GLOBULAR CLUSTERS AND GALAXY FORMATION

Duncan A. Forbes[1]

Globular clusters provide a unique probe of galaxy formation and evolution. Here I briefly summarize the known observational properties of globular cluster systems. One re-occurring theme is that the globular cluster systems of spirals and ellipticals are remarkably similar. Photometry, and the limited spectra available, are consistent with metal-poor clusters forming before the main spheroid component is established and the metal-rich ones forming at the same time as the spheroid in a burst of star formation. These observations are compared to a model for globular cluster formation in a ΛCDM hierarchical universe. One model result reported here is that S_N is determined at early times and little affected by late epoch mergers.

Globular clusters (GCs) trace the star formation and chemical enrichment history of their host galaxy. As such they provide a unique probe of galaxy evolution. They are also simple stellar systems and so may be easier to understand than the galaxies themselves which can possess a complex mix of stellar populations.

Good quality photometric data on GCs is now available for ∼ 50 E/S0s and a small number of spirals. In Fig. 1 we show the GC metallicity distributions for some galaxies with a range of Hubble types. Observations suggest that most moderate size galaxies have a bimodal GC metallicity distribution and that, to first order, they appear with the same mean values, at [Fe/H] ∼ −1.5, −0.5. This indicates the presence of two distinct GC subpopulations. Thus a simple one-stage collapse scenario for elliptical galaxies can be ruled out (a two-phase collapse remains a possibility; see Forbes, Brodie & Grillmair 1997). Studies of the *inner metal-rich* GCs in the Milky Way (eg Minniti 1995) and other spirals (Forbes, Brodie & Larsen 2001) suggest that such GCs are associated with the bulge component of spirals and not the disk. In this context, it is not surprising that dwarf galaxies, with little or no bulge, generally have few metal-rich GCs (see Fig. 1).

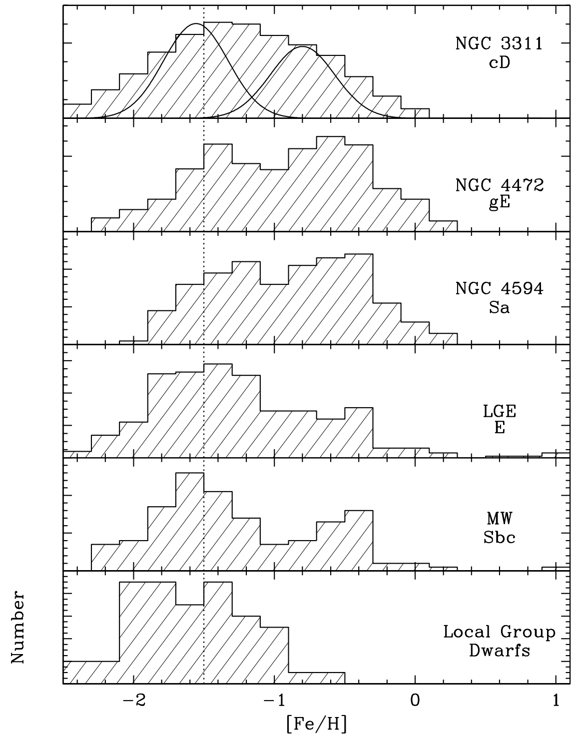

Fig. 1. Globular Cluster metallicity distributions for a range of Hubble types. All galaxies reveal a population of metal-poor clusters ([Fe/H] ∼ –1.5). Local Group dwarfs with little or no bulge component have very few metal-rich clusters, whereas all large galaxies with a bulge/spheroid possess metal-rich clusters ([Fe/H] ∼ –0.5).

Although all large galaxies have a metal-rich subpopulation, the mean metallicity of this subpopulation varies with galaxy mass (Forbes & Forte 2001). In other words the metal-rich GCs reveal a metallicity-mass relation. Interestingly, the metal-poor subpopulation appears to have a constant metallicity at [Fe/H] ∼ −1.5. This suggests that the metal-poor GCs are pre-galactic while the metal-rich ones know about the galaxy potential they form in. These trends are true for ellipticals, S0s and the bulges of spirals.

The GC systems of spirals and ellipticals share other common properties. The number of metal-rich

[1]Centre for Astrophysics & Supercomputing, Swinburne University, Mail# 31, PO Box 218, Hawthorn, VIC 3122, Australia (dforbes@astro.swin.edu.au).

GCs per unit *bulge/spheroid* light is roughly the same (with S_N (bulge) $\sim$ 1) for spirals and field ellipticals. Recently Larsen et al. (2001) showed that the mean sizes of individual GCs vary with metallicity for a range of Hubble types. Furthermore the GC luminosity function peak and width are remarkably constant between spirals and ellipticals. Thus the GC systems of spirals and ellipticals are more alike than they are different, suggesting similar formation processes.

Many presentations at this conference have focused on galaxy formation in a ΛCDM hierarchical universe. Observations of GCs provide another, alternative means in which test the predictions of this model. One of the most basic predictions of this picture is that the bulges of spirals and ellipticals formed in a similar way. Our observations of the similarities in the GC systems of bulges and ellipticals would support this view.

Recently we simulated the formation of GCs around ellipticals using the GALFORM semi-analytic code (eg Cole et al. 2000) in a ΛCDM universe. Details of this work can be found in Beasley et al. (2002) and is the subject of a poster at this conference by Beasley. Briefly, GCs are formed in two modes of star formation. In the first, or 'quiescent' mode, metal-poor GCs form in proto-galactic clouds. These gaseous clouds collapse/merge, giving rise to a burst of star formation. During this 'burst' mode, the vast bulk of the galaxy stars form along with the metal-rich GCs. The final GC system depends on the local galaxy environment and its mass (luminosity). For example, low luminosity field ellipticals tend to have a more extended star formation history which is more bursty in nature. We would expect such galaxies to reveal metal-rich GCs that are 3-5 Gyrs younger in the mean than the metal-poor ones which are ∼12 Gyrs old in all ellipticals.

Another interesting aspect of our modeling is the evolution of GC specific frequency S_N (number of GCs per unit galaxy starlight). In Fig. 2 we show the evolution of S_N for two galaxies of different luminosities. The plots show that S_N is largely determined at early epochs and shows little or no change in the last ∼8 Gyrs. In the case of the lower luminosity galaxy, it undergoes a major merger $\sim$ 5 Gyrs ago. However even though some new GCs are formed in that merger event, the effect on S_N is slight.

In conclusion, the comparison of model predictions from ΛCDM and observations of globular clusters are providing new insights into the formation mechanism and evolution of galaxies.

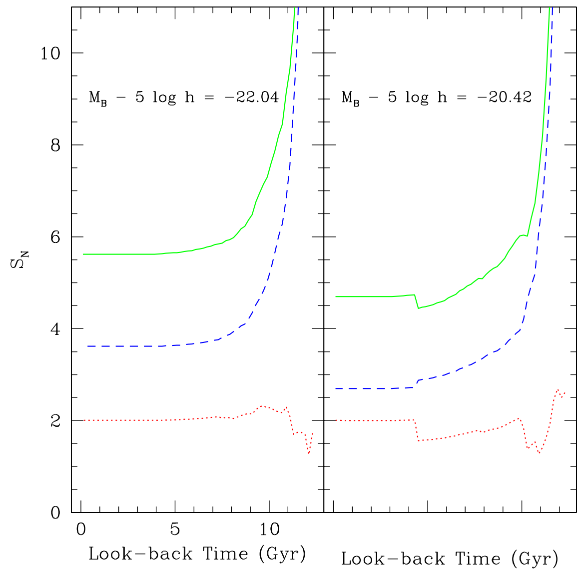

Fig. 2. Evolution of globular cluster specific frequency S_N with look back time for two different galaxy realizations from GALFORM. The dotted line shows the evolution of S_N for the red clusters, the dashed line for blue clusters, and the solid line for the total cluster system. The lower luminosity galaxy undergoes a merger at ∼5 Gyrs ago, which causes only a small increase in the overall S_N of the galaxy.

REFERENCES

Beasley, M., Baugh, C., Forbes, D., Sharples, R., Frenk, C., 2002, MNRAS, in press

Cole, S., Lacey, C., Baugh, C., Frenk, C., 2000, MNRAS, 319, 168

Forbes, D., Brodie, J., Grillmair, C., 1997, AJ, 113, 1652

Forbes, D., Brodie, J., Larsen, S., 2001, ApJL, 556, 83

Forbes, D., Forte, J., 2001, MNRAS, 322, 257

Larsen, S., Brodie, J., Huchra, J., Forbes, D., Grillmair, C., 2001, AJ, 121, 2974

Minniti, D., 1995, AJ, 109, 1663