investigation deals with the thousands of variable stars discovered by Terzan (Terzan, 1982, Terzan, 1990 and ref. therein) on ESO Schmidt plates. We have scanned 22 ESO Red Schmidt plates centred on the star 45 Oph., with the MAMA measuring machine (e.g. Guibert and Moreau, 1991). In this field, we have selected 150 variables with $\Delta m_R > 2$. The plates were calibrated with 55 photometric standards.

Light Curves

Two methods have been implemented to derive the light curves from the time sampling series. The first one (Renson, 1978), presents the advantage of not being too sensitive to gaps in the data. The periodogramme yields an estimate of the probability of false periodicity detection. Both methods lead to similar results in most cases, as exemplified by Figure 1. As a result, we have obtained light curves for 118 variables (80 % of the stars under investigation).

Developments in Progress

This programme is being continued by a systematic search for variables in the whole 100-square-degree field. It will require additional plates to cover the whole range of periods, as well as near infrared and radio measurements. Interpretation of these data will lead to a better knowledge of the period-luminosity relations for various kinds of objects, and understanding of the relations between the shape of the light curves, mass loss and other properties of variable objects.

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NGC 4636 – a Rich Globular Cluster System in a Normal Elliptical Galaxy

M. KISSLER[1], T. RICHTLER[1], E.V. HELD[2], E.K. GREBEL[3], S. WAGNER[4], M. CAPACCIOLI[5]

[1]Sternwarte der Universität Bonn, Germany; [2]Osservatorio Astronomico di Bologna, Italy; [3]ESO, La Silla, Chile; [4]Landessternwarte Heidelberg, Germany; [5]Dipartimento di Astronomia, Università di Padova, Italy

1. What Drives the Investigations of Globular Cluster Systems of Elliptical Galaxies?

In 1918 Shapley started to use the galactic globular clusters to explore the spatial dimensions of our Milky Way. Three quarters of a century later, we still cannot claim to have understood the properties of our globular cluster system (GCS) in the context of the early evolution of the Galaxy. This is mainly due to the fact that there are severe problems in disentangling age and metallicity, which are the most significant parameters in theories of galaxy evolution.

Given these problems with well observable clusters, what can we hope to learn from the study of faint images of globular clusters around distant galaxies, where individual clusters appear star-like and only integrated magnitudes can be determined?

Research on GCSs over the past 20 years showed that there is an amazing variety in the morphologies of GCSs (see Harris 1991 for a review). Most studies refer to elliptical galaxies, because globular clusters in spirals are normally much less numerous and they are difficult to identify due to the inhomogeneous background of bright stars or H II regions. Relating the properties of GCSs (such as total number of clusters, colour, and spatial distribution) to those of their host galaxies, the study of extragalactic GCSs leads to a new level of problems, which could not be foreseen by the study of the galactic GCS alone. One of the systematic patterns emerging from all previous studies is that the richness of a GCS depends somehow on the environment of the host galaxy. M87 became the first example of a giant elliptical galaxy, located in the dynamical centre of a rich galaxy cluster, found to be surrounded by a huge number of globular clusters (Baum 1955, Sandage 1961). Later on, very rich GCSs have been also discovered in the central giant ellipticals NGC 1399 in the Fornax cluster (e.g. Wagner et al. 1991), NGC 3311 in the Hydra cluster (Harris et al. 1983), and NGC 4874 in the Centaurus cluster (Harris 1987). Harris and van den Bergh (1981) introduced the "specific frequency" S as a quantitative measure: $S = N \cdot 10^{0.4(M_V+15)}$, where N is the total number of globular clusters and M_V the absolute visual brightness of the host galaxy. The above mentioned galaxies have S values between 12 and 18.

All galaxies that do not occupy central positions in galaxy clusters possess poorer GCSs, but a relation with the environment persists: e.g., the normal elliptical galaxies in the sparse Fornax cluster have a mean S value of 3, while for ellipticals in the rich Virgo cluster it is about 6. The interpretation of this tendency is far from being unambiguous, but the dependence on the environment suggests that interaction between galaxies may play a role.

Other morphological properties, for example the relation between the spatial distribution of clusters and the light profile of the host galaxy, or the luminosity function of globular clusters, also bear potential information which may finally lead us to an understanding of the formation history of GCSs and thus to gain deeper insight in the formation and structure of the host galaxies themselves. This field is still in the phase where the investigation of individual galaxies provides interesting and useful contributions to the general knowledge. The elliptical galaxy NGC 4636 appears to violate these general properties. NGC 4636 is supposed to be a member of the Virgo cluster of galaxies though it is lying well outside the main body of the cluster, in a region where the density of galaxies is quite low. Using photographic plates, Hanes (1977) determined a specific frequency of 9.9 ± 3 for the GCS of this galaxy, which is a surprisingly high value considering location and environment of NGC 4636. We reobserved NGC 4636 using CCD imaging to investigate the properties of its GCS with higher accuracy.

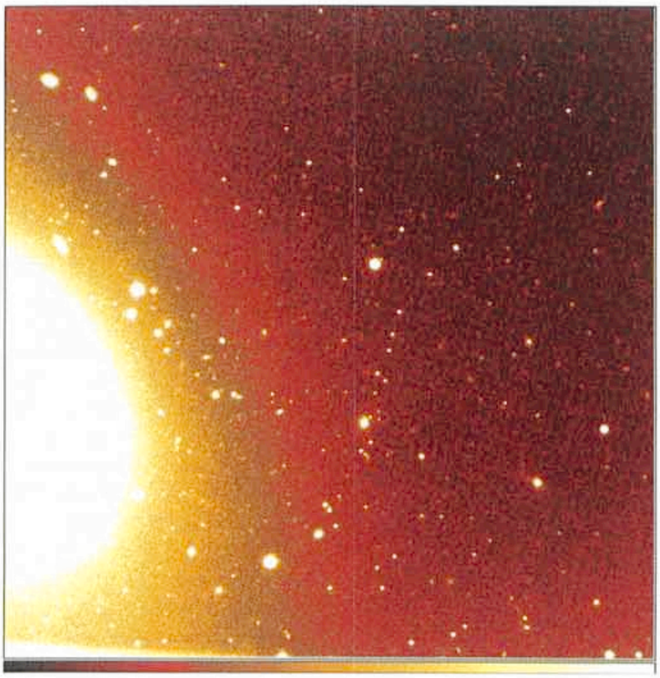

Figure 1: *Six NTT frames combined to a single image of one hour effective exposure time. The frame shows a 7.5′ × 7.5′ field north-east of NGC 4636.*

Figure 2: *The image shown above results from subtracting a model of the galaxy light, which has been obtained by a median filtering technique. This is the frame on which we performed our search and photometry of globular cluster candidates. The crowding of stellar-like images near the galaxy centre is striking.*

2. Our NTT Observations of NGC 4636

NGC 4636 was observed at the NTT using EMMI and a 1k Thomson chip in July 1992, in the context of a collaboration between German and Italian groups interested in the GCS problem. The seeing during our run was only moderate (1.5″) and this prevented an investigation of the luminosity function beyond its turnover (see section 4), but the data quality turned out to suffice for a study of the main properties of the GCS of NGC 4636. We combined six frames in the V filter of 10 minutes each to a frame of an effective exposure time of one hour (Figure 1). We modelled the galaxy light by a median filtering technique and subtracted it from the original frame to obtain a homogeneous background. We then ran DAOPHOT on the resulting image (Figure 2). About 1500 point sources down to a magnitude of 24.5 were identified. At the faint magnitude limit we reached a completeness in finding point sources of 60%.

We calibrated our data by simulating aperture photometry on a frame centred on NGC 4636. The zeropoint has been obtained from the photometry published by Poulain (1988), and we estimate a zeropoint error of 0.05 mag.

To account for contamination with background objects we statistically subtracted the objects found on a frame 7′ away from the galaxy centre, and considered the remaining objects as globular clusters belonging to NGC 4636.

3. The Specific Frequency of NGC 4636

To calculate the total number of globular clusters, we had to correct for the incomplete spatial coverage of the galaxy and for the fact that we only see the brightest part of the luminosity function (see below). After all corrections, we obtained a total number of 3500 ± 200 globular clusters around NGC 4636, which corresponds to a specific frequency of $S = 7.3 \pm 2.0$, if $(m - M) = 31.2$ and $M_v = -21.7 \pm 0.3$ are adopted. As can be noticed, the error in S is quite substantial. This is the consequence of the fact that S is very sensitive to the absolute brightness of the galaxy, and an error of 0.1 in $(m - M)$ implies an error of 10% in S.

This S value of 7.3 ± 2.0 for NGC 4636 is marginally below the one found by Hanes (1977), and slightly higher than the mean value for elliptical galaxies in the Virgo cluster. It is thus at the upper limit of what can be considered a "normal" specific frequency. However, the question remains what distinguishes NGC 4636 for example from NGC 4697, another Virgo elliptical with $S = 3.5$, but almost twice as bright. There is much room for speculation. NGC 4636 has an X-ray luminosity ten times as high as NGC 4697 (Roberts et al. 1991) and presumably a high dark matter content (Saglia et al. 1992). While the X-ray flux is not generally correlated with S, as the pair NGC 1399 and NGC 1404 in the Fornax cluster shows (Richtler et al. 1992), it may indicate a large total mass which in combination with a rich environment causes effective accretion of matter. This matter could be for example in the form of dwarf galaxies. We recall in this respect that the dwarf spheroidal in the constellation Fornax possesses 5 globular clusters. Adding 500 dwarf spheroidals of the Fornax type to NGC 4636 could account for 2500 clusters, but would increase its total luminosity by only 0.1 mag.

4. The Luminosity Function of the GCS: Gaussian or Power Law?

Apparently, globular cluster luminosity functions (GCLFs) exhibit a nearly universal shape, which in the past has been represented by Gaussians with dispersions of 1.3 mag and a peak or "turnover" of $M_v = -7.1 \pm 0.3$ mag, as derived for several ellipticals in the Virgo cluster (Secker & Harris 1993). For NGC 4636, we find the turnover to be at $M_v = 24.1$. This corresponds to a distance modulus of $(m - M) = 31.2 \pm 0.3$, which is in good agreement with previously determined distances of NGC 4636 (31.1 ± 0.4 using the supernova 1993a, Capaccioli et al. 1990; 30.96 ± 0.08 by surface brightness fluctuation, Tonry et al. 1990).

We believe that the choice of a Gaussian for a GCLF does not bear any physical significance. In particular, the possible existence of a universal turnover magnitude does not mean that there is a

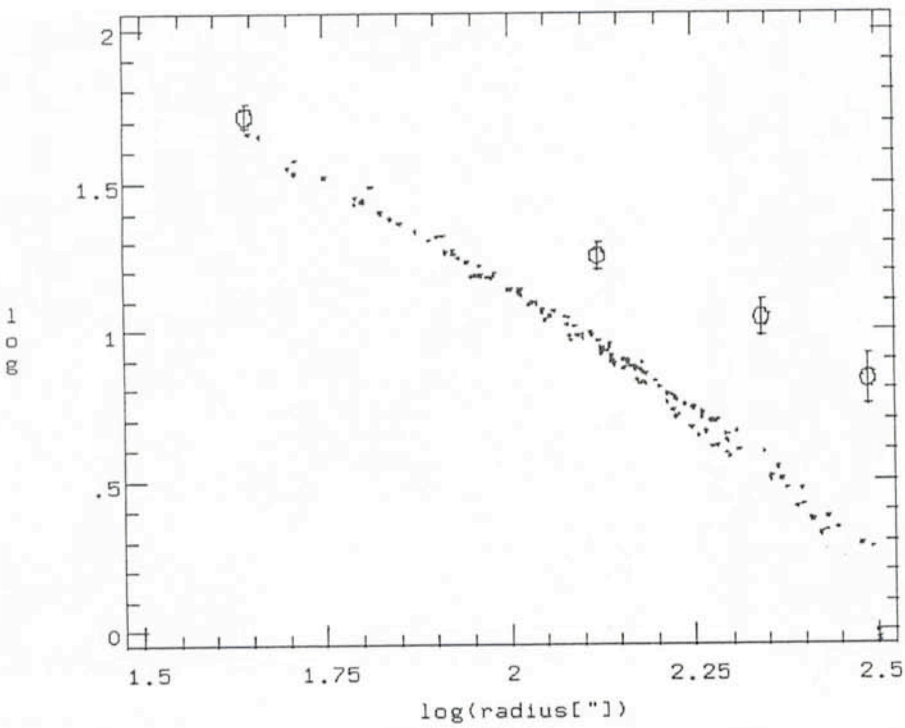

Figure 3: *This plot compares the profile of the surface density of globular clusters with the light of NGC 4636. The abscissa is the logarithm of the galactocentric radius (arcsec) along the major axis. The ordinate is the logarithm of the number of globular clusters per square arcmin. Open circles represent the globular cluster profile. The small dots are measurements of the galaxy light. The density profile of globular clusters is flatter than the galaxy light. This suggests that the globular clusters do not share the dynamical history of the field population.*

characteristic mass among globular clusters connected with this characteristic magnitude. Richtler (1993) and Harris & Pudritz (1993) show that the mass distribution of globular clusters in the Milky Way, M31, and some Virgo galaxies is well described by a power law $\frac{dN}{dm} \sim m^{-\alpha}$ where α is about −1.7. In the Milky Way and M31, i.e. in those galaxies where the luminosity function can be followed well beyond the turnover magnitude, this power law continues beyond the turnover magnitude and has a cut-off at very low masses, probably due to the dissolution of less massive clusters. Concerning NGC 4636, we transformed the luminosities of globular cluster candidates to masses using the relation given by Mandushev et al. (1991), and calculated the mass distribution of the globular cluster in NGC 4636. We found $\delta = -1.9$ which fits well to the Milky Way system. The existence of a power-law (which is equivalent to the absence of a characteristic mass scale) and its apparently universal shape are remarkable features. A satisfactory explanation has yet to be found.

5. The Density Profile

A further interesting question is whether the surface density of globular clusters decreases with increasing galactocentric distance in the same way as the galaxy light itself. If it does, this would indicate that globular clusters and field population behave dynamically in the same way and probably date from the same epoch of formation. For many galaxies this is not easy to investigate due to the large scatter in the globular cluster counts in small number statistics. In case of rich systems like the one discussed, the statistics are more trustworthy. We find the density profile of the GCS of NGC 4636 to be flatter than the galaxy halo light itself. If we represent both pofiles by a power law $\varrho \sim r^{-\alpha}$, where ϱ is the surface density of globular clusters and r the projected galactocentric distance, we get $\alpha = -1.0 \pm 0.1$ for the GCS and $\alpha = -1.5 \pm 0.1$ for the galaxy light. The density profile is plotted in Figure 3, where the ordinate is the logarithm of the number of globular clusters per square arcminute. The abscissa is the logarithm of the galactocentric radius in arcseconds along the major axis. The small dots are measurements of the galaxy light with an arbitrary offset. The four open circles represent the globular cluster density profile. Interestingly, this has also been found in other rich globular cluster systems (NGC 1399, Wagner et al. 1991; NGC 4472, Cohen 1988; NGC 4365 and 4649, Harris et al. 1991), while in poorer systems the GCSs seem to follow the light of the host galaxy (NGC 3379, Pritchet & van den Bergh, 1985; NGC 1404, Richtler et al. 1992). Again, this can be understood as an indication that rich cluster systems might be partially formed through merger or accretion processes.

6. Concluding Remarks

This investigation of GCS of NGC 4636 demonstrates that more questions are open than answered. The fundamental problem of what determines the total number of globular clusters in a galaxy is still open, but the first steps to an answer point in directions that are closely connected with general problems of galaxy structure and evolution. Moreover, the use of globular cluster luminosity functions as distance indicators will perhaps play an important role in the forthcoming VLT era. A huge potential of information about the physics of galaxies and their stellar populations awaits its exploitation.

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