On the relation between globular cluster specific frequency and galaxy type.

JJ Kavelaars
Department of Physics and Astronomy, McMaster University

ABSTRACT

The universality of the globular cluster luminosity function (GCLF) contrasts the variation seen in the specific frequency ($S_N$). The variation in $S_N$ has been shown to follow a linear relation with $L_X$ for brightest cluster galaxies [Blakeslee 1997]. Further, the variation of $S_N$ with galactic radius within individual giant ellipticals is seen to be a constant fraction of the gas density [McLaughlin 1998]. There are now a number of galaxies for which direct mass estimates based on the radial velocities of the globular clusters are available. By comparing the mass of galaxies determined in this way with the number of clusters within these galaxies we show that the fraction of mass which is converted into globular clusters is constant independent of galaxy type or environment. This implies that the process of globular cluster formation is not influenced by the host galaxy and supports the notion of the universal GCLF.
1. Introduction

Globular clusters (GCs) are ubiquitous and apparently obey a universal formation mechanism as evidence by the constancy of the globular cluster luminosity function (GCLF) [Harris 1991] However, this constancy of formation appears juxtaposed against the environments of the GCs host galaxies. The nature of this juxtaposition manifests itself in the variation of cluster specific frequency as a function of galaxy type and environment.

In order to compare globular cluster populations of two disparate galaxies (say an E galaxy compared to an S0) the total number of clusters about that galaxy should be normalized to some trait which both objects have in common. The common measure in use is referred to as the globular cluster specific frequency and is defined as

\[ S_N = N_t (M/L)_V^{0.4} + 15.0 \]  

[Harris & van den Bergh 1981] where \( N_t \) is the total cluster population and \( M/V \) is the integrated V magnitude of the galaxy.

Observations of the globular cluster systems of brightest cluster galaxies (BCGs) have revealed the compelling relationship between GC specific frequency and the X-ray luminosity \( (L_X) \) of the host galaxy [Blakeslee 1997, Harris et al. 1998]. This relation gives an intuitive explanation of the variation in \( S_N \) amongst the galaxies of the same type and suggests that galaxy mass is the determining factor in cluster formation.

Use of X-ray temperatures \( (T_X) \) to determine the radially dependent gas density within M87 and comparing this to the radial variations in cluster numbers has further revealed that the efficiency of cluster formation is a constant of the density of gas [McLaughlin 1998]. The evidence that the formation efficiency of globulars is a constant with radius is reassuring to the previous result for BCGs as the relation between cluster numbers and \( L_X \) was based solely on clusters within a distance of 32 per cubic kiloparsec of the BCG center.

The final piece of the \( S_N \) puzzle is the variation in \( S_N \) between spiral and elliptical galaxies.

2. \( S_N \) and galaxy type

Use of the \( S_N \) relation leads to the common result that spiral galaxies have a lower specific frequency than do ellipticals (Fig. 1). This result is further emphasized when the high \( S_N \) galaxies M87 and NGC 1399 are included and their total cluster populations are compared to their total luminosity. The reason for this variation of specific frequency is not yet well understood although many competing theories have been proposed and not all of these suggestions are obviously wrong.

The development of multi-object spectrographic devices has made the determination of the mass of remote galaxies using their cluster populations possible. These investigations use the clusters as test particles in the potential well of the parent galaxies mass distribution and provide a reasonable measure of the total mass of the galaxy (for example Bridges et al. 1997). Although the full decomposition of the mass distribution is not possible [Merritt & Tremblay 1993] the use of a model dependent mass estimator such as the projected mass estimator (PME) [Bahcall & Tremaine 1988] makes possible a comparison of the masses of the parent galaxies using the clusters themselves.

Several studies of galaxy halo masses using GCs as probes are now underway and the number of published results now makes clear the link between total cluster population and the mass of the parent galaxy.

3. Mass-Specific Frequency

Table 1 lists those galaxy whose masses have been determined via spectroscopy of the cluster population. For each of these galaxies the mass has been estimated using the PME modified to account for extended mass distributions [Heisler, Tremaine, & Bahcall 1985]. These estimates are not necessarily the most accurate for each individual galaxy (in the cases of M87, Cohen & Ryzhov 1997 and NGC 1399 Kissler-Patig et al. 1998 the large numbers of velocities available make possible a more complex model analysis) however, by using the same estimator similar biases are introduced for each galaxy and so a fair comparison of the relative mass of these galaxies is possible. Also shown is the radius out to which cluster velocities have been measured. When using the PME to determine the mass of a distribution the mass determined is that enclosed by the most distant test particles. Thus the mass quoted in the table is in fact the mass enclosed in the radius given for that galaxy.

As shown in Table 1 the mass-to-light ratios of these various galaxies are not constant. In fact the immediate indication is that galaxies with high values of \( S_N \) are also those with high values of \( M/L \). This begs the question of the mass-specific frequency. Defining a mass-specific frequency as the ratio of a galaxies cluster population interior to some radius, \( R \), to the mass of the galaxy within that radius provides the relation,

\[ S_M = N_T (R) \frac{23.2 \times 10^4 M_{\odot}}{M_{gal}(R)} \]  

where \( N_T (R) \) is the total cluster population interior to some radius \( R \) and \( M_{gal}(R) \) is the mass interior to that radius, as determined via the PME. The normalization factor \( (23.2 \times 10^4 M_{\odot}) \) is the mean mass of the Milky Way GCs assuming \( M/L = 2 \) [Harris 1996]. This definition is different from previous ones which relied on a constant value of \( M/L \) for a given galaxy type [Harris 1991, Zepf & Ashman 1993].
Table 1

Galaxy Properties

| Galaxy   | Type  | \( M_V \) | Mass \( (10^{11} M_\odot) \) | \( N_t \) | Radius \( kpc \) | \( S_N \) | \( S_M \) \( 10^{-4} \) |
|----------|-------|------------|-------------------------------|--------|----------------|--------|----------------|
| NGC 1399 | E1/cD | -21.1      | 50 \( \pm 10^b \)             | 2100 \( \pm 1000^a \) | 25    | 19 \( \pm 6 \) | 1.0 \( \pm 0.5 \) |
| NGC 4486 | E0/cD | -22.4      | 60 \( \pm 20^i \)             | 4800 \( \pm 500^b \) | 18    | 14 \( \pm 0.5 \) | 1.9 \( \pm 0.6 \) |
| NGC 4472 | E2    | -22.6      | 25 \( \pm 5^j \)              | 2200 \( \pm 600^c \) | 18    | 5.6 \( \pm 1.7 \) | 2.0 \( \pm 0.7 \) |
| NGC 4594 | Sa    | -22.3      | 5 \( \pm 1.5^k \)             | 660 \( \pm 200^l \)  | 14    | 2.3 \( \pm 0.7 \) | 1.9 \( \pm 0.8 \) |
| NGC 3115 | S0    | -21.45     | 10 \( \pm 4^m \)              | 415 \( \pm 50^n \)  | 19    | 2.0 \( \pm 0.5 \) | 1.6 \( \pm 0.6 \) |
| NGC 3031 | Sab   | -21.2      | 3 \( \pm 1^o \)               | 210 \( \pm 30^p \)  | 20    | 0.7 \( \pm 0.1 \) | 1.5 \( \pm 0.6 \) |
| M31      | Sb    | -21.7      | 4 \( \pm 0.4^q \)             | 250 \( \pm 100^r \) | 20    | 0.7 \( \pm 0.2 \) | 1.5 \( \pm 0.9 \) |

Note.— \( S_N \) [Harris 1991] determined using the entire cluster population and full integrated luminosity of the parent galaxy. The value for the specific mass frequency was determined using only clusters interior to the radius to which the mass of the galaxy has been determined. Keys refer to the reference section.

The values of \( S_M \) are listed in column 6 of Table 1 and the relation between parent galaxy luminosity and \( S_M \) is shown in Fig. 1. Clearly there is now no correlation between galaxy luminosity and cluster population and no obvious difference between the relative populations of spirals, ellipticals and cD galaxies, even those previously seen as super-abundant can now be reconciled by a single value of cluster formation efficiency.

The cause of the anomalous \( S_N \) values of some cD galaxies and the difference between \( S_N \) of spirals and that of ellipticals must lie in the stellar population. Already in the literature there are some suggestions to this explanation of the \( S_N \) values [Blakeslee 1997, Harris et al. 1998]. As the efficiency of cluster formation appears to be universal then it must be the star formation efficiency which varies. If the early burst of star formation results in a galactic wind shortly after the clusters formed but while there was still considerable gas left [Harris et al. 1998] then a high \( S_N \) system could result, leaving the expelled X-ray gas in the galaxy’s halo. Here the obvious discriminator between high \( S_N \) and low \( S_N \) systems is the rate and density of cluster formation and not its efficiency. At the time of formation of the GCs the super giant molecular clouds (postulated to be the progenitor object of GCs) would provide shielding against the UV radiation of the first generation of star formation, gas ejected from the progenitor would, however, find itself photo-ionized and unable to cool and form stars.

Fig. 1.— a) The specific luminosity frequency of GCs as a function of parent galaxy luminosity. b) The specific mass frequency of GCs as a function of parent galaxy mass.
4. Implication for galaxy formation

Accepting the preceding as true results in an implication regarding the star formation rate of a galaxy. Those galaxies with low values of $S_N$ are either more efficient at forming stars than their high mass cousins or the initial mass function of star formation in dense galaxies is tilted towards a preference for very massive stars early in that galaxies history. Although this first round of massive objects still contribute their mass they no longer contribute to the luminosity of the galaxy. In addition the universal efficiency of cluster formation implies that cluster formation occurs very early in the galaxy formation process, prior to the type of galaxy which will form having any chance to influence the number of cluster which it will posses.

The notion that a stellar wind might drive gas away from giant E galaxies could actually be the factor which eventually determines the type of galaxy which will form. Those galaxies with lower densities of initial cluster formation can have their proto-galactic chunks dissipationally settle into a disk while those which form in dense regions with large numbers of clusters and a strong galactic wind will not manage to drag enough gas down into a plane in order that a disk might form.

5. The universality of the GCLF

As stated in the introduction the universality of the GCLF is paradoxical when compared to $S_N$, however when compared to $S_M$ the paradox is removed. The correlation of galaxy mass with total population implies that the majority of clusters form prior to the determination of the final galaxy type. During this epoch the potential well of the proto-galaxy is likely to be much softer and the destruction of GCs via tidal stripping and evaporation is likely to dominate other modes of destruction. Further these modes are mostly dependent on the mass of clusters formed and so the proportion destroyed is likely to be constant among different proto-galaxies. The early epoch of cluster formation, when clouds massive enough to eventually form clusters are present, occurs with uniform efficiency in all the environments studied to date. Further measures of the mass distribution about galaxies of various types, sizes and stages of evolution should solidify this result.

The conclusions of this work are:

- Globular clusters are create with an efficiency which is independent of galaxy type and environment.
- Given the correlation between cluster numbers and mass and the run of $S_N$ with galaxy type: elliptical galaxies are less efficient at producing stars than are spirals.

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