FUTURE DIRECTIONS OF RESEARCH IN THE MAGELLANIC CLOUDS
Panel Discussion

Chairman: B. E. Westerlund
Astronomical Observatory, Uppsala, Sweden

Members of the panel: I. J. Danziger, K. C. Freeman, J. A. Frogel, J. A. Graham, M. Grewing, D. J. Helfand.

The aim of the panel discussion was to identify the most important remaining gaps in our knowledge of the Magellanic Clouds, and to find optimal ways of filling them. Particular attention has been paid to instrumentation available now and in the near future.

The following summary of the statements made by the members of the panel has been written by the Chairman on the basis of a tape recording of the discussion. The contributions by other participants have had to be left out as many parts could not be transcribed with sufficient accuracy from the tape. The same applies, unfortunately, also to parts of the statements by the members of the panel. Nevertheless, the summary should give a reasonably good idea of the main topics considered by the panel.

I. J. Danziger
European Southern Observatory, Garching bei München, F.R.G.

A truly important difference at the epoch of this conference as compared with the previous one on the Magellanic Clouds is that a good deal of work has been done now by theoreticians on the chemical evolution of galaxies, in particular on galaxies like the LMC. However, this conference has been dominated by the observers. It would have been important to have heard more from the theoreticians.

There are a number of things to be done to help those who do theoretical calculations on chemical evolution. Firstly, it is important to carry out direct measurements of the metallicity of individual stars. With the detectors now available much more can be done in that area. We do not necessarily have to work on very faint stars in the Clouds. It is, however, highly desirable to get good spectra of stars

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in the Bars of the Clouds. In addition to observing individual stars one should also aim at obtaining spectra of integrated parts of the bars. Some astronomers are working along this line, but we have not heard much about it here.

It will be particularly important to establish a photometric or a spectroscopic system that will make it possible to look at individual elements and say something about various groups of elements that are formed by different synthetic processes.

There has been some work reported here on old globular clusters in the SMC and their H-R diagrams. Since these are the most metal-poor of the systems it appears important to pursue that work as far as possible.

Another item regarding the chemical evolution of galaxies concerns the dependence of the slope of the Initial Mass Function on the metal abundance. Melnick and Terlevitch have made the case that this is so. It could be tested in the Magellanic Clouds. It is important, if it is correct, not only from the point-of-view of the chemical evolution, but also because it is telling us something about the physics of star formation.

Another point of importance: We lack any fundamental information about mass loss, particularly for late-type stars. Can anything be done about that in the Magellanic Clouds?

We were all struck by Mathewson's discussion of the SMC, dividing it into two. This suggestion is of interest even if it should not be true. Others at this meeting have talked about encounters between the SMC and the LMC. If that has happened, obviously - or is it obvious? - one galaxy could have borrowed some stars from the other, and some clusters and other material, too, at least until the next encounter when they might borrow it back. If this is true, it complicates the interpretation of the cluster contents of the Clouds, as they have then been mixed with each other. It is important to get this straight.

Finally, I wish to bring up a small item for the use of the Space Telescope. It should be used for a look at the SNRs in order to see what is produced in the supernova and what comes from the interstellar medium. The Space Telescope will be particularly advantageous for abundance work in the SNRs on elements and lines in wavelength regions not accessible from the Earth. The International Ultraviolet Explorer has not been reaching sufficiently faint. The Space Telescope also offers a better spatial resolution.

K. C. Freeman
Mount Stromlo and Siding Spring Observatories, Canberra, Australia

We have now in the general area of kinematics and dynamics some marvelous new data on the kinematics of the whole Magellanic system. We have seen some very complex velocities in the bridge and in the LMC and the apparent disruption of the SMC itself. All of this is well over our understanding. The question is what needs to be done theoretically, so that we can make use of what we have actually seen.

We need a hydrodynamic treatment of the dynamics of first of all the whole LMC - SMC system, and secondly of the LMC and the SMC themselves. This is within the realm of dynamical possibilities. It is not just a dynamics exercise, because it could lead to some understanding of the flow fields. These flow fields affect the star formation distribution. Two particular areas of interest are the Constellation III and the 30 Doradus region in the LMC. You may think that they are peculiar for the LMC. It is not so. Similar areas of star formation and similar processes are seen in other magellanic systems. It appears to have something to do with LMC-type systems. The kind of studies that should be carried out are: Start with Fujimoto's orbits and find out what happens to the whole system. Then, assume also a hyperbolic orbit and look at what happens to the Clouds during a single pass about our Galaxy. It is important to treat the Magellanic Clouds as a whole, because this makes the system more bound.

An important question is whether there exists a halo population in the LMC. I say it does not exist. John Graham says that I and others agreeing with me are misled. We should look at the RR Lyr stars. In the globular clusters there are some RR Lyr stars. In the Galaxy we find the so called halo objects in the halo, and this is a spheroidal system. When we look at edge-on Magellanic-Cloud-type systems we do not see any spheroidal components, so it would be surprising to find a halo in the Clouds. However, in our Galaxy we do see stars of quite low mass scattered all over the disk. It would not be too surprising to see similar stars in the Clouds.

What are actually the RR Lyr stars? They may, according to some astronomers, not be so old. It would be very useful to have this question settled.

With regard to the globular clusters an important question concerns their formation in the LMC. We know that the young blue populous clusters are globular clusters in every way except in age, which for them may be 10^7 years or even lower. This has been mentioned several times during the meeting. The question is, why are they forming now? They

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are abundant in the LMC; there may be a few in M 31, and, as far as we know, there are none in the Galaxy. One particular aspect of this is the question of binaries in globular clusters. There is a reasonable amount of evidence that galactic globular clusters with giants of about 0.8 solar masses have very few binaries. We do not yet know if this is a general property of Extreme Population II or a general property of globular clusters. We have a great opportunity in the LMC to study the stars in the young globular clusters. Their masses are of the order of 8 - 10 solar masses. That puts them in the category of Extreme Population I. These stars will then have to make up their mind: Either they are of Extreme Population I and the clusters are full of binaries, like this population in our Galaxy, or they are of Extreme Population II, and there are no binaries. There is much to be done about this problem, and the way to do it is obvious.

J. A. Frogel
Cerro Tololo Inter- American Observatory

I wish to make a few comments on the relevance of infrared (IR) astronomy for Magellanic Cloud research and about what it has altered in the picture. There are basically two areas where IR astronomy is capable of making important contributions. The first area is in observing all stars where you measure the photospheric radiation of the star itself. A group of us has been working on field stars and on cluster stars, and we have done our best in exploiting this particular area of IR astronomy.

The second area may be called more traditional IR astronomy. We look at the dust at wavelengths longer than 2 μm, and at 5 -10 μm at the longest. We try to find the thermal emission from the dust, that is re-radiated starlight. Very little of this has been done in the Magellanic Clouds, partly because it is rather much at the limit of the instrumentation at present, particularly at 10 μm and with the existing southern hemisphere telescopes. However, a lot is to be gained by pursuing this research and by improving the instrumentation. As has been pointed out at this meeting, when the results from IRAS become available there will be a lot of new ideas and a number of objects to look at. This will require a good deal of follow-up work from the ground. In particular, there will be dust emission from HII regions and molecular clouds and stars. Important is first of all that you can find out something about mass loss rates from stars by looking at the dust around them. If you can get spectra in the 10 μm region from the stars, you can see whether the dust consists of silicates of carboniferous material. This is clearly important for understanding something about the composition of the Clouds. It is also important to understand why the Clouds contain so much less dust than does the Milky Way.

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The ither aspect of dust emission concerns the birth of stars. A great deal of the infrared capacity during the past few years has been aimed at this question in the Galaxy. Important results have been derived by combining the IR observations with observations in the visual and radio bands, looking at molecules at mm wavelengths. This type of work, carried out in the Clouds, will yield very important, very exciting results on the star formation in the Clouds. It is a kind of a mystery there, because star formation is expected to occur in very dusty regions. In our Galaxy we find that star formation occurs in very extensive, very dusty regions. We do not see such extensive areas of dust in the Clouds, and yet, we know that star formation has been going on there in the relatively recent past. This is particularly evident in the LMC with its large number of supergiants and young clusters. Thus, we have to try to understand what is going on in the Clouds, and it looks likely that IR astronomy will provide the answer to this important question.

The imminent advent of high-resolution infrared spectroscopy is likely to yield important information about molecular abundance in late-type stars. Many molecules, in particular CO, have absorption bands only in the infrared. Thus, with the advent of multi-element spectroscopic detectors, and particularly if we can get a truly aperture-sized telescope in the southern hemisphere, great advances could be made in infrared spectroscopy. This would be important for understanding molecular abundances as well as for understanding the chemistry of the Clouds.

J. A. Graham
Cerro Tololo Inter-American Observatory, La Serena, Chile

The contrast between the research reported at this Symposium and at the IAU/URSI Symposium No. 20, held in Sydney 20 years ago, has been striking. In 1963 a number of surveys were reported, like the painstaking long-term spectroscopic work on supergiants in the Clouds by the Radcliffe astronomers, the radio surveys at Parkes, and the objective prism surveys with the Uppsala Schmidt telescope. Research is now carried out that was inconceivable at that time.

The Magellanic Clouds may be considered as laboratories for star formation and evolution and of extreme importance for our understanding of how galaxies form and evolve. We should appreciate that in the Clouds the globular clusters can still be resolved into individual stars. They are for us practically the last stage in studying the globular clusters in the Universe, before we go out into the very hazy realm of unresolved stellar systems and globular clusters.

The colour-magnitude diagrams of globular clusters presented 20 years ago could be interpreted in any number of ways. When we look at the most recently produced diagrams, they look unambiguous. It is essen-

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tial that this work on clusters be continuously refined. Most important is that we take care of getting the zero-points right and that we avoid systematic errors in our data. In this way we diminish the possibilities of trouble for the theoretical interpretations.

It is important to obtain as precise data as possible for the globular clusters in the Clouds, in particular for those containing RR Lyr stars. One such cluster is NGC 121. It contains RR Lyr stars, but it is now said to contain also a kind of carbon star. Is it old? Old means more than 10^{10} years. I would not accept an age for the RR Lyr stars of 5×10^9 years, i.e. the age of the carbon stars. This does not agree with the situation in the general field. If anyone wants to know what RR Lyr stars really are or wants to study really old metal-poor giants he should observe the western part of the SMC. That is where you find field Population II.

Supergiant stars may be difficult to use for abundance determinations, but their studies are still important. The Magellanic Clouds are excellent for studying massive stars. They are all at the same, rather well-known distance and we can determine there, better than in the Galaxy, how massive stars will get. They can also be studied at a reasonable spectroscopic dispersion. Thus, we may find out what is going on in them, what holds them together, and what occasionally tears them apart.

Some topics were either not mentioned at this Symposium or covered rather unsufficiently. Little was said about abundances. Today, when we discuss abundances, we do not have to stay with the bright supergiants. We can push on in magnitude to the normal, better behaved stars and do work of the type that has been done on stars on the giant branch of the globular clusters. It is of great importance to get good abundances for cluster stars and for field stars so that we can tie things down for studies of more distant galaxies.

Another neglected item here is that of binaries. Everyone wants to get masses for X-ray binaries, but nobody seems to care about determining masses for ordinary binaries. There are many of the latter to be found in the Clouds. We badly need to know more about stellar masses. We also need to know if in the Magellanic Clouds the same stellar mass-luminosity relation applies as in the Galaxy.

Finally, when you observe today you frequently sit in a warm control-room with your cluster on the TV-screen. It is easy then to forget all about the atmospheric conditions outside and go on taking your CCD frames. Later on you apply a mean extinction coefficient to that night without thinking about the fact that the coefficient is just a mean and hardly applied to that observing night of yours. We must remember that only when we apply the new wonderful techniques with great care and make good use of them in every other way, will they produce physically meaningful results.

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M. Grewing
Astronomical Institute, Tübingen, F.R. Germany

We have heard today about significant progress in the studies of the properties of both gas and dust in the Magellanic Clouds. The majority of these new data has been obtained with the International Ultraviolet Explorer (IUE) satellite, from low dispersion (6Å) spectra of a large number of stars in the Clouds, and from high resolution (0.2Å) observations for the brightest stars in the Clouds. These UV spectra are of particular importance since most of the resonance lines of the astrophysically relevant atoms and ions occur in this wavelength range and allow us to determine the physical state and chemical composition of the interstellar gas in the Clouds. Also, the slope of the extinction curve towards the ultraviolet and the strength of the 2200Å bump tell us something about the size distribution and composition of the interstellar dust.

In obtaining high resolution UV spectra of LMC and SMC stars, the IUE satellite was working at its sensitivity limit, i.e., only the brightest stars were accessible. These stars are known to greatly affect their circumstellar environment, both through their radiation and through their stellar winds. This introduces a potential bias into the interstellar medium studies. Also, due to their distribution accross the Clouds, they only allow probing the interstellar matter along very few lines of sight.

With the advent of the Space Telescope, this situation will change drastically. Basically all stars, which by their spectral type are suitable for interstellar medium studies, will then become accessible. The High Resolution Spectrograph (HRS) on the ST will also help to overcome, or at least lessen, another problem which has so far been hampering these studies; if the spectral resolution is not high enough to clearly separate individual line components arising from physically different regions along a particular line of sight (as is often the case with IUE observations), the quantitative determination of column densities and of element abundances becomes very uncertain if not impossible. Therefore, with the ST answers may be possible to questions like: (1) in what phases does the interstellar gas exist in the Clouds; do we find a variety of phases as in our Galaxy?, and (2) what are the chemical abundances and the abundance variations across the face of the Clouds which will reflect the amount of chemical processing and element mixing in these systems?

D.J. Helfand
Columbia Astrophysics Lab., New York

The planning for the next ten years is the following in X-ray astronomy: Now we have available EXOSAT. It was launched a couple of months ago. It is now said to have a lot of problems with the detectors.

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Functioning is anyhow a HRI-type detector, like the Einstein Observatory HRI. It is, however, considerably less sensitive, and it has only 10 arcsec resolution. The Japanese have satellites for systematic observations and they will probably keep one up until the year 2000. But their satellites, at least before 1990, have no capability to observe anything but bright sources. There is a Russian experiment planned but not yet on mission.

There is a break until 1987, when ROSAT will be launched. It is a German national project with a telescope similar to Einstein. It will go to about 2.5 keV. Its IPC detectors should be considerably better than Einstein's and the overall sensitivity of the telescope should be higher. It will do an all-sky survey. This has some useful aspects as it will see the Magellanic Clouds. It will, however, not be much available, at least not during the first two years.

At around 1990 there are an Italian and a British mission proposed, both with good spectroscopic capabilities. They should be sensitive enough to observe SNRs in the Clouds. However, neither proposal is actually funded yet. Towards the end of the period AXAF (Advanced X-ray Astronomy Facility) may come. It is not inconceivable, however, that it will never be launched.

What does this give for the Magellanic Cloud research?

With EXOSAT, higher resolution positions will be obtained of many of the unidentified sources that we know exist. No new sources will be found in the Clouds with it, however, and it is possible that not all already known will be reached.

Between 1984 and 1988 some high-energy observations of the Magellanic Clouds may be carried out with 2 or 3 instruments on the Shuttle. Typically, one instrument may get 20 hours observing time. Perhaps 2 or 3 hours of this will be for the Clouds. So there will not be much of this work done during the next five years. Some of the experiments may, however, be able to distinguish between SNRs and point sources, not because of high spatial resolution but because of spectra of higher resolution.

In 1988-90 we have ROSAT and its all-sky survey to a level of 0.01 counts/sec. It will cover the Magellanic Clouds and it should see some SNRs. It should also measure high-precission positions for all the point sources that observing time can be obtained for. According to present plans it will not be Shuttle serviceable, so it may only last a couple of years. It should carry out a survey of the Clouds that is about about 10 times better than the Einstein survey. We should see sources that we do not know now.

A careful analysis of existing data may lead to the identification of at least some SNRs in the Clouds. The large-scale structure of the

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interstellar medium in the Clouds should be looked at, in particular the regions of hot gas, e.g. the surroundings of 30 Doradus.

The ROSAT should open the possibility to look at starforming regions and clusters in the Clouds. If the clusters are similar to clusters in our galaxy, ROSAT should see some sources of that kind and we should be able to find out how many there are in clusters. Apart from the neutron star binaries we should see all cataclismic variables.

If in 10 years time we have AXAF we will be able to see in the Clouds O stars and B stars and all SNRs. There should be at least 300 of the latter, i.e. about 10 times as many as known now. We should also see them better than in our Galaxy.

What has been detected so far are Population I binaries and SNRs and the hot interstellar medium. This is all extremely young population, less than 10^7 years old. The X-ray sources may be divided into two classes: the just mentioned sources and the old sources such as novae, cataclismic variables, population II binaries. We have not been able to do much about the latter so far. Once we do, we will have sources connected with two age groups in the Clouds, those associated with the extremely young population and those associated with a population older than 10^9 years.