The Magellanic Clouds and the VLT

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The Magellanic Clouds do not need to be presented to the readers of the Messenger! I wish however to remind them of their interest in general:

(1) they are the closest galaxies of a type different from our own Galaxy;

(2) they are sufficiently close for detailed studies, similar to many of those which can be done in our Galaxy;

(3) they are relatively small systems compared to their distance, thus all the objects they contain are more or less at the same (known) distance; moreover, interstellar extinction is generally small; these properties make the Magellanic Clouds especially interesting for studying objects whose distance is difficult or impossible to obtain in our Galaxy (giant stars, AGB and post-AGB objects including planetary nebulae, symbiotic and other strange stars, X-ray binaries, novae, etc.);

(4) the abundances of heavy elements are different from those in our Galaxy; this allows to study the formation and evolution of stars as a function of abundance;

(5) linked to these differences in abundance, the properties of interstellar matter (ISM) in the Clouds are strongly different from those of the Galactic ISM.

It is obvious that the largest telescopes of the future like the VLT will be of much interest for Magellanic Cloud studies, since they will already be of interest for many Galactic studies. My goal in this article is to review some areas where the VLT will make possible considerable progress in our understanding of the Magellanic Clouds. The present study bears heavily upon a number of recent reviews by myself and by others, and upon the following books entirely devoted to the Magellanic Clouds: IAU Symposium No. 108; IAU Symposium No. 148; Recent Developments of Magellanic Cloud Research (1980, K.S. de Boer, F. Spite & G. Stasinska, eds., Observatoire de Paris); New Aspects of Magellanic Cloud Research (1993, B. Baschek, G. Klare & J. Lequeux, eds. Springer-Verlag, Berlin). I will make reference to some of the VLT instrumentation: for a general presentation see D'Odorico et al. 1991, *The Messenger* 65, 10. For the presentation of the 4 instruments under construction see Lenzen & von der Lühe 1992, *The Messenger* 67, 17 (CONICA, the high-resolution near-IR camera); Appenzeller & Ruprecht 1992, *The Messenger* 67, 18 (FORS, the focal reducer/low dispersion spectrograph); Moorwood 1992, *The Messenger* 70, 10 (ISAAC, the infrared spectrometer and array camera); Dekker & D'Odorico 1992, *The Messenger* 70, 13 (UVES, the UV-visual echelle spectrograph). The multi-fiber spectrograph FUEGOS is in Phase A only and no description is generally available yet.

Structure and Kinematics of the Magellanic Clouds

In spite of much effort, the structure of the Magellanic Clouds is not yet completely understood especially for the SMC which has a very irregular shape. The SMC contains up to 4 different gaseous components with different radial velocities and associated young stellar populations, but their relative location in depth and their distances are not well known. Interstellar absorption lines can show which component is in front of the studied star, but there are not yet enough such measurements due to the faintness of the suitable stars; the VLT will allow fast observation of interstellar lines (especially the sodium lines) in front of many stars; the most suited instrument will be UVES and also FUEGOS in its high-resolution mode (R = 30,000, enough for a kinematic study). However this does not give distances. They have to be obtained from cepheids using their period-luminosity relation preferably in the infrared. Measurement of the mean radial velocity of each cepheid will allow to know to which component it belongs. Present attempts at using this method have not been fully convincing for lack of photometric and radial velocity measurements covering evenly the period of the cepheid. While the photometry part of this programme does not necessarily require a very large telescope, the radial velocity one does, using correlation methods, if one wishes to observe a large number of cepheids. FUEGOS appears most adapted to this programme which would require an enormous amount of telescope time with single-object spectrographs. As a very important by-product, this programme will supply a data base for our understanding of the cepheid phenomenon. Similar interstellar absorption line and cepheid studies will also be interesting for the LMC: absorption lines in the LMC often show multiple velocity components, the origin of which is not well understood, and the cepheids will allow a direct measurement of the inclination and of the shape of the disk of the LMC.

Another topic of great interest is the kinematics of the old populations in the Magellanic Clouds. While the kinematics of the young population is well understood, that of the older one is much more difficult to study. Objects like planetary nebulae and carbon stars will yield the kinematics of intermediate-age populations: from what we know, they do not seem to differ much from that of the young populations. However the old clusters of the LMC seem to have a different kinematics from the younger clusters, but this observation is at the limit of the present telescopes and deserves confirmation with the VLT. We know almost nothing of the kinematics of the halo stars of both Clouds and this will be a new field to open with the VLT. Presumably FORS and FUEGOS are most suited for such studies.

Finally the VLT is needed for studying in detail the stellar population and (via observation of interstellar absorption lines on background objects) the interstellar matter in the bridge which connects the two Clouds and in the Magellanic stream. While young stars are known to exist in the Bridge, no bona fide member star has been found in the Stream. This may point to different origins, the Bridge being a tidal feature or at least having experienced a tidal perturbation responsible for star formation, and the Stream being perhaps due to tidal stripping. Observations with the VLT should allow to settle this long-debated question.

Interstellar Matter

Interstellar matter in the Clouds is very different from that in our Galaxy: the abundance of heavy elements is 4 and 10 times smaller in the LMC and the SMC respectively, the dust-to-gas ratio is smaller in the same proportions and the properties of dust are qualitatively different (smaller absorption bump at 200 nm, higher far-UV absorption, smaller far-infrared emission by very small dust particles). The higher far-UV radiation field together with the lower abundance of dust produce an increased photodissociation of molecular hydrogen, of CO and of other molecules which affect considerably the properties of the molecular clouds. I do not clearly see observations of the ISM which could be unique to the VLT, but it is clear that the very large sensitivity of this instrument will allow improvements with respect to what is done at present, for example by densifying the observations by FUEGOS of interstellar absorption lines allowing studies of the fine structure of the ISM, or by making easier visible and infrared observations of star-forming regions, interfaces between ionized and neutral gas, supernova remnants, etc. The latter studies will make use of FORS, ISAAC and perhaps CONICA. An interesting possibility which requires both high sensitivity and excellent image quality is to investigate through extinction (star counts and photometry) the internal structure of the molecular clouds (not accessible to the SEST). This will check if the properties of the molecular clouds in the Magellanic Clouds differ from those in our Galaxy only due to the differences in photodissociation as explained before, or due to differences in structure.

Stellar Populations and Star Formation

Due to various causes (not always well understood) the properties of stellar populations in the Magellanic Clouds differ from those in our Galaxy. For example, the Clouds like M 33 and a few irregular galaxies are known to contain young globular clusters which are lacking in our Galaxy. The youngest of all could be the dense clusters of O stars that ionize the biggest H II regions (30 Dor in the LMC and to a lesser degree N 66 in the SMC). Of course the dynamical study of those young clusters and also of those of intermediate age is of high interest since in our Galaxy only old globular clusters are seen. Such studies have started in particular with the ESO telescopes, but they will be made considerably easier by the VLT and will reach stars of earlier spectral type for which accurate radial velocities are more difficult to measure. Due to crowding one will have to use a medium-to-high resolution field spectrograph. Once again one will use FUEGOS in the compact fiber mode for the centre of the cluster, or in the normal mode for the rest of the cluster.

One very important goal of Magellanic Cloud stellar observations is to help understanding stellar evolution. While sophisticated models exist for this evolution, the physics introduced in these models is to a large extent arbitrary and as a result this evolution is still very poorly known: for example the evolutionary status of the progenitor of SN 1987A is still controversial. For low- and intermediate-mass stars, high-quality photometric and spectroscopic observations of individual stars in clusters of different ages and metallicities will help tremendously understanding their evolution; although much is presently being done with 4-m class telescopes, the VLT will allow doing more and better. For massive stars, the observational problem is more difficult. The only way to progress seems to locate the observed massive stars in a "theoretical" (L vs. T_{eff}) HR diagram, to measure their densities in the different parts of the diagram, to study surface abundance anomalies due to internal mixing, then to confront these observations with the predictions of models. It is also necessary to measure the strength of the stellar wind which plays an enormous role in the evolution. All this should be done for stars with different metallicities in order to understand the role of metallicity in the internal evolution and in the acceleration of the wind. The Magellanic Clouds are ideal places for such investigations. They contain a sufficient number of massive stars for statistical studies, they have very different metallicities and a comparison will be possible between a complete sample of stars belonging to Galactic open clusters and associations. One problem is to build the sample, requiring fine spectral classification of stars first selected by colours, and another one is to secure the high-resolution spectroscopy necessary for determining the abundance of carbon and nitrogen from their rather faint lines. It is also desirable to study the HR diagram down to 6–8 solar masses where the transition between the two main regimes of stellar evolution occurs. A 6-solar-mass star on the main sequence has V = 18 in the SMC, and it is clear that the VLT is necessary for high-resolution, high-quality spectroscopy of such a star. As one wants to perform this kind of analysis for several hundreds of stars in each cloud, a multi-objet spectrograph is required, once again FUEGOS.

Apart from this, the VLT will be ideal for detailed observations of all sorts of more or less exotic objects whose study in the Galaxy is hampered by the lack of distance information. This fauna is too varied to be discussed here in any detail. It seems to me that the AGB and post-AGB stars are the most interesting class of such objects. Their evolution is still very poorly known in spite of much effort – in part due to the lack of distance information in our Galaxy – and may depend on metallicity. Once again, a multi-object spectrograph is appropriate as the surface density of most classes of such objects (e.g. carbon stars) is relatively large.

Finally, observing star formation in a different context than the galactic one is a very exciting perspective. Already it has been demonstrated that massive stars occur in small compact groups in the Clouds, but we would like to know why and how, and also to know more about the formation of lower-mass stars. For this, one will use the VLT mainly in the near- and mid-infrared using ISAAC and the foreseen mid-IR imager/spectrometer. Such studies are still in their infancy in the Magellanic Clouds (only a few images in the K band have been published, for instance). While it is hard to predict what the outcome of future VLT studies will be in this field, it would be very surprising if the results would not be of great interest.

Chemical Abundances and Evolution of the Magellanic Clouds

In spite of being a relatively ancient topic, this is a very controversial one. Determinations of the abundances of heavy elements in different classes of young objects in the Magellanic Clouds often give discrepant results: while H II regions exhibit a remarkable degree of homogeneity in either Cloud, indicating efficient mixing of the interstellar matter during the evolution of the Clouds, young stars like hot or cold supergiants have been claimed to have rather different abundances between them and with the H II regions. If real, this result is very difficult to understand. However there are some doubts about determinations of abundances in supergiants, which are made difficult by the strong non-LTE effects and by problems in measuring effective temperature, gravity and interstellar extinction. One would very much like to have such determinations made in stars with higher gravities. Unfortunately these stars are faint in the Magellanic Clouds and generally out of reach of the present telescopes. This will be a very important programme for the VLT, presumably using UVES or FUEGOS. I will not specifically discuss the evolution of the Clouds, but it is underlying most of the previous discussion.

Conclusion

I hope to have convinced the reader that the VLT will allow very significant advances in our knowledge of the Magellanic Clouds, and perhaps more importantly of stellar evolution in general: I would like to stress once again how unique the Clouds are for studying the various stages of the evolution of massive stars and the late stages of evolution of stars of all masses. The most useful of all the foreseen focal-plane instruments for that purpose appears to be FUEGOS, and I very much hope that its construction will not be unduly delayed by budgetary restrictions.

Nuclei of Non-Active Galaxies with the VLT

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1. The Physical Properties of Galactic Cores and Nuclei

Since the very beginning of extragalactic studies it was realized that galaxies have very compact central parts. However, only in the last decades it has been fully appreciated that atmospheric seeing was the major limiting factor for the angular resolution that could be achieved from the ground and that, in turn, the observed core properties were often just artifacts of the limited resolution available (Hoyle 1965; Schweizer 1979, 1981). Of the two galaxies known in the late 1970s with truly resolved cores, one, M31, had a nuclear, very dense, spike roughly in the centre of its broader core, while the other, the radio galaxy M87, presented a central spike in the light profile, which was interpreted as due to an unresolved non-stellar point source. Despite this, the notion of *isothermal cores* was introduced, i.e. of cores with a light profile that flattens to a plateau at small radii. This was partly inspired by theoretical arguments, in practice it reflected precisely the kind of profile that seeing effects were producing. On the other hand, spectacular phenomena like the M87 optical jet opened up the issue of the nature of the nuclear energy sources in galaxies and of the possible existence of nuclear supermassive black holes. It is very intuitive that a supermassive black hole would affect the stellar orbits in the core, producing spikes in velocity dispersion and nuclear rotation curves with steep gradients. Theoretical arguments showed that a black hole would influence also the core light profile, by capturing stars in a very concentrated cusp detectable in the light profile. Indeed, both indicators were used by Young and collaborators (1978, 1979) to claim the existence of a central black hole in M87. Unfortunately, even models without a central black hole can be constructed able to give adequate fit to the data (Binney and Mamon 1982).

Developments in the following years were in a way frustrating. On the one hand the red herring of isothermal cores was brought up and followed by several investigators, who found less and less truly isothermal cores as the resolution increased. Even in the late 80s it was possible to find statements concerning a broad subdivision of galaxies into those with isothermal cores and those without. On the other hand, dynamicists were able to produce (often contrived) models able to fit the observed kinematic and photometric profiles of galaxies without the need of a supermassive black hole. Unfortunately, the intrinsic freedom allowed by stellar dynamics equilibrium configurations and the availability of powerful and flexible modelling techniques, makes it difficult to obtain an irrefutable proof of the existence of a black hole in any given galaxy (see, e.g., Kormendy 1993). Although the central black hole hypothesis is probably the simplest to explain objects like M87, it is important to obtain such a proof by improving resolution and accuracy of observations.

Galaxy cores are also important as benchmarks for theories of galaxy formation. Great progress has been made in this field, often guided by our interpre-

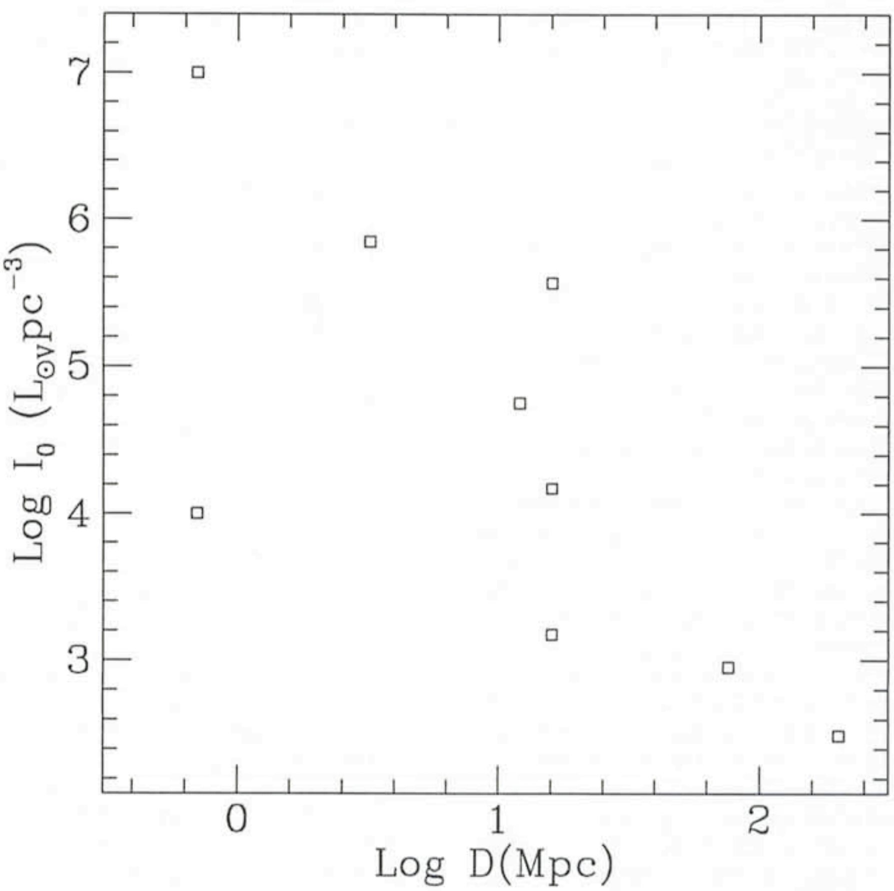

Figure 1: *The apparent central light density of galaxies appears to anticorrelate with galactic distance. This is a resolution effect also present in Hubble Space Telescope data (Crane et al. 1993).*