INTERNAL KINEMATICS AND STELLAR POPULATIONS OF THE POSTSTARBURST GALAXY SDSS J230743.41+152558.4

I. V. CHILINGARIAN1,2, S. DE RIJCK3, and P. BUYLE3

1 Observatoire de Paris-Meudon, LERMA, UMR 8112, 61 Av. de l’Observatoire, 75014 Paris, France; Igor.Chilingarian@obspm.fr
2 Sternberg Astronomical Institute, Moscow State University, 13 Universitetskii prospect, 119992 Moscow, Russia
3 Astronomical Observatory, Ghent University, Krijgslaan 281, S9, B-9000 Gent, Belgium; Sven.DeRijcke@UGent.be, Pieter.Buyle@UGent.be

Received 2009 January 9; accepted 2009 March 17; published 2009 May 11

ABSTRACT

We present the first 3D-spectroscopic observations of a nearby H\textsc{i} detected poststarburst, or E+A, galaxy, SDSS J230743.41+152558.4, obtained with the VIMOS IFU spectrograph at ESO VLT. Using the NBURSTS full spectral fitting technique, we derive maps of stellar kinematics, age, and metallicity out to 2–3 half-light radii. Our analysis reveals a large-scale rapidly rotating disk (v_circ = 300 km s^{-1}) with a positive age gradient (0.6–1.5 Gyr), and a very metal-rich central region ([Fe/H] = +0.25 dex). If a merger or interaction is responsible for triggering the starburst, the presence of this undisturbed disk suggests a minor merger with a gas-rich satellite as the most plausible option, rather than a disruptive major merger. We find spectroscopic evidence for the presence of an active galactic nucleus. This is an important clue to the feedback mechanism that truncated the starburst. The presently observed quiescent phase may well be a temporary episode in the galaxy’s life. SDSS J230743.41+152558.4 is gas-rich and may restart forming stars, again becoming blue before finally settling at the red sequence.

Key words: galaxies: elliptical and lenticular, cD – galaxies: individual (SDSS J230743.41+152558.4)

1. INTRODUCTION

In the nearby universe, galaxies have a bimodal color distribution, with a blue peak of star-forming galaxies separated from a red sequence of quiescent galaxies by a sparsely populated gap (Strateva et al. 2001; Baldry et al. 2004; Balogh et al. 2004). The number of red galaxies has roughly doubled since z \sim 1 (Bell et al. 2004). Red galaxies, on average, are more luminous than blue galaxies. Therefore, a simple cessation of star formation in a fraction of the blue galaxies followed by fading and reddening cannot explain this build-up of the red sequence. Starbursts are often suggested as a way of increasing a blue galaxy’s stellar mass before letting it fade onto the red sequence (Bell et al. 2004; Labbé et al. 2007), with mergers and interactions as possible starburst triggers (Bekki et al. 2005; Di Matteo et al. 2008). Mergers and starbursts have the additional appeal that they offer an explanation for the cessation of star formation: gas is being consumed by the starburst (Di Matteo et al. 2007) and is being expelled by active galactic nucleus (AGN) or supernova feedback (Buyle et al. 2008; Kaviraj et al. 2007). Thus, previously blue galaxies turn red and, through further dry mergers, can lead to the formation of the most massive elliptical galaxies observed in the nearby universe (Bell et al. 2006; Naab et al. 2006). This prompted us to investigate the crucial but transient poststarburst phase, during which a galaxy crosses the color gap, of this particular evolutionary pathway.

Poststarburst galaxies (PSGs, or E+A galaxies) have optical spectra with strong Balmer absorption lines, revealing young stars, but faint if any emission lines, ruling out major star formation (Dressler & Gunn 1983; Couch & Sharples 1987; Dressler et al. 1999). PSGs offer us a unique window on how their stellar kinematics out to several half-light radii (r_e). Clearly, the poststarburst phase is of crucial importance to furthering our understanding of the photometric evolution of the galaxy population.

In this Letter, we present for the first time two-dimensional spatially resolved kinematics and stellar population parameters for a gas-rich PSG, selected from the Goto et al. (2003) catalog, SDSS J230743.41+152558.4. With a redshift z = 0.0695, luminosity distance d_L = 302 Mpc (adopting a spatially flat cosmology with H_0 = 73 km s^{-1} Mpc^{-1}, \Omega_M = 0.27, \Omega_A = 0.73), distance modulus m - M = 37.40 mag, and a spatial scale 1.27 kpc arcsec^{-1}, this is a relatively nearby PSG. The few galaxies with known systemic velocities in a 200 kpc wide search column centered on SDSS J230743.41+152558.4 do not coincide in redshift and are spread over a very large redshift range (0.036 \lesssim z \lesssim 0.25), making it unlikely that they are physically connected with SDSS J230743.41+152558.4. We confirm the classification of SDSS J230743.41+152558.4 by Yagi & Goto (2006) as a field PSG.

This is the first paper in a series based on our VLT/VIMOS observations of three PSGs.

2. OBSERVATIONS AND DATA REDUCTION

The data have been obtained with the integral field unit (IFU) mode of the VIMOS spectrograph at ESO/VLT-Melipal by ESO staff in mid-2006. With the high-resolution “HR-blue” spectral setup, the 0.67 per lens spatial scale provides a field of view (FOV) of 27′′ × 27′′ (40 × 40 lenses). This setup offers a spectral resolving power R \sim 2500 between 4200 and 6300 Å. In total, we use 11 out of 12 obtained exposures, spatially dithered in order to work around broken IFU fibers, and each with an on-source time of 2000 s. The seeing FWHM varies between 0.7 and 1.2 arcsec. Line and flat-field calibration frames have been taken for every observing block (OB).

For the data reduction, we use the generic IFU data reduction pipeline implemented in ITT IDL. A brief description of the data reduction steps can be found in Chilingarian et al.

Based on observations made with ESO Telescopes at the La Silla or Paranal Observatories under programme ID 077.B-0657.
Night sky spectra are reconstructed from the lenses outside 5 rc of the galaxy to minimize contamination by the galactic stellar continuum and are subtracted from the science frames. Then, individual exposures are co-added, applying iterative sigma-clipping to remove cosmic ray hits, spatial and spectral shifts to account for spatial dithering, different heliocentric corrections and atmosphere differential refraction. Noise frames are computed using photon statistics and are processed through the same reduction steps as the science frames, up to the sky subtraction.

We use twilight and science frames contaminated by Moon (4 out of 12) to assess the data reduction quality and obtain quantitative estimates of the VIMOS spectral line spread function variations across the FOV, along the wavelength axis, and between different OBs. We fit the solar spectrum, taken from the ELODIE.3.1 stellar library (Prugniel et al. 2007), against the observed spectra in every lens at six wavelength intervals between 4000 and 6300 Å using the PPXF procedure (Cappellari & Emsellem 2004). From this test, we conclude that (1) wavelength calibration quality is better than 5 km s\(^{-1}\) between 4000 and 5900 Å; (2) spectral resolution (\(\sigma_{\text{inst}}\)) exhibits no significant variations across the FOV for individual quadrants, neither between observing blocks, although (3) it does change along wavelength (60–40 km s\(^{-1}\) from blue to red) and between quadrants; (4) high-order moments of the Gauss–Hermite parameterization (\(h_3\) and \(h_4\), van der Marel & Franx 1993) are close to zero except Q3 at \(\lambda < 4350\) Å, where \(h_3\) is modestly negative due to imperfect focusing; (5) systematic errors of the wavelength calibration become very important at \(\lambda > 5900\) Å, changing significantly between individual OBs so we restrict our analysis to shorter wavelengths.

3. DATA ANALYSIS

We use the NBURSTS full spectral fitting technique (Chilingarian et al. 2007b) with high-resolution (\(R = 10000\)) PEGASE.HR (Le Borgne et al. 2004) simple stellar population (SSP) models to extract kinematics and stellar population from the absorption-line spectra. First, we rebin the data to a target signal-to-noise ratio of 15 per bin using the Voronoi adaptive tessellation technique (Cappellari & Copin 2003). We use only that part of the VIMOS IFU FOV where the sky-subtraction uncertainty is sufficiently small, with a size of 18 × 18 lenses (12′′ × 12′′). The subsequent fitting procedure comprises the following steps: (1) a grid of SSP spectra with a fixed set of ages (spaced nearly logarithmically from 20 Myr to 18 Gyr) and metallicities (from −2.0 to +0.5 dex) is convolved with the wavelength-dependent instrumental response of VIMOS in every Voronoi tessella as explained in Chilingarian et al. (2007a); (2) a nonlinear least-square fitting against an observed spectrum is done for a template picked from the pre-convolved SSP grid using two-dimensional-spline interpolation on age (log \(t\)) and metallicity (Z), broadened with the line-of-sight velocity distribution (LOSVD) parameterized by \(v, \sigma, h_3,\) and \(h_4\) and multiplied pixel-by-pixel by an \(n\)th order Legendre polynomial (multiplicative continuum), resulting in \(n + 7\) parameters to be determined (we use \(n = 25\)).

We exclude narrow 12 Å wide regions around the H\(\beta\), H\(\gamma\), [O III] (\(\lambda = 4959, 5007\) Å), and [N I] (\(\lambda = 5199\) Å) lines from the fit in order to be able to detect faint emission lines. As shown in Chilingarian et al. (2007a, 2008), reliable SSP-equivalent age and metallicity estimates are obtained even if the Balmer absorption lines are excluded. Using the approach described in Chilingarian (2009) we estimate the excluded regions to contain only \(\sim 7\%\) of age-sensitive information.

4. RESULTS

We present the maps derived from the full-spectrum fitting in Figure 1. Those regions where the parameters have large uncertainties (e.g., greater than 15 km s\(^{-1}\) for \(v, \sigma, h_3,\) and \(h_4\) and multiplied pixel-by-pixel by an \(n\)th order Legendre polynomial (multiplicative continuum), resulting in \(n + 7\) parameters to be determined (we use \(n = 25\)).

We exclude narrow 12 Å wide regions around the H\(\beta\), H\(\gamma\), [O III] (\(\lambda = 4959, 5007\) Å), and [N I] (\(\lambda = 5199\) Å) lines from the fit in order to be able to detect faint emission lines. As shown in Chilingarian et al. (2007a, 2008), reliable SSP-equivalent age and metallicity estimates are obtained even if the Balmer absorption lines are excluded. Using the approach described in Chilingarian (2009) we estimate the excluded regions to contain only \(\sim 7\%\) of age-sensitive information.

We present the maps derived from the full-spectrum fitting in Figure 1. Those regions where the parameters have large uncertainties (e.g., greater than 15 km s\(^{-1}\) for \(v, \sigma, h_3,\) and \(h_4\) and multiplied pixel-by-pixel by an \(n\)th order Legendre polynomial (multiplicative continuum), resulting in \(n + 7\) parameters to be determined (we use \(n = 25\)).

We exclude narrow 12 Å wide regions around the H\(\beta\), H\(\gamma\), [O III] (\(\lambda = 4959, 5007\) Å), and [N I] (\(\lambda = 5199\) Å) lines from the fit in order to be able to detect faint emission lines. As shown in Chilingarian et al. (2007a, 2008), reliable SSP-equivalent age and metallicity estimates are obtained even if the Balmer absorption lines are excluded. Using the approach described in Chilingarian (2009) we estimate the excluded regions to contain only \(\sim 7\%\) of age-sensitive information.

We present the maps derived from the full-spectrum fitting in Figure 1. Those regions where the parameters have large uncertainties (e.g., greater than 15 km s\(^{-1}\) for \(v, \sigma, h_3,\) and \(h_4\) and multiplied pixel-by-pixel by an \(n\)th order Legendre polynomial (multiplicative continuum), resulting in \(n + 7\) parameters to be determined (we use \(n = 25\)).
### 4.1. Kinematics and Dynamics

SDSS J230743.41+152558.4 exhibits very regular, symmetric pure disk rotation with a semiamplitude of 90 km s\(^{-1}\) without any evidence for significant isovela twist. However, there is a significant misalignment of the kinematical and photometrical axes. We mention the evident large-scale bar oriented exactly along the galaxy’s minor axis (roughly north–south), which is visible on Sloan Digital Sky Survey (SDSS) images and also noticeable here in the reconstructed image. The rotation curve flattens out at ∼4\(\arcsec\) from the center, corresponding to ∼6 kpc or ∼3.5\(\arcsec\)r\(_e\) (Buyle et al. 2006; see Figure 2). The velocity dispersion declines from a central maximum of ∼110 km s\(^{-1}\) to 40–50 km s\(^{-1}\) at 6\(\arcsec\). The rather high v/\(\sigma\) in the outskirts of the galaxy also argue for the presence of a disk. One has to be careful with interpreting the high central values, because a rapidly rotating circumnuclear component smeared by atmospheric seeing may produce very similar effects. Weighing all the evidence, SDSS J230743.41+152558.4 is best classified morphologically as a barred lenticular or S0 galaxy. This is not surprising since, although the diversity is quite large, many E+As have S0-like morphologies (Yang et al. 2008).

We use a technique similar to that proposed by van Moorsel & Wells (1985) to determine the galaxy’s inclination, i, and the position angle of the major axis, P.A., from the stellar radial velocity field (the main difference being the nonparametric representation of the rotation curve). Fitting the velocity field in elliptical annuli in the radial range 0.7 < r < 6.0 gives P.A. = 131 deg and i = 30 deg. These values agree well with the shape and axial ratio of the outer isophote displayed in Figure 1. The peak projected velocity v ≈ 90 km s\(^{-1}\) = \(\sigma_\phi\) sin i, after correcting for inclination effects, yields \(\sigma_\phi\) ≈ 180 km s\(^{-1}\) for the mean tangential velocity. We adopt the value h\(_R\) = 0.8, provided by SDSS, for the exponential scale-length of the stellar density profile. Using these numbers, we estimate the circular velocity \(v_{\text{circ}}\) at a radius of 4\(\arcsec\), corrected for asymmetric drift using the method outlined in paragraph 4.8.2(a) of Binney & Tremaine (2008). For the outskirts of the galaxy, we assume the rotation curve to be flat (\(\sigma_\phi\) ≈ \(\sigma_R\)/\(\sqrt{2}\)) and the velocity dispersions to be independent of radius. We then arrive at the following expression for the circular velocity:

\[
v_{\text{circ}}(4\arcsec) \approx \sqrt{v_0^2 + \sigma_\phi^2 \left(2 \frac{4\arcsec}{h_R} - 1\right)}.
\]

Here, \(\sigma_\phi\) is the tangential velocity dispersion. Unfortunately, along the major axis, \(\sigma\) is a function of both \(\sigma_\phi\) and \(\sigma_z\), the vertical component of the velocity dispersion tensor. If we assume that we are dealing with a thin disk then \(\sigma_i \ll \sigma_\phi\) and \(\sigma_\phi \approx \sigma / \sin i \sim 80 \text{ km s}^{-1}\). In the case of an isotropic velocity dispersion tensor, \(\sigma_\phi \approx \sigma_z \approx 40 \text{ km s}^{-1}\). The first case yields \(v_{\text{circ}} \sim 300 \text{ km s}^{-1}\); the latter leads to \(v_{\text{circ}} \sim 220 \text{ km s}^{-1}\). The velocity width (W20) of the H\(_\alpha\) 21 cm emission of this galaxy is 286 ± 43 km s\(^{-1}\). This corresponds to a circular velocity \(v_{\text{circ}} \approx 143/\sin i \text{ km s}^{-1} \sim 286 \text{ km s}^{-1}\) (P. Buyle et al. 2009, in preparation), sitting comfortably between the two extreme values derived from stellar kinematics. We will adopt it here as our best-guess value. Using these numbers, we estimate the total dynamical mass within a 5 kpc radius at \(\sim 10^{11} M_\odot\).

With a total B-band absolute magnitude \(M_B = -20.5\) mag (P. Buyle et al., in preparation), logarithm of the peak circular velocity \(\log(v_{\text{circ}}) = 2.48\), logarithm of the central velocity dispersion \(\log(\sigma_\phi) = 2.04\), SDSS J230743.41+152558.4 sits exactly on the Tully–Fisher (1977) relation for elliptical and S0 galaxies (Bedregal et al. 2006; De Rijcke et al. 2007). It is slightly offset from the E/S0 Faber–Jackson relation (Faber & Jackson 1976; Gerhard et al. 2001; De Rijcke et al. 2005), being almost ∼1 mag too bright in the B-band for its velocity dispersion.

In Figure 3, we present the Fundamental Plane (FP; Djorgovski & Davis 1987) in \(\kappa\)-space (Bender et al. 1992). On the \(\kappa_2\) versus \(\kappa_1\) plot (the plane’s “face-on view”), the distinct
regions are occupied by dwarf (van Zee et al. 2004; Geha et al. 2003; De Rijcke et al. 2005; Chilingarian et al. 2008) and intermediate luminosity and giant early-type galaxies (Bender et al. 1992). The latter region is extended toward the upper-left corner of the plot by low-luminosity bulges and compact elliptical galaxies with M99cO (Chilingarian & Mamon 2008) being the most extreme case. SDSS J230743.41+152558.4, indicated by the red filled circle, falls in the region occupied by high-surface brightness low-luminosity bulges and ellipticals. Since the FP is defined for early-type galaxies (E/S0) assumed to be virialized systems, we should include the rotational energy into the total balance at first approximation as $\sigma^2 + v_z^2/2$. This moves SDSS J230743.41+152558.4 to the position indicated by the end of the green vector in Figure 3, toward the locus of bright E/S0 galaxies.

4.2. Stellar Populations and Nuclear Activity

In the stellar population maps, we clearly see a barely resolved core with a shape and size similar to that of the central $\sigma$-bump. The galaxy center reaches a significantly super-solar metallicity, up to +0.25 dex. The central SSP-equivalent age is 650 Myr, increasing to approximately 3 Gyr at 3′′ from the galaxy nucleus. The starburst region, where the very young population resides, is about 2 arcsec (2.5 kpc) across. Yagi & Goto (2006) observed SDSS J230743.41+152558.4 using long-slit spectroscopy and found large H$\beta$ equivalent widths out to 2.5 arcsec. The VIMOS data confirm the existence of an extended region showing a young stellar population, although the positive age gradient is significant. For a comparison with the SDSS DR6 spectrum (Adelman-McCarthy et al. 2008) of this galaxy, we integrate the light in the data cube inside a 3″ circular aperture and apply the full-spectrum fitting technique to both spectra. We find excellent agreement: all the kinematical and stellar population parameters, including $h_{4}$, are consistent within the uncertainties.

We fit the brightest emission line ([O iii] $\lambda = 5007$ Å) with a Gaussian to determine its amplitude (see Figure 4 (left)). Unfortunately, no precise measurements of radial velocities can be made due to the very low emission-line flux. The [O iii] emission is very centrally concentrated, arguing for the presence of a spatially unresolved emitting region. Careful inspection of the fitting residuals in the central region (Figure 4 (right)) reveals barely detectable emission in the forbidden [N i] line ($\lambda = 5199$ Å), which is a typical signature of a LINER or AGN. We therefore connect the central peak of the [O iii] distribution to possible nuclear activity. Fitting the SDSS DR6 spectrum in the full wavelength range of PEGASE.HR (3900 < $\lambda$ < 6800 Å) and subtracting the best-fitting template from the data reveal strong emission lines in H$\alpha$ and [N ii] ($\lambda = 6548, 6584$ Å). The high log([N ii]6584)/H$\alpha$ = 0.13 and log([O iii]5007)/H$\beta$ = 0.46 ratios support the LINER interpretation (Baldwin et al. 1981; Kewley et al. 2006). This would make SDSS J230743.41+152558.4 the second well-studied PSG to date in which low-power nuclear activity has been detected (Liu et al. 2007). As proposed by Kaviraj et al. (2007), AGN feedback may play a crucial role in quenching star formation in massive PSGs by expelling the gas. Buyle et al. (2008) find that most of the H i gas in the binary PSG system EA01A/B resides outside the stellar bodies of the galaxies, suggesting a feedback process powerful enough to physically displace large quantities of gas, such as AGN feedback (Silk & Rees 1998; Schawinski et al. 2009). At the same time, the faint H$\beta$ and [O iii] ($\lambda = 4959$ Å) emission lines are detected almost everywhere out to 3′′ from the galaxy center, suggesting weak ongoing star formation over a large part of the galaxy.

5. PAST AND FUTURE EVOLUTION

The distance to SDSS J230743.41+152558.4 corresponds to a light travel time of ~900 Myr. We estimate its B-band luminosity evolution using the PEGASE.2 (Fioc & Rocca-Volmerange 1997) evolutionary synthesis code. If we imagine SDSS J230743.41+152558.4 evolving passively during this period, it will fade by, at maximum, 1 mag if all its stars formed 700 Myr ago. In the more plausible case of a composite stellar population, the effect on the total $B$ magnitude will be even smaller, because the old population evolves slower than the young one, which has a lower mass fraction. This will make SDSS J230743.41+152558.4 resemble present-day intermediate-luminosity early-type galaxies (E/S0) in its position on the Faber–Jackson relation, the Kormendy relation (Kormendy 1977), and the FP (see the red vector in Figure 3). 4′′, or 3$r_e$, encloses about 75% of the light, resulting in a mass-to-light ratio of $M/L_B \sim 4$ in solar units. After 700 Myr of passive evolution, this will have increased to $M/L_B \sim 10$, at maximum. This is compatible with present-day early-type galaxies (Gerhard et al. 2001).

SDSS J230743.41+152558.4 turns to be a fast rotator if one applies the recently proposed classification (Emsellem et al. 2007). However, despite its regular morphology, given the presence of a dominating large-scale dynamically cold disk, we should not classify this object as a typical early-type galaxy. Major mergers and interactions may lead to strong, abruptly truncated star formation episodes, as shown statistically using numerical simulations by Di Matteo et al. (2007), resulting in the E+A phenomenon. Such violent events heat and often even completely destroy the disks, leaving little opportunity to explain the observed velocity field of SDSS.
J203743.41+152558.4. On the other hand, a minor merger of a large disk-dominated lenticular or early-type spiral with an intermediate-mass gas-rich satellite may be an acceptable explanation: young stars will actively form in the disk from the accreted intermediate-metallicity interstellar medium while the central star formation peak will consume the metal-rich gas often present in the circumnuclear regions of early-type galaxies.

Given the presence of neutral gas (Buyle et al. 2006), the quenching of star formation in SDSS J203743.41+152558.4 could very well be a transient phase. For instance, the gaseous component could have been dispersed by supernova or AGN feedback and may re-accrete after several hundred Myr, possibly restarting the star formation. If this object had been observed during a star-forming episode, it would have been classified as a barred late-type spiral (SBcd).

Deep H i radio observations have led to the detection of 21 cm emission in about 60% of the targeted PSGs (Buyle et al. 2006). Some of the detected PSGs are as gas-rich as local luminous infrared galaxies and mergers, possible progenitors of PSGs in the local universe (Kaviraj et al. 2007). The presence of large quantities of gas indicates that many PSGs might actually be observed during an inactive phase of the star-formation duty cycle. This suggests that the evolution from blue to red galaxy may encompass several cycles back and forth in the color–magnitude diagram before the galaxy finally settles on the red sequence.

I.C. acknowledges the RFBR grant 07-02-00229-a. Our study makes use of SDSS DR6. Funding for the Sloan Digital Sky Survey (SDSS) and SDSS-II has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, the U.S. Department of Energy, the National Aeronautics and Space Administration, the Japanese Monbukagakusho, and the Max Planck Society, and the Higher Education Funding Council for England. The SDSS Web site is http://www.sdss.org/. The SDSS is managed by the Astrophysical Research Consortium (ARC) for the Participating Institutions. The Participating Institutions are the American Museum of Natural History, Astrophysical Institute Potsdam, University of Basel, University of Cambridge, Case Western Reserve University, The University of Chicago, Drexel University, Fermilab, the Institute for Advanced Study, the Japan Participation Group, The Johns Hopkins University, the Joint Institute for Nuclear Astrophysics, the Kavli Institute for Particle Astrophysics and Cosmology, the Korean Scientist Group, the Chinese Academy of Sciences (LAMOST), Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, Ohio State University, University of Pittsburgh, University of Portsmouth, Princeton University, the United States Naval Observatory, and the University of Washington.

Facilities: ESO VLT (VIMOS)

REFERENCES

Adelman-McCarthy, J. K., et al. 2008, ApJS, 175, 297
Baldry, I. K., et al. 2004, ApJ, 600, 681
Baldwin, A., Phillips, M. M., & Terlevich, R. 1981, PASP, 93, 5
Balogh, M. L., et al. 2004, ApJ, 615, L101
Bedregal, A. G., Aragón-Salamanca, A., & Merrifield, M. R. 2006, MNRAS, 373, 1125
Bekki, K., Couch, W. J., Shiroya, Y., & Vazdekis, A. 2005, MNRAS, 359, 949
Bell, E., Naab, T., & McIntosh, D. H. 2006, ApJ, 640, 241
Bell, E. F., et al. 2004, ApJ, 608, 752
Bender, R., Burstein, D., & Faber, S. M. 1992, ApJ, 399, 462
Binney, J., & Tremaine, S. 2008, Galactic Dynamics (2nd ed.; Princeton, NJ: Princeton Univ. Press)
Buyle, P., De Rijcke, S., & Dejonghe, H. 2008, ApJ, 684, L17
Buyle, P., et al. 2006, ApJ, 649, 163
Cappellari, M., & Copin, Y. 2003, MNRAS, 342, 345
Cappellari, M., & Emsellem, E. 2004, PASP, 116, 138
Chilingarian, I. 2009, MNRAS, in press (arXiv:0812.3272v1)
Chilingarian, I. V., & Mamou, G. A. 2008, MNRAS, 385, L83
Chilingarian, I. V., Prugniel, P., Sil’chenko, O. K., & Afanasiev, V. L. 2007, MNRAS, 376, 1033
Chilingarian, I., Prugniel, P., Sil’chenko, O., & Koleva, M. 2007b, in IAU Symp. 241, Stellar Populations as Building Blocks of Galaxies, ed. A. Vazdekis, R. R. Peletier (Cambridge: Cambridge Univ. Press), 175–176
Chilingarian, I. V., et al. 2008, A&A, 486, 85
Couch, W. J., & Sharples, R. M. 1987, MNRAS, 229, 423
De Rijcke, S., Michielsen, D., Dejonghe, H., Zeilinger, W. W., & Hau, G. K. T. 2005, A&A, 438, 491
De Rijcke, S., Zeilinger, W. W., Hau, G. K. T., Prugniel, P., & Dejonghe, H. 2007, ApJ, 659, 1172
Di Matteo, P., Combes, F., Melchior, A.-L., & Semelin, B. 2007, A&A, 468, 61
Di Matteo, P., et al. 2008, A&A, 492, 31
Djorgovski, S., & Davis, M. 1987, ApJ, 313, 59
Dressler, A., & Gunn, J. E. 1983, ApJ, 270, 7
Dressler, A., et al. 1999, ApJS, 122, 51
Emsellem, E., et al. 2007, MNRAS, 379, 401
Faber, S. M., & Jackson, R. E. 1976, ApJ, 204, 668
Fioc, M., & Rocca-Volmerange, B. 1997, A&A, 326, 950
Geha, M., Guhathakurta, P., & van der Marel, R. P. 2003, AJ, 126, 1794
Gerhard, O., Kronawitter, A., Saglia, R. P., & Bender, R. 2001, AJ, 121, 1936
Goto, T., et al. 2003, PASJ, 55, 771
Kaviraj, S., Kirkby, L. A., Silk, J., & Sarzi, M. 2007, MNRAS, 382, 960
Kewley, L. J., Groves, B., Kauffmann, G., & Heckman, T. M. 2006, MNRAS, 372, 861
Kormendy, J. 1977, ApJ, 218, 333
Labbé, I., et al. 2007, ApJ, 665, 944
Le Borgne, D., et al. 2004, A&A, 425, 881
Liu, C. T., et al. 2007, ApJ, 658, 249
Naab, T., Khochfar, S., & Burkert, A. 2006, ApJ, 636, L81
Prugniel, P., Soubiran, C., Koleva, M., & Le Borgne, D. 2007, arXiv:astro-ph/0703658
Schawinski, K., et al. 2009, ApJ, 690, 1672
Silk, J., & Rees, M. J. 1998, A&A, 331, L1
Strateva, I., et al. 2001, AJ, 122, 1861
Tully, R. B., & Fisher, J. R. 1977, A&A, 54, 661
van der Marel, R. P., & Franx, M. 1993, ApJ, 407, 525
van Moorsel, G. A., & Wells, D. C. 1985, AJ, 90, 1038
van Zee, L., Skillman, E. D., & Haynes, M. P. 2004, AJ, 128, 121
Yang, Y., Zabludoff, A. I., Zaritsky, D., & Mihos, J. C. 2008, ApJ, 688, 945