EFOSC, the ESO Faint Object Spectrograph and Camera, has also a multi-object spectroscopic mode (see the *Messenger* No. 38 for a description of the instrument).

A file containing the coordinates needed to punch an aperture plate can be created by identifying the targets on a CCD frame (5 × 3 arcminutes in size) obtained with the same instrument. Up to 11 plates can be mounted at one time on the EFOSC aperture wheel. In the March test, a plate with holes corresponding to positions of peculiar H II regions in M 83 was prepared in the La Silla workshop and used successfully in the following night.

This observing mode will be offered to the users as of April 1, 1986.

A detailed description of the results of the tests and the operating manuals of OPTOPUS and EFOSC will be available by next fall.
S. D'Odorico

Submillimetre Spectroscopy on La Silla

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1. Of Pearls and Swine

Who would play a Stradivari violin at a country dance? Or who would mix very old Scotch with Coca-Cola? Not us. But we do things that look equally improper in the eyes of many astronomers. We employ fine optical telescopes to observe at submillimetre wavelengths, although for our purposes the surface accuracy of the mirror could be 1,000 times worse. One excuse which we (and the ESO Observing Programmes Committee) can offer is that at present there are no submillimetre telescopes that we could use instead of the optical ones. We believe that one can get information about star-forming regions through submillimetre observations that cannot be obtained by other means. This article is an attempt to convince you that this is the case.

2. The Value of Submillimetre Spectroscopy

There is a gap in observational astronomy between 20 μm and 1 mm that is only gradually beginning to be filled. This has two major causes. Firstly, the atmosphere is generally opaque because of water vapour and only in a few windows are observations possible from dry, high-altitude sites. La Silla is such a place. Secondly, up till a few years ago receiver technology at these wavelengths was not very advanced. However, all cold objects with temperatures below, say 50 K, emit predominantly at far infrared or submillimetre wavelengths. Molecular clouds are an example. H_2, CO and more complicated species can form, if they are shielded by a few magnitudes of visual extinction from the energetic UV photons of the interstellar radiation field, which would otherwise dissociate the molecules. This shield is supplied by dust grains. Many of the astrophysically relevant atomic and molecular transitions lie in the submillimetre region. The whole problem of the early stages of star formation depends observationally on infrared and submillimetre astronomy, because protostellar clouds are completely opaque in the optical. While far infrared and submillimetre continuum measurements can determine the luminosity of a protostellar object, spectroscopic observations yield information on the kinematics of the gas, necessary to understand the collapse, and on the temperature and density structure as well.

CO is a key molecule in the study of the interstellar medium. It is abundant, easily excited and readily observed in its ground rotational transitions. They are labelled by their quantum number J of the upper and lower level. The lowest transition J = 1–0 occurs at 2.6 mm wavelength. It is always optically thick in the line centre. However, due to velocity shifts of the gas through turbulent and systematic motion one can also look into the cloud and detect the warmer and dense regions around embedded stars. The radiation of these young or even pre-main-sequence stars is absorbed by the dust. The dust is at densities of more than 10^5 atoms per cm^3 thermally coupled to the gas and heats it. Such regions show an enhanced CO line temperature and are therefore called hot spots.

The J-th rotational level of CO lies 2.8 J (J + 1) degrees Kelvin above the ground level. A comparable gas temperature is needed for its excitation. So in the CO ground transitions one mainly sees the cool gas away from the heating sources. For the study of star formation one wishes to penetrate as closely as possible to the protostar. The J = 4–3 line at 0.65 mm wavelength already needs an excitation of 55 K. Gas at such a temperature is found only in the vicinity of an embedded star. It is part of the protostellar cloud and its dynamics is dominated by the gravitational pull of the central object. The kinematics strongly influence the shape of the lines. Systematic motions which encompass the whole protostellar cloud, such as accretion, rotation or outflow, may be present together with chaotic or turbulent motions. Other effects, which are also

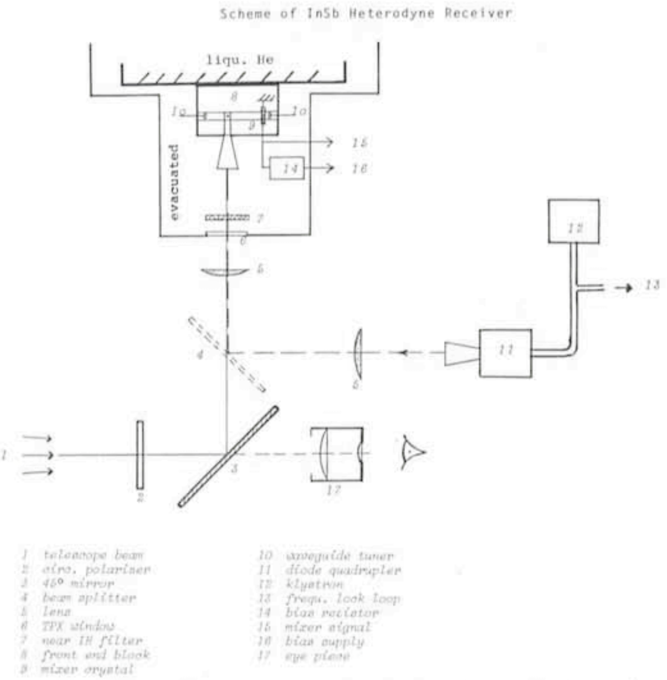

Fig. 1: *Schematic drawing of the Indium Antimonide heterodyne mixer receiver (0.65 mm wavelength). The crystal sits within a front-end block with a horn antenna and a tunable waveguide circuit; its dimensions are 0.04 × 0.04 × 0.2 mm. The local oscillator is a microwave klystron plus a Schottky diode quadrupler. Matching of the telescope beam to the beam shape of the horn antenna is done with lenses. The 45° mirror can be quickly exchanged by an eyepiece for optical pointing.*

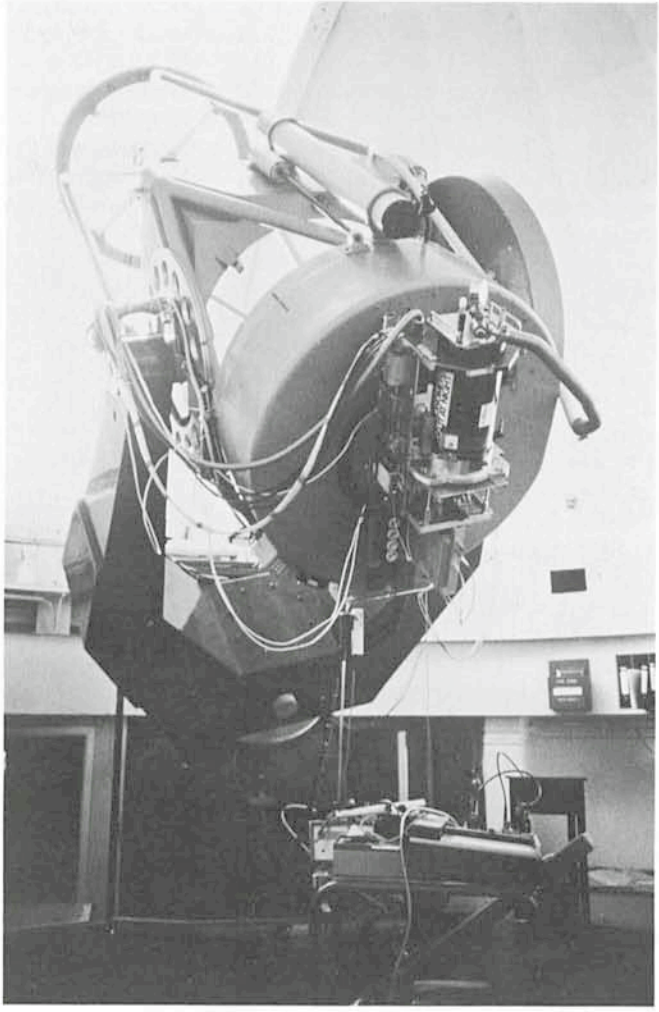

Fig. 2: *Our Indium-Antimonide submillimetre receiver mounted on the ESO 1 m telescope. The tiny receiver crystal is mounted within the black Helium dewar (cooled to 2 K). The feed optics underneath the dewar cannot be seen, left of the dewar is the local oscillator plate; pipes are for pumping on the Helium.*

important for the line shape, depend on the details of radiative transfer. For the submillimetre CO lines there is always the possibility of self-absorption in the line by cooler foreground material.

For a meaningful analysis of the CO cloud one has to combine the data of all lines available, including the optically thinner isotopic species. The most widely observed is $^{13}C^{16}O$, which is about 80 times less abundant than ordinary $^{12}C^{16}O$. Therefore optical depth effects do not play such an important role. This greatly simplifies the interpretation of the isotope lines. Unfortunately, the ^{13}CO J = 4−3 line cannot be observed from the ground. Although only 5 per cent shifted in frequency relative to ^{12}CO, it does not fall into an atmospheric window.

3. The Receiver

Our system is an indium-antimonide (InSb) receiver. At its heart is a semiconducting InSb crystal cooled by liquid helium to 2 K. At that temperature the electrons are only weakly coupled to the crystal lattice. When they absorb submillimetre photons, they increase their mobility and thus the conductivity of the crystal. The radiation of the astronomical object is mixed with that of the local oscillator (LO). The system has the inherent disadvantage that the resulting intermediate frequency (IF) has a bandwidth of only 1.5 MHz. For spectroscopy the LO therefore has to be scanned through a certain frequency range. We use a klystron as LO and multiply its frequency with a diode quadrupler. On the telescope we work at 460 GHz or 0.65 mm wavelength. Frequency drive telescope control, data stroring and processing are done with our own Hewlett-Packard 1000 computer. Fig. 1 displays the receiver schematically. We typically observe at 70 frequency points spaced at 1.5 MHz and thus have a velocity resolution of 1 km/s. The frequency range is scanned through ten times for about 10 s each, before the telescope is switched between ON and OFF position. We do not employ a chopping mirror.

The receiver has a system temperature of 800 K. It is small and light and technically simple, when compared to the future generation of diode mixers. Very important for a new spectral range, the receiver has also been well tested on the telescope under astronomically realistic conditions. Submillimetre nights are rare, everywhere. According to the very incomplete weather statistics, at best 20 per cent of the time can be used. When the sky is good for submillimetre astronomy, the observer is naturally tempted not to "waste" time on testing the system, but to do proper astronomy. However, spectroscopy is treacherous. We found that out once, while our system had not been fully tested: Looking at the well-known infrared and outflow source IRC 10216, we believed to have detected a line. Strength, width and shape looked reasonable. However, as we learned later, it was not a line, but just an artifact caused probably by reflections in the dome. In the meantime we have debugged and improved the system so that we feel safe to trust the data now.

4. Happy Faces

In July 1983 we had been granted seven nights both on the 1 m and on the 3.6 m telescopes. Such generosity is necessary for submillimetre observations considering the weather risk and the effort that goes into the mission: Three astronomers, the authors and A. Gillespie, an indispensable technician, F. Lauter, plus 700 kg of equipment had to be flown to Chile. Gillespie is the man who deserves the credit for starting the project at our Max-Planck Institute in Bonn five

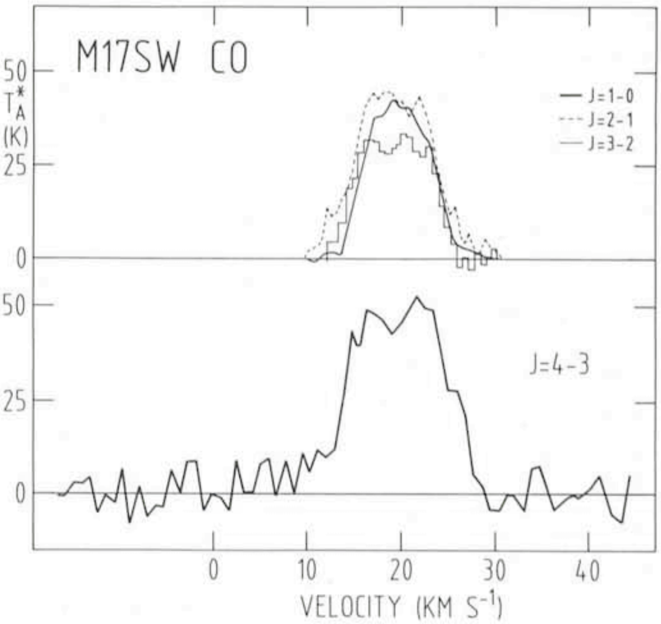

Fig. 3: *Our spectrum (bottom) of the CO J = 4−3 line in IRc 1 located in the molecular cloud M 17 SW. The top shows for comparison lower transitions observed with comparable resolution. References to them are given in Schulz et al. (1985,* Astron. Astrophys., *in press).*

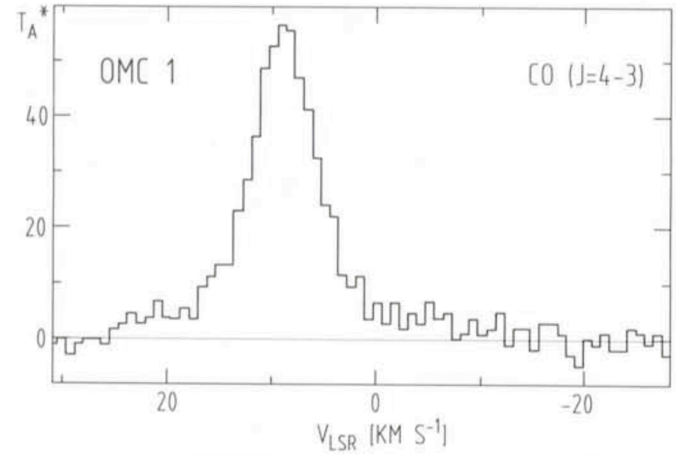

Fig. 4: *The J = 4–3 transition of CO in the Orion nebula (OMC 1). Two distinct components of the line can be seen emitted by two different parts of the cloud: a narrow and bright spike and—due to a large velocity dispersion—a very broad pedestal (the line wings).*

years ago. Meanwhile British industry has lured him away from astronomy.

The time on the 1 m was spent on testing the instrument (Fig. 2). On the 3.6 m we got two submillimetre nights; interestingly, they were not photometric. Only the extremely low humidity of 5 % indicated a very low water absorption column. Up till then only Orion had been seen in the CO J = 4–3 transition. Of course, there must be other such sources in the sky, but we were not sure that we could detect them. Orion is exceptional in a number of ways. As hot spots, the regions emitting the CO J = 4–3 line might have a small angular diameter and pass undetected because of beam dilution. Orion was for us a morning object, so we started with the infrared source IRc 1 in the molecular cloud called M 17 SW. It lies south-west of the giant young H II region M 17. The lower CO rotational transitions have their highest intensity towards IRc 1. We took our chance and were lucky. The detection was a gratifying experience; it was the first outside Orion. Now we know that this line is not uncommon and can be detected even with smaller telescopes at the price of lower spatial resolution. The spectrum of M 17 is shown in Fig. 3. Back in Bonn we constructed radiative transfer models for the propagations of the photons in the lines until our spectrum and those of the lower and isotopic (^{13}CO J = 1–0) transitions could be matched. The result was that the gas is not heated by the infrared object, which is probably a B0 star immersed in the molecular cloud, but by the O stars which excite the H II region. We concluded this because our models did not allow a temperature gradient in the cloud, as would be expected in the case of an internal heat source. We also found from the model that the gas does not have a systematic velocity, such as infall or outflow, but that it is highly turbulent and that the turbulence and the gas density peak towards IRc 1.

5. Outlook

CO submillimetre line observations have become possible only of late. One can expect them to give us clues about the environment of protostars. The J = 4–3 line is of particular interest. It comes from gas with temperatures which probably prevail in protostellar clouds. It also lies in an atmospheric window much less demanding than that of the next higher transitions (J = 6–5, 7–6), which are only observable from the ground under exceptional weather conditions. CO J = 4–3 spectroscopy will be a major activity with future submillimetre telescopes. Meanwhile we have to content ourselves with optical instruments.

To finally illustrate that one is already able to produce high quality measurements we present in Fig. 4 our spectrum of OMC 1: the plateau (broad wings) can clearly be seen. We hope that with such data we will be given another chance on La Silla.

Spectroscopy of Horizontal Branch Stars in NGC 6752

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1. Why a Globular Cluster

Globular clusters sit in the galactic halo as the most noticeable relics of the early epochs of galaxy formation. Being the oldest objects known and the only structured survivors of the complex initial galactic phases, they are the natural place where to look for information on the chemical composition of the matter emergent from the big bang (at least in first approximation).

One finds immediately that the heavy element (that is, elements heavier than helium) content is much in excess of what can be expected from a standard big bang nucleosynthesis. In fact, one observes in globular clusters a fraction by mass of elements from carbon on of at least 1.E–4, against a predicted abundance of about 1.E–12. Perhaps the easiest way to explain this pollution is in terms of globular cluster formation out of material enriched by the very first, metal-free stellar generations (Ref. 1).

At variance with what is believed for the heavy elements, the helium content in globular clusters is thought to be very close to the amount produced in the first three minutes of universal expansion. This belief rests on the difficulty of making (or destroying) large amounts of helium in "normal" stars (Ref. 2). So globular cluster members are the natural targets for an investigation on primordial helium. The best candidates are, in principle, the unevolved main sequence stars, but, unfortunately, no helium line is observable in these cool objects. The low surface temperature prevents observation also in red giants, so that only hot horizontal branch (HB) stars (that is, on the left side of the RR Lyrae gap) give the opportunity for helium detection.

However, the situation is not straightforward even for these objects. First of all, they are faint or very faint: $V \gtrsim 13.5$, so that only modern technology allows to reach them; secondly, it is necessary to know the effective temperature with good accuracy to obtain reliable abundances. This is a practically impossible task on the basis of observations in the U, B and V domains only; in fact, we are dealing with stars with effective temperatures of 15,000°K or more, for which the peak of emission falls below 2000 Å.