence of molecular material, all play a less significant role on the small length scales of the isolated, high-latitude cirrus features than they do in dust-to-gas correlations along heavily blended lines of sight at lower latitudes. Apparently cirrus features are commonly line-of-sight superpositions of kinematically different structures. Several of the infrared cirrus features show correlation with \(\text{H}\i\) emission at distinctly anomalous velocities. Cases of infrared emission associated with the radio-continuum Loops I and II are identified. These features have a lower dust-to-gas ratio than that found characterizing infrared cirrus associated with quiescent \(\text{H}\i\) material. Correlation with \(\text{H}\i\) emitting at intermediate negative velocities is also established; the dust-to-gas ratio of this material lies between that of the quiescent and distinctly anomalous cases. The dust-to-atomic gas ratio increases with galactic latitude for the fields considered. High dust-to-atomic gas ratios generally occur in regions of strong CO emission; there the corresponding \(60\,\mu\text{m}/100\,\mu\text{m}\) intensity ratio is smaller, indicating either a deficiency of small grain emission or a predominance of cooler material in these regions.

Key words: Galaxy (the): solar neighborhood – interstellar medium: dust – interstellar medium: clouds individual – interstellar medium: kinematics and dynamics – radio lines: 21-cm – infrared radiation

1. Introduction

The IRAS observations show emission from diffuse dust from essentially every direction in our Galaxy. At lower galactic latitudes, individual dust features can generally not be isolated for separate study because of the heavy blending of accumulated emission from long lengths of path through the galactic disk. At higher latitudes, individual dust structures can be identified. These cirrus dust features are associated with structures in the interstellar gas showing generally similar spatial distributions as projected on the sky. In particular the neutral atomic hydrogen emission (e.g. Low et al., 1984) and molecular carbon monoxide emission (Weiland et al., 1986) show spatial correlations with dust emission in the infrared. Although Terebey and Fich (1986) found a linear correlation between the far-infrared dust emission and the neutral atomic hydrogen column density for two heavily blended regions near the galactic equator, Boulanger et al. (1985, 1988) reported that deviations from a single correlation factor may occur for individual structures, isolated at high latitudes. There is also evidence for deviations from a linear correlation between the general, blended, 100-\(\mu\text{m}\) intensities and the \(\text{H}\i\) gas column densities contributed from the very long lengths of path observed at low latitudes (Perault et al., 1988; Sodroski et al., 1989; Deul and Burton, 1989; Deul et al., 1989); the most probable causes of these deviations are to be found in variations with position in the Milky Way of the \(\text{H}\i\) optical depth and of the strength of the optical flux illuminating the dust. Several cases have been found of dust cirrus structures correlated with the emission intensity of molecular gas (Heithausen, 1987). Most cirrus, however, have yet to be searched for CO emission. In those cases where CO emission has been observed it was found to coincide with the central, more intense, portions of the dust features (Weiland et al., 1986; Magnani et al., 1985).

Direct measurements of the distance to these cirrus features are lacking. Cirrus features identified more than some 15\(^\circ\) from the galactic equator are, however, no doubt largely confined to within a few hundred pc of the Sun. This is indicated in a general way by the measured scale height of the dust emission accumulated from the Galaxy at large, which is no doubt contributed by an ensemble of cirrus-like features. The correlations established with galactic \(\text{H}\i\) together with the well-measured \(\text{H}\i\) scale height likewise limits the distance of most higher-latitude cirrus material to less than a few hundred pc. This general conclusion is supported by those cirrus for which distances have been measured, for example by de Vries and Le Poole (1985) using star-counting techniques and by Hobbs et al. (1986, 1988) on the basis of associated optical absorption lines measured against stars of known distance. (Distances in this paper which depend on the distance of the Sun from the galactic center are based on \(R_0 = 10\,\text{kpc}\); velocities are expressed with respect to the local standard of rest.)

Knowledge of the energetics governing the local dust material requires knowledge of their kinematic structure. In view of the generally tight correlation between the far-infrared emission and the neutral atomic hydrogen column density it seemed plausible to investigate the kinematics of dust cirrus by examining the velocity structure of the associated gas. We observed a number of cirrus features in 21-cm line emission. From the velocity information inherent in the \(\text{H}\i\) observations, we could deduce the
kinematic structure of the dust feature by establishing that H I emission in a specific velocity interval correlated spatially with the far-infrared emission in a given part of the cirrus feature.

The cirrus dust features selected for the kinematic analysis were identified first in an all-sky 100-μm IRAS dataset from which zodiacal contamination was subtracted. The criteria for selecting candidate dust structures required that: (i) the cirrus features show coherent forms, spatially isolated on the sky, (ii) the cirrus features are each restricted in angular extent to less than some tens of degrees on the sky, (iii) the surrounding 100-μm emission should be smooth and well defined with respect to the feature of interest, (iv) the cirrus features are located at |b|>10° to avoid the worst line-of-sight blending in the H I data, and (v) they are located in the part of the sky accessible to the NRAO 140-foot radio telescope. The selected fields are typically 10° by 10° in size and are scattered over the accessible sky.

Seven cirrus fields were selected for subsequent observations in the H I line. These regions are identified below by the galactic coordinates of their field centers.

2. Presentation of the data

H I observations for the selected cirrus regions were made using the NRAO 140-foot radio telescope in Green Bank, equipped with an autocorrelator spectrometer operated in parallel mode giving 512 channels over a bandwidth of 1.25 MHz at a channel separation of 0.5 km s⁻¹. The instrumental baseline was largely accounted for by frequency switching. Integration times of 1 minute resulted in an rms noise of 0.1 K. Calibration revealed a systematic change of gain with changing elevation, which was corrected for in the final data. Conversion of antenna temperatures to the conventional nominal brightness temperature scale as defined by Williams (1973) was done using repeated observations of the standard field S6. The conversion constant derived by integrating the observed profiles and comparing this to the values given by Williams (1973) gave $T_b = 1.31 \pm 0.09 \ T_A$. The regions were sampled on a grid spacing approximately equal to the 20° resolution at 21 cm of the 140-foot telescope.

Single-dish H I data may be contaminated by stray-radiation contributions of up to 0.5 K (see Lockman et al., 1986) and especially important at the generally low emission levels encountered at high |b|. We accounted for the stray radiation following the method described by Lockman et al. This involved comparing the 140-foot data, after convolution with the (sidelobe-free) antenna pattern of the Bell Laboratories horn reflector, with the H I survey made at low-resolution with the horn telescope by Stark et al. (1985). Corrections applied to the 140-foot data amounted to up to 0.4 K. The general H I properties are described for each cirrus field by three measures: (i) the total H I column density, derived by integrating intensities over the velocity range observed; (ii) the first moment of the velocity distribution

$$v(l, b) = \frac{\int T_b(v, l, b) \ dv}{\int T_b(v, l, b) \ dv};$$

(1)

and (iii) the velocity width, determined from the second moment of the velocity distribution as

$$\sigma^2(l, b) = \frac{\int (T_b(v, l, b) - v(l, b))^2 \ dv}{\int T_b(v, l, b) \ dv} - v^2(l, b).$$

(2)

The integrations were performed for intensities brighter than 1.5 times the rms noise.

The infrared data were extracted from the IRAS Skyflux products at 12, 25, 60, and 100 μm and plotted at the same resolution and on the same sampling grid as pertaining for the H I data. The original Skyflux maps from all three HCON’s (see IRAS Explanatory Supplement, 1985), if observed, were first combined to create maps at the full Skyflux sampling of 2' x 2'. The resolution and sampling were then degraded by Gaussian convolution to the 20' angular resolution of the 140-foot telescope beam at 21 cm, and gridded at a spacing of 8' over the entire field. Then infrared maps were created by 4-point Lagrangian interpolation at the grid points observed in the 21-cm line. In this way both the infrared maps at the four IRAS wavelengths and the H I maps have identical sampling and resolution characteristics, allowing comparisons on a pixel-by-pixel basis. Finally, maps of the zodiacal emission at the IRAS bands corresponding to the model of Deul and Wolkstencroft (1988) were similarly sampled and subtracted from the infrared maps of the cirrus fields.

A Fourier filtering technique reduced the influence of striping caused by gain changes amongst neighboring IRAS scans. Conversion to ecliptic coordinates resulted in stripes running parallel across the maps. The infrared maps where then transformed to (amplitude, phase) space using a discrete Fourier transformation. In this domain it was possible to identify specific regions where striping dominated. These regions, amounting to less than 10% of the total area in the Fourier domain, were given zero weight; we excluded low spatial frequencies from the zero weighting in order to retain the total surface brightness in the map plane. A reverse discrete Fourier transformation was then performed, yielding maps of the infrared surface brightness as a function of position with striping considerably reduced. Some striping persists on the 3% level. Although the Fourier filtering does cause some modest loss of information on the structure parallel and perpendicular to the striping, we judged that the advantages of reduced striping outweighed the disadvantage regarding information which would in any case have been difficult to detect in the original maps. Finally, the de-striped maps were converted back to galactic coordinates.

The discussion below involves comparable sets of figures for each of the four cirrus fields. Figures labelled (a) show infrared emissivities in the 60-μm and 100-μm IRAS bands. Figures labelled (b) show the H I emission integrated over the entire observed velocity range, as well as the H I emission in three separate velocity channels, at the indicated central velocities. The left-hand panel of the figures labelled (c) shows a scatter diagram displaying the correlation between the 100-μm and the H I map intensities. The right-hand panel of the figures labelled (c) shows a histogram of the coefficient of the correlation between the 100-μm and 21-cm H I emission at a given velocity, plotted as a function of velocity. The correlation coefficient is defined here in the usual way as the squared value of the slope of the least-squares linear fit through the scatter diagram with y-values assumed to be a function of the x-values multiplied by the value of the inverse slope of the least-squares, linear-fit line through the scatter diagram with x-values assumed to be a function of the y-values; values of the correlation coefficient are therefore bounded by 0 and 1. Experience with the correlation measure showed the 100-μm and H I emissivities revealed an obvious correlation upon casual visual inspection for the cases where $r > 0.15$. © European Southern Observatory • Provided by the NASA Astrophysics Data System
The correlation-coefficient histograms enable determination of the velocity range over which significant correlation between the dust and the gas exists: different parts of the cirrus dust structures can be identified with H I gas counterparts at specific velocities. Such a kinematic separation is presumably a separation in depth. Maps of velocity and velocity width are not displayed because in order to be useful such maps must also contain information on the gas column density; the additional dimension requires an additional means of coding (e.g. colors) beyond that normally used. Where necessary, we mention the significant information in the text.

3. Discussion of the dust/gas relation in the selected cirrus fields

We note first that the correlation between the far-infrared intensities and the total H I column densities plotted in the left-hand panel of part (c) of the figures is approximately linear for each of the cirrus fields. Evidently, the causes of strong deviations from a linear relation (i.e. H I optical depths near unity, spatial variations in the interstellar radiation field, and the presence of large molecular complexes) which dominate the low-latitude \( I_{\text{IR}}/N_{\text{H I}} \) correlation (see Deul and Burton, 1989) do not play a significant role for these relatively small, high \( |b| \) fields. The optical depth of H I emission from lines of sight at \( |b| > 10^\circ \) generally is much smaller than unity. The global interstellar radiation field apparently does not vary significantly at the high latitudes and over the short length scales pertaining for the isolated cirrus structures. Cirrus features are typically within a few hundred pc of the Sun; the global interstellar radiation field changes appreciably over kpc scales, increasing rapidly toward the galactic center, but has a rather constant intensity outside 8 kpc.

The contribution of gas in molecular form to the total gas content of cirrus structures is still only poorly known; there have been few uniform-grid, detailed surveys of CO at \( |b| > 10^\circ \) (but see Magnani et al., 1985, and Dame et al., 1987). In those cirrus features where CO has been detected, the velocity-integrated intensities, \( W_{\text{CO}} \), correlate only with the most intense far-infrared emission peaks (Weiland et al., 1986; Heithausen, 1987). Restricting the analysis to the moderate and weaker far-infrared intensities, we may write

\[
I_{\text{IR}} = g \times N_{\text{H I}} + \text{constant}, \tag{3}
\]

where the constant accounts for the instrumental and sky background. The correlation factor, \( g \), depends on the infrared wavelength, the grain size distribution, and the temperature of the dust particles associated with the neutral atomic gas. Because the 60 \( \mu \)m/100 \( \mu \)m intensity ratio may be severely influenced by non-equilibrium emission from small grains (Drain and Anderson, 1985), we do not use this ratio to determine the dust temperatures of the large dust grains, but only as a measure of the characteristics of the local environment and of the general physical properties of the dust.

The cirrus field centered at 41\(^\circ\), −35\(^\circ\) contains a dust and gas structure with the shape of a capital letter “D”. Comparison of the 100-\( \mu \)m emissivity plotted in the left-hand panel of Fig. 1a with the H I total column density plotted in the upper-left panel of Fig. 1b shows a tight general correlation between the dust and gas spatial and emission properties. (Investigation of the dust properties at the shorter IRAS wavelengths is hampered by the particularly strong zodiacal emission in this region.) The general correlation of dust and gas is illustrated by the scatter diagram plotted in Fig. 1c; local deviations from the general trend are indicated by the spread of points about the mean correlation.

The velocity range over which the dust/gas correlation occurs can be determined by calculating the correlation coefficient between the 100-\( \mu \)m integrated emission and the H I emission found in each separate velocity channel. The right-hand panel of Fig. 1c shows these coefficients as a function of velocity. The correlation between dust and gas is strong over a well-defined, rather narrow, range of velocities.

The cirrus structure isolated in this field is evidently rotating. Except for the upper-left panel, which corresponds to integration over a large velocity range, the panels of Fig. 1b show the H I emission integrated over 2 km s\(^{-1}\) intervals centered on the indicated velocities. The velocity of the cirrus emission pattern increases regularly with decreasing longitude. The kinematics can be modelled by a shell of finite thickness, 9\(^\circ\) in diameter, with a rotation velocity of 20 km s\(^{-1}\) and a systemic velocity of −0.5 km s\(^{-1}\). The total mass in the cirrus feature can be estimated by deriving the gas mass from the integrated H I observations, assuming a distance of 200 pc, and by deriving the dust mass using a dust-to-gas mass ratio of 3 \( \times 10^{-2} \), found typical for dust in the Milky Way by Sodroski et al. (1989). The total interstellar mass derived under these assumptions is \( 10^7 M_{\odot} \). The rotational energy involved would then be of order \( 10^{24} \) erg.

We attempted to verify the distance to this cirrus feature using star-counting techniques (see e.g. de Vries and Le Poole, 1985; Magnani et al., 1985). The Leiden Astroscan photodensitometer measuring machine was used to extract isolated stars from Palomar Sky Survey blue plates, yielding the number of stars and the average background level in \( 1' \times 1' \) boxes. It turned out that the extinction toward the feature could not be determined, because of the limited sensitivity of the Palomar plates. The star-counting statistics did not reveal any fluctuations that correlated with the infrared intensity structure. (The star-recognition algorithm used in the analysis was limited to stars brighter than the 14th magnitude.) The maps of the local background density levels did, however, show clear density enhancements which correlate with the infrared structure. In addition to vignetting, local variations in density due to photographic copying, and residuals from bright stars left over after subtraction of the central peak, the background densities include a considerable amount of reflected light, not readily noticeable by naked-eye inspection of the plates. Although hampered by vignetting effects at the edges of the plates, we could determine the correlation between the infrared intensities and the local background densities. This correlation is illustrated in Fig. 1d, where a scatter diagram has been plotted showing, on a point-by-point basis, the infrared intensity versus the background density. Assuming the relation between the infrared intensity and the visual extinction found by de Vries and Le Poole (1985), we can compare our figure with their Fig. 2. We see that after converting infrared intensities to extinction values, our correlation is located on the flat part of the de Vries and Le Poole diagram. The positive correlation we still find for this feature illustrates that, even at the higher infrared intensities, the correlation with reflected light persists. The intensity of the reflected light lags behind with respect to the infrared intensity, because the reflected light primarily comes from the outer parts of the dust cloud.

The cirrus field centered at 275\(^\circ\), 74\(^\circ\) contains the intense cloud at 275\(^\circ\), 75\(^\circ\) and the weak, diffuse ridge of emission crossing 275\(^\circ\),
72° which were among the first IRAS cirrus features discovered. They were named features “B” and “X”, respectively, by Low et al. (1984). Low et al. compared the IRAS data with the then available H I data (Heiles and Habing, 1974), and concluded that X was an exceptional infrared cirrus feature in that it apparently did not have an H I counterpart; feature X was thought either to be much colder (<23 K) than feature B, which does have an obvious H I counterpart, or to be of extragalactic origin. Another reason for assigning a low temperature to X was that it shows little 60-μm emission (see the right-hand panel of Fig. 2a). We note, however, that feature X lies near the zodiacal dust bands (Dermott et al., 1986), which hinder derivation of reliable flux ratios from a zodiacal model which does not include these bands. Feature B can be identified in the 60-μm map; the 60 μm/100 μm intensity ratio of 0.22 is typical for galactic cirrus.

The newer H I data are more sensitive than those available to Low et al. (1984). The association of H I emission with the dust emission in feature X is illustrated by a comparison of Figs. 2a and 2b. The \( I_{100 \mu m}/N_{HI} \) ratio for feature B is somewhat lower than that for feature X; this is illustrated in the Fig. 2c scatter diagram, where the stronger 100-μm and H I intensities show a somewhat different relation than the weaker ones. Inspection of the H I maps also shows that both B and X are part of a large complex that extends beyond the limits of the region newly observed in H I.

The H I associated with the cirrus field centered near 275°, 74° reveals a remarkable kinematic behavior. The panels of Fig. 2b for the individual velocity channels show that features B and X are kinematically distinct. Feature B is most intense near \( -18 \) km s\(^{-1}\); Fig. 2c shows that the dust/gas feature extends to about \( -40 \) km s\(^{-1}\). Feature X dominates near \( -8 \) km s\(^{-1}\). Between these velocities the emission is weak. Separation in velocity space plausibly corresponds to separation in depth. No direct indication of the distance to these features is available. Kinematic distances cannot be derived at such high latitudes; in any case, the relevant velocities are clearly anomalous ones. Indirect arguments based on the measured thickness of the galactic H I layer suggest that the features are unlikely to be more than a few hundred pc away.

The filamentary structure in this field slants NE to SW. This orientation, particularly noticeable in the H I channel map at 2 km s\(^{-1}\), is the same as that of the northern tip of the North

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**Fig. 1a.** Distribution in galactic coordinates of the infrared emission from the cirrus field centered on \( l, b = 41°, -35° \). The contours at 100 μm progress from 10.33 MJy sr\(^{-1}\) in steps of 1.0 MJy sr\(^{-1}\); those at 60 μm, from 0.18 in steps of 0.21

**Fig. 1b.** Distribution of H I emission observed in the field containing the infrared cirrus feature illustrated in Fig. 1a. The grid spacings of the H I data are 24' in l and 20' in b; the H I spectra were centered on 0 km s\(^{-1}\). The upper left-hand panel shows the H I column density integrated over the total extent of the observed velocity range (256 km s\(^{-1}\)). The other panels show H I intensities integrated over intervals 2 km s\(^{-1}\) wide centered at the indicated velocity. The contours in the upper-left plot progress from 412 K km s\(^{-1}\) in steps of 51 K km s\(^{-1}\); the minimum, step pairs for the upper-right, lower-left, and lower-right panels are, respectively, 5.8, 3.4; 9.3, 2.7; and 4.7, 2.0. The cirrus field shows a clear signature of rotation.
Fig. 1c. Left: Scatter diagram showing the point-by-point correlation between 100-μm intensities and H I column densities in the cirrus field. Right: Histogram indicating as a function of velocity the correlation coefficient of the least-squares fit to the scatter diagrams of the 100-μm map and individual H I channel maps. The infrared emission of the cirrus feature shows significant correlation with H I emission in the velocity range $-7 \text{ km s}^{-1} < v < 20 \text{ km s}^{-1}$.

Fig. 1d. Correlation between scattered light (derived from a star-counting analysis on Palomar Sky Survey blue plates) and 100-μm intensities. The correlation function was determined on a pixel-by-pixel basis, at 4' by 4' pixel separation. Although the infrared intensity range lies near the high intensity extreme where the correlation found by de Vries and Le Poole (1985) shows a leveling off, a significant correlation remains.

Polar Spur. We note that the lower left-hand corner of the cirrus region coincides with the outer edge of the radio Loop I structure (Berkhuijsen, 1971; Spoolstra, 1972) associated with the Spur. Following Fejes and Wesselius (1973), Heiles and Jenkins (1976) discuss the association between the Loop I structure seen at 408 MHz, and a low-velocity H I shell-like structure identified in the Heiles and Habing (1974) survey. The spatial characteristics of the cirrus feature X, as well as the velocity characteristics identified here via association with the H I data, correspond to those of the partial H I shell seen in the Heiles and Habing (1974) survey. The H I filaments are separated by angular distances of 5°–15° from the structures in the radio-continuum loop. This morphology fits into the general supernova-remnant picture described by Chevalier (1974). At the position of the 275°, 74° cirrus field center, the line of sight passes the H I shell structure tangentially. This explains both the velocity at which we see the associated H I material and its position on the sky. The average velocity of the H I material that is correlated with the radio Loop
Fig. 2a. Distribution in galactic coordinates of the infrared emission from the cirrus field centered on 275°, 74°, chosen because it contains the two cirrus features, "B" and "X", identified by Low et al. (1984). Feature "B" is the bright knot near l = 275°, b = 75°; feature "X" is the ridge of low intensity crossing 275°, 72°. The contours at 100 μm progress from 0.96 MJy sr⁻¹ in steps of 0.31 MJy sr⁻¹; those at 60 μm, from 0.33 in steps of 0.15.

Fig. 2b. Distribution of H1 densities at different velocities in the cirrus features "B" and "X", with panels arranged as in Fig. 1b. The grid spacings of the H1 data are 45' in l and 15' in b; the H1 spectra were centered on -20 km s⁻¹. The contours in the upper-left plot progress from 179 K km s⁻¹ in steps of 35 K km s⁻¹; the minimum, step pairs for the upper-right, lower-left, and lower-right panels are, respectively, 0.8, 0.9, 1.2, 1.4; and 1.9, 1.1. Both cirrus features have H1 counterparts, but at substantially different velocities. The H1 emission associated with feature "B" shows maximum intensity at -18 km s⁻¹; that for feature "X", at -8 km s⁻¹. The slanted appearance (NE to SW) of most of the structures in this region follows that of the northern extension of the North Polar Spur.

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Fig. 2c. Left: Scatter diagram showing the point-by-point correlation between 100-\(\mu m\) intensities and \(\text{H} \, \text{I}\) column densities for the cirrus features “B” and “X”. The correlation is not tight, but it is significant. Right: Histogram indicating as a function of velocity the correlation coefficient of the least-squares fit to the scatter diagrams of the 100-\(\mu m\) map and the individual \(\text{H} \, \text{I}\) channel maps.

I structure on morphological grounds is about 0 km s\(^{-1}\). Spoestra (1972) derived a distance of 115 pc to the center of Loop I and a radius of 105 pc, putting the Sun almost on the shell structure. Therefore, the correlated \(\text{H} \, \text{I}\) material should roughly be at 45\(\pm\)30 pc distance, so that a small radial difference will result in large angular distances on the sky. The displacement of up to 15\(\arcdeg\) for the \(\text{H} \, \text{I}\) material amounts to radial displacement of some 8 pc. If the thickness of the shell is of the same order, it seems reasonable that the filamentary \(\text{H} \, \text{I}\) material identified with the cirrus feature X is associated with the radio Loop I structure.

The energy involved with the filamentary \(\text{H} \, \text{I}\) was derived using the calculation scheme of Heiles (1979). The total mass for the \(\text{H} \, \text{I}\) shell is 63 \(M_\odot\), with a density of 0.49 atom cm\(^{-3}\). If the shell is expanding at 65 km s\(^{-1}\) (Fejes and Wesselius, 1973), the energy involved is 1.2 \(10^{42}\) erg.

The \(\text{H} \, \text{I}\) cloud associated with the cirrus feature B shows a distinctly different spatial and velocity structure. It is unlikely to be part of the Loop I shell structure. The velocity range of feature B, between about \(-5 \text{ and } -40 \text{ km s}^{-1}\), is anomalous at such high \(b\), and requires explanation. Wesselius and Fejes (1973) pointed out that anomalous negative velocities are found in a number of \(\text{H} \, \text{I}\) structures near the North Galactic Pole, and developed a model of infalling gas to account for them. At the position of feature B the velocity derived from their model matches the observed one. The distance toward the gas complex is estimated by Wesselius and Fejes at 70\(\pm\)30 pc, placing this cloud beyond the Loop I \(\text{H} \, \text{I}\) material. Its total gas mass amounts to 0.1 \(M_\odot\).

The cirrus field centered at 247\(\arcdeg, 72\arcmin\) contains a dust and gas structure with an angular shape. It has a generally low infrared brightness, but can be identified in both the 60-\(\mu m\) and 100-\(\mu m\) material shown in Fig. 3(a). One of the zodiacal dust bands hinders its recognition at 12 \(\mu m\) and 25 \(\mu m\). Comparison of the integrated

\(\text{H} \, \text{I}\) column-density map shown in Fig. 3(b) with the 100-\(\mu m\) map indicates that the cirrus feature is spatially traced by gas as well as by dust. The Fig. 3c scatter diagram illustrates this correlation. The rather large scatter around the least-squares line drawn in this diagram can be attributed largely to noise in the IRAS data. The 60 \(\mu m\)/100 \(\mu m\) intensity ratio derived for this feature is 0.23, similar to that found for features B and X.

The kinematic behavior of the cirrus feature in the 247\(\arcdeg, 72\arcmin\) field is illustrated by the panels of Fig. 3b. There is \(\text{H} \, \text{I}\) emission that can be associated with parts of the dust feature extending to negative velocities \((v < -35 \text{ km s}^{-1})\) that are anomalous for such high latitudes. The velocity structure shows a gradient across the feature, with the most negative velocities concentrated on the right-hand (lower longitude) portion. The Fig. 3c histogram illustrates the velocities at which the \(\text{H} \, \text{I}\) channel maps and the 100-\(\mu m\) map correlate. The correlation is enhanced between \(-40 \text{ km s}^{-1}\) and \(-20 \text{ km s}^{-1}\), indicating that at these, anomalous, velocities \(\text{H} \, \text{I}\) gas is associated with the cirrus dust structure. Another correlation enhancement near 0 km s\(^{-1}\) shows a kinematically separate component. The velocity broadening is considerably larger for the more negative velocities \((\sigma_v = 35 \text{ km s}^{-1})\) than for the normal (i.e. near 0 km s\(^{-1}\)) velocities \((\sigma_v = 12 \text{ km s}^{-1})\).

Feature B and the angular feature in the 247\(\arcdeg, 72\arcmin\) cirrus field both have velocity characteristics consistent with those of the intermediate-negative-velocity complex extensive at high latitudes, discussed by Wesselius (1973) and by Wesselius and Fejes (1973). Both cirrus regions show enhanced dust/gas correlation in the \(-45 < v < -15 \text{ km s}^{-1}\) anomalous velocity range, as well as at the expected, near zero, velocities. Figures 2e–h of Wesselius and Fejes (1973) show a large complex of intermediate-negative-velocity \(\text{H} \, \text{I}\), which they estimate on the basis of stellar spectroscopy to be at an average distance of 70\(\pm\)30 pc. They describe the
phenomenon as either a supernova shell or as an infalling H I cloud. The velocity width of the complex is larger ($\sigma_v = 16$ km s$^{-1}$) than typical of H I conventional velocities ($\sigma_v < 10$ km s$^{-1}$). Thus, both the magnitude of the velocities and the profile widths in these two cirrus structures are similar to those of the intermediate-negative-velocity complex. It seems plausible that these cirrus features are local condensations in the general complex.

Because of their anomalous kinematic signature, it is interesting to ask if the infrared properties of the associated cirrus dust features differ from those of the cirrus features that are associated with H I emission at velocities closer to $v = 0$ km s$^{-1}$. Heating of dust particles by shocks in supernova remnants has been revealed by a comparatively high 60-\mu m flux (Braun and Strom, 1986). The proximity of the feature B and of the 247°, 72° field to the zodiacal emission bands has made it impossible to derive a reliable 60 \mu m/100 \mu m ratio. We note, however, that the $I_{100 \mu m}/N_{HI}$ ratio for the material associated with the anomalous-velocity component is lower (0.64) than that for the remaining structure (0.47), indicating either a difference in the dust-to-gas ratio, or in the physical properties governing the 100-\mu m emissivity per dust particle.

The cirrus field centered at 90°, -37° contains part of an extensive dust and gas structure with a rather complex shape. The spatial structure of the dust emitting at 60 \mu m and 100 \mu m,
shown in Fig. 4a, can be traced with some effort also at 12 μm and 25 μm. Comparison of the 100-μm map with the H I column-densitiy map in the upper-left panel of Fig. 4b shows a general correlation between the morphologies of the dust and gas. Deviations from the general correlation do occur locally, for example at l = 86°, b = -38°, where the H I emission is more than 50% more intense than one would expect on the basis of the correlation for the rest of the field. Figure 4c is a correlation scatter diagram for the entire region. The points below the lower dashed line, in the part of the diagram labelled b, correspond to the area with relatively high N_H I values around l = 86°, b = -38°. The points above the upper dashed line, in the part labelled c, originate from the high intensity points along the principal ridge of the cirrus feature and to the high intensities in the hook-shaped extension from the ridge.

The regions of the cirrus feature with somewhat different emission characteristics can also be distinguished kinematically. The remaining panels of Fig. 4b show three maps of H I emission integrated over 2 km s^{-1} intervals at the indicated central velocities. Most of the H I gas in this direction emits at velocities, within a few km s^{-1} of -5 km s^{-1}, normally expected for this general region of the sky. The concentration of H I emission at the slightly anomalous velocity of 2 km s^{-1} has very little associated dust emission. The H I emission centered at the very anomalous velocity of -51 km s^{-1} delineates the region of low I_{100 μm}/N_H I intensity ratio mentioned above; in this region the 60 μm/100 μm emissivity ratio is higher than elsewhere in the general cirrus field. The indicated dust temperature of 25 K for a lambda^{-2} emissivity law is a lower estimate because the intensities of the infrared emission associated with the H I material at the most extreme negative velocities are rather lower than the average of the region.

Regarding the anomalous velocity of -51 km s^{-1}, we note that very distant material at the longitude of this cirrus feature and confined to the galactic warp would appear at such velocities at positive, not negative, latitudes.

If we assume that the interstellar radiation field does not change strongly across the cirrus field, it seems plausible to surmise that the change in the I_{100 μm}/N_H I ratio and in the 60 μm/100 μm intensity ratio can be sought in the high-velocity nature of the portion of the cirrus emitting at -51 km s^{-1}. Shocks associated with material moving at supersonic speeds may cause excitation of interstellar material. A likely candidate for excitation is oxygen radiating in a line at 63 μm (Peterson, 1970; Harwit et al., 1986), which could enhance the detected 60-μm flux. The decrease in the I_{100 μm}/N_H I ratio might result from the different physical circumstances in the shocked region.

There is a general correspondence of the structure of radio Loop II, observed at 820 MHz by Berkhuijsen (1971) and at 408 MHz by Haslam et al. (1982), with that of the H I at -51 km s^{-1}. If the apparent correlation between the component of the cirrus at -51 km s^{-1} and the radio-continuum structure of Loop II is a physical one, then the anomalous velocity can perhaps be understood in terms of the estimated expansion velocity of the supernova remnant. Spiro et al. (1972) places the center of this remnant at 100 pc from the Sun. With an angular radius of 30°, the linear radius is 85 pc. We assume that the observed radial velocity of the cirrus component equals the expansion velocity of the remnant, and use the Heiles (1979) calculations scheme to determine the total mass, ambient density, and energy involved with the H I structure. To derive the H I column density of the negative-velocity cloud we integrated over those velocity channels that show this cloud above the rms level.
Fig. 4a. Distribution in galactic coordinates of the infrared emission from the cirrus field centered on 90°, -37°. The contours at 100 μm progress from 3.59 MJy sr⁻¹ in steps of 1.12 MJy sr⁻¹; those at 60 μm, from 0.68 in steps of 0.21. It is evident from comparison of 100-μm and 60-μm maps that different regions of the cirrus field have different 60 μm/100 μm intensity ratios.

Fig. 4b. Distribution of H I emission observed in the field containing the infrared cirrus feature illustrated in Fig. 4a. The grid spacings of the H I data are 24' in λ and 20' in b; the H I spectra were centered on -30 km s⁻¹. The contours in the upper-left plot progress from 412 K km s⁻¹, in steps of 51 K km s⁻¹; the minimum, step pairs for the upper-right, lower-left, and lower-right panels are, respectively, 0.2, 0.3; 0.5, 0.6; and 6.3, 2.7. Although the 100 μm/N H I correlation is generally tight, deviations from a simple relationship occur. The deviation near l = 86°, b = -38° can be associated in the upper right-hand panel with H I emission at extreme negative velocities (-51 km s⁻¹) and with a large velocity dispersion.
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Fig. 4c. Left: Scatter diagram showing the point-by-point correlation between 100-μm intensities and H I column densities for the 90°, −37° cirrus field. The two dashed lines delineate regions that correspond to structures of different physical nature (see text). Right: Histogram indicating as a function of velocity the correlation coefficient of the least-squares fit to the scatter diagrams of the 100-μm map and the individual H I channel maps. The correlation is enhanced near 0 km s⁻¹. The negative-velocity component seen in the upper right-hand panel of Fig. 4b cannot be identified here because its low intensities are overwhelmed by dust emission associated with intense H I at velocities near 0 km s⁻¹.

Fig. 4d. Contours of the ¹²CO emission for the cirrus field centered near 90°, −37° as observed by Magnani et al. (1985). Peaks of CO emission occur where the 60 μm/100 μm intensity ratio is low.

Furthermore, we assumed that the thickness of the continuum loop given by Spoolstra corresponds to the H I shell thickness. Under these assumptions, the total mass involved is 57 M☉. With the shell expanding into an ambient medium with density 0.85 atom cm⁻³, the energy involved is $1.1 \times 10^{52}$ erg.

The Fig. 4c kinematic histogram does not show the −51 km s⁻¹ component because the H I intensities involved are so low that local material dominates the structure at the position of anomalous-velocity H I cloud. The parts of the cirrus feature having the slightly negative velocities appropriate for directions near $l=91°$, $b=-36°$, do show enhanced correlation coefficients. The infrared emission associated with this H I material does not show the enhanced 60-μm intensities which are associated with the −51 km s⁻¹ component of the cirrus feature.

Magnani et al. (1985) observed molecular gas with the same spatial structure as the main ridge of this cirrus field, their Fig. 3 is redrawn here as Fig. 4d to allow comparison of the CO distribution with that of the H I and dust. The comparison shows that $N_{HI}$ is relatively deficient at positions where the CO emission peaks. There is evidently a smooth transition between the dust material associated with H I and with CO emission. If the dust inside molecular clouds (with no embedded heat source) is cooler than unshielded dust, then the 60 μm/100 μm ratio for those regions would be lower than for the other parts of the cirrus structure. This is observed to be the case. For peaks in the 100-μm maps at $l=86°$, $b=-42°$; $l=89°$, $b=-41°$; $l=92°$, $b=-38°$; and $l=94°$, $b=-35°$, there are only weak peaks, or none, in the 60-μm map. On average the dust temperatures derived at these positions is 3 K lower than for the rest of the general cirrus field feature, which has an effective dust temperature (calculated on the basis of a lambda−² emissivity law) of 22 K.

The three parts of this cirrus field which seem to show different physical conditions are separated in Fig. 4c by the dotted lines. The −51 km s⁻¹ component (in region b of the figure) contains relatively more H I gas than the other parts of the field; regions on the main ridge of the cirrus feature which contain substantial CO have a relatively low H I content of H I emission (region c). Gas and dust from the other parts of the cirrus field tend to be represented between the two dashed lines (region a).
The cirrus field centered at 54°, 15° can be followed over an extent of some 20° × 12°. Sofue (1983) identified a loop structure in maps in the radio continuum at 408 and 820 MHz, and pointed out that the loop is associated with an H i shell having similar characteristics to the shell and bubble structures identified by Heiles (1979). The appearance of the cirrus feature in the IRAS data suggests that it is a dust counterpart to Sofue's loop. Examination of the brightnesses at 100 μm and at 21 cm plotted in Figs. 5a and 5b shows a general correlation between the gas and the dust emission in this field. Assuming that this shell is a

Fig. 5a. Distribution in galactic coordinates of the infrared emission from the cirrus field centered on 54°, 15°. The contours at 100 μm progress from 11.56 MJy s⁻¹ in steps of 2.47 MJy s⁻¹; those at 60 μm, from 1.75 in steps of 0.42. This field is situated much closer to the galactic plane than the ones represented in Figs. 1–4. The shell-like structure appears at all four IRAS wavelengths.

Fig. 5b. Distribution of H i emission observed in the field containing the infrared cirrus feature illustrated in Fig. 5a. The grid spacings of the H i data are 20' in l and 20' in b; the H i spectra were centered on −30 km s⁻¹. The contours in the upper-left plot progress from 773 K km s⁻¹ in steps of 88 K km s⁻¹; the minimum, step pairs for the upper-right, lower-left, and lower-right panels are, respectively, 0.04, 0.6; 4.2, 1.4; and 9.7, 3.2. The total \( N_{\text{H}i} \) map shows a shell structure of the same general nature as those reported by Heiles (1979). There is a smooth variation with longitude of the velocity centroid of the structure. The shell structure, centered near 0 km s⁻¹, is kinematically distinct from other material emitting in this field.
stationary one we can calculate, using the method of Heiles (1979), the amount of energy needed to blow a hole of this size in the ambient H I. Adopting a kinematic distance of 1 kpc consistent with the central velocity of the structure, and using the $N_{HI}$ map of Fig. 5b we find that the mass of accumulated H I gas is 166 $M_\odot$, the ambient density 1.7 atom cm$^{-3}$, and the required energy input 2.7 $10^{51}$ erg.

Although the general dust/gas correlation in this cirrus field is strong, it is not linear; the scatter diagram of Fig. 5c shows that there is a tendency for the stronger 100-$\mu$m intensities to be associated with relatively weaker H I densities than would be the case for a linear correlation. The portions of the cirrus field at higher $b$ tend to dominate the lower left-hand corner of the scatter diagram; those at lower $b$, the upper right-hand corner. Especially at the lower latitudes, investigation of the specific cirrus structure may be confused by emission from unrelated structures in the general galactic layer of interstellar material. Lines of sight toward this field pass through the inner part of the Galaxy, where the intensity of the interstellar radiation field increases strongly towards the galactic plane. Such contamination could cause the excess 100-$\mu$m flux at the lower latitudes. It could also be the case that where the dust material becomes denser, hydrogen becomes largely molecular, resulting in relatively less 21-cm line emission. CO observations are not yet available to test this hypothesis for this region.

The velocity characteristics of the cirrus field can be identified from the H I channel maps. Gas associated with the cirrus dust shows a shallow kinematic gradient, with higher velocities on the lower-longitude side of the shell. The Fig. 5c histogram shows the broad velocity width of the material associated with the infrared emission. Although most of the infrared radiation is correlated with 21-cm emission at positive velocities, there is another range of velocities ($-90 \text{ km s}^{-1} < v < -50 \text{ km s}^{-1}$) where the correlation is also significant. Most of the correlated negative-velocity emission is found at low latitudes. The velocity range corresponds to large galactocentric radii ($R > 15$ kpc) in the warped outer part of the Galaxy. One must take care in interpreting this kinematic distance, however. The global morphology of the infrared emission in the Galaxy shows little dust in the far outer Galaxy. In view of the anomalous velocities found in other cirrus fields, it should not be ruled out that the dust and gas correlated at negative velocities in fact are physically associated with a localized, non-stationary, cirrus structure.

The shell-like structure of this field is also evident in the radio continuum surveys at 408, 820 and 1420 MHz (see Sofue, 1983). There is no H II region in the observed area, so the radio continuum emission is probably non-thermal. This is supported by the fact that the signature of the shell structure is more clearly seen at the lower frequencies. The synchrotron radiation of the shell structure indicates enhancement of the magnetic field in the cirrus feature. If the dust particles are aligned in the magnetic field, then the light of the stars in this direction will be polarized. There is a hint of a resemblance with the 100-$\mu$m and H I shell-like emission structure to be found in the polarization vectors of starlight published for this region by Mathewson and Ford (1970). Mathewson and Ford furthermore separated the polarization measurements into distance intervals, showing that the stars observed in this region are all located within 1 kpc of the Sun. Thus if alignment of the dust particles in the cirrus causes the polarization, then the shell structure must be located substantially closer than 1 kpc. This argues also against associating the dust and gas emission with material in the warped outer Galaxy.
and suggests that this cirrus field, like the others mentioned above, involves substantially anomalous velocities.

The cirrus field centered at 248°, 15° was originally chosen by Dr. H.J. Walker (priv. com.) as a cirrus object for detailed study. The current observations involve a grid centered at 248°, 15° and covering a region some 9° by 7° in extent. At infrared wavelengths the field contains a cloud of diffuse low-intensity emission with superimposed a boomerang-shaped ridge of intense emission centered at l = 251.5°, b = 15°. An additional cirrus structure, showing an excess 100-μm flux can be identified near 245°, 17°.5. The dust in the diffuse cloud emits strongly at 60 μm and at 100 μm, but weakly at the shorter IRAS wavelengths. The boomerang-shaped ridge is detectable in all four IRAS passbands. The structure near 245°, 17°.5 is primarily visible at 100 μm.

Figure 6a illustrates the temperature characteristics of the principal structures in this cirrus field. The low-intensity cloud contributes the points below 1.1 \times 10^7 Jy sr⁻¹ at 100 μm and below 2.2 \times 10^6 Jy sr⁻¹ at 60 μm; it has an effective dust temperature of 22 K. Above these values the boomerang-shaped ridge dominates; its effective color temperature is 25 K. The structure near 245°, 17°.5 can be identified in the scatter diagram with the group of points concentrated to the left of the main correlation and centered around the line I_{60 μm} = 1.8 \times 10^6 Jy sr⁻¹. The effective dust temperature of this structure is 20 K.

Comparison of the 100-μm map of Fig. 6a with the total H i column-density map of Fig. 6b shows that the dust and H i gas are correlated on a large scale (few degrees) but that the correlation breaks down on smaller scales. There are, however, two subregions where the general correlation is not followed. The third component mentioned above shows excess 100-μm emission compared to the average I_{100 μm}/N_{H i} ratio. We expect that a CO observation of this region would reveal a considerable amount of molecular material. The boomerang-shaped cloud also shows deviating I_{100 μm}/N_{H i} values.

Deviations from an otherwise constant I_{100 μm}/N_{H i} ratio can have several causes. The presence of molecular clouds is one possible cause, and as mentioned above is relevant in the case of the high-intensity ridge found in the cirrus field centered at 91°, -36°. In such an environment the dust grains are shielded from UV radiation and, in addition, much of the hydrogen will be in the molecular state. Local heating phenomena can also cause variations in the ratio. There is some evidence that this is the case for the boomerang-shaped cloud. Young stars embedded in a dense dust cloud heat the surrounding material causing excess infrared flux. The I_{100 μm}/N_{H i} ratio for the diffuse low-intensity cloud can be fit by the Draine and Anderson (1985) model with an interstellar radiation field similar to that in the solar vicinity. The boomerang-shaped cloud requires, however, an interstellar radiation field more than three times as intense to account for the enhanced I_{100 μm}/N_{H i} ratio. We note in this regard also that the velocity width of the boomerang-shaped cirrus feature (σ_v about 20 km s⁻¹) is greater than the width of the other parts of the cirrus structure (σ_v < 14 km s⁻¹).

Braun (1984) showed how to decompose the IRAS four-wavelength data into three separate images at different, constant color temperatures. Following Braun we decomposed the data into maps for the cool dust (22 K), for the warmer dust (> 25 K), and for the residual contaminating zodiacal emission (250 K). The technique provides the contribution to each pixel from cold, warm, and zodiacal dust, so that one may determine the separate contribution of warm material to a pixel by subtracting the fitted cool and zodiacal components. In this way we estimate the temperature of the boomerang-shaped cloud at 32 K, which is much warmer than derived from the color-color diagram of Fig. 6d before the decomposition. The Palomar Sky Survey blue

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**Fig. 6a.** Distribution in galactic coordinates of the infrared emission from the cirrus field centered on 248°, 15°. The contours at 100 μm progress from 5.88 MJy sr⁻¹ in steps of 1.41 MJy sr⁻¹; those at 60 μm, from 0.99 in steps of 0.35. The prominent boomerang-shaped ridge of high infrared intensities can be traced at all four wavelengths. Note that the subcloud in the 100-μm map near l = 245°, b = 17°.5 is evidently “cool”, because its 60-μm counterpart is scarcely detected.
plates covering this region show considerable extinction confined to the boomerang-shaped cloud, indicating high dust densities. It is therefore likely that embedded sources cause heating of the dust grains in this portion of the cirrus structure, but probably not in the other portions.

The cirrus field centered at 46°, 24° was pursued in H I over a region some 7° by 6° in extent. The Fig. 7a 100-μm map shows a cirrus structure with a number of pronounced peaks of rather strong infrared intensities. Unfortunately, determination of the background level needed for application of the destriping technique was hampered by the considerable amount of radiation in the general vicinity of this cirrus field.

The clumps observed at 100 μm generally have a lower 60 μm/100 μm ratio than found elsewhere in this cirrus field. CO observations have not yet been reported for this cirrus field. It is a good candidate for such observations, because it seems likely that the clumps contain substantial amounts of molecular material. The H I content of this field is shown in Fig. 7b. The Fig. 7c scatter diagram shows that the total N_{HI} is tightly correlated with the 100 μm intensities, although there is a general decrease in the I_{100μm}/N_{HI} ratio with decreasing latitude.

The kinematic characteristics of this cirrus field are rather simpler than those of the fields discussed above. We note that there is no velocity gradient across the field. The histogram of Fig. 7c shows that the dust and gas emission are correlated across a wide range of velocities. Outside the 0 km s^{-1} < v < 20 km s^{-1} velocity range the total flux in the H I channel maps is roughly 5% of that for the H I channel maps inside this range. Therefore,

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**Fig. 6b.** Distribution of H I emission observed in the field containing the infrared cirrus feature illustrated in Fig. 6a. The grid spacings of the H I data are 10' in l and 10' in b; the H I spectra were centered on 40 km s^{-1}. The contours in the upper-left plot progress from 733 K km s^{-1} in steps of 100 K km s^{-1}; the minimum, step pairs for the upper-right, lower-left, and lower-right panels are, respectively, 0.7, 0.8; 146, 55; and 107, 45. The total N_{HI} shows a general morphology very similar to that observed at 100 μm. The individual channel-map panels illustrate the velocity distribution across this cirrus field. Different parts of the boomerang-shaped, high-intensity ridge correlate with H I emission at different velocities.
we identify the H I material in the 0 km s$^{-1}$ < v < 20 km s$^{-1}$ velocity interval as the neutral atomic gas associated with the dust cloud. From the distribution of velocity widths of the portions of the H I profiles associated with the infrared emission we note that the center of this cirrus cloud has wider profiles than the edges. This suggests either a general expansion or contraction.

4. Discussion

The morphology of dust in infrared cirrus is well correlated with the morphology of associated H I gas. The kinematic structure of the cirrus features was examined in seven cirrus fields by identifying the velocity intervals in 21-cm data at which the dust-to-gas association is strongest. The velocities of the H I structures associated with the infrared cirrus span a large range. Cirrus features which may appear simple are in some cases superpositions of kinematically distinct components. The kinematic information allows separation of distinct infrared cirrus structures. The kinematic characteristics of the seven fields suggest that anomalous velocities are common among cirrus features. If that is the case, evidently some acceleration mechanism is an important aspect of the general cirrus phenomenon.

A considerable range of values in the I_{100 mm}/N_{HI} ratio (0.9–3.0 (M Jy s$^{-1}$)/(10$^{19}$ atom cm$^{-2}$); see Table 1) was found in the cirrus fields considered. We attribute variations in this ratio to changes in the intensity of the interstellar radiation field. The dust-to-gas ratio of the lower-latitude cirrus fields tends to be higher than at higher |b|. This tendency may be understood qualitatively in terms of the stronger radiation field which illuminates the lower-|b| cirrus.

Fig. 7a. Distribution in galactic coordinates of the infrared emission from the cirrus field centered on 46°, 24°. The contours at 100 μm progress from 5.19 MJy sr$^{-1}$ in steps of 0.82 MJy sr$^{-1}$; those at 60 μm, from 0.65 in steps of 0.29. The dust structure in this region is particularly clumpy.
Fig. 7b. Distribution of H\,\textsc{i} emission observed in the field containing the infrared cirrus feature illustrated in Fig. 7a. The grid spacings of the H\,\textsc{i} data are 16' in l and 15' in b; the H\,\textsc{i} spectra were centered on 0\,km\,s\(^{-1}\). The contours in the upper-left plot progress from 594 K\,km\,s\(^{-1}\) in steps of 53 K\,km\,s\(^{-1}\); the minimum, step pairs for the upper-right, lower-left, and lower-right panels are, respectively, 11.5, 0.9; 4.7, 1.5; and 2.0, 0.6. The total H\,\textsc{i} column-density map resembles the 100-\mu m map. The individual channel maps show the wide velocity range over which correlation with the infrared cirrus may be found.

Fig. 7c. Left: Scatter diagram showing the point-by-point correlation between 100-\mu m intensities and H\,\textsc{i} column densities for the 46\degree, 24\degree cirrus field. Systematic errors in the determination of the background levels contribute to the large scatter in this diagram. Right: Histogram indicating as a function of velocity the correlation coefficient of the least-squares fit to the scatter diagrams of the 100-\mu m map and the individual H\,\textsc{i} channel maps. The high correlation coefficients outside the 0\,km\,s\(^{-1}\) to 20\,km\,s\(^{-1}\) velocity range are misleading (see text).
Table 1. Radiation properties of the cirrus fields

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<th>Field-center</th>
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<th>$b=$</th>
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<th>90°</th>
<th>54°</th>
<th>248°</th>
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<td>0.26</td>
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<td>0.22</td>
<td>0.2</td>
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<td>100 μm/N$_H^a$</td>
<td>1.8</td>
<td>0.58</td>
<td>0.50</td>
<td>1.3</td>
<td>1.7--3.0</td>
<td>1.2</td>
<td>1.4</td>
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<tr>
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<td>0.47</td>
<td>0.93</td>
<td>1.9</td>
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<tr>
<td>100 μm/N$_H^b$</td>
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<td>0.5</td>
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Notes: The superscripts $^a$ and $^b$ refer to subregions described in the text; the units of the dust/gas ratios are MJy sr$^{-1}$ (10$^{10}$ atom cm$^{-2}$).

The kinematic separation also reveals differences in the radiative properties of the individual dust structures within one cirrus field. Three types of cirrus were identified in the fields considered: quiescent cirrus, associated with H I gas at the near-zero velocities expected at latitudes several tens of degrees from the galactic equator; cirrus that is associated both spatially and kinematically with radio continuum loops; and cirrus that is associated with the H I structures that have been identified as intermediate-negative-velocity clouds. Because the radiative properties of the dust differ strongly among the fields, we can only examine the relative differences within the fields to seek differences among the groups. For the cirrus field centered on 247°, 71° we found that the $I_{100 \mu m}/N_H$ ratio is smaller for material associated with the intermediate-negative-velocity cloud than for the quiescent material. For the cirrus center near 276°, 73° this ratio is also smaller for the intermediate-negative-velocity material than it is for the dust and gas associated with the Loop I structure. Finally, the dust-to-gas intensity ratio for the material associated with Loop II, is smaller than for the remaining quiescent cirrus. Although interpretation based on such a limited amount of information must be taken with caution, we do want to point out that there may exist a trend for the $I_{100 \mu m}/N_H$ ratio to be larger for the quiescent cirrus than for dust associated with the radio continuum loops or with the intermediate velocity material.

If the anomalous-velocity dust particles participate in shocks, then the 60 μm/100 μm intensity ratio may be higher than it is for material at velocities below the sound speed. This seems to be the case in the 90°, –37° field, where an increase in the velocity width of the H I profile follows an increase in the 60 μm/100 μm ratio. There are a number of possible causes for the enhanced 60-μm emission: these include shock heating of the dust particles (Braun and Strom, 1986), line radiation of neutral oxygen (Harwit et al., 1986), or a difference in the particle size distribution between that in the kinematically anomalous material and that in the quiescent material. The 60 μm/100 μm ratio is also influenced by the presence of molecular clouds. Both for cirrus field at 248°, 15° and for that at 90°, –37° sub-regions occur with an extremely low ratio (0.15–0.17). In the case of the latter field the 12CO observations of (Magnani et al., 1985) record the highest gas densities where the 60 μm/100 μm ratio is lowest. This may indicate either that the contribution to the 60-μm flux of small grains has been strongly diminished, or that the majority of the radiation at these positions is from dust at lower temperatures than that associated with atomic gas. We favor the first possibility because high-energy photons responsible for heating the small grains are more sensitive (Draine and Anderson, 1985) to extinction than the lower-energy photons responsible for the heating of the larger grains. The limb brightening at 12 μm found by Langer et al. (1988) for Barnard 5 may be direct evidence for this situation.

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References


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