Photometric and spectroscopic study of Abell 0671

Zhizheng Pan,1,2 Qirong Yuan,3 Xu Kong,1,2⋆ Dongxin Fan,4 Xu Zhou5 and Xuanbin Lin1,2

1 Center of Astrophysics, University of Science and Technology of China, Jinzhai Road 96, Hefei 230026, China
2 Key Laboratory for Research in Galaxies and Cosmology, USTC, CAS, China
3 Department of Physics, Nanjing Normal University, WenYuan Road 1, Nanjing 210046, China
4 Department of Physics and Electronics, Guangxi Teachers Education University, Nanning 530001, China
5 National Astronomical Observatories, Chinese Academy of Sciences, Datun Road 20A, Beijing 100012, China

ABSTRACT

In this paper, we present a photometric and spectroscopic study of the nearby galaxy cluster Abell 0671 (A671) with 15 intermediate-band filters in the Beijing–Arizona–Taiwan–Connecticut (BATC) system, and using Sloan Digital Sky Survey (SDSS) data. After a cross-identification between the photometric data obtained from the BATC and SDSS, we obtain a list of 985 galaxies down to \( V \sim 20.0 \) mag in a field of view of \( 58 \times 58 \) arcmin\(^2\), including 103 spectroscopically confirmed member galaxies. The photometric redshift technique is applied to the galaxy sample to determine further membership. After the colour–magnitude relation is taken into account, 97 galaxies brighter than \( h_{BATC} = 19.5 \) mag are selected as new member galaxies. Based on the enlarged sample of cluster galaxies, the spatial distribution and dynamics of A671 are investigated. The substructures of A671 are clearly shown by the sample of bright members. However, the substructures appear less significant based on the enlarged sample, which is mainly a result of larger uncertainties in the line-of-sight velocities of the newly selected faint members. The SDSS \( r \)-band luminosity function of A671 is flat at faint magnitudes, with the faint-end slope parameter \( \alpha = -1.12 \). The SDSS spectra allow us to investigate the star formation history of bright cluster galaxies. The galaxies in the core region are found to be older than those in the outskirts. No environmental effect is found for metallicities of the early-type galaxies (ETGs). Both mean stellar ages and metallicities in the bright member galaxies are found to be correlated strongly with their stellar masses assembled, and such correlations are dependent upon morphology. The positive correlation between age and stellar mass supports the downsizing scenario. By comparing the absorption-line indices of ETGs with state-of-the-art stellar population models, we derive the relevant parameters of the simple stellar population (such as age, [Fe/H], [Mg/Fe], [C/Fe], [N/Fe] and [Ca/Fe]). The ETGs at the cluster centre tend to have smaller H\( \beta \) indices, indicating that central ETGs are likely to be older. The distribution of the total metallicity indicator, [MgFe]', does not show any environmental effects. The relations between the simple stellar population parameters and the velocity dispersion in A671 are in good agreement with previous studies.

Key words: galaxies: clusters: individual: A671 – galaxies: distance and redshifts – galaxies: evolution – galaxies: kinematics and dynamics.

1 INTRODUCTION

According to the hierarchical scenario of structure formation, massive clusters form by merging small groups continuously and accreting field galaxies along the filament (West, Villumsen & Dekel 1991; West, Jones & Forman 1995; Colberg et al. 2000). Optical cluster surveys reveal that many galaxy clusters show evidence of dynamically bound substructures (Beers et al. 1991; Rhee, van Haarlem & Katgert 1991). A significant fraction (\( \sim 40–50 \) per cent) of clusters show multiple peaks or irregular surface brightness distribution in X-ray images, indicating that they are still at a dynamically active stage, far from equilibrium (Jones & Forman 1999; Schuecker et al. 2001). Compared with the Einstein–de Sitter case, clusters in the

⋆E-mail: xkong@ustc.edu.cn
early-epoch Universe are expected to be more relaxed and less substructured, as supported by many N-body simulation works (Crone, Evrard & Richstone 1996; Thomas et al. 1998). The fraction of substructured clusters at different redshifts is thus a useful statistical quantity, which is directly relevant to cosmology. Studies on the dynamics of galaxy clusters thus provide a unique tool for putting constraints on the models of cluster formation and evolution.

The dense environment in galaxy clusters should have influenced the physical properties and evolutionary path of the member galaxies. Previous studies have found that the observational properties of galaxies correlate strongly with the local galaxy environment (Gómez et al. 2003; Kauffmann et al. 2004; Baldry et al. 2006). One of the most well-studied relation in galaxy clusters is the morphology–density relation (Dressler 1980; Postman & Geller 1984; Whitmore & Gilmore 1991; Goto et al. 2003; Holden et al. 2007). The core region of a cluster is usually dominated by early-type galaxies (ETGs), while the outer region is dominated by late-type galaxies (LTGs). It is well appreciated that the LTGs gradually lost their gas reservoirs when they were accreted into the core region, and finally evolved into lenticular galaxies (S0). This picture of morphology evolution in galaxy clusters has been supported in studies of the high-z morphology–density relation (Dressler et al. 1997; Fasano et al. 2000; Postman et al. 2005; Smith et al. 2005). However, it is still uncertain and controversial how local galaxy environment affects the star formation histories (SFHs) of cluster galaxies.

At the Beijing–Arizona–Taiwan–Connecticut (BATC) system, much time has been spent observing a sample of more than 30 nearby (z < 0.1) galaxy clusters at different dynamic statuses. The aim is to study their dynamic substructures and luminosity functions, and the star formation properties of cluster galaxies. Abell 0671 (A671; z = 0.0502) is one target of the BATC galaxy cluster survey. Its Abell richness R is set to be 0 (Abell 1958), with Bautz–Morgan type II–III (Bautz & Morgan 1970). The X-ray emission from the cluster centre has been detected by the Einstein observatory and the ROSAT All-Sky Survey (RASS). The X-ray luminosity of A671 detected in the RASS 0.1–2.4 keV band is 0.9 × 10^41 erg s^{-1}, and the X-ray temperature is 3.1 keV (Ebeling et al. 1998), which confirms that this cluster is a relatively poor system. Fig. 1 shows the smoothed contours of the Einstein X-ray image and the radio map at 1.4 GHz from the National Radio Astronomy Observatory (NRAO) Very Large Array Sky Survey (NVSS), superimposed on the optical image in the BATC h band. No radio emission is detected at the centre of A671. The X-ray surface density contour is regular with a single symmetric peak, as reported by Jones & Forman (1999). However, the detailed structure of A671 is possibly blurred because of the low resolution (a spatial resolution of ~1 arcmin) and the large point spread function (FWHM ~1.5 arcmin) of the image from the Einstein Imaging Proportional Counter. It is easily seen that the X-ray emission peak does not coincide with the central brightest galaxy, IC 2378, with a positional offset of about 90 kpc. A671 is included in the cluster sample of the Wide-Field Nearby Galaxy Cluster survey (WINGS), and two substructures in A671 have been found by Ramella et al. (2007) recently. For a better understanding of the dynamics of A671, it is important to construct a large sample of member galaxies, and the faint galaxies (18.0 < m_r < 19.5) should be taken into account. In this paper, we present a multicolour photometry of the galaxies in the A671 region with the BATC system. We try to enlarge the sample of cluster galaxies by applying the photometric redshift technique to the spectral energy distributions (SEDs) of the BATC-detected faint galaxies. Based on the SDSS spectra of bright member galaxies, we derive the SFHs and chemical abundances, and we try to find clues about the environmental effects on the physical parameters of the cluster galaxies.

This paper is organized as follows. We present the BATC photometric observations and data reduction in Section 2. In Section 3, we analyse the galaxies with known spectroscopic redshifts in the A671 field. In Section 4, we use the photometric redshift technique to select faint member galaxies in A671. In Section 5, we investigate the dynamic substructures and luminosity function, based on the enlarged sample of member galaxies. In Section 6, we derive the SFHs and chemical abundances of the ETGs in A671. Finally, we summarize our work in Section 7. Throughout this paper, we assume the cosmological parameters as Ω_m = 0.3, Ω_L = 0.7, H_0 = 70 km s^{-1} Mpc^{-1}.

2 OBSERVATIONS AND DATA REDUCTION

The BATC survey is based on the 60/90-cm f/3 Schmidt telescope of the National Astronomical Observatories, Chinese Academy of Science (NAOC), located at Xinglong Station. The BATC system contains 15 intermediate-band filters, covering a wavelength from 3000 to 10000 Å, which are designed to avoid night-sky emission lines (Fan et al. 1996; Kong et al. 2000). The transmission curves of the BATC filters can be found in Fan et al. (1996). Before 2006 October, a Ford CCD camera with a format of 2048 × 2048 was mounted on the telescope, and photometric observations in 12 bands, from d to p, were carried out. The field of view was about 58 × 58 arcmin^2, with a scale of 1.7 arcsec pixel^{-1}. In order to pursue a better spatial resolution and higher sensitivity in three blue bands, a–c, a new E2V CCD with 4096 × 4096 pixels was then equipped. The field of view is now larger (92 × 92 arcmin^2) with a spatial scale of 1.35 arcsec pixel^{-1}. The newly equipped CCD camera has a high quantum efficiency of 92.2 per cent.

From 2003 March to 2007 October, in total we accumulated 50 h of exposure for A671 with 15 filters (see the observational
Table 1. Details of the BATC filters and observation information of A671.

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<th>Number</th>
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*a* Seeing of the combined image.

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3 ANALYSIS OF GALAXIES WITH KNOWN SPECTROSCOPIC REDSHIFTS

3.1 Distribution of spectroscopic redshifts

In order to study the dynamics of the galaxy cluster A671, 205 galaxies with known redshifts in our field of view are extracted from the SDSS Data Release 8 (DR8) galaxy catalogue. Fig. 2 shows the distribution of spectroscopic redshifts of these galaxies. The main concentration with a peak at \( z \approx 0.05 \) is isolated and less contaminated. There are 103 galaxies with 0.04 < \( z < 0.06 \), and these are selected as the member galaxies of A671, which we refer to as Sample I. To characterize the velocity distribution, we convert the spectroscopic redshifts (\( z_{\text{sp}} \)) into the rest-frame velocities (\( v \)) using

\[
v = c \frac{z_{\text{sp}} - \bar{z}_c}{1 + z_{\text{sp}}},
\]

where \( c \) is the light speed and \( \bar{z}_c \) is the cluster redshift with respect to the cosmic background radiation. We take the cluster redshift \( \bar{z}_c = 0.0502 \) for A671, given by the NASA/IPAC Extragalactic Data base (NED). The velocity distribution can be fitted by a Gaussian with a dispersion of \( \sigma = 625 \text{ km s}^{-1} \), which deviates significantly from a standard Gaussian function.

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To qualify the distribution of the radial velocities of member galaxies, we use the ROSTAT package (Beers, Flynn & Gebhardt 1990) to calculate two resistant and robust estimators—the biweight location (CBI) and the scale (SBII)—analogous to the velocity mean and the standard deviation. For these 103 galaxies, we achieve \( C_{\text{BI}} = 14\,561^{+82}_{-82} \, \text{km s}^{-1} \) and \( S_{\text{BI}} = 820^{+57}_{-50} \, \text{km s}^{-1} \). The errors are determined from the 68 per cent confidence limits based on 10 000 bootstrap resamplings of the velocity data. Taking a cosmological correction factor of \((1+z)^{-1}\) into account, the velocity dispersion of A671 should be \( 780^{+54}_{-54} \, \text{km s}^{-1} \). Aguerri, Sánchez-Janssen & Muñoz-Tuñón (2007) studied a sample of 88 nearby clusters. Only 72 galaxies were included in their sample, and a smaller \( S_{\text{BI}} \) was derived. They found that A671 has \( C_{\text{BI}} = 14\,599^{+11}_{-11} \, \text{km s}^{-1} \) and \( S_{\text{BI}} = 610^{+13}_{-13} \, \text{km s}^{-1} \). Our statistics is based on a larger sample, and is thus more reliable. Both studies confirm that A671 has a comparatively small velocity dispersion.

### 3.2 Spatial distribution and localized velocity structure

Because A671 is a nearby cluster, our BATC field of view cannot cover the whole cluster region. Our photometry focuses on a central field of \(3.4 \times 3.4 \, \text{Mpc}^2\). The radius of the galaxy cluster, \( r_{200} \), has been defined in previous studies as the boundary of a cluster, within which the mean inner density is \( 200 \rho_c \), where \( \rho_c \) is the critical density of the Universe (Gott 1972). We calculate \( r_{200} \) for A671 following the formula suggested by Carlberg, Yee & Ellingson (1997), where \( r_{200} \) is a function of velocity dispersion. By applying the \( S_{\text{BI}} \) that we have derived, the \( r_{200} \) of A671 is \( 2.25 \, \text{Mpc} \), corresponding to a slightly larger area than our field of view.

Before studying the dynamic structure of A671, we try to classify the 103 known members into ETGs and LTGs. The early-type members should meet the following two requirements: (i) no evident emission lines; (ii) no evident galaxy arms. First, we extract those galaxies with an equivalent width (EW) of \( \text{EW}(	ext{H} \alpha) \) <5 Å as early-type candidates. The \( \text{EW}(	ext{H} \alpha) \) values are taken from the Max-Planck-Institute for Astrophysics (MPA)/Johns Hopkins University (JHU) catalogue\(^1\) of SDSS galaxies. Then, we inspect their images given by the SDSS, and remove those galaxies with arms. As a result, the 103 galaxies are classified into 63 ETGs and 40 LTGs.

The left panel of Fig. 3 presents the spatial distribution of the 103 known member galaxies within our field of view, with the central position of A671, \( \text{RA} = 8^h28^m29^s, \text{Dec.} = 30\,25'01'' \) (for the J2000 equinox). We superpose the contour map of surface density, which has been smoothed by a Gaussian window with \( \sigma = 1.6 \, \text{arcmin} \). As shown in Fig. 3, the member galaxies are mainly concentrated in the central region within a radius of 1 Mpc. The irregular contour in the east and north corresponds to the two substructures found by Ramella et al. (2007). More statistical tests should be performed before we can reach the firm conclusion that there are substructures in A671.

To show the substructures of A671 in both the velocity space and the projected map, we make use of the \( \kappa \)-test (Colless & Dunn 1996) for the 103 galaxies. The statistical variable, \( \kappa_n \), is defined to quantify the local deviation on the scale of groups of \( n \) nearest neighbours. A larger \( \kappa_n \) indicates a greater probability that the local velocity distribution differs from the overall velocity distribution. The probability \( P(\kappa_n > \kappa_n^{\text{obs}}) \) can be calculated by Monte Carlo simulations with random shuffling velocities. When the scale of the nearest neighbours \( n \) varies from 3 to 9, the probabilities \( P(\kappa_n > \kappa_n^{\text{obs}}) \) are nearly zero, which means the substructure appears very obvious at different scales. A bubble plot at the scale of \( n = 6 \) is given in the right panel of Fig. 3. Because the bubble size is proportional to \( -\log P(D_n > D_n^{\text{obs}}) \), the clustering of large bubbles is a good tracer of dynamical substructure.

As we can see in the bubble plot, the central region of A671 is dominated by two clumps of bubbles, and a clump of large bubbles in the north-east is also remarkable. We refer to these three clumps as A, B and C, and these contain 16, 10 and 8 galaxies, respectively. In order to confirm whether these clumps trace the real substructures,

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\(^1\) http://www.mpa-garching.mpg.de/SDSS/DR7
Figure 4. Stripe density plot of the velocities of the spectroscopically con-
firmned galaxies in the whole cluster and in clumps A, B and C.

we present the velocity distributions for subsamples A, B and C in
Fig. 4, as well as the velocity distribution of the whole sample. It is
easily seen that the velocity distributions for the three clumps do
indeed deviate from that of the whole sample. The mean velocities
of the subsamples A, B and C are 14 638 ± 108, 15 567 ± 203 and
13 999 ± 711 km s⁻¹, respectively. The mean velocities of subsamples
B and C deviate significantly from the mean velocity of the whole
sample, 14 561 km s⁻¹. Although the mean velocity in clump A is
similar to that of the whole sample, the galaxies in clump A have a
remarkable bimodal velocity distribution, which could imply the
existence of two different groups. To quantify the bimodality signif-
icance, we apply the Gaussian mixture modelling (GMM) method
(Muratov & Gnedin 2010) to the velocity distribution for clump A.
The result shows that clump A consists of two components,
which peaked at 13 829 and 15 824 km s⁻¹. The unimodal velocity
distribution can be rejected at the 99 per cent significance level.

Although the velocity distributions of the subsamples deviate
significantly from the whole sample, their masses should also be
large enough if they are real substructures. The masses of A671
and its clumps can be estimated by applying the virial theorem.
Assuming that each subcluster is bound and that the galaxy orbits
are random, the virial mass (M_v) can be derived from the following
standard formula (Geller & Peebles 1973; Oegerle & Hill 1994):

\[ M_v = \frac{3\pi}{G} \sigma_v^2 D N_g \left( \frac{1}{\theta_{ij}} \right)^{-1}. \]  

Here, \( \sigma_v \) is the velocity dispersion in the line-of-sight direction, \( D \)
is the cosmological distance of the cluster, \( N_g = N(N - 1)/2 \) is the
number of galaxy pairs and \( \theta_{ij} \) is the angular distance between
galaxies \( i \) and \( j \). The viral mass of A671 is 9.49 × 10¹⁴ M⊙. Clump
B is the most remarkable of the three subsamples, with a viral mass
of 1.53 × 10¹⁵ M⊙. Clump A consists of two groups, both with a
viral mass of ~7.0 × 10¹³ M⊙. Clump C has a similar viral mass,
which is ~7.0 × 10¹³ M⊙. Thus, we conclude that A671 is not a
simple relaxed cluster, but is most likely at a dynamically active
stage.

4 SPECTRAL ENERGY DISTRIBUTION
SELECTION OF FAINT CLUSTER GALAXIES

The technique of photometric redshift can be used, instead of spec-
troscopy, to estimate the redshifts of galaxies, using the SED in-
formation covering a wide range of wavelengths. This technique
has been extensively applied to multicolour photometric surveys
to detect faint and distant galaxies, and it has been used for the sub-
sequent selection of cluster galaxies (Fernández-Soto, Lanzetta &
Yahil 1999; Ilbert et al. 2009; Kong et al. 2009). Based on the stan-
dard SED-fitting code called HYPERZ (Bolzonella, Miralles & Pelló
2000), for a given object, the photometric redshift \( z_{\text{ph}} \) corresponds
to the best fit (in the \( \chi^2 \) sense) of its photometric SED with the
template SED, which is generated by convolving the galaxy spectra
in the template library with the transmission curves of the specified
filters. In previous work, the accuracy of the photometric redshift
has been demonstrated using BATC multicolour photometric data
(Xia et al. 2002; Yang et al. 2004; Liu et al. 2011; Zhang et al.
2011). In our SED fitting, only normal galaxies are taken into ac-
count in the reference templates. Dust extinction with a reddening
law of the Milky Way (Allen 1976) is adopted, and \( A_V \) is allowed
to be flexible in a range from 0.0 to 0.5, with steps of 0.05. We look
for the photometric redshift of a given galaxy between 0.0 and 0.6,
with steps of 0.005. We apply this technique to all BATC galaxies
brighter than \( h_{\text{BATC}} = 19.5 \) mag. The SED-fitting procedure has
provided the best-fitting photometric redshift and its uncertainty for
each galaxy.

From the 205 galaxies with known spectroscopic redshifts \( z_{\text{sp}} \), we
select 167 galaxies (including 91 member galaxies) that have
been simultaneously detected in at least 12 BATC bands to derive
their \( z_{\text{ph}} \) values. A comparison between the \( z_{\text{sp}} \) and \( z_{\text{ph}} \) values is
shown in the top-left panel of Fig. 5. The error bar of \( z_{\text{ph}} \) corre-
sponds to the 68 per cent confidence level in the determination of
the photometric redshift. The solid line denotes \( z_{\text{ph}} = z_{\text{sp}} \), and the
dashed lines show an average redshift deviation of 0.02(1 + z). It is
obvious that our \( z_{\text{ph}} \) estimates are basically consistent with their
\( z_{\text{sp}} \) values. For 91 member galaxies in our spectroscopic sample,
the mean value and the standard deviation of their \( z_{\text{ph}} \) values are
0.0505 and 0.0112, respectively. There is no systematic offset in
the \( z_{\text{ph}} \) domain with respect to the \( z_{\text{sp}} \) distribution. Statistically,
85 member galaxies (about 93 per cent) are found to have their
photometric redshifts within the ±2\( \sigma \) deviation, in a range from
0.028 to 0.073. This demonstrates the robustness of our \( z_{\text{ph}} \)
estimate. This \( z_{\text{ph}} \) region can be applied as a selection criterion in
the following determination of membership for faint galaxies.

The top-right panel of Fig. 5 shows histograms of the photometric
redshifts for all galaxies down to \( h_{\text{BATC}} = 19.5 \) mag. The black
histogram shows the \( z_{\text{ph}} \) distribution for the 167 galaxies with known
spectroscopic redshifts, as mentioned above. As expected, the peak
in the \( z_{\text{ph}} \) distribution is around \( z = 0.05 \). In the bottom-left panel
of Fig. 5, we show the \( z_{\text{ph}} \) uncertainties for these 167 galaxies as
a function of the BATC \( h \)-band magnitude. It is remarkable that
the \( z_{\text{ph}} \) deviation of fainter galaxies tends to be larger. For the
faint galaxies with \( h_{\text{BATC}} = 18.0 \) mag, our \( z_{\text{ph}} \) estimate is still
robust, but with a larger uncertainty. For the remaining galaxies
without \( z_{\text{ph}} \) values, we show a plot of their \( z_{\text{ph}} \) uncertainties versus
BATC \( h \)-band magnitudes in the bottom-right panel of Fig. 5. The
larger \( z_{\text{ph}} \) uncertainties for faint galaxies are mainly a result of the
larger magnitude errors in photometry. For a reliable determination
of membership, based on the \( z_{\text{ph}} \) estimate, we exclude galaxies
fainter than \( h_{\text{BATC}} = 19.5 \) mag, and include galaxies with \( 0.028 <
(0.073 as member candidates. Because of the robustness of our
photometric redshift technique, as a conservative estimate, our
selecting criterion would be able to select 80–90 per cent of faint
members with the least contaminants.

It is well known that there is a correlation between colour and
absolute magnitude for ETGs (the C-M relation; Bower, Lucey

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Photometric and spectroscopic study of A671

Figure 5. Top-left: comparison between \( z_{\text{ph}} \) and \( z_{\text{sp}} \) of 167 galaxies detected with at least 12 BATC bands. The error bars show the 68 per cent significance coefficient level. The solid line denotes \( z_{\text{ph}} = z_{\text{sp}} \), and the dashed lines denote the deviation of 0.02(1 + \( z \)). There is no systematic deviation between the photometric redshifts and the spectroscopic redshifts. Top-right: \( z_{\text{ph}} \) distribution for the galaxies down to \( h_{\text{BATC}} = 19.5 \) mag, with a bin size of \( \Delta z = 0.004 \). The black histogram shows the \( z_{\text{sp}} \) of the 167 galaxies with \( z_{\text{sp}} \). The dashed line shows our selection criterion for the faint member candidates. Bottom-left: difference between \( z_{\text{ph}} \) and \( z_{\text{sp}} \) for the 167 galaxies with spectroscopic redshifts. Circles denote member galaxies and triangles denote non-members. The dashed lines denote the selection criteria for members (2\( \sigma = 0.023 \)). The error bars are given by the HYPERZ code, with the 68 per cent confidence level. Bottom-right: crosses denote 1\( \sigma \) errors of \( z_{\text{ph}} \) for the left galaxies with \( h_{\text{B} \text{A} \text{T} \text{C}} \)-band magnitude brighter than 19.5 mag in the field of view of A671.

& Ellis 1992), such that brighter ETGs appear redder. This can be used to verify the membership selection of the ETGs. The left panel of Fig. 6 presents the correlation between the colour index \( b - h \) and the BATC \( h \)-band magnitude for all the member candidates down to \( h_{\text{BATC}} = 19.5 \) mag. The right panel shows the SDSS colour index \( g - r \) and the \( r \)-band magnitude. The figures include the following categories of sources: (i) spectroscopically confirmed early-type member candidates (denoted by solid circles); (ii) spectroscopically confirmed late-type member candidates (denoted by solid triangles); (iii) newly selected faint member candidates (denoted by open triangles). The solid line represents the linear fitting with the 63 spectroscopically confirmed ETGs: \( b - h = -0.09(\pm 0.02)h + 3.47(\pm 0.43) \). The dashed line represents the 1\( \sigma \) deviation. The linear fit of the ETGs in the right panel of Fig. 6 is \( g - r = -0.026(\pm 0.006)r + 1.21(\pm 0.10) \). As shown in both panels, the early-type member galaxies follow a very tight C–M relation, and faint member candidates also basically follow the same C–M relation, but seem to be more scattered. This might be caused by some high-\( z \) galaxies that have been included with our faint member candidates. To exclude these contaminants, we use the SDSS C–M relation, and we remove the ETG candidates with colour indices \( g - r \) 0.15 mag redder than the red sequence denoted by the black solid line.

Finally, we obtain a list of 97 newly selected member galaxies. Combining these with the 103 spectroscopically confirmed members, we form an enlarged sample of 200 galaxies in A671, which we refer to as Sample II in the following.

5 PHYSICAL PROPERTIES OF A671

5.1 Spatial distribution and velocity structure

The left panel of Fig. 7 shows the projected positions of the galaxies in Sample II, superposed with the contour map of surface density smoothed by a Gaussian window with \( \sigma = 1.6 \) arcmin. The 103 member galaxies with known spectroscopic redshifts are denoted by solid symbols and the 97 photometrically selected galaxies are denoted by open symbols. Circles and triangles represent the early-type and late-type member galaxies, respectively. Our BATC multicolour photometry makes it easier to find a large number of faint
Figure 6. The left panel shows the BATC C–M relation, using the colour index $b - h$ and $h$-band magnitude, for the spectroscopically confirmed members and the galaxies with $0.028 < z_{ph} < 0.073$. The right panel shows the SDSS C–M relation, using the colour index $g - r$ and SDSS $r$-band model magnitude. The solid circles denote the spectroscopically confirmed ETGs in A671. The solid triangles denote the spectroscopically confirmed LTGs in A671. The open triangles denote the newly selected galaxies with $0.028 < z_{ph} < 0.073$. The solid (red) lines represent the subsequence fitted with the known early-type members, and the dashed (red) lines represent $1\sigma$ of the best-fitting C–M relations. In the right panel, the uppermost solid line (black) represents our selection criterion based on the SDSS C–M relation.

Figure 7. Left: spatial distribution of all member galaxies in Sample II. Solid symbols denote the galaxies with known spectroscopic redshifts, while open symbols represent newly selected members. Circles denote red-sequence galaxies, while triangles denote those below $1\sigma$ of the red sequence. Right: a bubble map shows the local velocity distribution for groups of six nearest neighbours for all the member galaxies.

member galaxies, and it makes the underlying substructure along the north-east direction more remarkable. Basically, the distribution of faint galaxies traces that of bright galaxies, and no significant substructures are found with Sample II.

The morphology segregation becomes more remarkable in Sample II. Both bright and faint ETGs are highly concentrated in the core region, while the LTGs are scattered in the outskirts. The shape of contour map seems to agree with the X-ray image, which might demonstrate the reliability of our membership selection based on the BATC multicolour photometry.

In order to detect potential substructures in A671, we perform the $\kappa$-test for Sample II. The right panel of Fig. 7 shows a bubble plot that characterizes the degree of difference between the localized velocity distribution, for groups of six nearest neighbours, and the overall velocity distribution. We performed $10^3$ simulations to estimate the probability $P(\kappa_n > \kappa_n^{obs})$ for different group sizes. The probability is found to be more than 5 per cent in all cases, which means that no substructure is detected at the $2\sigma$ significance (see Table 2). This is inconsistent with the conclusion that we came to based on Sample I. We think that the substructure unveiled by the spectroscopic redshifts is true. The above inconsistency can be explained by the fact that the velocities derived from the $z_{ph}$ estimates are not accurate enough to reflect the subtle velocity structure. The abnormality in the velocity distribution of substructures might
have been smoothed/swept by the \( z_{ph} \) uncertainties of the 97 newly selected faint galaxies. So, the \( \kappa \)-test on Sample II might be misleading. Follow-up spectroscopy of these faint member galaxies is needed if the substructures in A671 are to be investigated in detail.

### 5.2 Luminosity function

The luminosity function (LF) is a key diagnostic for clusters because it is tightly related to dynamical evolution and the merging history of galaxy clusters. The LF has been widely studied over the past decades, and it is well described by the Schechter function (Schechter 1976):

\[
\phi(L) dL = \phi^\ast \left( \frac{L}{L^\ast} \right)^\alpha \exp\left( -\frac{L}{L^\ast} \right) dL.
\]

Here, \( \phi^\ast \), \( L^\ast \) and \( \alpha \) are the normalization parameter, the characteristic luminosity and the slope parameter at the faint end, respectively. In the domain of absolute magnitude, the Schechter function can be expressed as

\[
\phi(M) dM = \phi^\ast 10^{0.4(\alpha+1)(M^\ast-M)} \exp[-10^{0.4(M^\ast-M)}] dM,
\]

where \( M^\ast \) is the characteristic absolute magnitude.

The greatest challenge when measuring the LFs of galaxy clusters (GCs) is that it is necessary to pick out cluster members from the background galaxies along the line of sight. Ideally, the spectroscopic redshifts are needed for all galaxies in order to exclude non-members in the cluster field. Unfortunately, spectroscopic measurements are time-consuming. Our BATC photometry enables us to select a set of cluster member candidates by utilizing the photometric redshift technique. As seen in Fig. 5, the accuracy of \( z_{ph} \) is a function of the apparent magnitude of the galaxy. Further corrections are still needed to remove the contribution of contaminant sources and to compensate for missing members when investigating the LFs. Unfortunately, the exact form of the correction function, particularly at faint magnitudes, is difficult to derive.

Using the SDSS \( r \)-band photometric data, we perform the statistical background subtraction to estimate the contribution of non-members to the number counts of galaxies in the cluster direction, by measuring the projected number counts of field galaxies outside the cluster region. The background is estimated using a region of \( 12 \times 12 \) Mpc\(^2\), centred on the cluster centroid, outside the cluster region defined by a radius of 3 Mpc, where the contamination from cluster galaxies should be negligible. Following the method of Paolillo et al. (2001), we first generate a density map of galaxies in the background region by convolving the projected distribution of galaxies with a Gaussian kernel of \( \sigma = 250 \) kpc in the cluster rest frame (the typical size of a cluster core). Then, we mask out all density peaks from the background region that are above the 3\( \sigma \) level. The masked-out regions cover about 3.3 per cent of the whole background area. Finally, we calculate the number counts from the remaining galaxies to estimate the background number counts in the cluster direction.

Recent studies have proved that the LFs of GCs do vary with clustercentric radius (Beijersbergen et al. 2002; Hansen et al. 2005). A suitable region should be chosen, which is large enough to contain most member galaxies and does not include much projected contamination. We adopt an aperture of \( r = 30 \) arcmin, centred at the cluster centroid (about 1.7 Mpc at the rest frame of A671). The results of the background estimation and the final LF are shown in Fig. 8. The apparent magnitudes are converted to absolute magnitudes by the relation

\[
M = m - DM(z) - K_{0.1}(z),
\]

where \( DM(z) \) is the distance modulus as determined from the redshift, assuming a particular cosmology. \( K_{0.1}(z) \) is the \( K \)-correction from a galaxy at \( z \) to \( z = 0.1 \). We estimate \( K_{0.1}(z) \) using the software \textsc{kcorrect} (version 4.1.4; Blanton et al. 2003). As shown in the bottom-right panel of Fig. 8, a single Schechter function can fit the data very well. The best-fitting parameters are \( \phi^\ast = 21.0, M^\ast = -21.6 \) and \( \alpha = -1.12 \), which are in good agreement with those of de Filippis et al. (2011). No strong ‘upturn’ is observed at faint magnitudes for A671.

### 6 STAR FORMATION HISTORY AND ELEMENT ABUNDANCES

As mentioned in the introduction, many previous studies have supported the idea that galaxy properties strongly correlate with local environment. The remarkable morphology-segregation of A671

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**Table 2. Results of the \( \kappa \)-test for member galaxies.**

<table>
<thead>
<tr>
<th>Neighbours size (n)</th>
<th>( P(k_n &gt; k_{ph}^{(n)}) ) Sample I (per cent)</th>
<th>( P(k_n &gt; k_{ph}^{(n)}) ) Sample II (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1.4</td>
<td>34.7</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>35.9</td>
</tr>
<tr>
<td>5</td>
<td>2.8</td>
<td>65.3</td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>74.8</td>
</tr>
<tr>
<td>7</td>
<td>0.5</td>
<td>71.5</td>
</tr>
<tr>
<td>8</td>
<td>0.7</td>
<td>65.7</td>
</tr>
<tr>
<td>9</td>
<td>1.4</td>
<td>62.0</td>
</tr>
</tbody>
</table>
demonstrates that the morphologies of member galaxies strongly correlate with their local environment. In this section, we investigate the SFHs of the confirmed member galaxies by applying models of stellar population synthesis to their observed spectra. Two models are used: (i) we fit the SDSS spectra using the STARLIGHT code (Cid Fernandes et al. 2005, 2007; Mateus et al. 2006) in order to derive the physical parameters based on their SFHs; (ii) we compare the absorption line indices (the Lick/IDS indices) of the member ETGs with the model predictions developed by Schiavon (2007, hereafter S07) to put constraints on the SFHs and chemical enrichment.

6.1 Fitting spectra with STARLIGHT

We fit the SDSS spectra of the member galaxies with the STARLIGHT code, which aims to fit an observed spectra with a linear combination of theoretical simple stellar populations (SSPs). The model spectrum is given by

$$M_\lambda = M_{\lambda_0} \left( \sum_{j=1}^{N} x_j b_{j,\lambda} r_\lambda \right) \otimes G(v_\star, \sigma_\star),$$

(5)

where $M_\lambda$ is the model spectrum, $M_{\lambda_0}$ is the synthesis flux at the normalization wavelength $\lambda_0$. $N$ is the total number of SSP models, $x_j$ is the so-called population vector, $b_{j,\lambda}$ is the $j$th SSP spectrum at $\lambda$ and $r_\lambda = 10^{-0.4A_\lambda}$. $G(v_\star, \sigma_\star)$ represents the reddening term. The term $G(v_\star, \sigma_\star)$ denotes the line-of-sight stellar motions modelled by a Gaussian distribution centred at velocity $v_\star$ and with a dispersion of $\sigma_\star$. In this paper, the SSP base is made up of $N = 45$ SSPs, three metallicities ($Z = 0.2Z_\odot$, $2.5Z_\odot$) and 15 ages (from 1 Myr to 13 Gyr), which are taken from the evolutionary models in Bruzual & Charlot (2003). We adopt the galactic extinction law of Cardelli, Clayton & Mathis (1989) with $R_V = 3.1$.

All spectra observed by the SDSS are shifted to the rest frame, and then interpolated into a resolution of 1 Å before fitting. The wavelength regions of the emission lines are masked out. Fig. 9 shows the spectral fitting for the brightest cluster galaxy (BCG) of A671. As demonstrated by this figure, the combination of SSP spectra can fit the observed spectrum very well.

STARLIGHT presents the SSP fraction, the intrinsic extinction $A_V$, the velocity dispersion $\sigma$ and the stellar mass $M_\star$. Following Cid Fernandes et al. (2005), we derive the flux- and mass-weighted average ages, which are defined as

$$\langle \log t_{\star}\rangle_L = \frac{\sum_{j=1}^{N} x_j \log t_j}{\sum_{j=1}^{N} x_j}, \quad \langle \log t_{\star}\rangle_M = \frac{\sum_{j=1}^{N} u_j \log t_j}{\sum_{j=1}^{N} u_j},$$

(6)

Here, $x_j$ is the flux-weighted population vector (i.e. the fraction of flux contributed by certain SSPs) and $u_j$ is the mass-weighted population vector. The average metallicities $\langle Z_L \rangle$ and $\langle Z_M \rangle$ can be derived in a similar way.

6.1.1 Star formation history via STARLIGHT fitting

As illustrated by Cid Fernandes et al. (2005), the individual output vector can deviate dramatically from the simulated input value. However, the average values of stellar age and metallicity should be more reliable, whether they are weighted by light or mass. The flux-weighted age is more sensitive to the young stellar component, so the mass-weighted age is more essential and intrinsic. The situation is the same for the average metallicity. Here, we take the average ages and metallicities weighted by stellar mass. Because the stellar population in ETGs is dominated by old components, the average ages of the ETGs are within a relatively narrow range.

Fig. 10 presents the derived mass-weighted ages and metallicities as functions of the clustercentric radius $R$ and the total stellar mass $M_\star$, assembled in cluster galaxies. The upper two panels show the mass-weighted ages and metallicities as a function of $R$. The galaxies in the core region ($R < 400$ kpc) of A671 are denoted by solid symbols. The remarkable morphology–density segregation of A671 is clearly shown in these two panels. The LTGs (denoted by triangles ) are located in the outskirts (denoted by open triangles ), and have younger stellar ages. However, the ETGs that have older stellar ages are located in the core region. For the ETGs of A671, no correlation is found between metallicities and $R$.

The lower two panels of Fig. 10 present the correlation of mass-weighted ages and metallicities with stellar mass. Both ages and metallicities are found to be correlated strongly with stellar mass, and such correlations are dependent upon morphology. In general, the most massive galaxies have older ages and richer metallicities. For the LTGs in A671, the linear correlations of age and metallicity with stellar mass appear tighter and steeper. Even for ETGs with similar stellar mass, the ETGs in the core region tend to have older ages than ETGs in the outskirts. However, the ETG metallicities do not seem to vary with the clustercentric radius.

http://www.starlight.ufsc.br

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For decades, the age–metallicity degeneracy has been a problem for stellar population analysis. Nevertheless, the combined use of multiple absorption-line indices seems to be a promising approach to solve this problem (Kong & Cheng 2001). In this section, we measure the absorption lines of the ETGs in A671 and we compare these with state-of-the-art SSP models in order to infer their ages, metallicities and $\alpha$-enhancements.

### 6.2.1 Lick index measurements

The bandpasses of the Lick indices are defined in table 1 of Worthey et al. (1994). We measure the Lick indices with a modified version of the Lick_EW routine in the EZ\_AGES package developed by Graves & Schiavon (2008). The Lick_EW routine reports the errors of each Lick index calculated in the way suggested by Cardiel et al. (1998). The SDSS spectral resolution (69 km s$^{-1}$) does not match the originally defined resolution of the Lick indices. The Lick_EW routine smooths the SDSS spectra to the resolution of the Lick/IDS system before measuring the indices. For galaxies with high velocity dispersion, the smoothed absorption features in the SDSS spectra are at a poorer resolution than even the Lick resolution. The Lick_EW routine will apply a $\sigma$-correction for these galaxies. The output includes the measurements of $\sigma$-corrected indices and their errors.

### 6.2.2 Simple stellar population model and stellar population parameters

Our goal is to use the S07 model to derive the SSP-equivalent parameters. First, we create a grid to fit three parameters: age, [Fe/H] and [Mg/Fe]. We use the solar-scaled isochrones and the Salpeter initial mass function suggested by the EZ\_AGES documents. [O/Fe] is set to be zero, and the other $\alpha$ elements are tied to Mg. The ages range from 1.2 to 17.7 Gyr, and [Fe/H] ranges from $-1.3$ to 0.2. Other details can be found in S07 and Graves & Schiavon (2008).
Figure 11. The index plot on the S07 model grid, assuming [α/Fe] = 0.2, shows [MgFe]' versus Hβ. The solid and open circles represent the ETGs in the core region and those in outskirts, respectively.

The three parameters are derived following two steps. (i) For each galaxy, we first calculate the age and [Fe/H] using Hβ and ⟨Fe⟩, at all [Mg/Fe]. (ii) We compare the pair (Fe) ⟨Fe⟩ = 0.5(Fe5270 + Fe5335) and Mgb with models at the median age obtained in the first step, and we calculate new [Fe/H] and [Mg/Fe]. We then update the ages by interpolating the ages found in the first step with [Mg/Fe] derived in the second step, and we iterate the second step with the new age. Usually, two iteration steps are needed before convergence. For those measurements beyond the model grids, we set the parameters to be the boundaries (i.e. the maximum or minimum of the models).

Before deriving the stellar population parameters of our sample with the SSP models, we compare our measurements to the predictions of each model on the grids of age and metallicity. In Fig. 11, our measurements of Hβ and [MgFe]' are compared with the S07 models, assuming [α/Fe] = 0.2, where the index [MgFe]' is defined as follows:

\[ [\text{MgFe}'] = \sqrt{\text{Mgb}(0.72\text{Fe5270} + 0.28\text{Fe5335})} \]

Here, [MgFe]' is a good indicator of metallicity, and it is almost independent of the variations in the α/Fe ratio (Thomas, Maraston & Bender 2003, hereafter TMB). To convert between [Fe/H] and [Z/H], we adopt the relation given by TMB, [Z/H] = [Fe/H] + 0.94[α/Fe], and we assume [Mg/Fe] = [α/Fe]. The median age is about 7 Gyr, but with a large scatter. Most of the core-region galaxies have very small Hβ values, and occupy the oldest end of the age distribution. [MgFe]’ is mainly distributed along [Z/H] = 0, and does not have any environmental effects.

We present the derived six SSP parameters as a function of velocity dispersion σ in Fig. 12. Galaxies that fall outside the model boundary are not included in the figure. The parameter errors are given by the fitting procedure for each galaxy. We compute an average error for each parameter by weighting the output error of an individual galaxy with its signal-to-noise ratio. As presented in Fig. 11, the majority of the galaxies falling outside the model boundary are located in the core, which makes it hard to investigate the environmental effects. Although only 46 ETGs can be fitted by the model, the relations between the SSP parameters and velocity dispersion σ are still remarkable.

In the top-left panel of Fig. 12, the SSP ages show strong dependence upon velocity dispersion, and the low-σ galaxies span a wider age range, indicating that the low σ galaxies have various possible SFHs compared with high-σ galaxies. Similar results are found in the bright galaxies in Coma by Price et al. (2011). It is worth noting that the SSP ages derived by the S07 model are not compatible with the average stellar ages given by the STARLIGHT fitting. First, the SSP ages in the STARLIGHT code range from 1 Myr to 13 Gyr,
while the range of SSP ages in the S07 models is from 1 Gyr to 17.7 Gyr. The typical age of ETGs found from the \textsc{starlight} fitting (see Fig. 10) is older than 7 Gyr. In Fig. 11, the ETG ages derived by the S07 model span a wider range. Additionally, \textsc{starlight} gives the best-fitting ages without errors. The S07 model determines the ages by comparing several combined indices with the theoretical model, and the measurement errors can greatly affect the output ages. For galaxies whose indices are located near the model boundary, the measurement errors of indices will cause greater uncertainties in the parameter fitting.

The top-middle and top-right panels display the relations of [Fe/H] and [Mg/Fe] with \( \alpha \). The [Fe/H]–\( \alpha \) correlation is very tight, with a correlation coefficient of \( r_\alpha = 0.513 \), whereas the [Mg/Fe]–\( \alpha \) correlation is weak. Previous studies have found that [Mg/Fe] is strongly correlated with \( \alpha \) (Thomas et al. 2005; Zhu, Blanton & Moustakas 2010). We should bear in mind that the tightness and the slope of the linear correlation depend very much on the sample size. Considering our small sample size and the intrinsic scatter of this correlation, a relatively weaker [Mg/Fe]–\( \alpha \) relation is still reasonable.

In the three bottom panels of Fig. 12, we present the [C/Fe]–\( \sigma \), [N/Fe]–\( \sigma \) and [Ca/Fe]–\( \sigma \) relations. Only a weak correlation of [N/Fe]–\( \sigma \) is found, with a correlation coefficient of \( r_\sigma = 0.404 \). The results of our fitting are similar to those in Graves et al. (2007), and their results are based on a large sample of about 6000 red-sequence galaxies from the SDSS.

7 DISCUSSION

We have investigated the dynamics of A671 based on the spectroscopically confirmed members. The result of a \( \chi^2 \)-test strongly suggest that A671 has significant substructures. Many authors have found that a large fraction of galaxy clusters have substructures (Dressler & Shectman 1988; Mohr, Fabricant & Geller 1993; Yuan, Zhou & Jiang 2003; Yang et al. 2004), indicating that massive clusters can assemble their masses and grow up by accreting small groups. The contour map of member galaxies in A671 fits well with the X-ray intensity contour map. Ramella et al. (2007) have suggested that there are two substructures in A671. The location of one substructure is associated with the potential substructure B, and the other is in the south part of cluster, which is not significant enough to be detected by the \( \chi^2 \)-test. Their algorithm for finding substructures is based on the projected positions of galaxies, and does not utilize redshift information. In their sample, 73 per cent of clusters were found to have substructures, and this fraction is higher than in most studies. Their magnitude limit for galaxy samples is \( V \simeq 21.2 \) mag, much fainter than our limiting magnitude \( h_{\text{BATC}} = 19.5 \) mag. Thus, the projection effect cannot be ignored, and some substructures that they have found could be false. After the inclusion of 97 newly selected galaxies, substructure B is enhanced, while another substructure appears less prominent. Follow-up spectroscopy of these faint galaxies is needed to reveal the details of the dynamical substructures in A671.

The remarkable morphology–density relation indicates that the cluster environment does indeed play an important role in the evolution of cluster galaxies. A visual inspection of the C–M diagram shows that a large fraction of bright member galaxies \( (h_{\text{BATC}} < 18.5 \text{mag}) \) have evolved to be ‘red sequence’, and faint member galaxies with \( h_{\text{BATC}} \sim 19.0 \) mag are found to have considerable star formation activity. When the galaxies are accreted into a cluster, their star formation activities are expected to be suppressed by some important processes, such as tidal stripping and ‘harassment’ (Moore et al. 1996), ram pressure stripping of the gas disc (Abadi, Moore & Bower 1999) and the removal of the gas reservoir surrounding each galaxy (Balogh et al. 2002).

We have derived the average ages and metallicities for member galaxies by fitting their spectra. The most remarkable feature of the age distribution is that the ETGs in the core region are older than those in the outskirts. Thomas et al. (2005) have found that ETGs in a dense environment have average ages that are \( \sim 2 \) Gyr older than those in a field environment. They derived the ages by comparing the Lick indices with the prediction of the TMB model. Our results confirm their conclusion even though the average ages are derived using different methods. This can be interpreted in two ways. On the one hand, theoretical work shows that dark matter haloes in dense environments were assembled earlier than average (Gao, Springel & White 2005). As a result, the galaxies in the core regions of clusters formed earlier than those in the outer regions, and thus have older stellar ages. On the other hand, the older stellar age of ETGs in the core region can be explained by the lack of recent star formation, compared with those in the outer region. Galaxy clusters have dense gas with high temperature, and the galaxies in the core region lost their gas reservoirs by interacting with the dense intracluster medium (usually by ram pressure stripping). Thus, the galaxies in the core region should be gas-poor, and have fewer possibilities of recent star formation. Aside from age, the total metallicities of ETGs show a subtle dependence on environment, which agrees well with Zhu et al. (2010). A larger sample of cluster ETGs is needed to investigate the environmental effects on chemical evolution.

The dependence of age on stellar mass can be explained using the downsizing scenario for galaxy formation (Cowie et al. 1996). In this scenario, star formation lasts longer in less massive galaxies than in more massive galaxies. Thus, on average, massive systems will have older SSP ages. Evidence of the downsizing effect in the local Universe has been put forward by many recent studies on the stellar population of ETGs (Nelan et al. 2005; Graves et al. 2007; Zhu et al. 2010; Price et al. 2011). The age–\( \sigma \) slopes in these studies span a range between 0.35 and 0.93. The different values for the slope are mainly a result of the different properties of the samples (e.g. galaxy type, sample size, etc.) and the methods of index correction (e.g. emission infill correction, velocity dispersion correction, etc.). Price et al. (2011) tested the robustness of their observed age–\( \sigma \) slope against these two factors when they studied the stellar population in Coma. In their test, they used a stricter emission-line cut and different methods of velocity dispersion correction. Only a slight change in the age–\( \sigma \) slope was found in their tests. They concluded that their data robustly support the downsizing scenario.

The \( \alpha \)-abundance of ETGs is also very dependent on \( \sigma \). The \( \alpha \) elements are mainly from Type II supernovae, and the iron-peak elements come mainly from Type Ia supernovae. The stronger \( \alpha \) enhancement in the more massive elliptical galaxies might imply that their star formation time-scale is shorter than that of less massive elliptical galaxies, before the delayed Type Ia supernovae enrich the star-forming regions with iron-peak elements. The observed \( \alpha \)-abundance–\( \sigma \) relation fits well with the prediction from hierarchical models with feedback (De Lucia et al. 2006).

8 CONCLUSION

In this paper, we have presented a photometric study of A671 using the BATC multicolour system and SDSS data. The main conclusions can be summarized as follows.
(i) About 7000 sources are detected in a BATC field of $58 \times 58$ arcmin$^2$ centred on A671, and their SEDs in 15 intermediate bands are obtained. The 985 galaxies brighter than $h_{\text{BUTC}} = 20.0$ mag are selected by cross-identifying our BATC source catalogue with the released catalogue of SDSS galaxies. There are 205 galaxies with known spectroscopic redshifts in our field of view, among which 103 galaxies with $0.04 < z_{\text{sp}} < 0.06$ are selected as spectroscopically confirmed members of A671. The sample of bright member galaxies is composed of 63 ETGs and 40 LTGs.

(ii) We investigate the dynamics of A671 based on the 103 spectroscopically confirmed members. The result of a $\chi^2$-test on different scales strongly suggests that A671 has significant substructures. Three potential substructures have been suggested using the method of localized deviation of velocity distribution.

(iii) The photometric redshift technique is applied to the 985 galaxies for the determination of further membership. Our photometric redshifts $z_{\text{ph}}$ of the bright members are basically consistent with the spectroscopic redshifts $z_{\text{sp}}$. Based on the statistics of photometric redshifts, galaxies with $0.028 < z_{\text{ph}} < 0.073$ are selected as member candidates. After further selection by the $C-M$ relation, 97 galaxies down to $h_{\text{BUTC}} = 19.5$ mag are selected as faint members of A671.

(iv) Based on the enlarged sample of member galaxies, the spatial distribution and the velocity structure of A671 are studied. Because the large $z_{\text{ph}}$ uncertainty of faint galaxies have smoothed the localized abnormality in the velocity distribution, the $\chi^2$-test of the enlarged sample does not confirm the three substructures mentioned above. The morphology segregation becomes very remarkable after the faint members are taken into account. The luminosity function in the SDSS $r$ band shows a flat slope at the faint end, $\alpha \sim -1.12$.

(v) The mass-weighted stellar ages and the total metallicities of the bright members are derived by fitting their spectra with the spectral synthesis code STARBURST99. The ETGs in the core region have older ages than those in the outskirts. The more massive ETGs are found to be older than the less massive ETGs. No environmental effect is found for the metallicities of the ETGs. Strong correlations of mean stellar age and metallicity with stellar mass are confirmed, and such correlations are found to be dependent upon morphology. The positive age–mass correlation supports the downsizing scenario.

(vi) A set of Lick indices of ETGs is measured in order to derive their SSP-equivalent stellar parameters (such as age, [Fe/H], [Mg/Fe], [C/Fe], [N/Fe] and [Ca/Fe]) by utilizing the S07 model. The ETGs at the cluster centre tend to have smaller $H_\beta$ indices, indicating that central ETGs are likely to be older. The total metallicity indicator $\text{[MgFe]}^+$ does not show any environmental effects. The relations between the six SSP parameters and velocity dispersion $\sigma$ are also studied, and in A671 they are found to be in good agreement with previous studies.

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