CO lines because it is situated in the Galactic plane. Further observations of all these projects are planned during 1989.

Molecular observations of a bright carbon star. The third brightest carbon star in the sky at 12 μm, IRAS 15194-5115, is located in the southern sky. It has properties similar to IRC + 10216 (the brightest carbon star and situated in the northern sky), which has a very well studied spectrum with many detected molecules. IRAS 15194-5115 is situated at a larger distance, however. Booth, Johansson, Nyman, Olofsson, and Wolstencroft have observed the IRAS source in many molecular transitions to compare it with IRC + 10216. CO, ^{13}CO, CS, HCN, HNC, HC_3N, C_2H, C_3H, C_4H, C_3N, SiS, and SiC_2 have been detected. The lines are about 10 times weaker than those in IRC + 10216 confirming the larger distance to the IRAS source, but the relative intensities of the molecular lines with respect to the CO (J = 1-0) line intensity are the same within a factor of two between the two sources. Figure 3 shows a CO (J = 2-1) spectrum of IRAS 15194-5115. Preliminary CO maps give a source size of 24″ (deconvolved with the beam) in the CO (J = 2-1) transition and 33″ in the CO (J = 1-0) transition.

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Molecular Clouds and Galactic Structure

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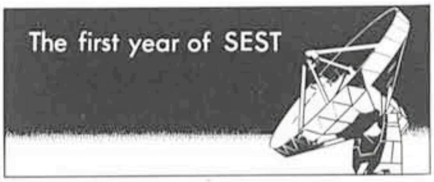

One of the features of the SEST is its sub-arcminute resolution, allowing one to observe molecular clouds at high spatial resolution, as described in a number of the other reviews in this issue. However, the SEST can also be used to investigate the large-scale distribution of the molecular cloud ensemble. Such a study, focused on the outer Galaxy, is the topic of this contribution.

Molecular clouds consist almost exclusively of H_2, which is, however, difficult to detect. CO is the next most abundant molecule in interstellar space, and it has easy-to-observe transitions in the mm-wavelength range. Because CO is primarily excited through collisions with H_2, it is possible to infer the distribution of the latter from that of CO.

The Outer Galaxy

The outer Galaxy, defined as those reaches of our system with galactocentric distances R larger than $R_\odot$ (= 8.5 kpc; the distance of the Sun to the galactic centre), has gained renewed interest as a region of study. From observations of H I emission it has become clear that at $R > R_\odot$ there are large-scale systematic deviations from a flat distribution (called 'warping') as well as a significant increase in the thickness of the gaseous disk (called 'flaring'). Such a morphology is in marked contrast to that of the inner Galaxy, where the atomic gas is confined to a disk of thickness ~250 pc (~120 pc for its molecular counterpart). The same phenomenon is seen in a number of other spiral galaxies, which in turn has stimulated astronomers to have a closer look at their own backyard. Almost all information on the distribution and motion of material at large R has come from observations of H I, mostly because all other "tracers" are confined to the inner Galaxy. It is important, however, to extend our knowledge of the outer Galaxy beyond what can be found from the 21-cm emission. We would like to know, for instance, the distribution and kinematics of the molecular material, an essential ingredient for the study of the influence of a changing galactic environment on star formation.

Much observational work, especially in CO, has already been devoted to the study of individual molecular clouds at $R > R_\odot$. But the larger scale picture suffers from incompleteness. Molecular clouds in the outer Galaxy are much more sparsely distributed than in the inner parts, and the intensity of the emission is generally low. Large-scale surveys, done on a regular grid, are out of necessity carried out with either severe undersampling or low sensitivity, and are in general confined to $|b| < 5°$. These constraints imply that many clouds, especially at larger distances, will be missed due to beam dilution, or due to the galactic warp.

IRAS sources

A representative view of the population of molecular clouds in the outer parts of the Galaxy can only be obtained if one knows where to look, such that the chance of detecting a CO emission line is high. In this way even a large telescope like the SEST can be used to derive the large-scale distribution of molecular gas. Jan Wouterloot (now at the University of Köln) and I searched for CO in the direction of a large sample of IRAS sources in the outer Galaxy, in a project started in September 1987 (when we used the SEST in test time, and we were both at the MPIfR in Bonn). These sources were selected from the IRAS point source catalog, on the basis of their colours, as having a high chance of being associated with regions of star formation. As all star formation takes place in molecular clouds, these IRAS sources act as flags for the location of the clouds in which they are embedded. A number of these IRAS sources are located close to optically visible H II regions, but many are not. The latter could be (ultra) compact H II regions, or be associated with a pre-main-sequence object.

In order to account for the galactic warp, the sources were selected in a latitude range between +10° and −10°. Initially the longitude range of the sample was chosen to be between 165° and 280°, and was later extended down to l = 85°, using the IRAM 30-m telescope.

Spatial Distribution

CO was detected towards 1077 (83 %) of the 1302 sources selected in this way. We found CO emission towards these sources at velocities of (absolute values) up to 110 kms^{-1}. This is quite a difference with uniform-grid surveys, or surveys of optical H II regions, where very little emission, if any, is found at velocities in excess of 50 kms^{-1}. Using a rotation curve (i.e. the relation that gives the velocity of rotation around the galactic centre as a function of R, assuming all objects are in circular rotation), a kinematic distance could be derived for each CO emission component. In terms of distance, we found CO emission up to 15 kpc from the Sun, and out to R ≈ 20 kpc. In many cases more

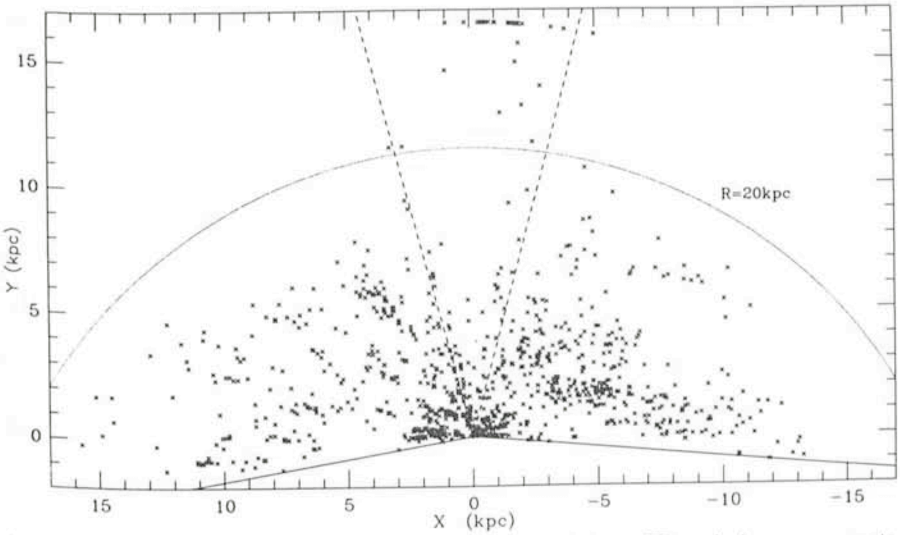

Figure 1: *Distribution projected onto the galactic plane of those CO emission components associated with the selected IRAS sources. The Sun is at (0,0); the galactic centre at (0,−8.5). The full-drawn lines show the longitude limits of the sample. The dashed lines mark the region within 15° of the anticentre where kinematic distances are very uncertain; objects in this region are excluded from the final sample used in the data analysis.*

than one emission component was found towards a particular IRAS source. Identifying the one that is associated with the IR source usually did not pose a problem, as one of the components was always stronger and broader than the others. Most of the not-associated emission comes from local ($d < 1$ kpc) clouds.

Figure 1 shows the distribution on the galactic plane of the CO emission associated with the IRAS sources. The dashed lines mark a region near $l = 180°$, where kinematic distances are very uncertain. Note that very few clouds are at $R > 20$ kpc. Because the sample was chosen such that the IR sources had colours of star-forming regions, we conclude that no star formation takes place at distances larger than that (otherwise we would have detected it).

We also see that distant objects are found more or less evenly distributed in longitude. There are more molecular clouds with embedded IR sources in the second quadrant than in the third. In the second quadrant a concentration of clouds occurs around $R = 12$ kpc, which we associate with the Perseus arm. No large-scale spiral arm feature can be distinguished which extends over both galactic quadrants.

The distribution of the CO emission perpendicular to the plane shows that the molecular material partakes in the galactic warp, with clouds reaching heights of 800−1000 pc at the largest distances. Similarly, the molecular gas disk shows an increase in thickness with increasing R, eventually approaching that of the HI.

Sources that would have a flux S (25 μm) > 0.25 Jy if they were at $d = 15$ kpc, would be visible over the whole range of distances where CO emission was found. Excluding those around $l = 180°$ (see Fig. 1), this sample contains 416 IRAS/CO sources (i.e. molecular clouds), which were used to derive the distribution of H_2.

Assuming that the number of far-IR sources per unit of H_2 mass is constant (as indicated by a preliminary study), we can derive the surface density of H_2 ($\sigma(H_2)$) as a function of R, by calculating the number of IR sources per square pc, and scaling the value at $R_\odot$ with the value of $\sigma(H_2)$ at that location. We find that $\sigma(H_2)$ decreases from a value of 1.80 $M_\odot pc^{-2}$ at the Sun, to 0.64 $M_\odot pc^{-2}$ at $R = 14$ kpc, to 0.015 $M_\odot pc^{-2}$ at $R = 20$ kpc. This decrease is much slower than what was derived from earlier, general-sampling CO surveys. From our data, we derive a total mass of $5.8\ 10^8\ M_\odot$ residing in H_2 clouds at $R > R_\odot$.

This project shows how the SEST can be used to increase our knowledge of an important aspect of our Galaxy, the large-scale distribution of molecular clouds. The dataset contains of course much more information, which space unfortunately does not permit me to write about; a detailed account of this work has been submitted to *Astronomy and Astrophysics*.

It's a pleasure to thank ESO and the staff at the SEST for providing and maintaining this very user-friendly telescope, and Jan Wouterloot for making improvements on the manuscript.

The Galactic Centre

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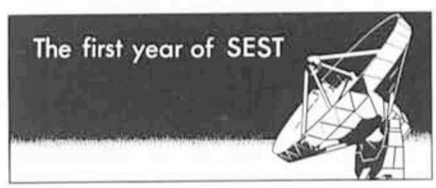

One of the most interesting and mysterious regions of our Milky Way galaxy is the Galactic Centre (GC). Lying at a distance of 8.5 kpc in the direction of Sagittarius, it is best observed from the southern hemisphere. However, great masses of intervening dust in the plane of the Galaxy produce 30 magnitudes of absorption and the GC is not observable in the optical region. Most of the knowledge that we possess about the GC has been obtained at infrared and radio wavelengths, using northern hemisphere telescopes. These observations are often hampered by the low elevation of the object, resulting in atmospheric problems and short observing sessions. With its declination of about −30°, the GC becomes almost a zenith object at transit over La Silla and is therefore well suited for studies with SEST.

The inner ten parsecs of the Galaxy contain a giant molecular complex which surrounds the strong continuum radio sources at the nucleus, known collectively as Sgr A. This region somewhat resembles the nuclei of more active galaxies (even to the extent of possibly containing a $3\ 10^6$-$M_\odot$ black hole) and its proximity to us is of course a great advantage, making possible observations with high spatial resolution. The inner one hundred parsecs of the Galaxy contain more exotic objects, such as continuum threads, filaments and arcs, as well as the most significant star-formation region in the Milky Way, namely Sgr B2.

Four GC projects have been in progress during the first year of SEST and more are in the offing in the near future: