Trouble in the Magellanic Clouds!

First Results from the Key Programme on Coordinated Investigations of Selected Regions in the Magellanic Clouds

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Does star formation proceed in an orderly way? How homogeneous are the Magellanic Clouds in their metal content? Is the motion of the gas complexes well behaved?

In the course of the Key Programme we started to doubt that our companion galaxies show systematic behaviour. After two fairly successful observational seasons with (except for the slitless spectroscopy and the photometry) good observing conditions, conflicting evidence on some of the fundamental questions has been obtained.

Our Key Programme was among the first to be accepted and has as speciality those two southern-sky galaxies which unfortunately can be observed under good conditions only in the southern summer. This means that the observational progress is slower than in programmes of survey nature. In addition, although our Key Programme does require a fairly large amount of telescope time, it consists of small subprogrammes, each of which takes a number of nights equal to that of any regular ESO proposal. In short, especially the coordination aspect is important, both time-wise and with respect to the objects (Regions) where the research is carried out. The regions had been selected on scientific grounds (see de Boer et al., 1989); here we show pictures of the Magellanic Clouds with the Regions marked (Fig. 1).

The subprojects we are working on are the following: (1) spectroscopic survey with EFOSC (Marseille, Paris, Uppsala); (2) CCD photometry in small fields within the regions (Bonn); (3) IRAC photometry of the same (Baltimore, Leiden); (4) stellar spectroscopy for the study of element abundances in the hot stars (Heidelberg) and cool stars (Meudon) of field and clusters; (5) the investigation of the interstellar absorption lines (Trieste, Paris); (6) the study of the spectra of emission nebulae (Paris). All these projects are carried out in coordination and it is this aspect which promises (and starts to show) new scientific results.

During our first observing runs we concentrated on two of the regions with the young clusters NGC 330 and NGC 1818. But also in Region E in the upper edge of supershell LMC 4, in which one finds an old cluster and young stars, as well as in the supernova field observations were carried out. In all cases puzzling effects have been found. A review of earlier work and of new results also from our Key Programme may be found in the conference proceedings edited by de Boer, Spite and Stasinska (1989) and by Haynes and Milne (1991) respectively.

Age Versus Metallicity

Region A in the SMC contains the young cluster NGC 330 which stands out from the field. Its age derived from our CCD photometry is of approximately 10 Myr. The surrounding field population (if homogeneous) has an age of at least a factor of 10 larger. The cluster contains blue supergiants, while the field is almost devoid of these. Observations of the cluster area have been performed with EFOSC1 in the slitless mode using a grism and an Hα+[NII] interference filter. Thanks to special software routines (Muratorio and Azzopardi, 1990) this survey resulted in the identification of about twice as many new Hα emission-line objects as in the Curtis-Schmidt telescope spectroscopic survey of the same field. This led to estimate the total number of Hα emission-line objects in the SMC to about 40,000 (Meyssonnier and Azzopardi, 1991). In particular, about sixty Hα emission-line stars have been discovered in the cluster NGC 330 (Fig. 2), while only 10 were known to Feast (1972). With the normal BVR CCD observations, also an Hα wide filter was used for a few exposures. Including also Strömgren photometry, Grebel developed in her Diploma thesis an elegant method to isolate the Be stars in the sample. Her identifications could be confirmed completely with the EFOSC data. From the final account of that work (Grebel et al., 1991) we show the colour-colour plot (Fig. 3), demonstrating an exceptional high Be star fraction in that SMC cluster.

Metallicity problems with NGC 330 emerged in a combination of studies. Spite, Richtler and Spite (1991) and Barbuy et al. (1991) confirmed results of work carried out before the Key Programme, in showing that the metal content of red supergiants in NGC 330 is −1.0 to −1.1 dex. Very similar results

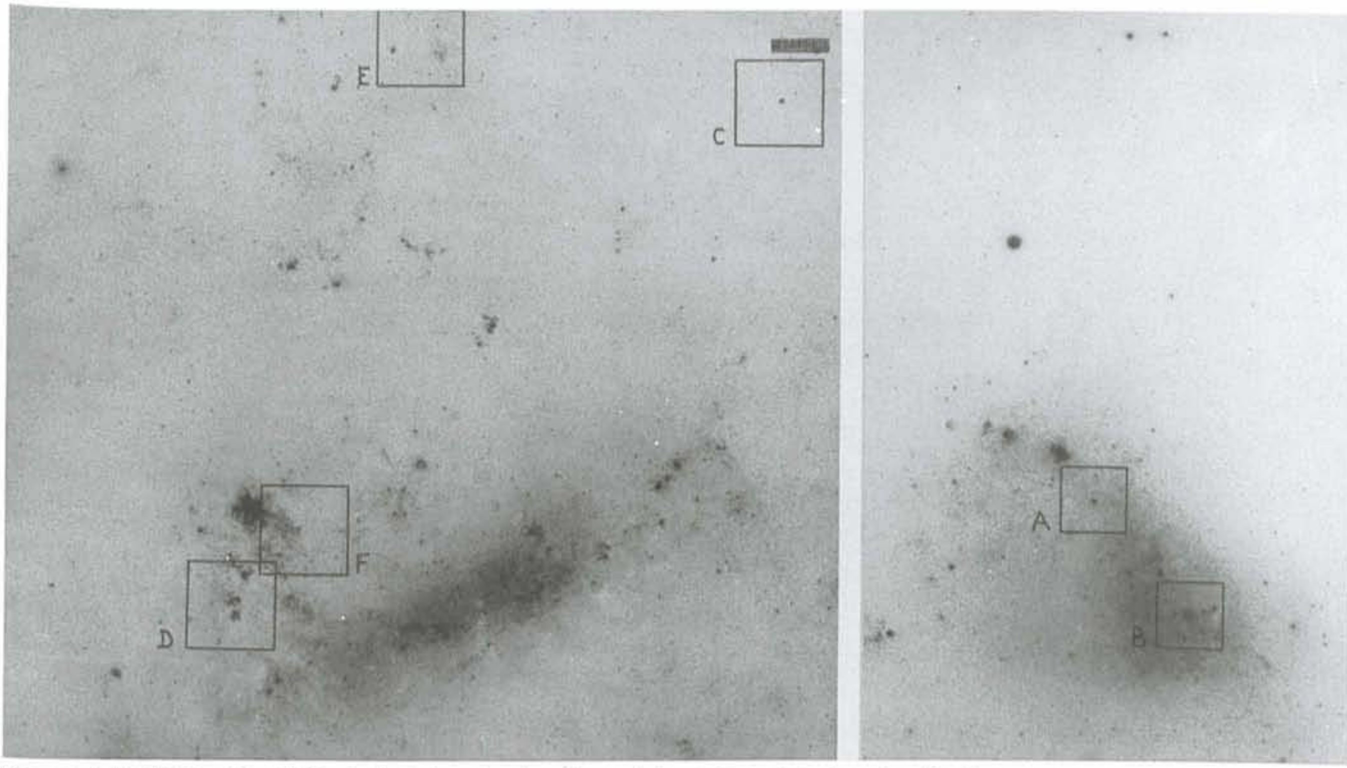

Figure 1: *In the SMC and the LMC a total of six regions have been defined where all studies of our Key Programme are concentrated. Region A: NGC 330 and field, poor in gas and dust; Region B: N27 and crowded field, rich in gas and dust; Region C: NGC 1818 and field, poor in gas and dust; Region D: N 159 and field, rich in gas and dust; Region E: NGC 1978, NGC 1948, and N49, some gas and dust; Region F: SN 1987A and field, gas and dust. (Picture with thanks to Reiner Donarski, ESO.)*

have been obtained from one hot star in NGC 330 (see Reitermann et al., 1990, Jüttner et al., 1991). For work on hot stars it was necessary to obtain also IUE spectra to get reliable effective temperatures. For the field stars, earlier data by Spite, Barbuy and Spite (1989) and by Russell and Bessell (1989) from Mt. Stromlo, indicated that the field has a metal content of −0.6 to −0.7 dex. This was confirmed in a related study, where Grebel and Richtler (1991) could show from CCD Strömgren photometry that the red giants and supergiants in NGC 330 have indeed a lower metallicity than those in the surrounding field, the difference being of the order of 0.5 dex. In short, the cluster NGC 330 is younger than the surrounding field stars but with a metallicity clearly below that of the field. This means that the SMC must be chemically very inhomogeneous! A similar effect had been found spectroscopically in Region C in the LMC which contains NGC 1818 (Richtler, Spite and Spite, 1989; Reitermann et al., 1990). Here the data could not yet be substantiated through photometry.

The abundance pattern of the elements in the Magellanic Clouds (Table 1) is in general not well understood. The large carbon deficiency found in the SMC HII regions (Dufour et al., 1982) is neither found in the stars of NGC 330 (Barbuy et al., 1991) nor in those of the surrounding field. The question thus is: are the analyses of the stars wrong or those of the HII regions, or perhaps both? Or is C still depleted in HII-region dust? The emission-line object sub-project (which was started late in the Key Programme) should soon give additional information. Type I planetary nebulae will be studied (C-N-O processes) and IUE data are being collected. How does the C abundance affect the dust content and the molecule formation in the Clouds? A related interesting result is that europium (an r-process element) is relatively enhanced in the stars of NGC 330 (Spite, Richtler and Spite, 1991). Does this indicate a more primitive phase of chemical evolution in the Clouds (Westerlund, 1990)?

The values for the extinction in the Clouds cause trouble too. For the study of the abundance in the red supergiant stars it is of utmost importance to have a very accurate temperature determination and here the photometry group has provided some input. But also the extinction may play a role. Recently, Bessell (1991) has critically analysed the information available on the extinction toward the SMC. He found that E(B–V) is rather of the order 0.1 than negligibly small. In an effort to contribute to the discussion with our Key Programme, the strengths of the interstellar sodium lines in the spectra obtained for our stars in and near NGC 330 were analysed. It is found by Molaro and collaborators that the foreground E(B–V), as derived from the strengths of the NaI lines and the correlation of N(NaI) with E(B–V), amounts to 0.08 to 0.1 mag. Even a small contribution by the SMC gas would bring the total E (B–V) near 0.11 mag. This new result indicates that some of the earlier abundance studies may have to be reworked!

Region E in the LMC, in the NW corner of the larger LMC-4 supershell,

Table 1. *Derived metal abundances relative to solar*

			C/H	O/H	Fe/H	Eu/Fe
SMC	Region A	cluster	−0.9	−1.1	−1.0	+0.7
		field	−0.9	−0.8	−0.6	+0.4
		HII regions	−1.5	−0.8	–	–
LMC	Region E	cluster	–	−0.5	−0.9	+0.6
		field	−0.5	–	−0.3	–
		HII regions	−0.8	−0.5	–	–

HII-region data from Dufour et al. (1982)

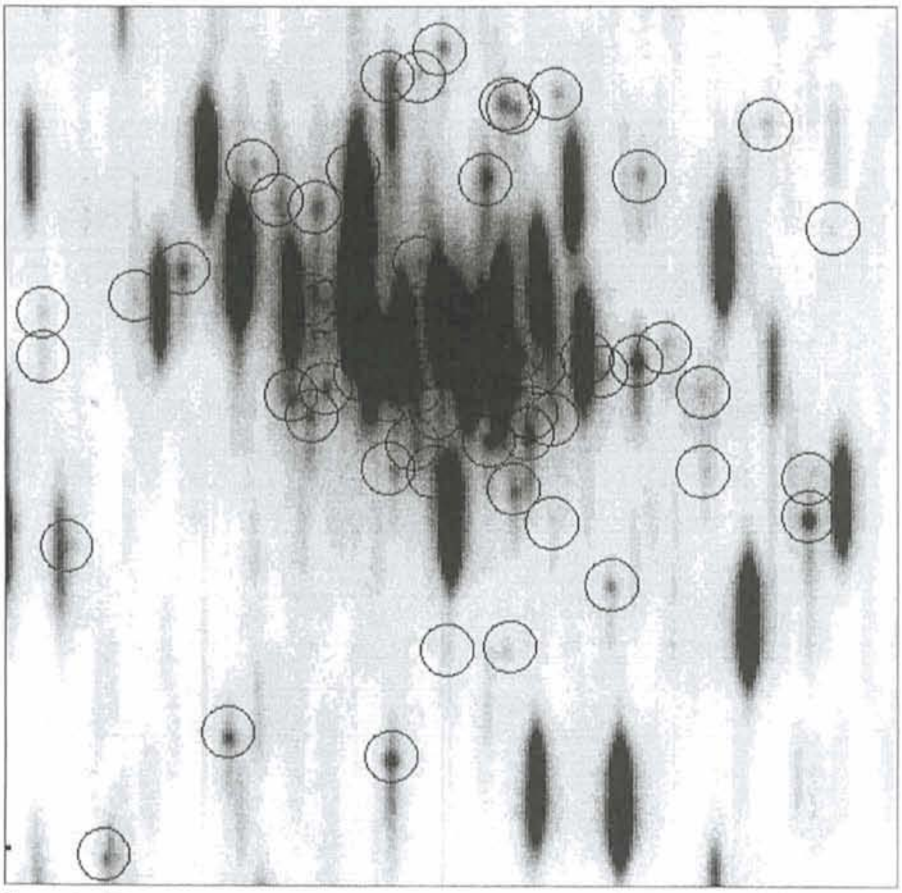

Figure 2: *Slitless spectroscopy of the young globular cluster NGC 330 with EFOSC (900 sec. exposure) through the red 300 grism (270 Å/mm) and an Hα+[NII] filter (6569Å/100Å). Emission-line objects (see open circles) show up clearly due to the Hα line (Azzopardi et al., in preparation).*

contains the old cluster NGC 1978, the young association NGC 1948 and the more compact young cluster with the emission nebula N 49. From spectra of a few stars we learned that the metallicity is about −0.4 but with an overabundance of Si in the sense [Si/Fe] = 0.4. Field spectroscopy is now available as well as CCD photometry in a strip covering NGC 1978 and NGC 1948. Field spectroscopy led to the detection of several new faint Hα emission-line objects including a few compact HII regions. In addition, EFOSC slitless spectroscopy (using the B1000 grism giving 850 Å/mm dispersion and a 1025 Å band-width interference filter at 4885 Å) resulted in the identification of a new faint planetary nebula and of some new carbon star candidates in NGC 1978 and its surrounding field. The large and most elliptical of all the LMC clusters, NGC 1978, is definitely older than 2 Gyr (Bomans et al., in prep.). In this strip the brighter part of the young population of the underlying field has an age of about 1 Gyr, but there are also stars which formed only 70 Myr ago. The association NGC 1948 is prominent due to its larger surface density of stars and its lower age of about 20 Myr. Synthetic colour-magnitude diagrams generated (Vallenari et al., in prep.) indicate that most likely there has been a longer period of star formation and not just a recent single burst.

Measurements in the infrared with IRAC have not been possible yet because the new detectors did not arrive in time on La Silla to be adequately used by our Key Programme. The field spectroscopy and the photometry have suffered substantially from bad weather.

The first spectra of planetary nebulae and HII regions have been obtained, but it is too early to comment on abundances.

Approaching Gas Clouds?

The investigation of the interstellar medium was, due to its imminent importance, concentrated in the first period of the Region F around SN 1987A. Very good CaII and NaI interstellar line profiles have been obtained for more than a dozen of stars. The line profiles provide unique information on the structure of the ISM and many separate absorbing clouds can be recognized. One of our goals is to define the depth structure of the gas. For this the absorption lines are compared with HI 21-cm emission-line data available in the literature. From the 21-cm data it has been known for a long time that there are three main gas complexes in the LMC, based on their radial velocities. These are at about 240, 270 and 300 km s^{-1} (heliocentric). All these components are present in the area of 30 Dor and thus in the field of the SN 1987A. Vladilo et al. (1991) could show that the 270 km s^{-1}, gas is not seen in absorption so that one must conclude that it is in the background of the LMC. Since the bulk of the material is near 290 to 300 km s^{-1}, one witnesses in the 270 km s^{-1} gas a large amount of mass approaching the rear of the LMC! The nature of our data as well as the essentials of this result can be seen in Figure 4.

The depths of the stars can now also be inferred from the IS data. Simply speaking, the more absorption components are seen, the deeper into the LMC the stars are located. Here also extinction studies will help, in the same way as others have shown that the SN 1987A itself was rather in the rear of the LMC. This line of approach is now also being used in Region E, and results will be available in the near future.

Interactions of Programmes

One very important aspect of the workings of the Key Programme collaboration is that data are being obtained in the same regions and on the same fields for the mutual benefit. Several examples can be given.

The spectroscopic surveys together with the CCD photometry provide input for the groups doing high-resolution stellar spectroscopy for abundance determinations. Indications for the spectral type are needed, but in particular also colour and brightness is of great value

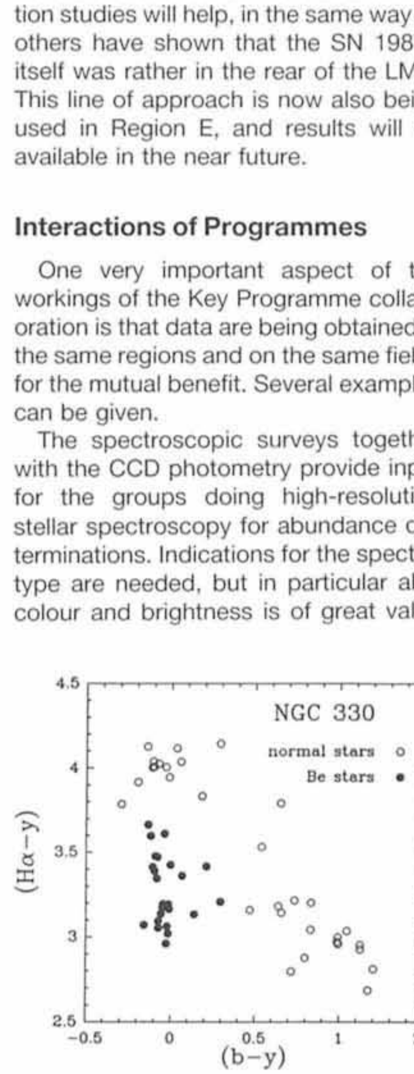

Figure 3: *In a two-colour plot, involving Hα wide and Strömgren b and y, the normal stars show up along a line just below the diagonal in the diagram. Stars having Hα emission lines are bright at Hα (thus giving in 2.5 log (I(Hα)/I(y)) a smaller value) and appear below the sequence of normal stars (data from Grebel, Richtler and de Boer, 1991). This plot illustrates the exceedingly large fraction of Be stars in NGC 330.*

for the classification of the stars as main sequence or evolved star as well as with respect to the suitability for stellar and interstellar spectroscopy. In the spectroscopic survey data hitherto unknown emission-line objects have been discovered, objects to be further investigated by the emission nebula project.

The stellar spectra give in many cases preliminary information on the interstellar absorption lines, although often extra observations are required because of the very high resolution needed. And, as indicated before, the IS work helps to determine the value of the extinction, an essential parameter in the abundance studies.

The very existence of our Key Programme has stimulated others to pool efforts and work on the same regions as defined by us.

The abundance studies of hot and cool stars have benefitted much from the collaboration with M. Bessell from Mt. Stromlo. Not only are observing programmes coordinated, but the fact that Bessell analysed thus far stars of spectral type not addressed by us adds weight to our mutual research.

Right from the beginning, it was foreseen that our Key Programme would interact strongly with the ESO Key Programme on SEST CO observations of the Magellanic Clouds coordinated by Lequeux and Israel. For Regions C, D, and F the 12CO (1–0) observations are complete and some exist for the 12CO (2–1) transition. Region B has been partly covered and Region E is being planned.

In New Zealand, W. Tobin started patrolling some of our CCD fields in search for variable stars. The Mt. John University Observatory (see Tobin, 1991) is farther to the south than any other easily accessible facility, albeit with on average poorer weather conditions, but with better conditions for long-term monitoring programmes.

Finally, in cooperation with our Key Programme, observing programmes are being carried out with ROSAT on the MCs. In particular the Regions in the LMC will get good coverage being so near to the orbital pole of that satellite.

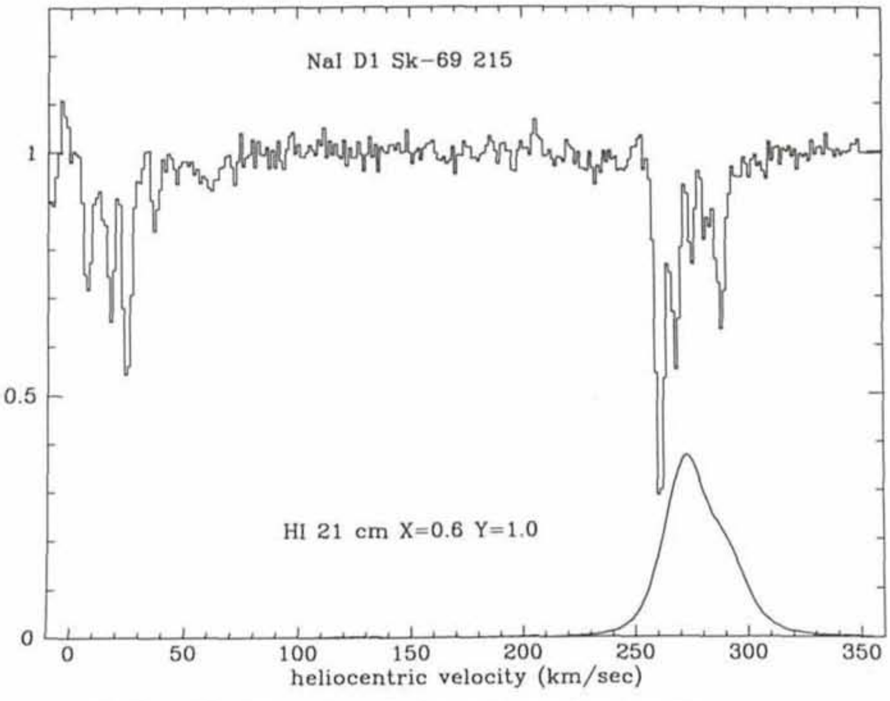

Figure 4: *The interstellar NaI spectrum obtained at a resolution of 100,000 in an exposure of 5400 sec. with the 3.6-m shows the great detail of the structure of the interstellar medium in the LMC in Region F. For comparison the HI 21-cm profile from Rohlfs et al. (1984) is shown to demonstrate that (as in all lines of sight in Region E) the strong HI 21-cm emission 270 km s^{-1} component is essentially absent in absorption. Since most of the material in this direction has a velocity near 300 km s^{-1}, the 270 km s^{-1} gas must be approaching this part of the LMC from the rear (Vladilo et al., 1991).*

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Visit to the ESO Headquarters

ESO was pleased to receive high-level visitors from Germany and Switzerland at the Headquarters in Garching, near Munich.

On October 31, 1991 Ministerialdirigent Dr. H. Strub and Ministerialrätin Dr. A. Hansen (ESO Council delegates) spent a day with ESO staff to inform themselves about the latest developments at ESO, in particular about the VLT project.

Presentations were made by senior ESO staff, and the guests from Bonn received detailed replies to their various questions. At the end of the day Drs. Hansen and Strub met with the German staff members in the auditorium where a very useful exchange of views took place.

On November 13, the new Swiss Consul General, Mr. P.A. Studer, and Vice Çonsul, Mr. R. Bloch, came to the ESO Headquarters to learn about ESO-Swiss interactions. They were very pleased to become better acquainted with our organization, and ESO was happy to learn about the interest of the local Swiss authorities in promoting good political and industrial contacts between ESO and their home country.