THE LARGE-SCALE STRUCTURE OF LOCAL H I, DUST, AND GALACTIC RADIO CONTINUUM

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Abstract. The correlation of H I and dust at high latitudes gives different results depending on whether one uses galaxy or reddening data for the dust distribution. It is not certain to what extent this depends on differences in the gas to dust ratio or on difficulties in determining the amount of dust from the optical data. The correlation of H I and continuum radiation shows H I structures associated with the large-scale loops. There is also a coincidence of a hole in both the H I and continuum.

I want to discuss two aspects of the interstellar medium that have been illuminated to some small degree by the Hat Creek survey of H I at intermediate galactic latitudes (Heiles and Habing, 1974; Heiles and Jenkins, 1974). I discuss them here because they both have relevance to the structure of the Galaxy within a few hundred parsecs of the Sun.

I. H I and Dust

(a) RADIO DATA

Many people have correlated the gas, as determined from 21-cm emission, and dust, as determined either from reddening measurements or from galaxy counts. Lilley (1955) formed the first correlation, which has been confirmed rather well, quantitatively speaking, by most of the later studies. However, a recent study by Wesselius and Sancisi (1971) using the Lick galaxy counts by Shane and Wirtanen (1967) and the 21-cm line data of Tolbert (1971), both averaged over 10° by 10° squares, seemed to show that the correlation was not so good as previously thought and perhaps even nonexistent. This is also in contrast to the recent study using UV line measurements and reddening by Savage and Jenkins (1972), who found a good correlation, albeit with large scatter.

Optical astronomers have in recent years gathered a wealth of data on interstellar reddening, and the Shane and Wirtanen (1967) galaxy counts yield data on total extinction. The Hat Creek intermediate latitude 21-cm line survey provides an essentially completely sampled data base for the H I column density. Comparison of these sets of data provides new degrees of statistical confidence due to the large number of independent samples on the sky. These comparisons are currently being performed by Heiles and Jenkins (1974), and I would like to give a progress report on our present results and their possible implications.

Earlier in this symposium you have seen some of the 'photographs' of H I column density in the sky made by Heiles and Jenkins (1973) from the Hat Creek survey data. We have made a similar photograph of the Shane and Wirtanen (1967) galaxy counts from a machine-readable copy of the counts kindly provided to us by Professor Peebles. Comparison of the two photographs is rather striking in that the number of

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galaxies drops where the hydrogen is present in large quantities, and vice versa. Comparison of these two 'photographs' then shows the qualitative correlation of H I and dust, which simply reflects the old result of Lilley (1955). A quantitative comparison can be made by considering all of the some 30000 individual data points in the two sets of data. We can then make a point correlation diagram comparing the number of galaxies and the amount of H I. This diagram shows a very high degree of correlation with an average relation which differs somewhat from the correlation presented earlier in the symposium, derived from H I versus reddening data, by Kerr.

However, the distribution of points around the average relation looked suspicious and led us to break the data up into separate latitude ranges. This result is quite startling in that the slope of the average relation between galaxies and H I is a rather smooth and well-defined function of galactic latitude. The slope is largest at low latitudes and falls smoothly to zero at high latitudes. The qualitative behavior of the latitude dependence of slope was the same for positive and negative galactic latitudes, with some small but significant quantitative difference.

If we accept the galaxy counts as reliable indicators of extinction, this behavior leads to two possible conclusions concerning the correlation of extinction and hydrogen:

(i) There is no extinction at high latitudes

(ii) There is extinction at high latitudes, but it is not correlated with the presence of H I

There is one simple way to test the possible conclusion (i). If there is no extinction at high latitudes then the distribution of galaxy counts with latitude should not vary as expected for a plane-parallel distribution of dust. Shane and Wirtanen (1967) investigated the latitude dependence of galaxy counts and found it to be accurately consistent with a plane-parallel distribution of dust in the Galaxy; in this way they were able to derive the extinction towards the pole of the Galaxy, about 0.5 mag (photographic). This argues against interpretation (i).

There is another piece of evidence against interpretation (i). This is the dependence of H I on galactic latitude. Averaging over all longitudes we find that there is *less* hydrogen at high latitudes than would be expected from a plane-parallel distribution of gas. The pictures shown earlier in the symposium by van Woerden, made from the Dwingeloo survey at high latitudes (Wesselius and Fejes, 1973), also show this phenomenon. This argues that the reason the correlation between gas and dust breaks down at high latitudes is that the gas is absent at high latitudes (relatively speaking) while the dust is distributed in a fashion completely consistent with the plane-parallel distribution.

(b) OPTICAL DATA

This interpretation, however, is at variance with the reddening results of optical astronomers which have recently been used by Sandage (1972, 1973) to argue against the existence of any extinction at all above latitudes of 50°. In short, the galaxy counts imply the existence of substantial extinction at high latitudes whereas the reddening data imply the existence of no extinction.

We are thus left with an ambiguous situation in which we have the following two alternatives:

(i) *Favored by most optical astronomers: The galaxy counts do not reliably measure extinction, while the reddening measurements do.* In this case the dust/gas ratio goes to zero towards the galactic poles in the vicinity of the Sun. It is important to realize that this happens *only* in the vicinity of the Sun; if it happened everywhere in the Galaxy, we would be back to our plane-parallel distribution of dust/gas and hence both dust and gas separately.

In this case the universe is anisotropic with an excess of galaxies towards our own galactic poles. This excess, combined with the non-plane-parallel distribution of dust, is distributed in such a manner as to precisely mimic what we would observe if instead the galaxies were distributed isotropically and the dust in a plane-parallel layer.

(ii) *Apparently favored by galaxy counts and H I data: Galaxy counts do reliably measure extinction, while the reddening measurements don't.* In this case the ratio of total to selective extinction becomes larger than about 12 at the higher latitudes. This implies that dust grains towards the galactic poles in the vicinity of the Sun are bigger than normal. This can only occur in the vicinity of the Sun; otherwise the reddening would also exist in a plane-parallel distribution. In this case the dust and H I cannot be uniformly mixed and gas/dust ratio becomes smaller at the higher latitudes in the vicinity of the Sun. It is tempting to speculate that some of the H I has been converted to unobservable (in the 21-cm line) H II by the same process responsible for the existence of intermediate and high velocity gas. In this case the new distance scale of Sandage (1972) is incorrect in the sense that the Hubble constant is larger than his derived value by something like 20%.

At the moment I cannot tell you which of these alternatives is correct. We are currently analyzing the different sets of data and hope to have an answer within a few months.

II. H I and Radio Continuum Radiation

Association of low-velocity H I with radio continuum radiation of the North Polar Spur (Loop I) has been noticed by several authors, most recently by Berkhuijsen *et al.* (1971). There is a low velocity H I loop lying a few degrees outside the continuum loop. These authors also noticed correlations with continuum Loop III, using only a single H I scan at $b = +30°$ (from Grahl *et al.*, 1968). At the longitudes where Loop III crosses this latitude they found small-diameter features with high velocity dispersions, greater than 40 km s^{-1}, and high velocities as well. Fejes and Verschuur (1973) find what appears to be a significant correlation of H I density and velocity structure with Loop III, again using data restricted to a small segment of the circumference of the loop. Their correlations take the form of an absence of gas at one place and a split of low velocity gas into two velocity components at another place.

The H I color photographs of Heiles and Jenkins (1973), in which color indicates velocity, together with a similar 'photograph' of radio continuum radiation made from the data of Berkhuijsen (1971), enable these comparisons to be made over the whole circumference of the continuum loops. The H I loop just outside the North Polar Spur (Loop I) contains filamentary structure, some of which has been mapped by Dieter (1964) and Verschuur (1974). The photograph shows that the continuum loop also contains filamentary structure which is similar in appearance to the H I filaments.

The correlation of high velocity dispersion in the H I with radio continuum Loop III is confirmed and extended to include intermediate and high velocity gas. The color photograph shows that much of the intermediate velocity H I at positive latitudes exists in a loop which is coincident with continuum Loop III. In addition, the high velocity gas at positive latitudes (as summarized by Verschuur, 1973) also exists in a loop; this loop lies slightly outside the intermediate velocity H I loop. Both of these lie on the continuum loop, whose width is much bigger than that of the hydrogen loops. At negative latitudes, intermediate velocity H I also appears inside Loop II; the statistical significance of this association is questionable, however, because the H I data do not exist for the full range of langitude at the negative latitudes due to an absence of southern hemisphere data.

The photographs show two new correlations, previously unsuspected. As pointed out in this symposium by Sancisi, there is an absence of continuum radiation in a region about 10° in diameter centered near $l=165°$, $b=-18°$; this is coincident with an absence of H I. Second, near the north celestial pole, there is a very striking elliptically-shaped H I filament, about 25° in diameter, centered near $l=135°$, $b=+35°$. Inside this filament there is little hydrogen as compared with the amount in the filament. The inner boundary of this filament corresponds almost exactly to the boundary of a similarly-shaped hole in the continuum radiation. Most of this filament contains low velocity gas with considerable velocity structure. At one end of the filament the gas is moving at intermediate negative velocities.

It has been fashionable in some astronomical circles to associate the continuum loops with some sort of explosive phenomenon. It is easy to continue this analogy to the continuum holes mentioned in the above two paragraphs. In my own mind I have tended to do this, with little justification other than having been influenced in attitude by Berkhuijsen *et al.* (1971). In the discussion following this paper, however, we will hear some potent arguments against the explosion interpretation.

Note added in proof. More recent work shows that the relation between galaxy counts and extinction differs by a factor of about 2 from that usually assumed; that the extinction as inferred from galaxy counts has a dependence on galactic latitude, separate from any dependence on the intensity of 21-cm emission; and that the latitude-dependent slope mentioned above is probably more properly described as a threshold phenomenon. The effect of these developments is to reduce, but probably not completely eliminate, the discrepency between extinctions derived from galaxy counts and from reddening measurements. At present progress is rapidly being made and the reader is urged to consult either the author or the paper which will, hopefully, appear on this subject.

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DISCUSSION

Menon: In your plots of the gas to dust correlations did you assume that all the gas is at the same temperature? If so, how can you say that every time there is a decrease in intensity, it is due to molecule formation?

Heiles: Decrease in H I dust could be due *either* to molecule formation *or* to low temperatures. In some areas, especially near the galactic center, we believe it is low temperatures. Others, like Orion and Perseus, are almost certainly molecular because other types of data are more consistent with that approach. In other areas we don't know.

Shakeshaft: If Sandage is wrong in his belief that there is no extinction above 50° latitude, what difference does it make to his current value of the Hubble constant?

Heiles: The difference would be equivalent to roughly 0.5 mag, I believe. This is about 25% in distance.

Shakeshaft: You attribute the correlation between 'holes' in the H I and 820 MHz continuum maps to 'explosions' which have blown material away. Does not one generally associate explosions with enhancement of continuum radiation rather than reduction?

Heiles: You are perfectly correct. As Mathewson has pointed out to me, another thing which argues against 'explosions' is the narrowness of the H I lines. Explosions should provide big line widths as well as large velocities, but large widths aren't seen.

Sancisi: E. Berkhuijsen and I have compared in detail the distributions of dust, neutral hydrogen and continuum radiation in the Taurus-Perseus region. We find that to the minimum of H I emission centered at about $l = 166°$, $b = -18°$, (diameter $\approx 12°$) there corresponds an equally striking minimum in the continuum. The regions of largest interstellar extinction as shown by star and galaxy counts do not lie in the direction of the 'hole' but at its low and high longitude side, and tend to coincide approximately with the H I concentrations making up the Perseus and the Taurus cloud comples.

Heiles: Yes, I agree. But the dust actually seems to be located partially inside the hole, on its edge and definitely inside the main hydrogen peak.

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Mathewson: People talk about all these loops being supernova remnants. But there is just no widening of the velocity profile. I think your H I maps show the loops to be structural features of the magnetic field, not the general magnetic field but the field in our vicinity. This is particularly so where the neutral hydrogen filaments come right across the plane. If you put the whole loop as defined in the continuum on the H I, they just wouldn't coincide over the whole arc. This is an important point. It helps to establish that the optical polarization measurements are right in assuming a continuation across the plane. There is dust in the neutral hydrogen, because we get optical polarization, a lot of it.

Weaver: Holes in the gas can be made by processes other than explosions. The local arm, moving at circular velocity, can run into a mass of gas moving at less than circular velocity. The slow-moving gas will smash a hole right through the local gas. This appears to be what is happening, for example, in the region $l = 120°$, $b = +40°$, where the low velocity gas is very weak. A jet of gas here is moving over our heads at high velocity; the low velocity hydrogen is very weak.

Kerr: In the work I reported on observations in the directions of globular clusters, we found the gas-to-dust ratio to be independent of latitude. We estimated the amount of dust from reddening effects, whereas yours comes from extinction. There is apparently some important difference between reddening and extinction phenomena. Another possible interpretation additional to those you mentioned is that the clumpiness of the dust (which may vary with latitude) may be affecting different types of observations in different ways.

Van Woerden: Plots of hydrogen column density, N_H, versus latitude, b, averaged over all longitudes, may hide important information and, therefore, lead to erroneous conclusions. Fejes and Wesselius (1973, *Astron. Astrophys.* **24**, 10) have investigated the run of N_H with b separately for small longitude intervals. They show that much of the anomaly in this run can be attributed to the 'low-velocity hole' (a prominent minimum in the sky distribution of neutral hydrogen, centered at $l \sim 160°$, $b + 70°$, and extending over some 70°) and to the *'Scheve Schijf'* (a disk-like feature of low-velocity hydrogen, tilted 45° to the galactic plane).