SUBSTRUCTURE WITHIN GALACTIC SPIRAL ARMS AS DERIVED FROM STUDIES AT 21 CM

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Detailed structure within the spiral arms of our Galaxy is suggested by hydrogen-line spectra taken with high resolution in frequency [1]. The spectra show much detail in each maximum (spiral arm). It is not clear, however, if this frequency structure refers to fine structure in depth or in velocity dispersion or in both. Fine structure in position and depth has been inferred from 21-cm drift curves taken across the nearby spiral arms. The results of three investigations will be discussed. Two have been published in some detail [2, 3] and will only be summarized here.

1. DENSE H I CLOUDS IN AURIGA AND CYGNUS

Drift curves at 21 cm were taken across regions in Auriga and Cygnus using a bandwidth of 18 kc/s and a beamwidth of 1°.6. These showed in Auriga an area 3° × 0°.7 at declination = 40°.5, and right ascension = 5^h06^m, which was 10 °K below the temperature of surrounding parts of the sky. This region in Auriga coincided in position with a dust cloud that produced 0.25 magnitudes of absorption. Similar drift curves were taken from a declination 25 to 55 degrees, and right ascension 19 to 23^h; they revealed 6 elongated regions cooler than their surroundings. Their positions are plotted in Fig. 1 as heavy dotted lines superposed on a map of integrated star brightness obtained from Pannekoek's photometric survey [4]. They coincide with obscured regions which are thus associated features. The region at right ascension 21^h00^m, declination 31 to 38 degrees, for example, is called the "Fish on the Platter" and has been extensively studied by Franklin [5]. It lies at 1.6 kiloparsecs and exhibits 1.5 magnitudes of absorption.

These 21-cm results can be adequately explained in terms of cool, dense, neutral-hydrogen regions lying between the bulk of the galactic neutral-hydrogen emission and the sun. These regions or clouds absorb the background emission and radiate at a brightness temperature lower than their surroundings. An attempt has been made to estimate the physical conditions within the clouds.

A unique value for the temperature of the Auriga cloud was derived from a detailed spectral analysis of the region. The kinetic temperature of the neutral hydrogen was 60 °K compared with 125 °K for the mean value in the Galaxy. Only the observed brightness temperatures of the Cygnus clouds were recorded; they are consequently upper estimates of the kinetic temperature and ranged from 25 to 60 °K.

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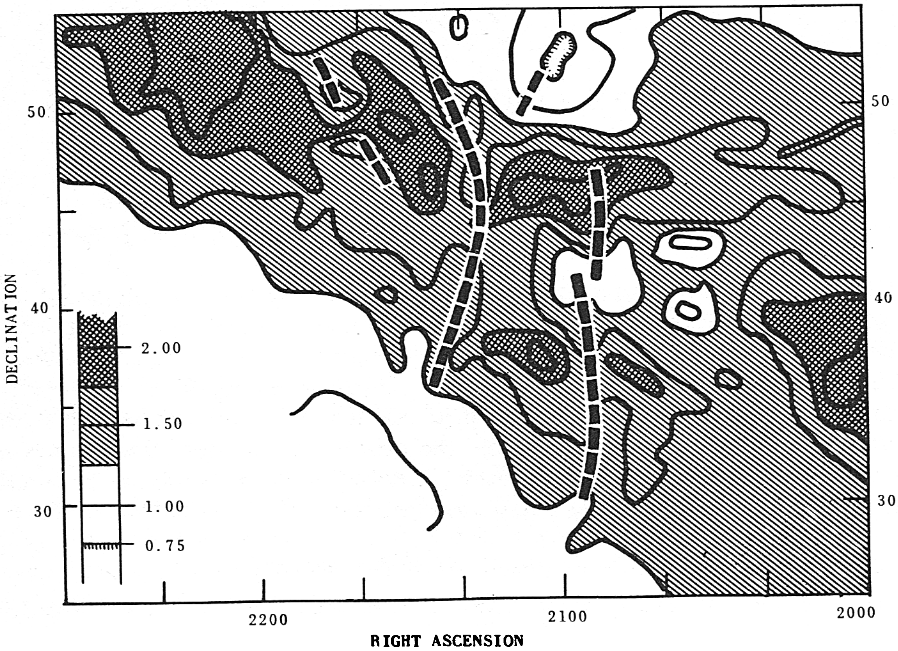

FIG. 1. Contours of integrated star brightness (after Pannekoek) in the Cygnus region. Cool and dense neutral hydrogen clouds are shown by heavy broken lines.

The velocity dispersion (η) within a neutral hydrogen cloud will be defined as the half-width of the half-intensity points of the optical-depth (τ) spectrum. The Auriga cloud had a value of η of 5 km/second, while the average of the Cygnus clouds was 6.5 km/second. These estimates are much higher than the thermal broadening of 1 km/second corresponding to the observed temperatures. The broadening is probably a result of turbulence.

The neutral-hydrogen density of the clouds has been calculated from the observed optical depth and temperature. The Auriga cloud contains 250 cm^{-3}; an estimate for the Cygnus clouds gives 50 to 100 cm^{-3}. Such high densities within dust clouds have also been found by Heeschen [6] and Lilley [7].

A mechanism for cooling dense dust and gas clouds is described by Spitzer [8] and Kahn [9]. Assuming that the proportions of the constituents of interstellar clouds remain the same, then on increasing the density of neutral hydrogen the dust and gas density will increase linearly, while the density of molecular hydrogen (the cooling agent) will increase as the square of the density of atomic hydrogen. If an average cloud of kinetic temperature 125 °K has its density increased by 4 or 20, its temperature would fall to 60 or 40 °K respectively according to theory.

2. NEUTRAL AND IONIZED HYDROGEN IN CYGNUS X

Cygnus X, the extended radio source in Cygnus, has been shown to have the spectrum of an H II region with a peak emission measure of about 7000 cm^{-6} parsecs. It is irregular in shape and extends over an area 5 × 10 degrees.

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The neutral-hydrogen absorption spectrum of Cygnus X shows absorption in the first and second spiral arms in this direction. The absorption temperature in the first arm is that expected from a source lying beyond it. In the second spiral arm, however, the apparent absorption effect is twice that accounted for by absorption alone. These results can be explained by the removal (viz., ionization) of neutral hydrogen from the position of Cygnus X to form an H II complex; in which case the density of neutral hydrogen removed may be put numerically equal to the number of free electrons created. The density within the region may then be estimated at approximately 6 cm^{-3}, and the depth at 200 parsecs. This dimension is comparable with the width of Cygnus X. Its density is three times the density found in the center of an average spiral arm.

This region of the sky shows the densest grouping of O and B stars. Several groups lie between 1.5 and 2.0 kiloparsecs and are most likely associated with the radio source. If the frequency (−35 km/second) at which the neutral hydrogen is removed is interpreted in terms of distance, Cygnus X lies at 6 kiloparsecs. The possibility of peculiar systematic velocities makes this estimate rather uncertain especially in view of the optical evidence. If the source were at 6 kiloparsecs it would require eighty type O5 stars. However, at 2 kiloparsecs only ten type O5 stars would be necessary; the observed O-type stars contribute 80 percent of this latter ionizing power. Cygnus X would thus appear to be an extensive low-density region produced by the ionization of a large section of a spiral arm in the direction of Cygnus. Its mass is 10^7 solar masses if situated at 6 kiloparsecs (or 10^6 solar masses at 2 kiloparsecs).

3. THE LOCAL SYSTEM

Studies of the brightest B-stars suggest that the sun lies near the center of a system of early-type stars some 500 parsecs in diameter. Its center lies in the direction of Carina ($l = 240$ degrees). The system is inclined to the galactic plane at 12 degrees [10]. There are 5000 stars in the group brighter than A0 (i.e., $\sim 5 \times 10^4$ solar masses). Some diffuse nebulae also lie along the equator of the local system.

A preliminary analysis has been made of a hydrogen-line survey of the regions within 40 degrees of the galactic plane that have velocities near zero. The region $l = 40$ to 150 degrees will be considered here.

The first step in attempting to detect the existence of hydrogen in a local system was to assume that the background hydrogen was symmetrically placed about the "radio" galactic plane (inclined at 1°.5 to Ohlsson's plane). Local hydrogen was then observed at a given longitude as an excess either at positive or negative galactic latitudes. The results are plotted in Fig. 2 in terms of the number of hydrogen atoms in a 1-cm^2 column in the line of sight.

The analysis was extended for latitudes below 10 degrees over the longitude range 320 to 0 to 220 degrees by using Muller and Westerhout's catalog of 21-cm spectra [11]. As above, the difference between northern and southern latitudes was estimated; it is expressed as the number of hydrogen atoms/cm^2

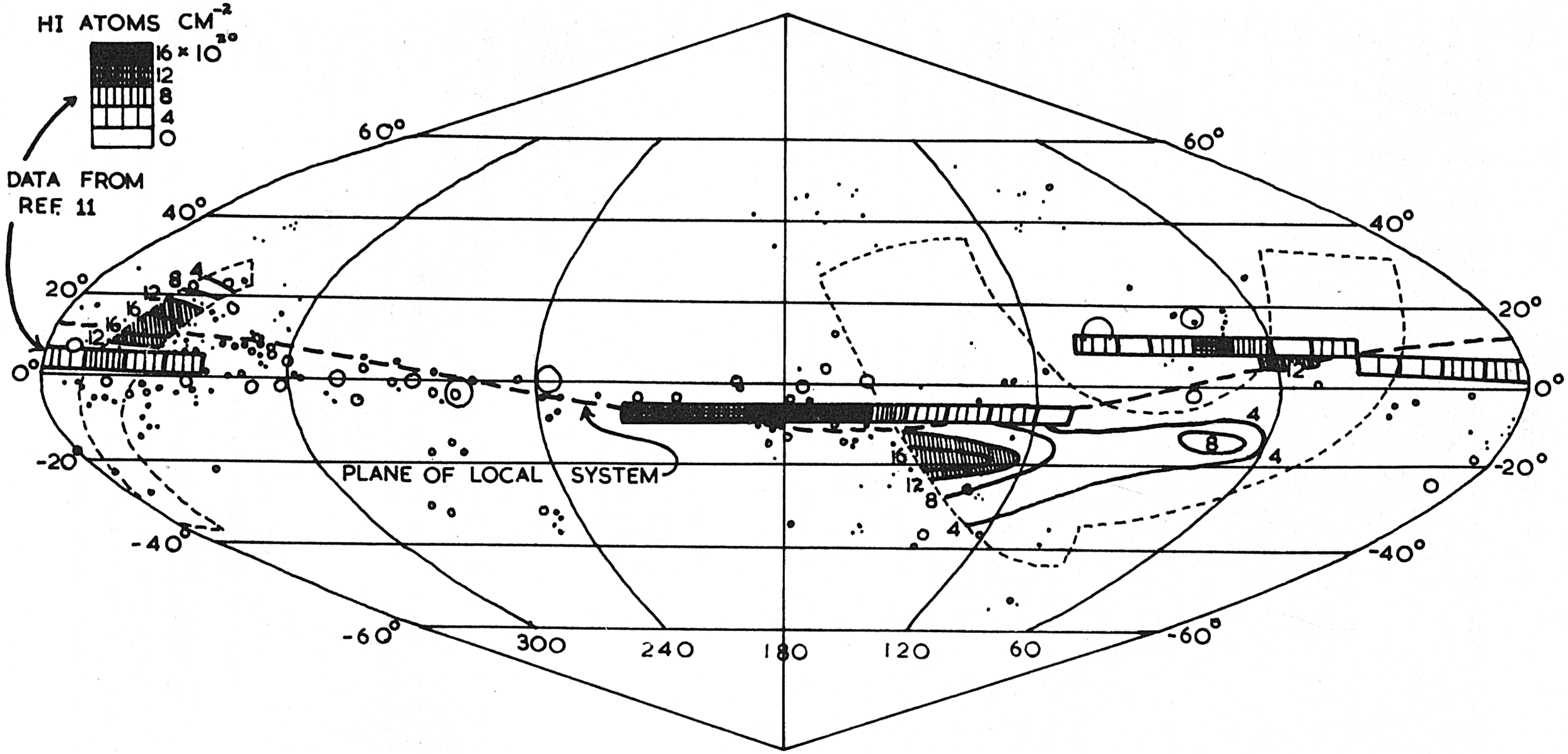

FIG. 2. The local system in galactic coordinates. Contours of excess of neutral hydrogen are given at intervals of 4×10^{20} atoms per cm². Data from reference 11 are also plotted between latitudes 5 and 10 degrees. Obscuring dust clouds (after Lundmark) are shown by circles and dots.

in the line of sight. Fig. 2 also shows the equator of the local system and the distribution of obscuring clouds (after Lundmark [12]).

The deviations of local hydrogen from the galactic plane as seen in the northern hemisphere follow the line of the local system to a first approximation. An estimate of the mass of the system can be made by assuming that the hydrogen is distributed in depth in the same way as the B stars are distributed. The value, which must be regarded as highly uncertain at present, is 10^6 solar masses. This preliminary analysis suggests that the local system containing an excess of early-type stars is rich in neutral hydrogen.

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Discussion

Bok: (1) Why does Dr. Davies depend on drift curves rather than on profiles? (2) How does Dr. Davies distinguish between temperature variations and density variations?

Davies: The Cygnus regions had an angular diameter of a size comparable to a beamwidth and were delineated most clearly on drift curves.

The "cool-cloud" model was used because of the inadequacy of alternative models. For example, removing hydrogen from the deficiency region would give a fall of the brightness temperature of several degrees. The observed effects are tens of degrees. The "cool-cloud" model is strengthened by the association of dust clouds, which can produce the cooling.

Westerhout: I understand that you base your assumption of low temperatures only on the fact that your regions are rather small. Because they are small you do not think they are just local structure. Isn't that dangerous, and couldn't there just as well be hydrogen deficiency rather than such low temperature?

Schmidt: How do you determine the kinetic temperature of the cool regions and how does the derived mass depend on the temperature?

Davies: See reference [2] in my paper.