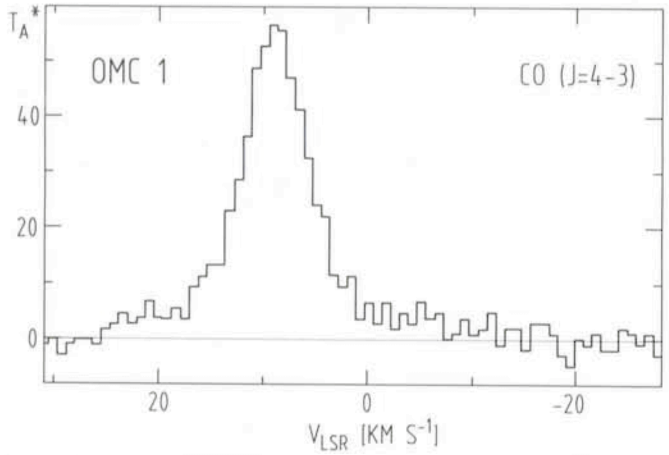

Fig. 4: *The J = 4–3 transition of CO in the Orion nebula (OMC 1). Two distinct components of the line can be seen emitted by two different parts of the cloud: a narrow and bright spike and—due to a large velocity dispersion—a very broad pedestal (the line wings).*

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.

2. Why NGC 6752

This cluster is especially interesting. It exhibits the most developped blue "horizontal" (actually vertical) branch known at present (Fig. 1), with no RR Lyrae variables. It is therefore a good example of the so-called "second parameter" problem, which consists in a violation of the general rule for HB morphology: "the lower the heavy element abundance, the bluer". On the contrary, NGC 6752 has more heavy elements than clusters such as M15 or M92, which have much shorter HBs with a not negligible population of RR Lyrae variables. (See Refs. 3 and 4 for reviews on globular clusters.)

Since so much of our knowledge on the early phases of the universe rests on an understanding of globular cluster evolutionary status, an exhaustive investigation of this peculiar cluster, with special reference to the HB problem, was started by a group of astronomers from several European institutions. The cluster is being studied from many points of view: (i) a statistically significant C-M diagram (Ref. 5); (ii) spectra in the optical range for HB stars obtained from ESO and AAT telescopes, analysed through synthetic spectra procedures (Refs. 6 and 7); and (iii) spectra in the far UV by means of the IUE satellite to finally overcome the difficulty in temperature determination for hot HB stars (Refs. 6 and 7).

Until now, almost 20 HB star spectra in the optical range and with intermediate dispersion have been obtained (mostly at the ESO 3.6 m telescope); 8 of these stars have been observed with IUE, mostly in the SW range (1200 Å–2000 Å). Incidentally, the SWP spectrum for the faintest object – V = 17.76 – ever observed with IUE was probably obtained in the course of this programme.

Fig. 2 exemplifies the procedure to achieve a reliable evaluation of effective temperatures for stars with an IUE spectrum.

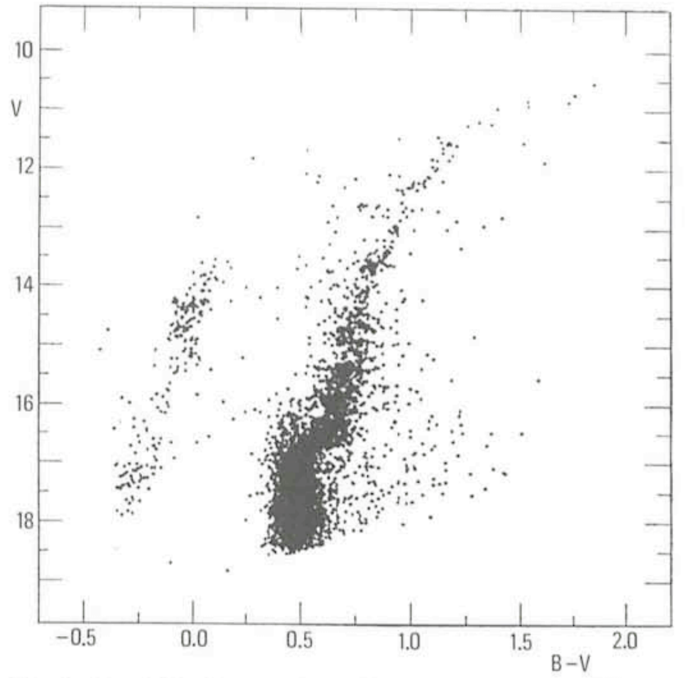

Fig. 1: *The C-M diagram for NGC 6752 recently obtained by Buonanno et al. (Ref. 5). Note the exceptionally developped "horizontal" branch that stretches below the turn-off magnitude: a unique case up to now.*

When the absolutely calibrated SWP spectrum is fitted to the V magnitude and is compared to theoretical predictions from stellar model atmospheres (Ref. 8), the effective temperature

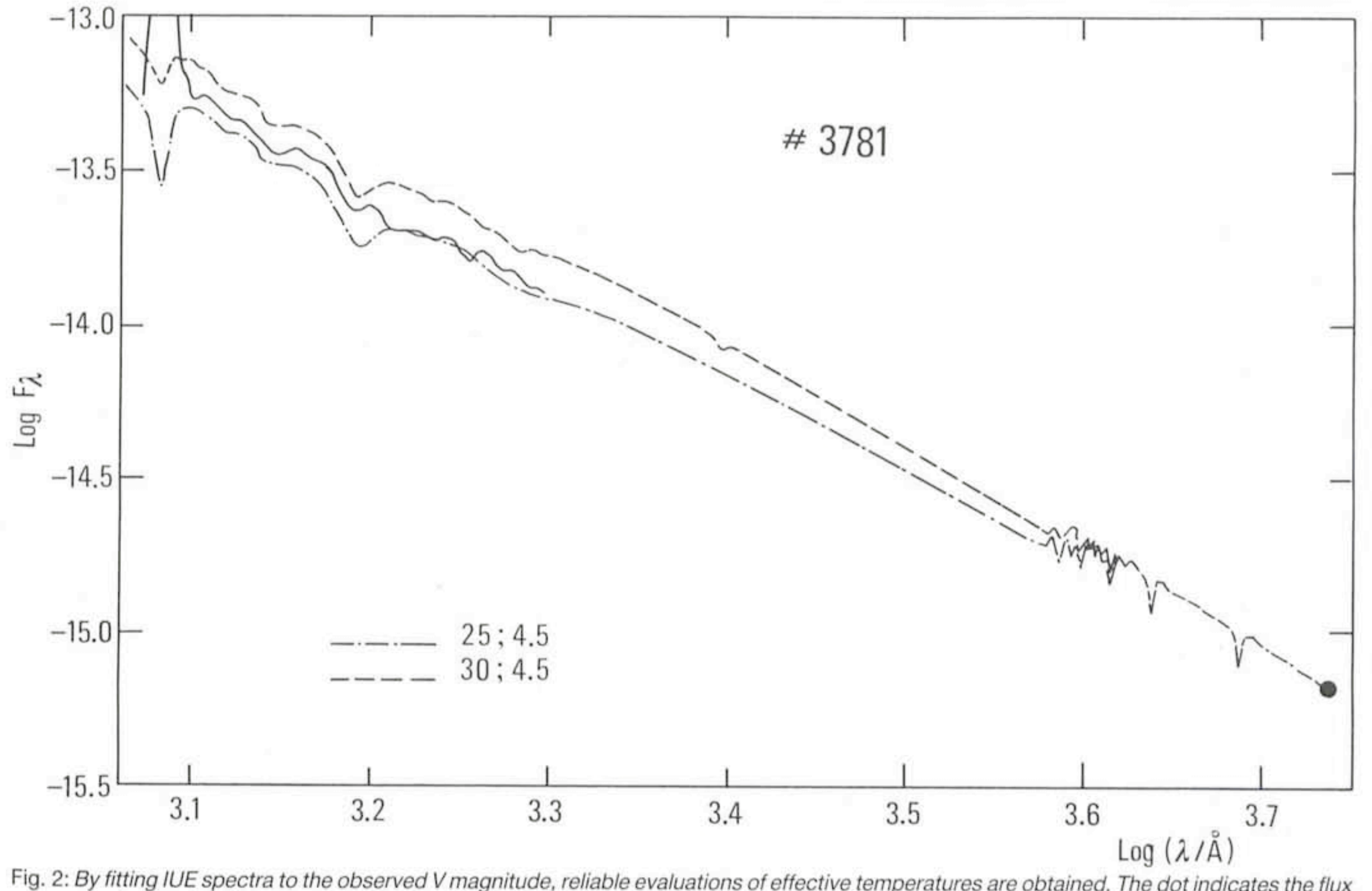

Fig. 2: *By fitting IUE spectra to the observed V magnitude, reliable evaluations of effective temperatures are obtained. The dot indicates the flux corresponding to the visual magnitude; the IUE SWP spectrum (after rebinning in bands of 40 Å) is also shown (continuous line). The two comparison spectra are taken from Kurucz model atmospheres at the indicated temperatures (in units of 1000°K) and gravities (logarithm of).*

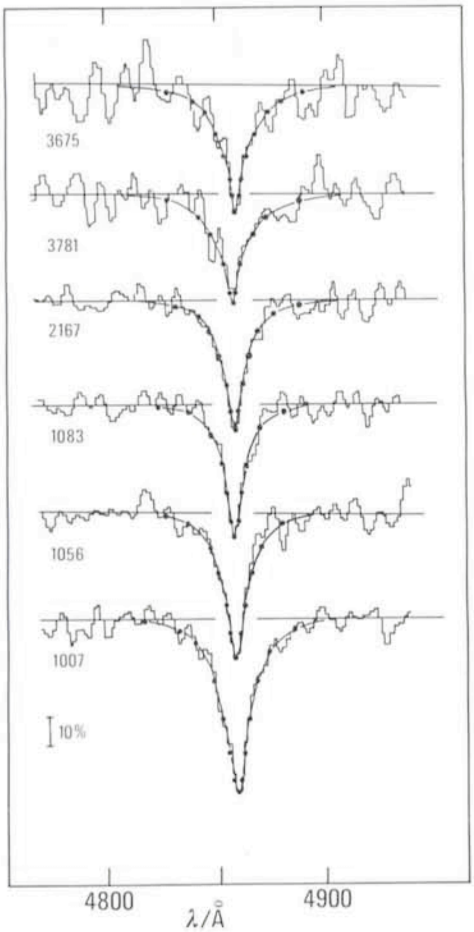

Fig. 3: *Theoretical line profiles fitted to the observed Balmer lines in hot HB members of NGC 6752. Once the effective temperature is known from IUE observations, gravity is determined through the detailed fits of Hβ (in the figure), Hγ and Hδ.*

(T_e) can be determined to within 1,500°K or less. It is a very satisfactory accuracy for these objects, especially those with V > 16, which up to now were collectively classified as having T_e about 25,000°K.

The knowledge of T_e allows now a meaningful fitting of synthetic spectra to the observed hydrogen and helium lines. This work has been done by Uli Heber and R. P. Kudritzki (Ref. 7); Figs. 3 and 4 show some of the results, which have been quite remarkable. For the first time, helium has been observed directly in Population II stars and, besides, there is convincing evidence that helium is depleted in the atmospheres of these objects. In fact, the helium abundances, Y, in the Table show a one-to-one relation with the value of surface gravity, as expected under the gravitational sedimentation hypothesis.

Star: 3–118	V: 17.76	Log G: 5.40	Y: ≲ 0.01
3781	16.96	5.14	= 0.02
2167	15.76	4.27	= 0.11
1083	15.33	4.16	= 0.14

From these observations the lower limit for helium in Population II turns out to be Y (mass fraction) = 0.14. Current estimates give a higher value for primeval helium, but we have to remember that it is likely that sedimentation is already acting in the hot (T_e = 16,000°K) and condensed star # 1083.

So once again globular clusters confirm their importance as an "observational laboratory" where to check theories – and where to get new ideas – on stellar structure and evolution.

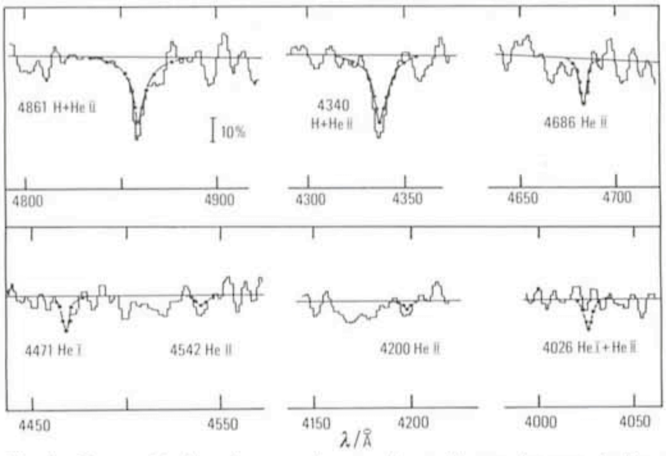

Fig. 4: *Once effective temperature and gravity are known, helium abundance is obtained from the equivalent widths of selected helium lines.*

Already observations with the instruments at our disposal, both ground and space based, are carrying us close to the heart of fundamental problems in stellar evolution; we are confident that the new technology telescopes and the Space Telescope will allow a qualitative, final jump.

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