CONFERENCE SUMMARY

J R MOULD
Palomar Observatory, California Institute of Technology
Pasadena, Calif. 91125
USA

1. Introduction

It is traditional to begin a review on the subject of the Magellanic Clouds with a discussion of the distance of the Clouds. Feast did this in his introductory remarks to the meeting, and I shall not resist the temptation to reflect a little on this subject. At the Tubingen meeting we gave some thought to a new controversy between a (short) distance modulus of 18.2 for the LMC and the more traditional (Long) distance of 18.7. The short distance was primarily the result of main sequence fitting to LMC clusters resulting from new CCD photometry. A consensus has arisen since that time, and is represented at this meeting by results presented by Walker and Caldwell, and earlier by Reid and Strugnell (1986) and recently by Jacoby *et al.* (1990), that the best value of $(m\text{-}M)_0$ is 18.45±0.15 for the LMC (which is also the average of the short and long values). This is obtained, however, by given low weight to (firstly) recent work on the absolute magnitude of RR Lyrae stars based on the Baade-Wesselink technique and (secondly) the aforementioned main sequence fitting results

If Gerard de Vaucouleurs were here, he would undoubtedly urge us to "spread the risk" and give full consideration to all distance estimators. This is the only way to average out systematic errors whicvh are the scourge of the distance scale. By the time of the next Magellanic Clouds symposium I hope we shall have seen more work on main sequence fitting with better imaging of star clusters and an interferometric calibration of the Cepheid calibration in the Milky Way. By an interferometric calibration I mean measurement of the angular diameter changes of Cepheids in the solar neighbourhood. This variant of the Baade-Wesselink technique has the great advantage that it is essentially geometrical and has no dependence on any photospheric temperature scale. Resolution should be feasible for the nearest short period Cepheids with stellar interferometers that are now being built (for example, at one of our host institutions). The Magellanic Clouds will then be crucial to the extragalactic distance scale in extending the period-luminosity relation from short to long periods.

One reason we gather to talk about the Magellanic Clouds is so that we can return to our colleagues and say 'How can you say you understand X in distant galaxies, when we don't understand Y in the Magellanic Clouds?' In this case X = H_0, and Y is the distance.

2. Structure and kinematics

Next we considered the structure of irregular galaxies - an oxymoron, if ever there was one. For the LMC it is clear that a tilted disk model fits the kinematic data. We were told that it is important

R. Haynes and D. Milne (eds.), The Magellanic Clouds, 7–12.

https://doi.org/10.1017/S0074180900199930 Published online by Cambridge University Press

to include the effect of the transverse velocity of the LMC in comparing any such model with observations. Westerlund considered that the best value of the inclination of this disk to the plane of the sky was 45°. A single disk is now seen to fit the gas, planetary nebulae, Miras, and intermediate age clusters. This disk has a rising dispersion with "lookback" time according to Hughes. It has a well-defined rotation curve. It appears that the oldest star clusters, those of type VII, whose special prototype nature was stressed by van den Bergh, are alone in populating a separate disk.

In other words, the LMC is not such an irregular galaxy. It is worth remembering that in a truly irregular galaxy the radial direction is no less complex than the transverse directions, and in the SMC the radial direction seems to be more complex. The SMC was described by Lequeux as "a loose association of gas and stars". According to Caldwell its elongation in the radial direction is a maximum of 19 kpc, with a central core of just 8 kpc. The velocity dispersion of the planetary nebulae and carbon stars is approximately 25 km s^{-1}, and there seems to be no rotation.

In future work we can hope to see a study of the kinematics of the McCarthy and the Azzopardi carbon stars. This should tie down the parameters of the disk unequivocally. We can also look forward to extension of the rotation curve of the LMC by measurement of the velocities of the most eastern and western objects along the lines of the poster by Storm. Regarding the kinematics and dynamics of the Clouds, we may ask 'How can you say you understand the distribution of matter in distant galaxies, when we don't understand it in the LMC?'

3. Star formation

The subject of star formation in the Magellanic Clouds was a much larger concern in this meeting than in Tubingen. In part, this is because of the availability of new telescopes such as IRAS and SEST. But, in addition, the existence of a dramatic burst of star formation in the 30-Dor region makes the LMC a special place to pursue these investigations. The birth of a star cluster in this region was identified in spectacular pictures shown by Walborn and Meylan. We saw a speckle image of R136, and the problem discussed in the panel meeting in Tubingen was dramatically resolved. This was a fine example of an advance in astronomical instrumentation answering an important question and making previous arguments seem redundant. In addition, the stellar contents of HII regions in the Clouds were reviewed by Kennicutt, presenting us with the most direct view yet of the massive end of the IMF.

We have a zeroth order model for this burst of star formation centred on 30 Dor in the model by Dopita *et al.* (1985). However, it is now clear that the situation is much more complex even in the central regions, as the $H\alpha$ pictures of Meaburn have shown. Reid *et al.* (1987) have shown the need to investigate fully the age spread in star formation resulting from the wave that has propagated through this region. We saw radio continuum and IRAS images that suggest we need to consider the possible breakout of the ionization front from the HI disk with its otherwise circular supergiant shell. We need to build on this simple model for a large burst of star formation.

4. Star formation history

We also considered the star formation history of the Magellanic Clouds. This is an area in which the work itself seems to proceed in bursts; the previous burst was initiated by Butcher (1977). It is useful to remind ourselves how we know what we know about the star formation history of the solar neighbourhood. Here the definitive work is that of Twarog (1980) who employed Stromgren photometry of F stars in the vicinity of the Sun to determine how fast stars were peeling off the main sequence as a function of time. In the Magellanic Clouds where we know the distances of the corresponding stars, we can use just UBV photometry to do the same experiment. The crucial magnitude range for measuring the star formation rate on billion year timescales is 20th-23rd magnitude. The photometry must be accurate and complete, however, and better imaging is required to achieve this. The NTT at ESO or HST after 1993 would meet these requirements.

An area where special attention would be warranted is the Bar of the LMC. The red colours that we saw in Bothun and Thompson's (1988) images tell us that is one of the oldest of the LMC's stellar populations, but we don't really know much about the star formation history of the Bar. Since this is the most crowded region of the LMC, it is probably more accessible to a luminosity function analysis than to the colour-magnitude approach of Twarog. Butcher showed us simulations by Mighell which indicate just what you can expect to get out of luminosity function analysis, and I think in the case of the LMC Bar, it would be very appropriate.

Two questions which are easy to pose also deserve attention. Is the cluster age gap (4-10 Gyrs) a real indication of the star formation history? Da Costa showed us that the NGC clusters respect the gap. But van den Bergh told us that the type VII clusters belonged to a special primordial population. So perhaps the gap in what people sometimes like to call populous clusters (i.e. types I-VI) is one-sided and due to fading or disruption. One could invent a scenario in which there was a burst of $10^5 M_\odot$ clusters 15 Gyrs ago, followed by steady formation of $10^4 M_\odot$ clusters, which fade out of the NGC catalog in 4 Gyrs.

The second question is: is the spread in M/L versus time real? Figure 1 shows the data that were presented in this meeting on M/L clusters. I have, for no especially good reason, limited the diagram to studies of M/L based on individual stars rather than integrated light. As Meylan points out, these techniques are complementary. Is the spread in Figure 1 real, or is it due to different cluster kinematics? If it is real, is it due to variations in IMF between clusters? Further work is required to answer these questions, but it is very encouraging to see progress in this important empirical constraint on models for the evolution of stellar populations.

Once again, if we don't understand the star formation history of the Magellanic Clouds, how can we say we understand it in distant galaxies?

5. Chemical enrichment

As regards the chemical evolution of the Clouds, a number of important questions arose. Not many of them are well answered yet. How can we improve our determination of Z(t) in the LMC? Clearly the cluster data are very sparse and may well remain so. The answer is to analyze field star metallicities. Again, Twarog's (1980) study of the solar neighbourhood is the prototype for the LMC, and UBV photometry to ±0.01 mag in U-B of main sequence F and early G stars is a good way to do this. Why is [O/Fe] negative in the Clouds? Observations presented at this meeting by Bessell and Russell, Spite *et al.* and Williams and McWilliams were in agreement on this point. We think we understand whey the Milky Way is oxygen underdeficient (e.g. Gilmore *et al.* 1989, Wheeler *et al.* 1989) at low metallicity. But why are the Clouds oxygen overdeficient?

Why are the Wolf-Rayet star statistics and the X-ray binary statistics different in the Clouds from the Milky Way? Hutchings and Cowley and Smith showed the data, and the suggestion is that low metallicity and thus low mass loss may be responsible for these effects. Kudritzski told us that a fully consistent theory of mass loss in early type stars is at hand. It would be very exciting if a quantitative theory of the evolution of massive stars could make some predictions about the endpoints of stellar evolution for $M > 10 M_\odot$.

https://doi.org/10.1017/S0074180900199930 Published online by Cambridge University Press

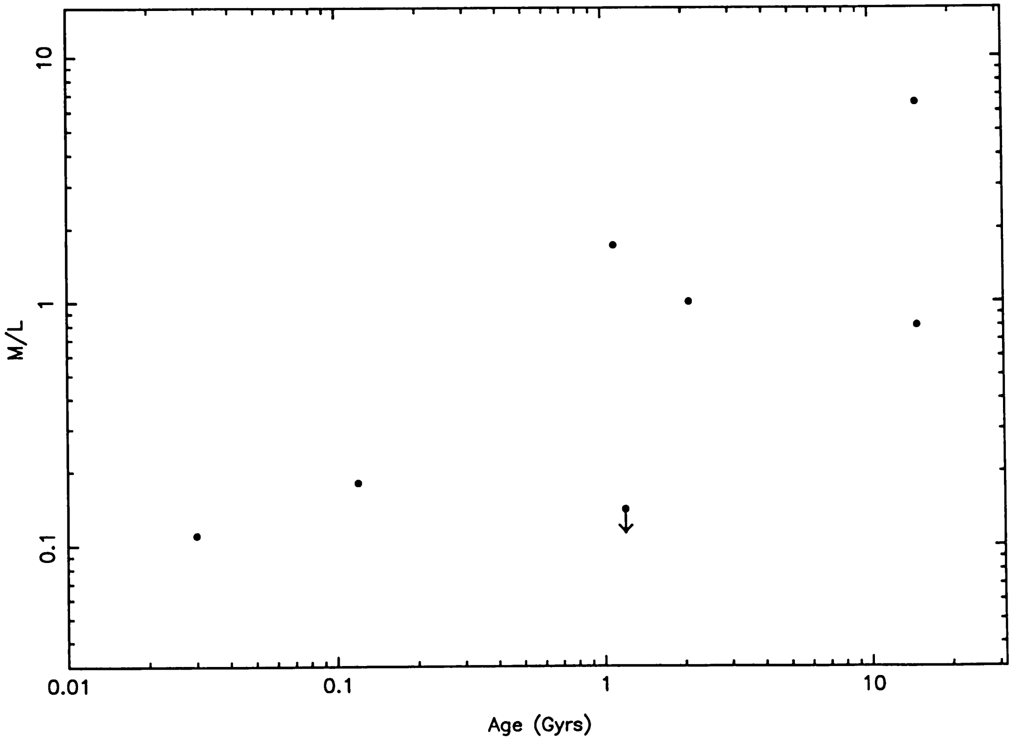

Figure 1. Visual mass to light ratio (in solar units) versus age for seven Magellanic Cloud star clusters. This is composed of observations by Fischer, Mateo and Seitzer and collaborators presented at this meeting. The clusters are NGC 419, 1783, 1835, 1866, 1978, 2157 and 2257. Ages are from Mould and Da Costa (1988) (except NGC 2157 - 3 x 10^7 years - Hodge 1983).

Turning finally to the effect of intermediate mass stars on chemical evolution, why is CN production on the AGB different in the Clouds? The evidence that this is the case was presented here by Barlow and by Dopita from analysis of planetary nebulae. But a detailed theory of AGB evolution is not available to account for this. From the work on carbon stars in the Clouds we have a good idea of how the AGB is populated at 10^9 years, a fair idea of how it is populated at 10^8 years, but nothing very firm concerning what a $3x10^7$ year AGB is like. Good data exist bearing on this question; we have studies of the LPVs discussed by Wood, field colour surveys presented by Reid, and cluster data from Frogel *et al.* (1990). We need a quantitative theory of AGB evolution, envelope composition, and mass loss to tie these numbers together.

6. Interstellar medium

The interstellar medium of the Magellanic Clouds is an area where progress since Tubingen has been limited by the need for new observing facilities. The two facilities that have come along have been IRAS and the low-resolution CO surveys. Both have posed puzzles as regards the physical interpretation of the data they have produced. To understand the IRAS data, we need to know more about the nature of dust in the interstellar medium, its constituents, the heating mechanism, and the size distribution. Some interesting correlations bearing on these matters were presented at the meeting by Sauvage. Carbon monoxide offers us similar problems of interpretation to wrestle with, such as the CO/H_2 conversion factor and some advanced photochemistry problems.

The future for understanding the interstellar medium in the Clouds still looks bright, with the appearance of new opportunities to observe each of the three phases of the ISM and its corresponding diagnostics. The hot phase can be observed in x-rays and absorption lines with ROSAT and HST. The warm phase can be studied through pulsar dispersion measure and the $H\alpha$ distribution. The cold gaseous phase can be examined in CO and HI with SEST and the AT. The dust will be probed by ISO, and the very coldest component will be detected by AST/RO. This pioneering submillimetre project in Antarctica is particularly exciting. Geographically, Antarctica is the ideal observatory site for study of the Magellanic Clouds. Those of us who work at shorter wavelengths should watch these developments closely.

All these new facilities are offering us higher spatial resolution, which we need in the Magellanic Clouds, even more than we need greater sensitivity.

7. The Magellanic System

Lastly, we considered two models for the formation of the Magellanic Stream. The tidal model has been around for long enough to attract criticism, and, thanks to Fujimoto's efforts, has been worked out in detail so that it can be checked. The first problem for the model is that there are no stars in the Magellanic Stream, as work by Irwin has confirmed. A possible solution to this problem is to confine the gas and heat the stars. However, a 5 km s^{-1} velocity dispersion which seems large for such a young population would not be enough to achieve separation. Another one is not to have any stars in the Stream material originally. A second problem for the model is that previous encounters of the Large and Small Clouds produce other disks, but it now seems that the young and intermediate age disk is one and the same.

The ram pressure model has not been worked out in sufficient detail to confront with observations. Just how dense a hot Galactic corona is required, and should that density be more obvious in absorption line observations?

There is some evidence that the two models themselves are merging, in particular as regards the confinement of the Magellanic Stream. The problem clearly deserves more work, and the motivation is clear: what can we say about distant interacting galaxies, if we don't understand the interaction of the Magellanic Clouds?

8. Conclusion

The Magellanic Clouds have everything. We have seen a wealth of new data at this meeting which makes what we knew in 1983 seem very modest. With new observational prospects for this decade we can hope for a revolution in our understanding. This will no doubt make the questions we have considered this week seem trivial compared with the problems confronting us in 1997.

One further, very important word. I would like to convey our thanks to the organizers of this meeting, especially to Ray Haynes, Doug Milne, Julienne Harnett and their many helpers for doing so much to ensure that a scientifically profitable and enjoyable time was had by all.

9. References

Bothun, G., Thompson, I. (1988), *Astron. J.* **96**, 877.
Butcher, H. (1977), *Astrophys. J.* **216**, 372.
Dopita, M., Mathewson, D., Ford, V. (1985), *Astrophys. J.* **297**, 599.
Frogel, J., Mould, J., Blanco, V. (1990), *Astrophys. J.* **352**, 96.
Gilmore, G., Wyse, R., Kuijken, K. (1989), *Ann. Rev. Astron. Astrophys.* **27**, 555.
Hodge, P. (1983), *Astrophys. J.* **264**, 470.
Jacoby, G., Walker, A., Ciardullo, R. (1990), preprint.
Mould, J., Da Costa, G. (1988), *Progress and Opportunities in Southern Hemisphere Astronomy*, V. Blanco, M. Phillips (eds.) (Astron. Soc. Pacific Conference Series, v.1) p.197.
Reid, I.N., Mould, J., Thompson, I. (1987), *Astrophys. J.* **323**, 433.
Reid, I.N., Strugnell, P. (1986), *M.N.R.A.S.* **221**, 887.
Twarog, B, B. (1980), *Astrophys. J.* **242**, 242.
Wheeler, J.C., Sneden, C., Truran, J. (1989), *Ann. Rev. Astron. Astrophys.* **27**, 279.