VLT spectroscopy of globular clusters in the Sombrero galaxy

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Abstract. We have obtained intermediate-resolution VLT spectroscopy of 75 globular cluster candidates around the Sa galaxy M 104 (NGC 4594). Fifty-seven candidates out to ~ 40 kpc in the halo of the galaxy were confirmed to be bona-fide globular clusters, 27 of which are new. A first analysis of the velocities provides only marginal evidence for rotation of the cluster system. From Hβ line strengths, almost all of the clusters in our sample have ages that are consistent, within the errors, with Milky Way globular clusters. Only a few clusters may be 1–2 Gyr old, and bulge and halo clusters appear coeval. The absorption line indices follow the correlations established for the Milky Way clusters. Metallicities are derived based upon new empirical calibrations with Galactic globular clusters taking into account the non-linear behavior of some indices (e.g., Mg2). Our sample of globular clusters in NGC 4594 spans a metallicity range of −2.13 < [Fe/H] < +0.26 dex, and the median metallicity of the system is [Fe/H] = −0.85. Thus, our data provide evidence that some of the clusters have super-solar metallicity. Overall, the abundance distribution of the cluster system is consistent with a bimodal distribution with peaks at [Fe/H] ∼ −1.7 and −0.7. However, the radial change in the metallicity distribution of clusters may not be straightforwardly explained by a varying mixture of two sub-populations of red and blue clusters.

1 Observations and reduction

Multiobject spectroscopy of globular cluster candidates in the halo of M 104 was obtained using FORS1 at the ESO VLT in service mode in April 2000. Five MOS setups were observed with exposure time 2 × 50 min each with the 600B grism and 1′′ wide slitlets, yielding a resolution of ~ 6 Å (FMHM). All the available 19 movable slits were used, giving the highest priority to globular clusters spectroscopically confirmed by Bridges and coll. [2]. In total 75 objects were observed, including candidates visually selected on the basis of their shape and magnitude. Since most targets were observed in more than one mask, the typical target exposure time is 200 min. Long-slit spectra of Galactic globular clusters spanning a wide range in metallicity were also obtained for radial velocity and line strength calibration.

The MOS spectra were extracted and wavelength calibrated using IRAF standard tasks. The cross-correlation task FXCOR was employed to measure radial velocities, using integrated spectra of Galactic globular clusters as templates,
Fig. 1. The calibration of the Mg2 index against metallicity shows a distinct non-linearity. The labeled symbols with error bars represent the Galactic globular cluster templates. Superimposed are model curves from Bressan et al. [1] for two different ages. The solid line represents the empirical calibration of Brodie & Huchra [3], valid up to \([\text{Fe/H}] \sim -0.7\), while a change in slope is seen for metal-rich clusters (dotted line).

and checking the velocity systematics against synthetic spectra of simple stellar populations [9]. In total 57 objects were confirmed to be globular clusters in the Sombrero galaxy on the basis of their radial velocities, 27 of which are new.

2 Metallicities and ages

Absorption line indices were measured for all the confirmed clusters, after convolving the spectra with an appropriate wavelength-dependent kernel to match the resolution of the Lick/IDS system. The line strengths were measured using the passbands defined by Worthey et al. [10]. The measurements of the template Galactic globular clusters were compared with previous index data [3] to put our measurements on a standard system. Small offsets were applied to some indices
Fig. 2. The diagnostic diagram using H$\beta$ against Mg2 for globular clusters around M 104 (filled squares). Also shown are the calibration data for Milky Way globular clusters (open squares with error bars); overplotted is a model grid from Bressan et al. [1].

(e.g., Mg1, Mg2), while no corrections were needed for narrow-band indices such as Mg$b$. The correlations between different metal line indices are well defined and give a consistent picture of metal line strengths in the M 104 globular clusters. Analysis of the relative abundances of iron-peak versus $\alpha$-elements, and comparison with models including non-solar abundance ratios (e.g., [8]), will be presented in a future paper.

The metallicities of globular clusters in M 104 were derived following the empirical approach based on the index-metallicity relations for Galactic clusters. Weighted mean metallicities were calculated using several indices [3]. The assumptions behind the empirical calibrations are that clusters in M 104 are as old as those in the Milky Way, and the abundance ratios follow the same trend with metallicity as in the Milky Way globular cluster system. This approach has the advantage of providing a robust, model-independent ranking based on direct
Fig. 3. Left: the radial velocity vs. radius for globular clusters around the Sombrero galaxy. East is to the left. The open circles are globular clusters less metal-rich than [Fe/H] = −1.2. The line is a least squares fit to the data. Right: the spatial distribution of clusters with approaching (open circles) and receding velocities (filled circles). The size of the symbols is proportional to the velocity relative to the systemic motion. A cross marks the galaxy center.

For some indices, the index-metallicity relation becomes distinctly non-linear for metal-rich clusters. An example is given in Fig. 1 for the Mg2 versus [Fe/H] relation. The non-linearity is confirmed by the spectral synthesis models, and was previously noticed by others ([4], [5]). As a result, a straightforward extrapolation of the non-linear behavior of Mg2 and other indices, we adopted two different slopes for clusters below and above [Fe/H] = −0.7. For clusters less metal-rich than this value, our calibration is identical to the original one [3]. Details on the new relations for very metal-rich clusters, as well as abundances derived from comparisons with models, will be given elsewhere. We find a range in metallicity from [Fe/H] = −2.13 to [Fe/H] = +0.26 with a mean value [Fe/H] = −0.90. Some clusters with super-solar abundances are indeed present in M 104. Very few clusters appear to be more metal-poor than [Fe/H] = −1.8.

Diagnostic diagrams of Balmer line strengths against metal line indices were used to estimate the ages of globular clusters in the halo of M 104. Figure 2 shows the distribution of clusters in the diagram using Hβ against Mg2. Most globular clusters in M 104 appear consistent with an old age, comparable to that of Milky Way globular clusters. The clusters in the halo of M 104 appear to be coeval with the clusters in the inner (bulge) regions studied by [6]. Only for a few clusters is
The metallicity distribution of globular clusters in M 104, plotted separately for the inner \((r < 7 \text{ kpc})\), left panel) and outer regions \((r \geq 7 \text{ kpc})\), right). This figure indicates a composite nature for the globular cluster system.

\[ \text{H} \beta \text{ is strong enough to be consistent with an age } \sim 2 \text{ Gyr. Measurements of other Balmer line indices are in progress.} \]

### 3 Kinematics

Figure 4 shows the radial velocities of candidates with \(400 < v_r < 2000 \text{ km s}^{-1}\), which are probable members of the globular cluster system of M 104. The clusters on the E side have \(\langle v_r \rangle = 1132 \text{ km s}^{-1}\) with a velocity dispersion \(\sigma_v = 187 \text{ km s}^{-1}\). On the W side, the velocity dispersion is \(\sigma_v = 234 \text{ km s}^{-1}\) and the mean radial velocity 1052 km s\(^{-1}\). The velocity distribution is non-gaussian on the E side due to the presence of a distinct group of clusters with radial velocities < 900 km s\(^{-1}\). Given the large scatter of the velocity measurements, the evidence for rotation is marginal. A linear fit including all data points gives a small difference for the mean cluster velocities on the E and W sides, indicating a very shallow rotation curve, \(\sim 4.5 \text{ km s}^{-1} \text{ kpc}^{-1}\). With the present data, no difference is obvious between the kinematics of metal-rich and metal-poor clusters. A larger sample of precise radial velocities will be necessary to establish the presence of rotation for the M 104 halo clusters, and further observations are planned to this aim. Figure 4 also shows (right panel) the spatial distribution of clusters with approaching and receding velocity. This distribution might suggest that the kinematic axis is inclined with respect to the photometric minor axis.
4 Conclusions

The metallicities derived from spectroscopy of globular clusters in the bulge and halo of M 104 confirm a bimodal [Fe/H] distribution, in agreement with the results from photometry ([6]; Moretti et al. 2002, this volume) and with the spectroscopic results for the inner cluster sample ([7]). A two-gaussian fit to the distribution has two peaks at [Fe/H] ≈ −1.7 and [Fe/H] ≈ −0.7, very similar to those of globular clusters in our Galaxy (see also [6]). The abundance distribution indicates that out to 15 kpc, the metal-rich clusters are 4 times more abundant than the metal-poor ones. A plot of globular cluster metallicities against the distance from the center shows that metal-rich clusters are more numerous near the galaxy center. This radial gradient has been mostly interpreted as caused by a changing mix of two (metal-rich and metal-poor) cluster populations. However, Fig. 4 suggests that the global [Fe/H] distribution is produced by superposition of cluster populations whose properties vary in a complex way as a function of distance from the galaxy center. Bimodality seems to be an (over)simplified description of the metallicity distribution of globular clusters in M 104 – reality is probably more complex than we thought in this and many other galaxies.

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