The poor cluster of galaxies S639

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ABSTRACT

We have studied the poor southern cluster of galaxies S639. Based on new Strömgren photometry of stars in the direction of the cluster, we confirm that the Galactic extinction affecting the cluster is large. We find the extinction in Johnson B to be \(A_B = 0.75 \pm 0.03\). We have obtained new photometry in Gunn r for E and S0 galaxies in the cluster. If the Fundamental Plane is used for determination of the relative distance and the peculiar velocity of the cluster, we find a distance, in velocity units, of \((5706 \pm 350)\ km\ s^{-1}\), and a substantial peculiar velocity, \((839 \pm 350)\ km\ s^{-1}\). However, the colours and the absorption line indices of the E and S0 galaxies indicate that the stellar populations in these galaxies are different from those in similar galaxies in the two rich clusters Coma and Hydra I. This difference may severely affect the distance determination and the derived peculiar velocity. The data are consistent with a non-significant peculiar velocity for S639 and the galaxies in the cluster being on average 0.2 dex younger than similar galaxies in Coma and Hydra I. The results for S639 caution that some large peculiar velocities may be spurious and caused by unusual stellar populations.

Keywords: dust, extinction – galaxies: clusters: individual: S639 – galaxies: distances and redshifts – galaxies: elliptical and lenticular, cD – galaxies: fundamental parameters – galaxies: stellar content.

1 INTRODUCTION

The relation known as the Fundamental Plane (FP) may be used for determination of relative distances to E and S0 galaxies (e.g. Dressler et al. 1987; Jørgensen, Franx & Kjærgaard 1996, hereafter JFK96; Bagley 1996; Hudson et al. 1997). The FP relates the effective radius, \(r_e\), the mean surface brightness within this radius, \(\langle I \rangle_e\), and the (central) velocity dispersion, \(\sigma\), in a relation that is linear in logarithmic space (Djorgovski & Davis 1987; Dressler et al. 1987). The FP has a low scatter (15–20 per cent in \(r_e\)) and is therefore a valuable tool for studies of peculiar velocities of galaxies and clusters (e.g. Bagley 1996; Hudson et al. 1997). The use of the FP for determination of distances and peculiar velocities relies on the assumption that the FP is universally valid. Several authors have investigated possible differences in the FP related to the cluster environment (e.g. Burstein, Faber & Dressler 1990; Lucey et al. 1991; de Carvalho & Djorgovski 1992; JFK96; Bagley 1996). Only de Carvalho & Djorgovski find that the environment has significant effects on the FP. These authors find field galaxies to be brighter than the cluster galaxies of similar effective radii and velocity dispersions; de Carvalho & Djorgovski also find field galaxies to be bluer and have weaker Mg\(_2\) line indices than cluster galaxies with similar velocity dispersions. This is in general agreement with studies that show that E and S0 galaxies in the outer parts of clusters have weaker Mg\(_2\) and \(\langle Fe \rangle\) indices than those in the central parts of clusters (Guzmán et al. 1992; JFK96; Jørgensen 1997).

In this paper we study the poor cluster of galaxies S639, previously studied by JFK96. The cluster identification is from Abell, Corwin & Olowin (1989). The cluster has a radial velocity in the cosmic microwave background (CMB) frame of \(c_{\text{CMB}} = 6545\ km\ s^{-1}\) and is located \(\approx 28^\circ\) from the direction to the large mass concentration known as the ‘Great Attractor’ (Faber & Burstein 1988). The velocity dispersion of the cluster is \(456^{+83}_{-74}\ km\ s^{-1}\) (JFK96). Its richness is 14 measured as the number of galaxies with magnitudes between \(m_3\) and \(m_3 + 2\) (Abell et al. 1989); \(m_3\) is the

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magnitude of the third-ranked galaxy. S639 has a smaller velocity dispersion and is poorer than clusters like the Coma cluster and the Hydra I cluster. Coma and Hydra I have velocity dispersions of $1010^{+12}_{-8} \text{ km s}^{-1}$ and $608^{+38}_{-39} \text{ km s}^{-1}$, respectively (Zabludoff, Huchra & Geller 1990). The richnesses given by Abell et al. (1989) are 106 for Coma and 39 for Hydra I.

Using the FP for 10 E and S0 galaxies in S639, JFK96 found a large peculiar velocity of the cluster, $v_{pec} = (1295 \pm 359) \text{ km s}^{-1}$ relative to the CMB frame. Further, JFK96 found that the galaxies in the cluster follow a $M_g - \sigma$ relation offset from the relation established for their full sample of 11 clusters. The galaxies in S639 had on average weaker $M_g$ indices -- see also Jørgensen (1997). JFK96 tried to correct the derived peculiar velocity of the cluster for the offset in the $M_g$ indices by including an $M_g$ term in the FP. The result was $v_{pec} = (879 \pm 392) \text{ km s}^{-1}$. However, the coefficient for the $M_g$ term is not well determined (cf. JFK96).

S639 is located at low Galactic latitude, $(l, b) = (280^\circ, 11^\circ)$. Thus, the Galactic extinction is large and uncertainties in the adopted value may severely affect the precision of the derived distance and peculiar velocity for the cluster.

The main issue discussed in this paper is whether the large peculiar velocity of S639 found by JFK96 is real or the result of incorrect correction for the (large) Galactic extinction, selection effects, or unusual stellar populations. In order to reach conclusions about these issues, we have obtained additional photometry of galaxies in S639, giving a sample of 21 E and S0 galaxies with available photometric and spectroscopic parameters. We have also obtained Strömgren $uvby\beta$ photometry for stars in the direction of the cluster. This photometry is used to determine the Galactic extinction affecting the cluster.

The sample selection for the E and S0 galaxies and the available data are briefly described in Section 2. The determination of the Galactic extinction is covered in Section 3. In Section 4 the FP is discussed and used for determining the distance to the cluster. The importance of the stellar populations is investigated in Section 5. The conclusions are summarized in Section 6.

The relations between the parameters for the galaxies established in this paper are determined by minimization of the sum of the absolute residuals perpendicular to the relations. This fitting technique has the advantage that it is rather insensitive to a few outliers, and that it treats the coordinates in a symmetric way. The uncertainties of the coefficients are derived by a bootstrap method. (See also JFK96 for a discussion of this fitting technique.)

2 Sample Selection and Data

The sample of E and S0 galaxies in the poor cluster S639 used in the analysis by JFK96 was selected based on sky survey images. This sample was by no means complete. We have obtained additional photometry in Gunn $r$ of galaxies within the central $25 \times 35$ arcmin$^2$ of the cluster. We aimed at constructing a magnitude-limited sample of E and S0 galaxies from the photometry from Jørgensen, Franx & Kjærgaard (1995a, hereafter JFK95a), our new photometry in Gunn $r$ and the spectroscopic data from Jørgensen, Franx & Kjærgaard (1995b, hereafter JFK95b) and Jørgensen (1997). We classified the galaxies based on our charge-coupled device (CCD) images. For galaxies outside the central area, the classifications from JFK95a were adopted. In order to check our classifications further, we subtracted models of the best-fitting elliptical isophotes from the images of the galaxies. None of the galaxies in the sample shows residual spiral arms after the model subtraction. Thus, we find it unlikely that our sample is contaminated by early-type spirals. The accidental inclusion of a few early-type spirals in the fainter part of the sample, for which the residual spiral arms may be difficult to detect, will not affect our results significantly, since none of the results depends critically on the faintest third of the sample.

The final sample contains 21 E and S0 galaxies for which both photometric and spectroscopic parameters are available. Within the central $25 \times 35$ arcmin$^2$ the sample is 90 per cent complete to a total magnitude of 15.5 mag in Gunn $r$ (magnitudes corrected for Galactic extinction, $k$-corrected and corrected for cosmological dimming). Further, we have data for two fainter galaxies, and two galaxies outside the central area.

2.1 Available data for the galaxies in S639

The new photometry of S639 was obtained with the Danish 1.5-m telescope, La Silla, 1997 March 22–28. We used the DFOSC (Danish Faint Object Spectrograph and Camera) equipped with a 2k $\times$ 2k thinned Loral CCD. The data were reduced with standard methods. Two-dimensional (2D) surface photometry of the galaxies and the effective parameters were derived in the same way as in JFK95a. The magnitudes of the new data were standard-calibrated by means of zero-point offsets relative to the photometry from JFK95a. The comparison of the aperture magnitudes with the data from JFK95a has an rms scatter of 0.01 mag. More details of the data reduction are given in Appendix A.

JDK95a derived the $(g - r)$ colours for 10 of the E and S0 galaxies in S639. The colours were measured within the effective radii in Gunn $r$. We have transformed the $(g - r)$ colours to $(B - r)$ using the relation $(B - r) = 0.88(g - r) + 0.73$. We established the relation from colour data for a total of 41 E and S0 galaxies in the clusters Abell 194, DC2345–28 and Hydra I (JFK95a; Milvang-Jensen & Jørgensen, in preparation). The rms scatter of the relation is 0.025.

We use spectroscopic data from JFK95b and Jørgensen (1997). Velocity dispersions are available for 21 E and S0 galaxies. The absorption line indices $M_g$, $\langle Fe \rangle$ have been measured for 20 of those galaxies, and four galaxies have measured H$\beta_0$. The $M_g$ and $\langle Fe \rangle$ line indices are on the Lick/IDS system (named after the Lick Image Dissector Scanner; Faber et al. 1985; Worthey et al. 1994). The H$\beta_0$ index is related to the Lick/IDS H$\beta$ index as H$\beta_0 = 0.866 $H$\beta + 0.485$ (Jørgensen 1997). All the spectroscopic parameters are centrally measured values corrected to a circular aperture with a diameter of 1.19 h$^{-1}$ kpc (JFK95b, Jørgensen 1997). H$g = 100$ h km s$^{-1}$ Mpc$^{-1}$. The line indices are corrected for the effect of the velocity dispersion.

The photometric and spectroscopic parameters for the galaxies in S639 are given in Appendix A.
2.2 Reference samples in other nearby clusters

We use the Coma cluster and the Hydra I cluster as reference clusters. The photometric data for the Coma cluster are from JFK95a. The spectroscopic data are from the literature (Davies et al. 1987; Dressler 1987; Lucey et al. 1991; Guzmán et al. 1992) and have been calibrated to a consistent system by JFK95b. We also use new spectroscopic data for additional galaxies in the Coma cluster (Jørgensen, in preparation). The data for the Hydra I cluster are from JFK95a, JFK95b and Milvang-Jensen & Jørgensen (in preparation).

The sample of E and S0 galaxies in Coma covers the central 64 × 70 arcmin² of the cluster and is 93 per cent complete to a magnitude limit of 15.05 mag in Gunn r. This sample contains 116 galaxies. The sample of E and S0 galaxies in Hydra I covers the central 46 × 76 arcmin² of the cluster and is 80 per cent complete to a limit of 14.5 mag in Gunn r. This sample contains 45 galaxies. Both samples include a few galaxies below their magnitude limit. The line indices ⟨Fe⟩ and Hβo are available for subsamples of the samples in Coma and Hydra I.

There are three reasons to use these large samples of galaxies in Coma and Hydra as the reference samples, rather than making use of all the clusters studied by JFK96. First, our S639 sample is magnitude-limited and we therefore expect more accurate results by comparing this sample with other magnitude-limited samples, rather than using the incomplete samples from JFK96. Secondly, the JFK96 sample contains two clusters with smaller velocity dispersions than S639 and comparable offsets in the Mg₂ index relative to the Coma cluster. Thus, including these clusters in the reference sample would make that sample inhomogeneous. Thirdly, our goal is to discuss the reality of the large peculiar velocity of S639 found by JFK96. JFK96 derived peculiar velocities under the assumption that Coma is at rest relative to the CMB frame. In this paper we make the same assumption in order to facilitate the comparison with the results from JFK96.

3 THE GALACTIC EXTINCTION IN THE DIRECTION OF S639

The Galactic extinction affecting observations of extragalactic objects is traditionally determined from the H i mapping done by Burstein & Heiles (1982). From this mapping we obtain a Galactic extinction in the direction of S639 of A_v = 0.80. However, in some areas, especially near the Galactic plane, the extinction has been found to be different from estimates based on the Burstein & Heiles maps (e.g. Burstein et al. 1987; Jønch-Sørensen 1994b). In the following we therefore use two other methods to estimate the Galactic extinction in the direction of S639: Strömgren photometry of stars in the direction of the cluster, and the colour–Mg₂ relation for galaxies in the cluster.

3.1 The Strömgren photometry

S639 was observed as part of a program to obtain Strömgren uvb-y-β photometry of stars in the directions of several galaxy clusters at low Galactic latitude. The observations were obtained with the Danish 1.5-m telescope, La Silla, 1996 March 13–29. The telescope was equipped with the DFOSC. The reduction and calibration of the photometry are described in detail in Appendix B. Here we concentrate on the determination of the Galactic extinction in the direction of S639.

Intrinsic colours can be estimated in the uvby-β system for individual stars of spectral types ranging from B to G type. This has been used extensively to map the reddening in the solar neighbourhood (Hilditch, Hill & Barnes 1983; Franco 1989). Recently deep CCD-photometry surveys have made it possible to trace reddening to large distances, hence all the way through the Galactic dust disc using individual stars (Jønch-Sørensen 1994b; Jønch-Sørensen & Knude 1994). Nissen (1994) reviewed the calibrations and the accuracy of the derived parameters. He showed that the rms scatter of the residuals in the calibrations sets the limit of the precision with which E(b − y) can be derived to 0.009. This corresponds to an uncertainty of 0.012 in E(B − V) and 0.050 in A_B. We use E(B − V) = 1.35E(b − y), A_v = 4.2E(b − y) and A_y = 5.57E(b − y) to convert between reddening and Galactic extinction.

In Fig. 1 distance versus E(b − y) is shown for the stars in the direction of S639. The typical uncertainty on E(b − y) is ≃0.04. The relative distance uncertainty is ≤30 per cent for V ≤ 16 mag and increases rapidly for fainter stars (see Appendix B). The mean reddening E(b − y) for stars at distances larger than 750 pc is 0.106 with an rms scatter of 0.031. The solid curve in Fig. 1 represents the predicted E(b − y)–distance relation for a model from Jønch-Sørensen (1994b) with a vertical scaleheight of the (diffuse) absorbing material of 140 pc and a local normalization of 0.42 atom cm⁻³. For other parameters of the model, see Jønch-Sørensen (1994b). The model indicates a total reddening of E(b − y) = 0.14, equivalent to A_v = 0.78, for objects situated outside the disc. From this we find the visual absorption acquired through half the diffuse disc in this direction of the Galaxy to be A_v sin b = 0.11 (b in this expression is the Galactic latitude). This value can be com-
pared with the results for the seven fields surveyed by Jønch-Sørensen (1994b) and Jønch-Sørensen & Knude (1994). The result for the S639 direction is comparable with $A_y \sin b=0.13$ found for the low-latitude field $(l, b) = (262^\circ, +4^\circ)$, but lower than the 0.21 found for $(l, b) = (270^\circ, +35^\circ)$.

The reddening caused by the diffuse interstellar medium may be understood as contributions from both diffuse interstellar clouds and an intercloud medium (e.g. Knude 1979b). The typical reddening due to a diffuse cloud is $E(b-y) \approx 0.03$ and the average number of clouds intercepted is 4.3 per kpc (Knude 1979a, 1981). The intercloud medium contributes with only $E(b-y) \approx 0.001$ per 100 pc (Knude 1979b). In total this yields a reddening of $E(b-y)=0.14$ kpc$^{-1}$ along a line of sight in the disc. In the direction of S639, a distance of 1 kpc corresponds to a height above the plane of 190 pc, or about 1.5 times the scaleheight of the diffuse medium. Thus, based on the results from local data we would expect the reddening towards S639 due to the diffuse interstellar medium to be close to $E(b-y)=0.14$, as indicated by Fig. 1. Two distant stars in the observed field show low reddening. This may be a result of the ‘stochastic’ nature of the distribution of the clouds, or simply of the rather large measurement errors on $E(b-y)$ for the individual stars. The two stars have reden-
ings of approximately 0.03 and 0.07, and may represent lines of sight that intercept one and two clouds, respectively.

The sampling and accuracy of the present results do not allow for a specific mapping of clouds or tracing of reddening variations across the field. The best estimate of the typical reddening affecting the observations of the galaxies in S639 is $E(b-y)=0.14$, corresponding to $E(B-V)=0.19$, $A_y=0.59$ and $A_b=0.78$.

3.2 The $(B-r)-M_g$ relation

E and S0 galaxies in nearby clusters are known to follow a relation between the colour and the $M_g$ index (Burstein et al. 1988; Bender, Burstein & Faber 1993). If we assume that the relation is universal, then it may be used as an independent way of estimating the Galactic extinction. The assumption means that we expect it to be a universal property of these galaxies that the global stellar populations match the central stellar populations (cf. Bender et al. 1993), since the colours are measured within large apertures (the effective radii) while the $M_g$ indices are measured within much smaller apertures. The colour–$M_g$ relation was used by Burstein et al. (1987) to estimate the Galactic extinction affecting galaxies at some directions close to the Galactic plane. The relation has also been used recently by Schlegel, Finkbeiner & Davis (1998) to calibrate the DIRBE/IRAS dust maps to Galactic reddening (DIRBE: Diffuse Infrar-

We assume that E and S0 galaxies in S639 follow the same $(B-r)-M_g$ relation as E and S0 galaxies in Coma and Hydra I. The $(B-r)-M_g$ relation for Coma and Hydra I is shown in Fig. 2. The data for the E and S0 galaxies in S639 are overplotted. With a Galactic extinction of $A_b=0.72$ for S639, the data for the cluster are consistent with the Coma and Hydra I $(B-r)-M_g$ relation. The rms scatter of the $(B-r)-M_g$ relation for S639 is 0.04. This gives an uncertainty on $A_b$ of $\pm 0.03$, equivalent to an uncertainty on the Galactic extinction in Gunn $r$, $A_r$, of $\pm 0.02$.

In the following we use the average of $A_b$ derived from the Strömgren photometry and the $A_b$ determination based on the $(B-r)-M_g$ relation. We adopt $A_b=0.75 \pm 0.03$ ($E(B-V)=0.18 \pm 0.01$) for all the galaxies in S639, where the uncertainty is half the difference between our two determinations. The corresponding Galactic extinction in Gunn $r$ is $A_r=0.47 \pm 0.02$. We note that our determination of $E(B-V)$ for S639 agrees with the dust maps from Schlegel et al. (1998). These maps imply a mean value of $E(B-V)=0.152 \pm 0.024$ within the central $25 \times 35$ arcmin$^2$ of the cluster.

4 THE FUNDAMENTAL PLANE FOR S639

In Fig. 3(a) we show the FP for S639 edge-on. The effective radii are in arcsec and the mean surface brightnesses are given as $log \langle I \rangle_\gamma=0.4 \langle \mu \rangle_\gamma-26.4$. $\langle I \rangle_\gamma$ has units of $L_\odot$ pc$^{-2}$. The solid line on the figure is the FP for nearby clusters found by JFK96,

$$\log r_e = (1.24 \pm 0.07) \log \sigma - (0.82 \pm 0.02) \log \langle I \rangle_\gamma + \gamma.$$  

The zero-point is defined by the present sample of galaxies in S639. The rms scatter for S639 is 0.122 in log $r_e$.

If we fit the FP to the S639 data we find

$$\log r_e = 1.32 \log \sigma - 0.78 \log \langle I \rangle_\gamma + 0.007 + 0.30 \quad \pm 0.09 \quad (1)$$

with an rms scatter 0.136 in log $r_e$. Thus, the FP for S639 is not significantly different from the FP found for nearby clusters (JFK96), or the FP fitted to the Coma and Hydra I

![Figure 2. The $(B-r)-M_g$ relation. Large squares, S639; small triangles, Coma and Hydra I. Typical error bars are given on the figure. The solid line is the relation derived from Coma and Hydra I. $(B-r)=(1.36 \pm 0.22)M_g+0.77$. The rms scatter in $(B-r)$ for the galaxies in S639 is 0.04. The Galactic extinction for S639 was assumed to be $A_b=0.72$. This gives consistency with the $(B-r)-M_g$ relation for the Coma and Hydra I galaxies.](image)
samples (Jørgensen, in preparation; Milvang-Jensen, Jørgensen & Jønch-Sørensen, in preparation). In the following we use the FP established by JFK96.

Fig. 3(b) shows the FP edge-on with the effective radii given in kpc ($H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$). The data for S639 have been overplotted upon the data for the clusters Coma and Hydra I. We have assumed that the peculiar velocity of S639 is zero. The solid line on this figure is the FP with the zero-point defined from Coma. The offset between Coma and S639 and $0.100 \pm 0.027$ in log $r_e$. This may be interpreted as due to a non-zero peculiar velocity of S639. We assume that the Coma cluster is at rest relative to the CMB frame and has $cz_{\text{CMB}} = 7200$ km s$^{-1}$ (JFK96). We then find the distance of S639, expressed as the expected radial velocity, to be $(5706 \pm 350)$ km s$^{-1}$. This implies a peculiar velocity of $(389 \pm 350)$ km s$^{-1}$. If we include a correction for the cluster’s offset in the $M_g – \sigma$ relation (see Section 5), as also tried by JFK96, we find a distance of $(5989 \pm 378)$ km s$^{-1}$ and $cz_{\text{CMB}} = (556 \pm 378)$ km s$^{-1}$. The results were not corrected for Malmquist bias. Based on the rms scatter of the FP, we expect the Malmquist bias from a homogeneous density field to be $\approx 1.3$ per cent (cf. Lynden-Bell et al. 1988).

For both methods the peculiar velocities of S639 found here are smaller than those found by JFK96. The differences are partly a result of the larger sample of galaxies included in the present study, and partly a result of the slightly lower value assumed of the Galactic extinction. Our result confirms, however, that if the FP without any Mg term is used for distance determination for S639, then a large positive peculiar velocity is found.

The rms scatter of the FP for S639 is slightly larger than found for the Coma and the Hydra I clusters (JFK96; Jørgensen, in preparation; Milvang-Jensen et al., in preparation). Part of this may be caused by variation of the Galactic extinction over the field of S639. Our Strömgren photometry for the stars in the field is not accurate enough to investigate this. However, for other fields within 30° of the Galactic plane, values of the rms scatter in $E(b – y)$ of 0.035–0.10 have been found (Jønch-Sørensen 1994b; Jønch-Sørensen & Knude 1994). If the field of S639 has similar variations in $E(b – y)$ it would result in a contribution of $\approx 0.04$ to the rms scatter of the FP (measured in the direction of log $r_e$). This explains only a small part of the scatter in the FP for S639, but it does bring the unexplained part of the scatter, $\approx 0.10$ in log $r_e$, into better agreement with recent results for Coma and Hydra I (Jørgensen, in preparation; Milvang-Jensen et al., in preparation).

5 THE STELLAR POPULATIONS OF THE GALAXIES

In this section we investigate whether the offset between the FP for S639 and the FP for Coma and Hydra I may be the result of differences in the stellar populations in the galaxies.

E and S0 galaxies show a number of relations between the velocity dispersions, the absorption line indices and the colours. Differences in the stellar populations of galaxies in different clusters are expected to show up as differences in these relations. We establish the differences as zero-point offsets for the S639 sample relative to the relations for the Coma and Hydra I samples. In order to interpret the offsets in terms of differences in the mean age and/or metallicity of the stellar populations, we use the single stellar population models from Vazdekis et al. (1996). Table 1 gives the expected changes in the line indices, the $M/L$ ratio and the colour due to changes in the age and/or metallicity. These relations are valid for models with ages larger than 5 Gyr and a bimodal initial mass function (IMF) with a high-mass slope identical to a Salpeter (1955) IMF ($\mu = 1.35$).

Table 1. Model predictions from Vazdekis et al. (1996).

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_g$</td>
<td>$0.12 \log \text{age} + 0.19[M/H] + 0.14$</td>
</tr>
<tr>
<td>$\log &lt;\text{Fe}&gt;$</td>
<td>$0.12 \log \text{age} + 0.25[M/H] + 0.34$</td>
</tr>
<tr>
<td>$\log H\alpha$</td>
<td>$-0.27 \log \text{age} - 0.135[M/H] + 0.51$</td>
</tr>
<tr>
<td>$\log M/L_\odot$</td>
<td>$0.63 \log \text{age} + 0.26[M/H] - 0.16$</td>
</tr>
<tr>
<td>$(B-r)$</td>
<td>$0.36 \log \text{age} + 0.36[M/H] + 0.83$</td>
</tr>
</tbody>
</table>

Note. $[M/H] = \log Z/Z_\odot$ is the total metallicity relative to solar.

The relations between the velocity dispersions and the line indices Mg$_2$, Fe/H and Hbeta indices as well as between the velocity dispersion and the colour ($B-r$) are shown in Fig. 4. The ($B-r$)–$\log \sigma$ relation in Fig. 4(a) was established from the Coma and Hydra I galaxies, while the relations between the line indices and the velocity dispersion are adopted from Jørgensen (1997). The galaxies in Coma and Hydra I follow these relations.

The galaxies in S639 are offset relative to the ($B-r$)–$\log \sigma$ relation, the Mg$_2$–$\log \sigma$ relation and the Hbeta–$\log \sigma$ relation. The galaxies are on average bluer, have smaller Mg$_2$ indices and have larger Hbeta indices than the galaxies in Coma and Hydra I. Table 2 summarizes the offsets for all the relations. The table also gives the offset for the FP in terms of an offset in the $M/L$ ratio, assuming that the peculiar velocity of S639 is zero.

We use the stellar population models to estimate the change in age or metallicity that would create the measured offsets in the various parameters (see Table 2). We assume that the offsets are due either to age variations only, or to metallicity variations only. The offset in Fe/H and $\log M/L$ are all consistent with a difference between the mean ages of the galaxies in S639 and the galaxies in Coma and Hydra I of $-0.2$ dex. Though the Fe/H indices are consistent with this, it is obvious from Fig. 4(c) that the offset in log Fe/H is caused by four galaxies with very small Fe/H, while these galaxies show the same offsets in Mg$_2$ and $\log M/L$ as the full sample. A possible reason may be that the galaxies in S639 have a lower abundance ratio [Mg/Fe] than the bulk of E and S0 galaxies in Coma and Hydra I. It requires better measurements of Fe/H to investigate further this potential problem with our interpretation.

If we interpret the offsets as being due to a systematic offsets in the metallicity, while there is no difference in the mean age, we find a mean difference of $-0.12$ dex, based on the offsets in ($B-r$) and Mg$_2$. However, a difference in the metallicity cannot fully explain the offset in the $M/L$ ratio. In this case S639 may have a non-zero peculiar velocity of $\approx 490$ km s$^{-1}$. We also note that the offset in Hbeta cannot be fully explained by a metallicity difference.

6 CONCLUSIONS

The Galactic extinction in the direction of the poor cluster of galaxies S639 has been determined from Strömgren $uvby-\beta$ photometry for stars in the direction of the cluster. Further, we have tested the consistency of the derived Galactic extinction by using the ($B-r$)–Mg$_2$ relation for E and S0 galaxies in the cluster. Our best estimate of the Galactic extinction in the direction of the cluster is $A_B = 0.75 \pm 0.03$.

The FP for S639 has been established based on a sample of 21 E and S0 galaxies. The coefficients for the FP for this
cluster are not significantly different from those of the FP for the Coma and Hydra I clusters, and are also in agreement with previous results for other nearby clusters (e.g. JFK96). Under the assumption that the FP (coefficients and zero-point) is universal, we find a distance, in velocity units, to S639 of \( (5706 \pm 350) \text{ km s}^{-1} \). This implies a peculiar velocity for the cluster of \( (839 \pm 350) \text{ km s}^{-1} \).

The E and S0 galaxies in S639 have significantly smaller Mg indices, larger H\( \beta \) indices and are bluer than E and S0 galaxies of similar velocity dispersions in Coma and Hydra I. The offset in the FP for S639 relative to Coma and Hydra I may be the result of a difference in the stellar populations, rather than of a large peculiar velocity for S639. The data are consistent with a zero peculiar velocity and mean ages of the S639 galaxies 0.2 dex younger than the mean ages of similar galaxies in Coma and Hydra I. Alternatively, the Mg indices and the \( B-r \) colours are consistent with a metallicity difference of 0.1 dex, with galaxies in S639 having a lower metallicity than those in Coma and Hydra I. In this case the peculiar velocity of S639 is \( \approx 490 \text{ km s}^{-1} \). However, this interpretation is not consistent with the strong H\( \beta \) indices measured for the four galaxies, for which we have measurements of this index.

We conclude that the peculiar velocity of S639 is most likely overestimated if the FP is used as a distance determinator for this cluster. Even though many studies have shown that the FP (and the \( D_n-s \) relation, which is a projection of the FP) to a large degree is universally valid (e.g. Burstein et al. 1990; JFK96; Baggley 1996), our results for S639 caution that there may be exceptions (see also Gregg 1992). When distance determinations are attempted, the best approach will be to obtain colours and line indices together with the other required data. This will give the possibility of identifying clusters (and galaxies) that deviate strongly from the mean relations between the various global parameters. These clusters can also be expected to deviate from the FP otherwise valid for the bulk of the E and S0 galaxies. One may attempt to include an Mg term in the FP in order to correct for the effects caused by differences in the stellar populations. However, the coefficient for such a term is not well determined (cf. JFK96), and the peculiar velocities derived with this method may not be accurate enough for investigations of large-scale flows.

ACKNOWLEDGMENTS

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REFERENCES


APPENDIX A: PHOTOMETRY FOR THE GALAXIES

Observations were obtained for five CCD fields, covering the central 25 x 35 arcmin\(^2\) of S639. The exposure time for each field was 2 x 5 min in Gunn \( r \). The CCD images were

reduced in a standard way. This includes correction for bias, and flat-field correction with dome flat fields with an additional correction for the low-frequency variation derived from flat fields obtained at twilight. The pixel-to-pixel accuracy of the flat-field correction is 0.6 per cent, while the accuracy of the correction for the low-frequency variation is better than 1 per cent.

The two images of each field were registered and added before determination of the photometric parameters of the galaxies. The determination of the photometric parameters was done in the same way as in JFK95a. Two-dimensional surface photometry for the galaxies was derived with the program package GALPHOT (Franx, Illingworth & Heckman 1989; Jørgensen, Franx & Kjærgaard 1992). This package fits a full 2D model to the image of a galaxy. The results are radial profiles of the surface brightness, the ellipticity, the position angle and the deviations of the isophotes from ellipses, as well as the growth curves of the galaxies.

The magnitudes were standard-calibrated by means of offsets relative to the photometry presented in JFK95a. Fig. A1 shows the comparison of aperture magnitudes for the two sets of data, after the offset has been applied. The rms scatter of the comparison is 0.01 mag.

Effective radii and surface brightnesses were derived by fitting the growth curves of the galaxies with growth curves for \( r^{1/4} \) profiles. The seeing was taken into account. We refer to JFK95a for further details.

We have compared the effective parameters derived from the new data to those given in JFK95a. There are 11 galaxies.

Table A1. Photometric and spectroscopic parameters for S639 galaxies.

<table>
<thead>
<tr>
<th>Galaxy</th>
<th>( \log r_e )</th>
<th>( \langle \mu \rangle_r )</th>
<th>( (B - r) )</th>
<th>( \log \sigma )</th>
<th>( M_{24} )</th>
<th>( \log &lt;Fe&gt; )</th>
<th>( \log H_\beta_{GC} )</th>
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<tr>
<td>E264G23</td>
<td>1.24</td>
<td>20.63</td>
<td>1.14</td>
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<td>E264G24</td>
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<td>18.92</td>
<td>1.06</td>
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<td>0.273</td>
<td>0.502</td>
<td>0.392</td>
</tr>
<tr>
<td>E264G26*</td>
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<td>20.74</td>
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<td>2.115</td>
<td>0.243</td>
<td>0.456</td>
<td>...</td>
</tr>
<tr>
<td>E264G28*</td>
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<td>21.44</td>
<td>...</td>
<td>2.191</td>
<td>0.242</td>
<td>0.450</td>
<td>...</td>
</tr>
<tr>
<td>E264G300</td>
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<td>20.01</td>
<td>1.15</td>
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<td>0.315</td>
<td>0.462</td>
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</tr>
<tr>
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<td>0.497</td>
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<tr>
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<td>20.35</td>
<td>1.11</td>
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<td>0.500</td>
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<td>J09</td>
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<td>1.856</td>
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<tr>
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<td>...</td>
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<tr>
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<tr>
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<td>...</td>
<td>2.154</td>
<td>0.252</td>
<td>0.501</td>
<td>...</td>
</tr>
</tbody>
</table>

Notes. *Spiral galaxy, not included in the analysis. \( r_e \) is in arcsec. \( \langle \mu \rangle_r \) and \( (B - r) \) have been corrected for the Galactic extinction (\( A_v = 0.75; A_r = 0.47 \)), k-corrected and corrected for the cosmological dimming. The total correction for \( \langle \mu \rangle_r \) is 0.586 mag, which has been subtracted from the standard calibrated magnitudes. The total magnitudes can be calculated as \( m_e = \langle \mu \rangle_r - 5 \log r_e - 2.5 \log 2 \pi \). The typical internal uncertainties on \( \log r_e \) and \( \langle \mu \rangle_r \) are 0.01 and 0.04, respectively. The \( (B - r) \) colours are derived from \( (g - r) \) given by JFK95a using the relation \( (B - r) = 0.88(g - r) + 0.73 \). The spectroscopic parameters are from JFK95b and Jørgensen (1997); see these references for uncertainties on the parameters.
in common. For differences derived as ‘JFK95a’—‘this paper’ we find mean offsets of $\Delta \log r_V = -0.006 \pm 0.019$ with an rms scatter of 0.063; $\Delta \log \mu_V = -0.02 \pm 0.06$ with an rms scatter of 0.22; $\Delta \log \mu_V = 0.01 \pm 0.03$ with an rms scatter of 0.10. The combination $\Delta \log r_V - 0.35(\log \mu_V)$ that enters the FP has also been compared. We find the difference to be $0.001 \pm 0.003$ with an rms scatter of 0.011. For the galaxies in common we use the average of the photometric parameters given in JFK95a and the new parameters derived here.

Table A1 lists the average photometric parameters for all the observed galaxies. The table also gives the spectroscopic parameters used in the analysis. These data are from JFK95b and Jørgensen (1997). Further, the $(B-r)$ colours derived from the measured $(g-r)$ colours (JFK95a) are listed.

APPENDIX B: STRÖMGREN PHOTOMETRY FOR THE STARS

Strömgren photometry of S639 was obtained with the Danish 1.5-m telescope, La Silla, using the DFOSC. We used a $2k \times 2k$ thinned Loral chip (W11-4). Because of problems with the stability of the flat fields, the chip could not be used in the UV-flooded mode. The stability problem of the flat fields was avoided by using the unflooded mode, but the resulting response in the $u$ band was $\leq 10$ per cent. Furthermore, in unflooded mode the chip had a very low quantum efficiency (QE) near the edge of the frame. As a consequence only the central 1450 $\times$ 1450 pixels were used for the Strömgren photometry. This area corresponds to 9.5 $\times$ 9.5 arcmin$^2$ on the sky.

The exposure times were $2 \times 45$ min in $u$, 20 min in $v$, 10 min in $b$ and $y$, 12 min in $\beta_{\text{sub}}$, and 40 min in $\beta_{\text{narrow}}$. Further, sequences of observations with shorter exposure times were obtained in order to tie-in the bright and faint stars in the field.

The CCD images were reduced in a standard way, correcting for bias and flat-field corrected. Twilight sky flat fields were used for all six filters. The accuracy of the flat-field correction is $\approx 1$ per cent in all filters except in $u$ where the effect of the low edge QE is noticeable as an increase in the noise.

B1 Transformation to the standard system

During the first seven nights of the observing period, simultaneous observations were performed using the Danish 0.5-m telescope (the Strömgren Automatic Telescope, SAT), La Silla. The SAT was used for photoelectric observations of the $ubvy$-primary standard stars, some of the secondary standard stars used for the CCD photometry, and some bright stars in the CCD program fields (though none in S639). The SAT also supplied nightly extinction coefficients. For the rest of the period in which no SAT observations were available, we used the mean extinction coefficients for the first period. One night was used for CCD observations of E-region standard stars (Jønch-Sørensen 1993). A total of 17 standard stars were observed. Transformations from instrumental magnitudes to $V$, $(b-y)$, $m_V = (V-b) - (b-y)$, $c_V = (u-v) - (v-b)$ and $\beta$ were derived. The rms scatter of the transformations was 0.011, 0.010, 0.011, 0.057 and 0.013, respectively. The transformations will be described in more detail in Milvang-Jensen et al. (in preparation). The transformations are valid for stars from A type to early G type. These stars have $2.58 \leq \beta \leq 2.90$, corresponding to $0.43 \geq (b-y) \geq 0.0$ and luminosity classes V–III.

B2 The limiting magnitude and the accuracy of the magnitudes

In the observed field 110 objects have complete $ubvy$-data. The final sample used for the $E(b-y)$ analysis was limited to 22 stars meeting the restrictions implied by the applied calibrations (see Section B3). The low sensitivity of the CCD at short wavelengths limits the sample of stars with complete $ubvy$-information to stars brighter than $V = 17$ mag. The limiting magnitude in the other filters is $V = 20$ mag. For stars brighter than $V = 17$ mag the internal uncertainties are $\sigma_v \approx 0.008$ mag, $\sigma_{b-y} \approx 0.012$, $\sigma_{v-b} \approx 0.018$, $\sigma_{b-y} \approx 0.065$ and $\sigma_b \approx 0.008$. The poor UV response is manifested in the large uncertainty of the $c_v$ index.

B3 Determination of $E(b-y)$ and $M_v$

Intrinsic colours can be estimated in the $ubvy$ system for individual stars of spectral types ranging from B to G type. The $\beta$ index $(\equiv \beta_{\text{narrow}} - \beta_{\text{sub}})$ is not affected by reddening and is an effective temperature indicator for the stars in question. For definitions and properties of the $ubvy$ system, see Crawford (1975).

In this program we concentrate on F- and early G-type stars since these stars are common and the calibration of $ubvy$-indices in terms of both intrinsic colours and astrophysical parameters such as $M_v$, $T_v$ and $[\text{Fe/H}]$ is well-established. We follow closely the procedure outlined in Jønch-Sørensen (1994a,b).

We use the intrinsic colour calibration of $(b-y)_0$ by Olsen (1988): $(b-y)_0$ is calibrated using $\beta$ as indicator of the effective temperature with corrections of the luminosity and the metallicity via terms involving $c_v$ and $m_v$, respectively (see Olsen 1988 for details). The rather complex relation between the three indices means that the uncertainty on the derived $E(b-y)$ depends upon position in the $(\beta, m_v, c_v)$ space. There is no tight relation between $V$ and the uncertainty on $E(b-y)$ as one might have expected from the relation between the magnitude uncertainties and $V$. However, there is an effect of the spectral type in the sense that the uncertainty on $E(b-y)$ increases near the cool end of the sample. For $(b-y)_0 \leq 0.39$ the average uncertainty is $\langle \sigma_{E(b-y)} \rangle = 0.022$, while for $(b-y)_0 \geq 0.4$ the luminosity is $\langle \sigma_{E(b-y)} \rangle = 0.070$. The average uncertainty for our sample is $\langle \sigma_{E(b-y)} \rangle = 0.039$.

The distances are estimated from $M_v$, which is derived using the calibration by Crawford (1975). Again $\beta$ is the main parameter with corrections of the luminosity from $c_v$. The uncertainty of the derived $M_v$ is closely correlated with $V$, increasing from $\langle \sigma_{M_v} \rangle = 0.17$ mag for $V \leq 14$ mag to 0.93 mag for $V \geq 16$ mag. This includes contributions from the uncertainties on $E(b-y)$ and $V$. The uncertainties on $M_v$ correspond to (formal) relative distance uncertainties between $\approx 10$ and $\approx 45$ per cent. Note that the rms scatter of the calibration of photometric distances is $\approx 15$ per cent (cf. Nissen 1994).