The Chemical Composition of Stars in Open Clusters

P. E. Nissen

Until now few high-dispersion spectra have been obtained of stars in galactic star clusters and most of the spectra are of giant and supergiant stars that are very difficult to analyse. To reach fainter clusters and intrinsically fainter (main-sequence) stars in the nearer clusters, more photons are necessary. This is exactly the great advantage of the VLT, and Dr. Poul Erik Nissen of the Astronomical Institute in Aarhus, Denmark, explains how he would like to carry out such a programme.

It is in principle possible to find the chemical composition of a galaxy as a function of position and time by measuring abundances of stars with different birthplaces and ages, provided that their atmospheres represent the composition of the gas from which they were formed. Such studies may therefore give important information about the chemical evolution of galaxies and even about the composition of the matter in the very early phases of the Universe.

The fact that the relative abundances of the elements in the solar atmosphere agree so well with the relative abundances found in meteorites indicates that solar-type stars, i. e. late F and early G main-sequence stars, have indeed the same atmospheric composition as the material out of which they were formed. Also the composition of most nearby B main-sequence stars agrees well with the composition of interstellar matter as found from observations of H II regions. On the other hand the atmospheres of red giants are at least in some cases contaminated by elements produced in the star itself. The same may be the case for supergiants, and apart from that, it is very difficult to derive reliable abundances for such stars because of their complicated atmospheric structure. Thus giants and supergiants are more questionable as tracers of composition in galaxies, and I shall not consider them in the following.

How Far Will the VLT Reach?

In order to derive detailed abundances of an F or G star we must observe its spectrum with a resolution of about 0.1 Å. With a lower resolution too many lines in the spectrum overlap and the continuum is not well defined, so that the equivalent widths of weak absorption lines—most suitable for abundance work—cannot be measured with sufficient accuracy. Furthermore the noise must be as low as 2 per cent, which means that about 2,500 photons have to be counted per 0.1 Å, assuming that the photon shot noise is the dominant error source.

Bearing in mind that the flux of a star of visual magnitude $V = 0^{m}0$ is 10^3 photons $cm^{-2}s^{-1}Å^{-1}$ and assuming that the telescope, spectrograph and detector have an overall efficiency of 5 per cent, it is easy to calculate that with a 3.6 m telescope it will take about 4 hours to detect 2,500 photons per 0.1 Å for a star of $V = 16^{m}$. The corresponding magnitude for a 25 m telescope is $V = 20^{m}$. This may be considered as limiting magnitudes for detailed abundance work on F and G stars, as one hardly wants to spend more than 4 hours on one star. For B-type stars we may be able to go about one magnitude fainter because a resolution of 0.25 Å will be sufficient to resolve their less crowded spectra.

I should remark here that since the efficiency of present-day telescope-spectrograph-detector combinations is not as high as 5 per cent, a limiting magnitude of about $14^{m}5$ is probably more realistic, for example with the ESO 3.6 m echelle spectrograph that is now under construction. However, I expect that the detector efficiency will be improved from about 0.20 to 0.60 in the (near?) future so that an overall efficiency of 5 per cent can be achieved.

The limiting distances for abundance work corresponding to the estimated limiting magnitudes are given in Table 1 for an F8 V star and a B0 V star. The case of an interstellar absorption of 2^{m} is applicable for studies of stars in the outer regions of the galactic plane.

Table 1. Limiting distances for detailed abundance determinations of stars for a 3.6 m and a 25 m telescope.

Spectral type	Interstellar absorption	Absolute magnitude	Limiting distances 3.6 m	25 m
B0 V	0^{m}	-4^{m}	160 kpc	1100 kpc
B0 V	2	−4	63	440
F8 V	0	4	2.5	17
F8 V	2	4	1.0	7

It is seen that with existing telescopes it is possible to perform abundance studies of B main-sequence stars in a major part of our galaxy and even in the Magellanic Clouds. However in order to reach B stars in a few nearby spiral galaxies, e. g. M 31, M 33 and IC 1613, a 25 m telescope is essential and I expect this to be an important programme for the VLT.

Evolution in Time and Space

In case of F and G-type stars it is seen from Table 1 that existing telescopes can reach only the solar neighbourhood, whereas the VLT can cover a substantial part of our galaxy. With such a telescope it will be possible to study the unevolved stars in a number of globular clusters and thus to solve one of the presently most interesting astrophysical problems: Are the different abundances found for the giant stars in certain globular clusters, e. g. in ω Cen, of primeval origin or are they a result of stellar evolution? However, I shall leave this interesting investigation to somebody else and concentrate on a study of abundances of stars in open clusters.

As far as we know, all stars in a given cluster are formed at about the same time, with the same chemical composition,

Fig. 1: *NGC 6025, $\alpha_{1950} = 16^h00^m$, $\delta_{1950} = -60°22'$. According to Feinstein (P.A.S.P.* **83,** *800, 1971) this cluster is at a distance of 760 pc and has an age of 10^8 years. The brightest stars are of magnitude 8^m, whereas the late F and early G dwarfs are around 14^m. From the ESO (B) Atlas.*

and are moving with nearly the same space velocity. By averaging observational data for a number of stars in a cluster it is therefore possible to determine its distance, space velocity, composition and age much more accurately than can be done for a single field star. Especially the age of a cluster can be determined fairly accurately by the aid of the turn-up from the main sequence in a colour-magnitude diagram, whereas the ages determined for individual F stars are very uncertain because they evolve so slowly.

This is the main reason why open clusters are such excellent tracers of the chemical evolution of our galaxy. By studying them we will hopefully be able to solve two main problems in modern astronomy, namely, how has the composition of the galactic disk evolved in time and in which way does the composition vary as a function of position in the disk at a given time? If these questions can be answered for a number of the most important elements such as H, He, the CNO group, the α-particle elements, the iron group, and the r and s process elements, then we will have a good possibility to discriminate between different models of evolution of galaxies. Furthermore we will gain new insight into a number of important astrophysical problems: What was the initial composition of our galaxy or in other words, which were the end-products of the big-bang phase of the Universe? In what quantities are the different elements synthesized and ejected from stars of various masses? In which way does the initial mass function for stars vary as a function of time and position in our galaxy?

The Initial Programme

With these general ideas in mind I shall briefly outline how much we already know about the variation of the chemical composition of the galactic disk in space and time, and what we may expect to learn from the observations with the VLT.

Considering first the abundance of the disk as a function of time, we note that earlier findings of a correlation between metal abundances and ages for disk population stars have been questioned as being due to selection effects. However, I think that the statistical analysis by Mayor (*Astron. Astrophys.* **48,** 301, 1976) of nearby F dwarfs, for which the Strömgren m_1 index can be used as a metal abundance indicator, shows that the galactic disk at the solar distance from the centre has been enriched by a factor of 2 in metals during its lifetime. A study of, say, 25 open clusters of different ages with about the same birthplaces would give a much better value of this factor and may reveal if it is different from element to element. As most of these clusters probably can be found within 1 kpc from the sun this part of the programme can be carried out with existing large telescopes.

The VLT Study of Distant Clusters

The second part of the programme, i.e. the determination of possible abundance gradients in the galactic disk, requires however the VLT, because in this case it is important to be able to study clusters at distances of up to 6 kpc or so. Recent work has shown that large-scale abundance gradients are indeed present in the disk. I may refer again to the work of Mayor, who found a decrease of the metal abundance by a factor of 2 over a distance of 3 kpc in the radial direction. Abundance determinations of H II regions (Peimbert, IAU Symp. **84,** 1978) have revealed a similar radial gradient in oxygen abundance and even larger for nitrogen. The latter method is very powerful because the light from H II regions is *emitted* in the spectral lines that are used in the abundance studies. One may therefore ask whether a study of abundance gradients by the aid of *absorption* lines in star clusters is of any interest compared to this method. I think so, first of all because it is very important in science that the same problems are studied with entirely different and independent techniques, secondly because the abundance determinations of stars probably are more accurate than those of H II regions, and thirdly because the stars allow studies of a number of interesting elements that are not represented in the spectra of H II regions.

A certain class of open clusters is of particular interest, when we want to determine abundance gradients, namely those clusters that are young enough to contain B main-sequence stars of spectral types earlier than B7 and old enough to contain F stars that have contracted to the main sequence. These clusters have a turn-up from the main sequence between spectral types B2.5 and B7 and their ages lie between 25 and 100 million years. Well-known examples are the α-Persei cluster and the Pleiades. For such clusters we have the interesting possibility of determining abundances for both the B stars and the F stars. It means that certain elements, that are not seen in the spectra of F stars, e.g. He and Ne, or are poorly represented, e.g. C, N, and O, can be studied for the B stars and vice versa.

After having tried to justify my observing programme, it may now be defined as follows: A number of clusters of the above-mentioned type with distances from the galactic centre between 7 and 16 kpc will be selected, and in each cluster high resolution spectra of 3 F-type stars will be observed. If we estimate the average observing time to be 2 hours per star it means that a total of 16 clusters can be studied during the 10 nights that are available. Figures 1 and 2 show two clusters that probably will be on the programme, namely NGC 6025, a relatively nearby cluster, and Basel 4, one of the most distant known open clusters.

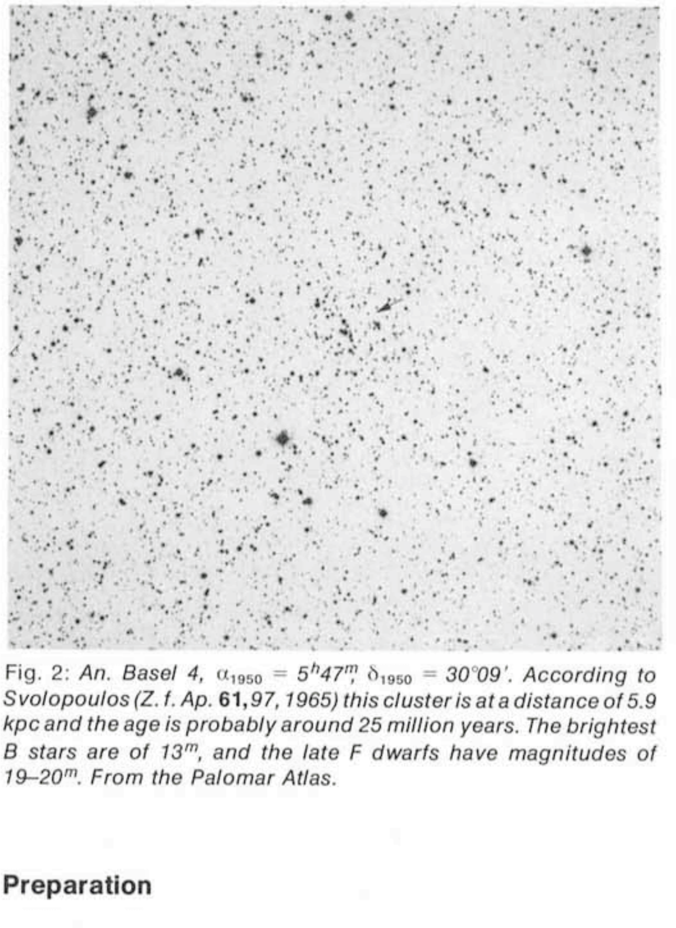

Fig. 2: *An. Basel 4,* $\alpha_{1950} = 5^h47^m$, $\delta_{1950} = 30°09'$. *According to Svolopoulos (Z. f. Ap.* **61,** *97, 1965) this cluster is at a distance of 5.9 kpc and the age is probably around 25 million years. The brightest B stars are of* 13^m, *and the late F dwarfs have magnitudes of* $19–20^m$. *From the Palomar Atlas.*

Preparation

It is clear that such a programme at the VLT has to be prepared very well in advance and that many supporting observations should be carried out with smaller telescopes. Most important will be: Photoelectric uvby and Hβ photometry in order to determine distances and ages of the clusters. Radial velocity and proper motion measurements in order to derive space velocities. Medium-dispersion spectroscopy to get spectral types and information on possible peculiarities or duplicity. These different types of observations will also serve to determine membership of the clusters. They can all be carried out with existing telescopes, except the proper motion measurements. For the most distant clusters they should be as accurate as $\pm$ 0.″0002 year^{-1}, and that can only be achieved by the Space Telescope with a reasonable time base of, say, 10 years.

Finally I want to mention that from the uvby photometry of the F dwarfs in the clusters one also derives the m_1 index, which is a very good measure of the abundance of the iron peak elements (Nissen and Gustafsson, Astronomical Papers dedicated to Bengt Strömgren, Copenhagen University Observatory, p. 43, 1978). Thus it is clear that we get some important information on the chemical evolution of the galaxy already from the preparatory part of the programme. So—VLT or not—there is a good reason to strengthen our research on open clusters.