ESO-1048S

0 1160 0040102 0
Fermilab Library

Resolving Distant Galaxies Into Stars

D. Minniti and T.R. Bedding

European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748
Garching bei München, Germany

1 Introduction

With telescopes such as the VLT, many projects of extragalactic astronomy will be transformed into stellar astronomy. The instrument specifications for CONICA at the VLT give a limiting magnitude of $m_H = 26.3$ (3σ in 1 hour integration). Taking a naive example, the brightest stars in the Galaxy reach $M_K = -11.2$ (Humphreys 1988), or $M_H = -11.5$. Therefore, in a perfect universe without any confusing sources, we would be able to detect one of these stars at a distance modulus of $m - M = 37.8$, or $D = 360$ Mpc. This is further away than Virgo — further even than Coma — and is approaching cosmologically interesting distances. In short, it is a **BIG** number. Of course, the universe is not perfect and sources are not isolated. In order to assess the capabilities of the VLT, we will discuss a more realistic example aimed at addressing a specific problem in galaxy formation.

Galaxy formation is an important area of study in modern astronomy. In particular, the formation of bulges of spirals and elliptical galaxies and the relationship between them remains an area of considerable uncertainty. Did they form shortly after the Big Bang in a short period of intense activity that consumed all the gas and prevented further star formation? Or did they have several episodes of star formation, somehow triggered by mergers or accretion processes? In this case, the observed light would come from both old and intermediate age stars.

The issue can be resolved by constructing luminosity functions (LFs) and colour-magnitude diagrams (CMDs) for the stars in ellipticals and bulges, and comparing these with predictions from stellar evolutionary theory. The theory is fairly well understood, having been tested and calibrated on open and globular clusters spanning a wide range of ages and metallicities. The project requires photometry to identify and measure luminosities for the stars at the top of the asymptotic giant branch (AGB). This method would complement the existing integrated spectroscopic data and would allow one to study the stellar distribution, to separate the different populations, and to estimate the ages, metallicities and distances of these populations.

Dec 1994

2 Observing in the near–infrared

There are several advantages to obtaining CMDs in the near–IR:

• Giant stars have the peak of their spectral energy distribution here, increasing the contrast relative to the underlying fainter and bluer stars.

• We avoid the degeneracy in the optical colours of the red giant branch. This degeneracy makes it difficult with optical photometry to determine ages or metallicities, especially for the more metal–rich populations that dominate bulges and ellipticals.

• The transformation between the photometric observations and theory (Mbol, Teff) is easier in the IR than in the visible.

• Extinction and reddening due to dust are less ($A_K = 0.1 A_V$).

New IR arrays under development (both HgCdTe and InSb) should deliver higher quantum efficiency over an expanded wavelength range. The large formats will allow a reduction of the pixel scale on the sky and/or an increase in the area coverage (see Rieke 1994).

Adaptive optics in the IR will give two benefits. Firstly, it will allow a substantial gain in sensitivity for point-source photometry by reducing the diameter of stellar images, thus increasing the signal relative to the background sky. Secondly, the increased resolution reduces confusion in crowded regions. We should not forget that VLT + AO will have higher angular resolution than HST + Nicmos.

3 What has been done before?

The bulges of all 3 spirals of the Local Group (MW, M31 and M33) have been well studied in the near–IR, as has the dwarf elliptical M32. Figure 1 shows CMDs for the three Local-Group galaxies, which are all at about the same distance. In all three cases, the top of the AGB is clearly seen and has a sharp cutoff at $K \simeq 16$. Measuring this cutoff magnitude in more distant galaxies should allow one to determine the distance.

Here is a summary of results obtained from infrared CMDs:

• In the bulge of M31, Rich & Mould (1991) found that the brightest giants are brighter than stars in globular clusters, concluding that the M31 bulge must be younger than the globulars. These results were disputed by Renzini (1992), DePoy et al. (1993), and Davies et al. (1992). More recently, Rich et al. (1993) expanded their observations, supporting their original conclusions.

• In the dwarf elliptical M32, Freedman (1992), and Elston & Silva (1992) found evidence for a luminous intermediate-age population. This suggests an episode of star formation in the last 5 Gyr.

• The M33 bulge was detected and resolved by Minniti et al. (1993). They find a trace for a young stellar population in the inner regions of M33 on the basis of H-band LFs. Minniti et al. (1994) presented further IR CMDs, confirming the presence of a bluer plume of younger objects. With the help of the isochrones

of Bessell et al. (1991) we can get an estimate of ages and metallicities of these populations.

The Local Group galaxies are the only ones where these kinds of studies have been done. Obtaining CMDs for more distant galaxies would clearly be a very significant result. In particular, this would give access to both normal and giant ellipticals, neither of which are are present in the Local Group (see Freedman 1994). In addition, M32 is anomalous in many respects (e.g., Rose 1994), so it may not be representative of the distant and more luminous elliptical galaxies.

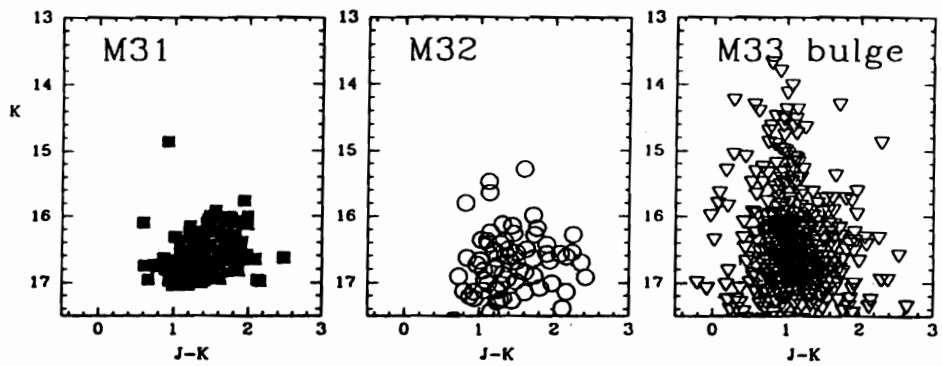

Fig. 1. Colour-magnitude diagrams for the brightest stars in three Local Group galaxies. Left: the bulge of M31 (Rich & Mould 1991). Middle: the dwarf elliptical galaxy M32 (Freedman 1992). Right: M33 (Minniti et al. 1994).

4 What can be done now?

Until now, it has not been possible to obtain photometry for individual stars in galaxies beyond ~1 Mpc. Thanks to advances in adaptive optics, this should now be achievable with 4-m class telescopes. We will use COME-ON+ to obtain infrared photometry of the brightest stars in the a giant elliptical galaxy NGC 5128 (Cen A). This galaxy is of particular interest because of its special status as the closest radio galaxy and because it shows evidence of having undergone a recent interaction. We will obtain deep H and K' photometry in two fields centred on foreground SAO reference stars that are conveniently placed at 4.5 and 11 arcmin from the nucleus. With these observations, we hope to construct luminosity functions and colour-magnitude diagrams of the brightest stars in Cen A, which we will use to derive the distance to the galaxy and estimate ages for the youngest stellar populations.

5 What can be done with VLT?

The VLT with CONICA and adaptive optics will extend the distance to which we can resolve stars in bulges and ellipticals by a large factor. The following estimates are based on specifications given in the VLT instrument booklet. The best filter for deep photometry is H, where the bolometric corrections are also straightforward (e.g. Bessell & Wood 1984). However, photometry in a second band is desirable to add colour information.

CONICA will reach a 3-sigma limiting magnitude of $H = 26.3$ in one hour, with a scale of 12.8 mas/pixel. Finding a bright star to use as wavefront sensor next to these galaxies should not be a problem in most cases, since the AO system at the VLT will use stars as faint as $V = 16$. ISAAC will be about three magnitudes less sensitive in H because of the absence of adaptive optics, although tip–tilt correction would give some improvement.

Based on these limiting magnitudes, CONICA will detect the brightest stars in bulges and ellipticals out to a distance modulus of $m - M = 34.8$ (D = 91 Mpc) and sample the top of the luminosity function out to $m - M = 33.8$ (D = 57 Mpc). These figures are based on an absolute magnitude of $M_H = -8$ for the brightest giants in spheroidal populations of Local Group galaxies (neglecting reddening). For comparison, for the Centaurus group has $m - M = 27.5 \pm 0.3$, Virgo has $m - M = 31.1 \pm 0.5$ ($D = 17$ Mpc, $Vr = 1000$ km/s) and Coma has $m - M \sim 35$ ($Vr = 4500$ km/s). Therefore, we should be able to perform a line-of-sight depth study of Virgo and Coma.

6 What is the limit?

We cannot go as far as one wants, because of crowding and pixel size problems, and more important problems like contamination from the Milky Way and background galaxies. The limits will be dictated by the following effects, which will make these observations challenging:

- Field crowding $\longleftrightarrow$ Limited pixel size:

This is the main limiting factor. To overcome this, we can chose the appropriate surface brightness level so that crowding is not a problem. DePoy et al. (1993) illustrated effect for M31.

- Contamination:

The line of sight to distant objects goes through the halo of our Galaxy, which contains many low mass stars. These can be estimated down to very faint magnitudes using simple Galactic models, and turn out not to be important. The contamination by background galaxies is expected to dominate at very faint K magnitudes. In principle, this could be accounted for by observing control fields.

- We need bright stars conveniently located to use for wavefront sensing.

7 Final remarks

The VLT will transform extragalactic astronomy into stellar astronomy. There will be no need to rely on models and observations of the integrated light to find the physical properties of distant galaxies. Our technical requirement is simply that CONICA achieves the performance described in the booklet. With this, we will be able to determine ages, metallicities and distances for the stellar populations of very distant galaxies. We might also be able to put important constraints on galaxy formation, and decide on the history of mergers for a particular galaxy, just by looking at its shells and shreds.

Finally, we note that pushing the distance limit to which we can resolve individual stars in the IR with the VLT also means pushing the limit where the surface brightness fluctuations method is useful. Additionally, considering the suggestion put forward by G. Jacoby at this meeting of using surface brightness fluctuations of globular clusters as a distance indicator, we might consider obtaining a 3–dimensional picture of the galaxy distribution within several hundred Mpc, independently of radial velocity measurements.

References

Bessell, M. S., Brett, J. M., Scholz, M., & Wood, P. R. 1991. AAS, 89, 335
Bessell, M. S., & Wood, P.R. 1984, PASP, 96, 247
Davies, R. L., Frogel, J. A., & Terndrup, D. A., 1991, AJ, 102, 1729
Elston, R., & Silva, D. R. 1992, AJ, 104, 1360
Freedman, W. L. 1992, AJ, 104, 1349
Freedman, W. L. 1994, in "Local Group Galaxies", eds. A. Layden & J. Storm (ESO: Garching) in press
Humphreys, R. M., 1988, in ASP Conf. Ser. IV, p. 103
Minniti, D., Olszewski, E., & Rieke, M. 1993, ApJ, 410, L79
Minniti, Olszewski & Rieke 1994 in "Local Group Galaxies", eds. A. Layden & J. Storm (ESO: Garching) in press
Renzini, A. 1992, in I.A.U. Symp. 153 "Galactic Bulges", eds. H. Dejonghe & H. Habing (Dordrecht:Kluwer), p. 151
Rich, R.M. & Mould, J.R. 1991, AJ, 101, 1286
Rich, R.M. & Mould, J.R., & Graham, J. R. 1993, AJ, 106, 2253
Rieke, M. 1994, in "Astrophysics with IR Arrays", ed. I. S. McLean, in press
Rose 1994, AJ 107, 206

This book was processed by the author using the TEX macro package from Springer-Verlag.