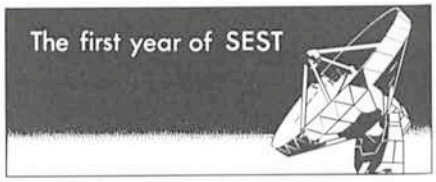
Interstellar Chemistry



P. FRIBERG, Onsala Space Observatory, Sweden

The research regarding interstellar chemistry with SEST can be divided into three categories: (i) searches for new molecules, (ii) studies of known molecules in order to shed light on their formation, and (iii) spectral scans – systematic observations of large frequency bands in a few interesting sources. Spectral scans give a good overview, not only of the chemical content, but also of physical traits. Typical excitation temperatures for different species give a handle on the kinetic temperature. The variation of excitation temperature with energy level and/or molecular state reveals regions of different temperature and density inside the beam (point-spread function) of the telescope. Of course, unidentified lines and unexpected molecules are also found.

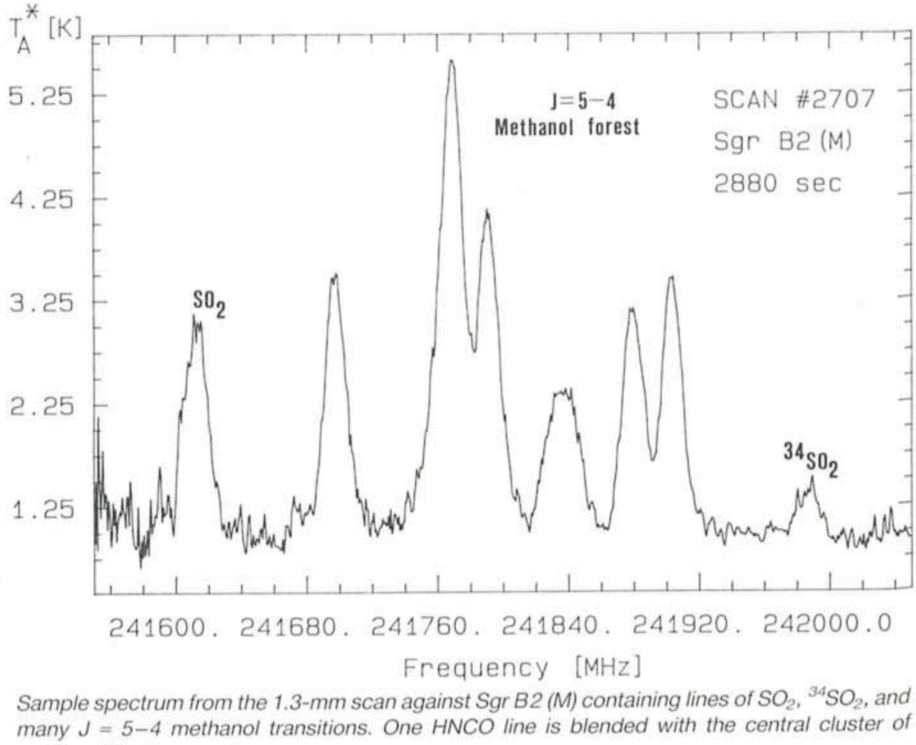
Two searches for new molecules have to my knowledge been done. Both searches only set upper limits on the abundance, i.e. neither molecule was detected. Gerin et al. (1989) searched for HCOCN in Orion and Sgr B2. They determined that HCOCN is less abundant than other large organic molecules such as cyanoacetylene (HC_3N) and methyl formate ($HCOOCH_3$). Irvine et al. tried to confirm the existence of propadienone (H_2C_3O) in Sgr B2 by observing several adjacent rotational transitions. One transition, observed at Nobeyama, had previously been tentatively assigned to propadienone. The previously observed line was confirmed but one of the adjacent rotational transitions was missing and two others were doubtful due to blending with other lines. Hence, in contrast to its isomer, propynal (HC_2CHO), propadienone has not been detected in the interstellar medium.

However, observations at 80 GHz ($\lambda \approx 3.7$ mm) led to a possible detection of another molecule, deuterated water (HDO), in Sgr B2. Observations of deuterated molecules towards the Galactic centre are very rare. Determining the abundance of deuterated molecules close to the Galactic centre can help to determine the Galactic deuterium gradient and resolve the question of non-cosmological deuterium formation. Since at least 15 other lines appeared in the same 500 MHz wide spectrum the risk for an accidental coincidence is very big. However, the tentative identification is supported by 1.3 mm observations (see later).

To try to understand why protonated carbon dioxide ($HOCO^+$) is only observed towards clouds close to the Galactic centre (Sgr A and Sgr B2 clouds), Minh et al. have mapped Sgr A in the $4_{04}-3_{03}$ rotational transition ($\lambda \approx$ 3 mm). It turns out that $HOCO^+$ is distributed like more commonly encountered molecules. Hence the reason for the unique abundance of $HOCO^+$ in the Galactic centre clouds affects the bulk of these clouds. The investigators argue that the most probable reason is that the Galactic centre clouds encounter more frequent shock waves in which the parent molecule carbon dioxide (CO_2) can be formed from CO and OH. The carbon dioxide is then protonated by reactions with H_3^+, N_2H^+, . . . Since other protonated molecules are not unusually abundant in these clouds, the high $HOCO^+$ abundance is traced to CO_2 and not to the protonating species H_3^+, N_2H^+, . . .

Spectral scans at the 1.3-mm range of Sgr B2 and LMC are also in progress. The observations of LMC by Johansson et al. provide a good test of the assumptions in chemical model calculations because of the lower metallicity in LMC. The observed $C^{18}O/^{12}CO$ line intensity ratio is close to 1/500 (much lower than the value observed in the Galaxy but equal to the terrestrial $^{18}O/^{12}C$ isotope ratio) while the observed $^{12}CO/^{13}CO$ line ratio is close to the "Galactic" value of five. The interpretation is not easy since the ratios are affected not only by the curve of growth and carbon isotope ratios but also by cloud structure and self shielding against UV dissociation. Hence, the apparent non Galactic $C^{18}O/^{12}CO$ line intensity ratio may be due to the lower metallicity in the LMC and not to differences in isotope ratios.

The scan in Sgr B2 (Bergman et al.) has so far covered the range between 238.85 to 243.85 GHz (5 GHz). Three positions are observed in the Sgr B2 cloud – two active regions with signs of on-going massive star formation (compact H II regions, OH and H_2O masers) and one position in the ambient cloud. While the spectra are very rich towards the active regions with about 15–30 lines per GHz, the line density is only 4 lines per GHz towards the ambient cloud position. The spectra towards the active regions are dominated by lines from methanol, methyl cyanide (vibrationally excited), and ethyl cyanide. It is also apparent that the northern of the two active regions (Sgr B2 (N)) contains the hottest material since the spectra contain lines from transitions between states of much higher energy than towards the other active region. The estimated temperature of the hot gas is 100–130 K and 60–80 K for the northern and southern region, respectively.



Sample spectrum from the 1.3-mm scan against Sgr B2 (M) containing lines of SO_2, $^{34}SO_2$, and many J = 5–4 methanol transitions. One HNCO line is blended with the central cluster of methanol lines.

The southern active region Sgr B2 (M) exhibits pronounced emission from SO_2. About 20% of the lines have not been identified and the identifications of at least another 10% are very questionable. It has to be stressed that the work to identify the lines is far from completed yet. One of the lines preliminarily identified is another HDO line, which supports the identification at 80 GHz. Still the line density is high enough to make a two-transition identification doubtful. We hope to be able to confirm the HDO identification in our next observing run (June 1989).

References

Bergman, P., Friberg, P., Hjalmarson, Å., Irvine, W.M., Millar, T.M., Ohishi, M. (in progress).

Gerin, M., Combes, F., Encrenaz, P., Destombes, J.L., 1989, *The Messenger* No. **56,** p. 59.

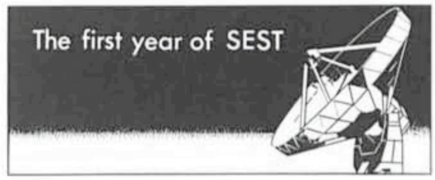
Irvine et al. (in preparation).

Johansson, L.E.B., Olofsson, H., Hjalmarson, Å., Gredel, R., 1989 (private communication).

Minh, Y.C., Irvine W.M., Friberg, P., Johansson, L.E.B., 1989, *Ap. J.* (in press).

Evolved Stars

L.-Å. Nyman, SEST, La Silla



Introduction

Studies of evolved stars using sub-mm and mm-wave telescopes such as the SEST are mainly concerned with the very last stages of the life of a star, when it throws away its outer envelope and is surrounded by a shell of dust and gas. The dust obscures the star optically and most studies of stars at this stage of their evolution have been made in the radio and infrared regions of the spectrum. The circumstellar gas consists mainly of molecular hydrogen, H_2, but also of other less abundant molecules (e.g. CO, SiO, OH, H_2O, HCN, etc.), which are important since they radiate in the radio region, something that is not these case for molecular hydrogen. These molecules can be used to study the properties of the circumstellar envelope (CSE), e.g. to determine mass-loss rates, which are important for the evolution of the star, and to study the chemistry of the envelope.

These studies are important because the envelope contains processed material from the interior of the star that is now returned to the interstellar medium. The material will eventually be incorporated into new stars, making our Galaxy evolve chemically. The mass loss is important for the evolution of a star, since its end point is determined by how massive it is. A star with a mass $> 1.4\ M_\odot$ should end as a supernova, but because of the extensive mass loss in the final stages of its life, even a star of $10\ M_\odot$ will lose enough mass to put it below this limit, and it will end as a planetary nebula and later as a white dwarf. Many of the observations with the SEST telescope have been made of stars at different stages in the final point of their lives and a brief summary of stellar evolution will be given below.

Stellar Evolution

Stars with masses $< 10\ M_\odot$ spend most of their lives on the main sequence, quietly burning hydrogen to helium in the core. When the hydrogen is exhausted in the core, the star moves up the Red Giant Branch (RGB) burning helium in a shell around the core, which is contracting and becoming hotter and hotter. Finally it is hot enough for helium to start burning, and the star moves to the horizontal branch burning helium to carbon and oxygen. Eventually the helium is exhausted in the core and the star starts to move up the Asymptotic Giant Branch (AGB). At this stage it consists of a degenerate carbon-oxygen core surrounded by a thin helium burning shell.

It will now reach a phase in its life where many things will happen on a relatively short time scale. When all the helium in the core has been converted to carbon and oxygen, hydrogen and helium will start to burn alternately in a thin shell around the core. Every time a critical mass of helium has been processed from the hydrogen burning it ignites with a flash, a thermal pulse (TP). Between the helium flashes a deep convection layer brings up processed material to the surface of the star and it may even change its composition from being oxygen-rich to carbon-rich. The star will also become unstable and start to oscillate. The pulsations will form shock waves in the photosphere, supplying energy to lift the gas to regions that are cool enough for dust formation. The radiation pressure on the dust will accelerate it away from the star dragging the gas along with it, forming an expanding CSE.

In the final stages of the AGB the mass loss increases rapidly and a superwind occurs. Almost all the matter in the hydrogen envelope is stripped from the star. The remnant core contracts rapidly at constant luminosity and the ejected material drifts outward. When the surface temperature is hot enough to produce UV photons, the ejected gas is ionized and a planetary nebula (PN) is formed. Eventually the gas disperses and the star will become a white dwarf.

Since the star is surrounded by a thick dust shell during the last phases of its life, it is difficult to study it optically. The

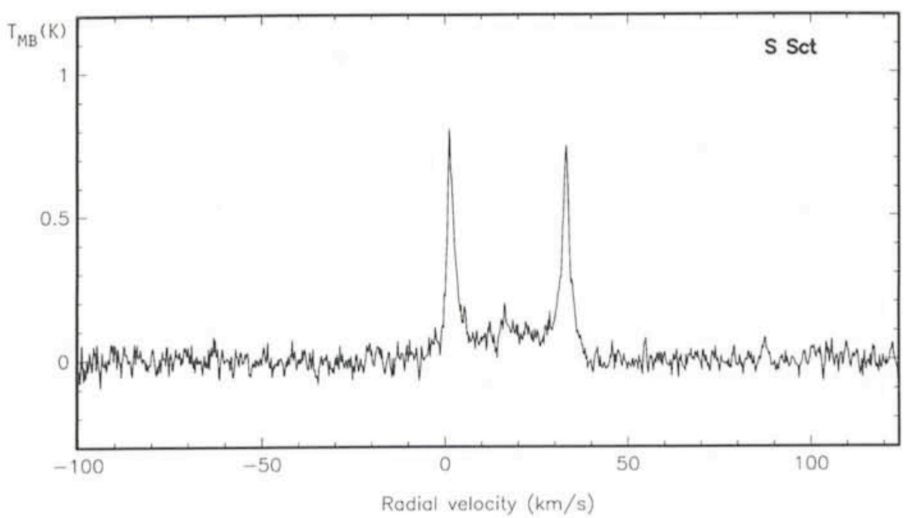


Figure 1: *A ^{12}CO (J = 1-0) spectrum of the bright carbon star S Sct. The double-peaked line profile and the map data suggest that the circumstellar envelope is detached from the star, i.e., its mass loss has decreased considerably during the last few thousand years. This may be an effect of a thermal pulse during the AGB evolution.*